PUB ACTIVE, BEAUTIFUL, CLEAN WATERS

Active, Beautiful, Clean Waters

Design Guidelines 4TH EDITION

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 initiative by PUB, Singapore's National Water Agency, the country has embarked on a journey to a City of Gardens and Water.

Since its inception in 2006, the ABC Waters Programme has led the way to transform how Singapore manages surface water. From functional drains to well-designed waterways that serve multiple purposes, from traditional stormwater management to sustainable stormwater management that detains and treats runoff at source.

1.1 TRANSFORMING INTO A CITY OF GARDENS AND WATER

Over the years, Singapore has developed a pervasive drainage network of 17 reservoirs and more than 8000km of drains, canals and rivers. 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 aims to harness the full potential of our waterbodies to improve the quality of not only 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.

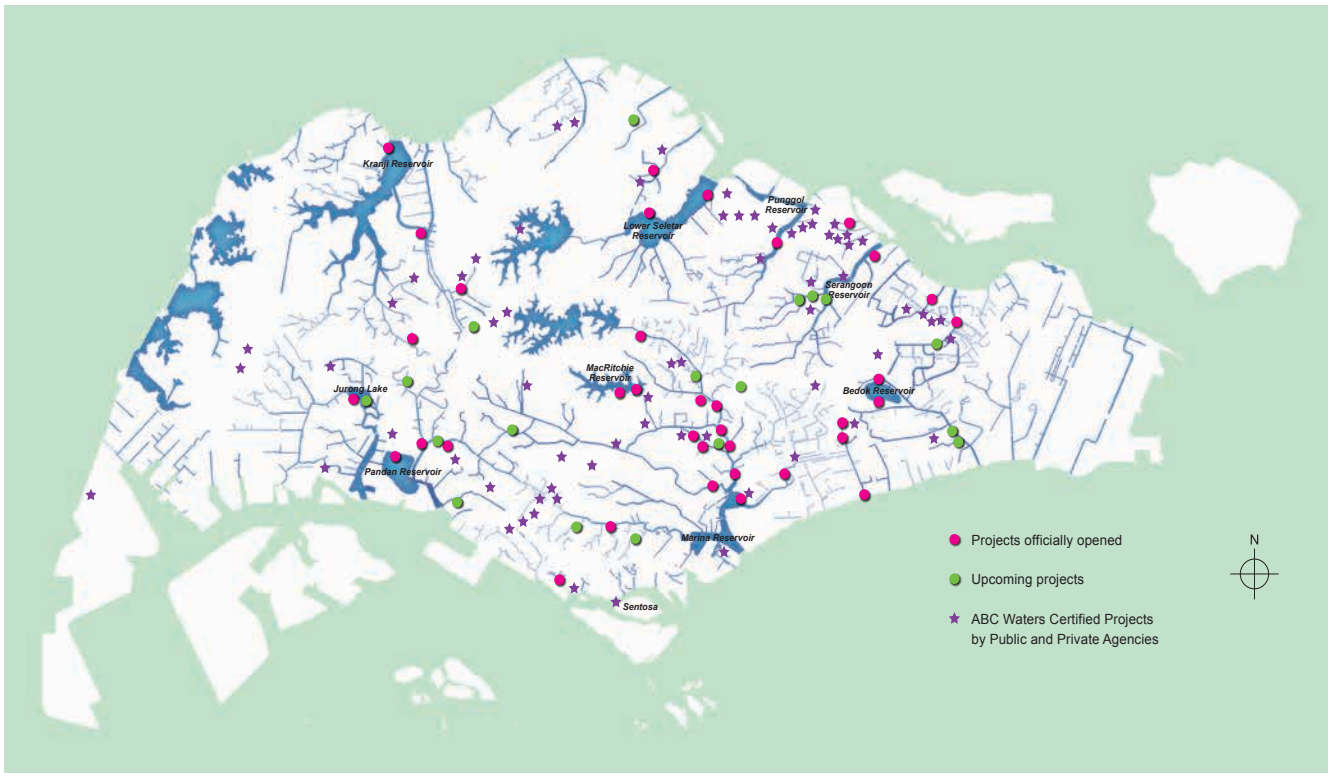


Fig. 1.1 Blue Map of Singapore

Since the inception of the ABC Waters Programme in 2006, we have seen many successful ABC Waters projects completed with many more upcoming. Our blue spaces are slowly being integrated with the urban fabric of Singapore. Yet, there remains a great deal of untapped opportunities: aside from our waterbodies and waterways, the catchment upstream has much potential to be unlocked. Going forward, proliferating or mainstreaming the ABC Waters concepts throughout the catchment will play an important role to improve the urban runoff quality and enhance the liveability of the urban environment as our city state continues to develop.

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 as well as to maintain the quality of water in our waterways and reservoirs.

1.3 ABC WATERS

The aim of the ABC Waters Programme is to seamlessly integrate the Environment (Green), Waterbodies (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.

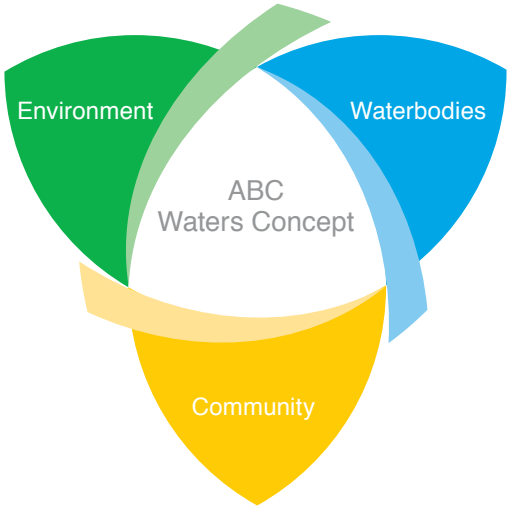


Fig. 1.2 ABC Waters Concept

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. More than 30 ABC Waters projects have been completed as of March 2018.

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. A vital part of this concept is the implementation of ABC Waters design features, which are natural systems that detain and treat 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. To proliferate the concept, PUB encourages public agencies and the private sector to adopt ABC Waters design features in their developments to reap these environmental benefits and achieve sustainable stormwater management.

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. Over the years, PUB continues to update the Guidelines with more examples of projects and innovative designs.

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. To date, many exemplary projects by public agencies and private sector have been certified and there are many innovative good designs in recent certified projects, signalling that the industry professionals have progressed in their capability on ABC Waters designs.

In 2011, PUB and the Institution of Engineers Singapore (IES) rolled out the ABC Waters Professional Programme aimed at building the expertise of industry professionals in the area of ABC Waters design features. To date, there is a sizeable pool of ABC Waters Professionals who are trained to carry out ABC Waters design for developments.

Fig. 1.3 ABC Waters Certification Award Ceremony 2016

Moving forward, the direction is towards "mainstreaming" of ABC Waters design and for ABC Waters design to become a fundamental element of urban planning. The challenge is to chart the course to change ABC Waters design from a "good to have" option to a "vital public good" necessity that provides multi-benefits.

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 waterbodies. 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.

1.4 BENEFITS OF EMBRACING THE ABC WATERS CONCEPT

Create Communal Spaces and Areas

ABC Waters sites bring the community closer to water and creates new recreational spaces for all to enjoy. Through adopting the ABC Waters concept, the spaces near waterways and waterbodies become an inviting and vibrant environment with facilities for residents and the larger community.

Fig. 1.4 Kolam Ayer ABC Waterfront – Floating deck to bring communities closer to the waterbody

Fig. 1.5 Sg Ulu Pandan (left) and Kallang River at Potong Pasir (right) – natural drainage improves the aesthetics of the urban hardscape

Fig. 1.6 A bioretention basin in Waterway Ridges which detains and treat stormwater runoff before discharging to downstream waterways

Educating the Public

At the core of the programme is the social aspect of getting the public involved in ensuring sustainability of scarce water resources by inculcating a sense of stewardship towards water. ABC Waters sites can also provide experiential learning for the younger generation to learn about sustainable stormwater management.

Deploy ABC Waters Design Features to Meet Other Government Agencies' Initiatives

ABC Waters design features are also recognised by several government agencies as a way of meeting the requirements of their programmes.

The BCA Green Mark Scheme is a benchmarking scheme that incorporates internationally recognised best practices in environmental design and performance. The Scheme recognises ABC Waters design as one of the best stormwater management practices.

Enhance Aesthetics and Biodiversity of the Landscape

ABC Waters design enhances the aesthetics and biodiversity of the landscape while slowing down the flow of stormwater runoff. This creates local green corridors by integrating nature into urban life.

Detain and Treat Stormwater Runoff

ABC Waters design features are natural treatment elements to detain and treat runoff before it is discharged to downstream waterways and waterbodies. With upstream planning and seamless integration with the landscape and drainage system, both hydrological benefits and water quality improvement can be realised, in addition to other environmental benefits.

ABC Waters design features are natural green features with plants. They can be considered as one form of greenery under Urban Redevelopment Authority's Landscaping for Urban Spaces and High-rises (LUSH) Programme to satisfy the requirements for landscape replacement.

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.

2.1 TRADITIONAL STORMWATER MANAGEMENT

Singapore receives about 2,400 mm of rainfall annually. 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 waterbody. In the past, most natural waterways such as Kallang River and Sungei Sembawang were designed as U-shape concrete channels to increase their conveyance capacity and reduce bank erosion. With continual urbanisation and climate change, rainwater runoff increases and the drainage channels need to be enlarged from time to time.

With two-third of Singapore's land area as water catchment, it is important to improve surface water quality from urbanised catchment areas so as to ensure a cleaner water supply in Singapore's reservoirs. Traditional concrete channel could do little in this aspect. As such, there is a need to develop a sustainable way to treat the rainwater runoff before channelling it into our reservoirs through the drains and canals.

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 cover the entire spectrum of the drainage system, flood risks can be more significantly reduced and effectively managed.

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

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

PATHWAY
The means or routes through which stormwater is conveyed

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

RECEPTOR
Where stormwater flows may propagate to and affect infrastructure

SOLUTIONS AT RECEPTORS
refer to measures to protect areas where the stormwater flows may end up, e.g. flood barriers for buildings, etc.

Fig. 2.2 Source-Pathway-Receptor Approach

2.3 ABC WATERS MANAGEMENT STRATEGY

To complement source solutions, ABC Waters design features can also provide detention of stormwater and treat 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 introduce additional flexibility within the system to cope with urbanisation and climate change. In particular, ABC Waters design features can be innovatively designed or integrated with other stormwater detention systems (i.e. detention tanks, stormwater ponds, etc.) to shave off the peak flows generated by intense rainfall. When implemented on a catchment wide basis, this reduces the risk of flooding at the development site and the larger catchment area. In addition, the features remove pollutants to mitigate the deterioration of runoff quality due to urbanisation.

Individual developments are therefore requested to implement ABC Waters design features to mitigate the impacts of urbanisation on waterbodies 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).

What happens to stormwater?

All the runoff goes into drains and straight into canals.

The water level in the canals rises very quickly.

Fig. 2.3 Traditional stormwater management

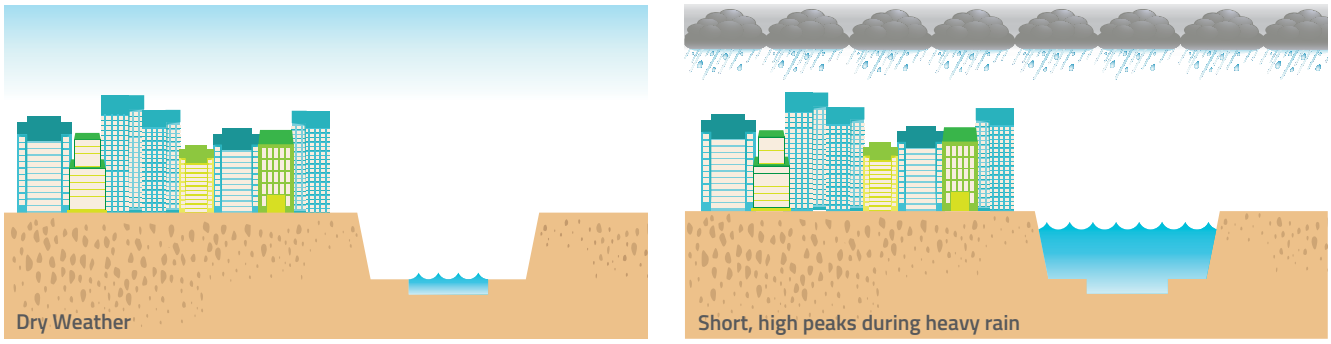


Fig. 2.4 Water levels in the canals under traditional stormwater management

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 re-use of harvested water 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 rainwater runoff through these features to remove pollutants before the water is collected and used for non-potable purposes.

Runoff is detained and treated on site

... and slowly released into the drains and canals.

Finally, runoff is slowed down and cleaner water will flow into our reservoirs.

Fig. 2.5 ABC Waters management strategy

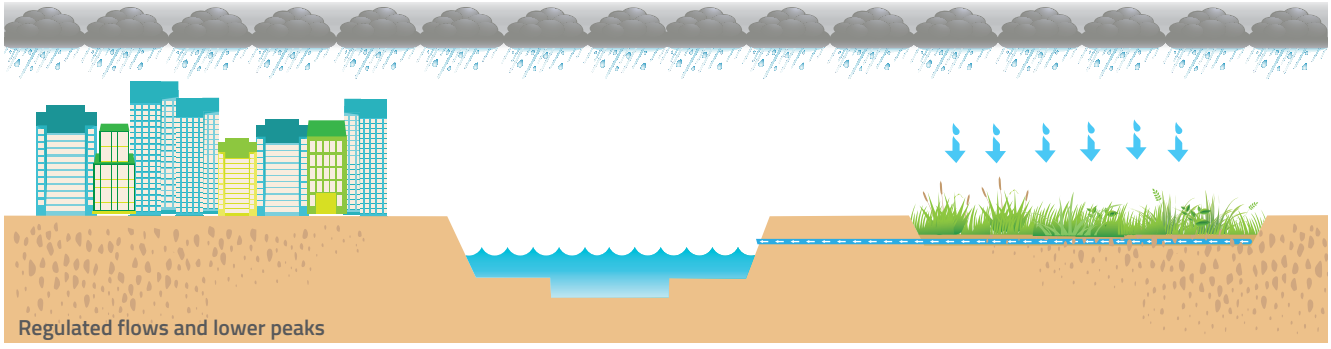


Fig. 2.6 Water levels in the canals if the ABC Waters management strategy is applied catchment-wide

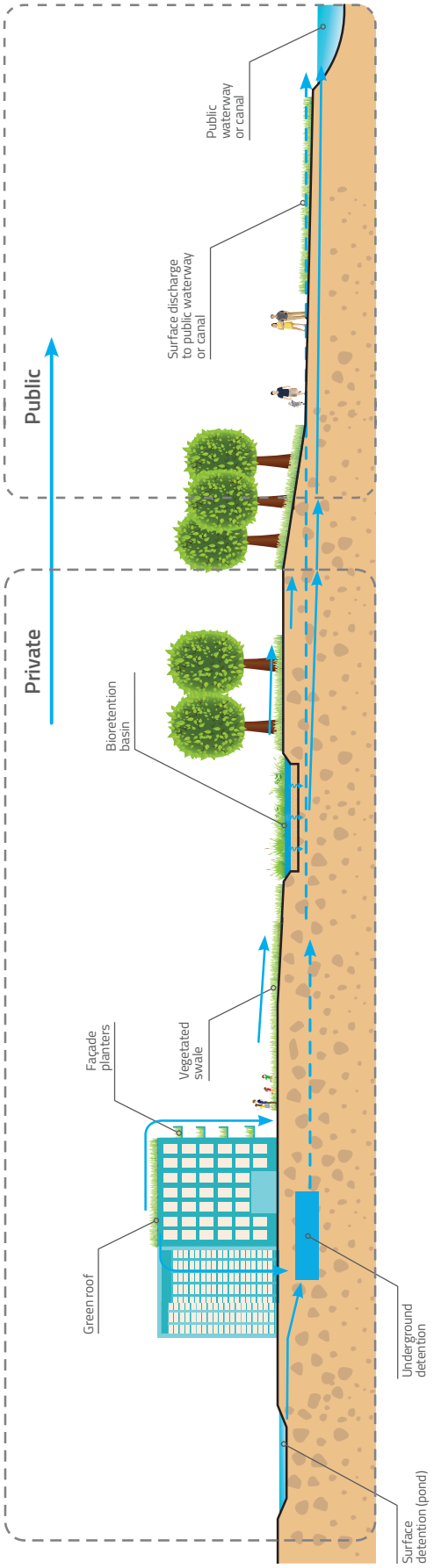


Fig. 2.7 An example of how ABC Waters design features can be integrated within a building development to slow down runoff

2.5 MAINSTREAMING THE ABC WATERS DESIGN

When planners, architects and engineers include ABC Waters concepts in the upstream process of planning, there is opportunity for a holistic stormwater system that serves multiple functions of detention, treatment and drainage of stormwater runoff in a development. Combining architecture, landscape design and engineering, such integrated approach can create flexibility in the system and remove downstream implementation challenges. The example of Waterway Ridges, a collaboration between the Housing & Development Board (HDB) and PUB, piloted the large scale implementation of ABC Waters design in a holistic manner within a public housing precinct. This was only possible when the vision of an "ABC Waters Precinct" was set out in the early stages of planning and design, where ABC Waters design features were deliberately proposed and devised intentionally throughout the development site.

As ABC Waters design progressively becomes entrenched as planning norms to be adopted, Singapore can begin to see more seamless and upscaling of ABC Waters projects. With wider adoptions by developers and the pervasive incorporation of ABC Waters design features throughout the whole water catchment, Singapore can realise the full potential of the ABC Waters management strategy in ensuring slower and cleaner runoff in our waterways and waterbodies.

SECTION 3

GUIDELINES FOR ABC WATERS MANAGEMENT STRATEGY

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

This chapter highlights the key considerations that the designer should be familiar with when adopting 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 https://www.pub.gov.sg/Documents/COP_Final.pdf)

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

- **On-site Stormwater Detention Tank Systems Technical Guide** (This document is available for download at https://www.pub.gov.sg/Documents/detentionTank.pdf)

- The **Code of Practice on Environment Health**, which addresses the various aspects of mosquito control. (This document is available for download at http://www.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 runoff from ABC Waters design features, including constructed wetlands and retention ponds, could be stored on-site for reuse. Any excess water must subsequently be discharged to a roadside drain or an outlet drain/waterway.

From January 2014, developers/owners for all industrial, commercial, institutional and residential developments greater than or equal to 0.2 hectare in size 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 the catchments (https://www.pub.gov.sg/drainage/floodmanagement).

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

Subjected to the approval of PUB, ABC Waters design features can 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) Consideration for 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 (such as 1-in-3-month 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. 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 peak flows from the catchment of ABC Waters design features.
- The minimum engineering requirements for surface water drainage are specified in the latest edition of the Code of Practice on Surface Water Drainage.

ii) Consideration for Water Quality Improvement

The stormwater quality objectives or the performance targets of ABC Waters design features are directed at the protection of urban waterbodies 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.

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

Table 3.1 Stormwater quality objectives for Singapore

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

iii) Site Investigation

Site investigation, especially soil property test and services detection, are to be carried out before commencing physical works on site. It is necessary to take note of abnormalities or hindrances observed during site investigation so that design can be reviewed to suit site condition. This will also minimise delay of work during construction stage.

iv) Plant Selection

Plants are essential for the proper functioning of ABC Waters design features. Plants help to stabilise swales and batter slopes and maintain the infiltration capacity of the filter media. Not all plant species are suitable for all these functions. A list of plants that are used for the filter media in bioretention systems is in Chapter 6 of the Engineering Procedures for ABC Waters Design Features. The list can serve as a guide but their suitability, based on site conditions, must still be assessed by the designer. Designers can also make reference to “Sustainable Landscape”, a publication by the Centre for Urban Greenery and Ecology (downloadable from NParks website https://www.cuge.com.sg/landscapeservices/main/landscape-weed-mgmt-and-sustainable-landscape-e-book.html).

a. Within Treatment Area

Plants with fibrous roots are generally better in keeping the infiltration capacity of the soil media. Hardy plants, that can survive in sandy and low-nutrient soil as well as wet conditions, are required for features like bioretention systems that get inundated during rain events. Water plants are suitable for constructed wetlands. Additional considerations include capability of plant species for better removal of pollutants like nitrogen and heavy metals.

b. Channel and Batter Slope

Ground covers are normally used for vegetated swales and batter slope of bioretention systems to prevent soil erosion. Tall plants are normally not recommended for the flow channel of swales, as they obstruct the flow of runoff and increase the roughness coefficient of the channel.

c. Surrounding Area

- To minimise the usage of thorny plants (eg: Caesalpinia pulcherrima) alongside footpath.
- To minimise encroachment of plants onto footpaths by leaving a 500mm buffer zone along planting verges that abuts footpaths.
- To minimise usage of hefty and large growing plants at corners (potential blind spots).
- Avoid having long stretches (>20m~) of monoculture to minimise undesirable pest issues that targets specific species (for example, planting one species of *Ipomea pes-caprae* along the whole stretch of a waterway could attract large swarms of leaf footed bugs).

v) Provision of Maintenance Access

- Maintenance gates for workers to access workzones beyond railings
- Vehicular maintenance access (if necessary)

vi) Subsoil Pipes

Subsoil pipes shall be connected to a sump (either overflow or a separate sump) instead of discharging directly into surrounding drains for ease of maintenance checks.

vii) Inlet Zone

Provide a forebay at the inlet of features to prevent scouring / erosion and facilitate sedimentation. The overflow and outlet of the feature shall be positioned away from the inlet as to prevent short circuiting of flow path.

viii) Gravels

Gravels used in the forebay or bottom of swales are to be appropriately sized or embedded to prevent being washed away.

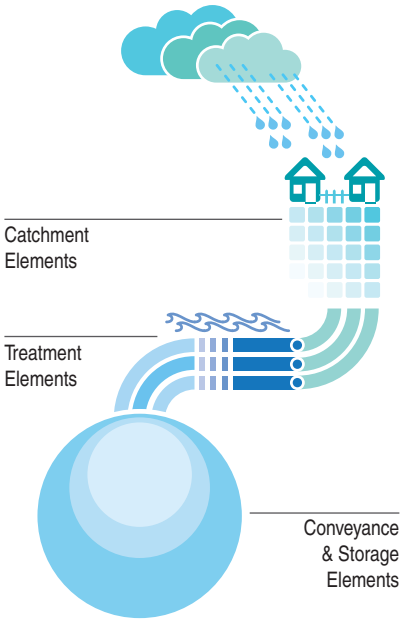
ix) Safety Considerations

A risk and safety assessment shall be conducted to identify potential safety hazards that might occur after the implementation of stormwater management measures. It is foremost to put public safety as the most important consideration and is the responsibility of the developer and / or Qualified Person (QP) to ensure that all applicable safety standards are met and a system of safety is set up and in place. The designer shall develop a risk assessment form or a safety design checklist to check the safety aspect of the design. The checklist should be reviewed early during project development, and identify factors in the design that ensure safe construction, operations and maintenance. Inputs from the construction team and maintenance agent should be sought when drawing up the checklist.

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 can 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 is critical that ABC Waters design features are incorporated into the development plans.

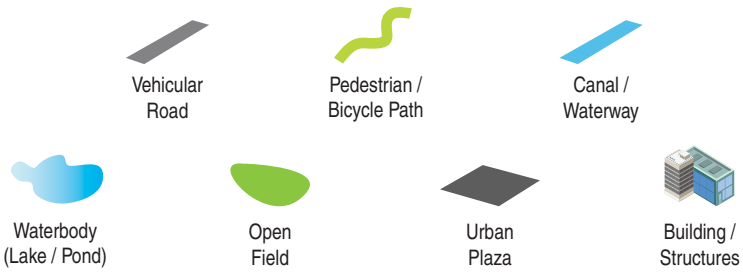
In this section, we will examine the elements involved in a typical stormwater passage and discuss the following elements in detail:

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 waterbodies (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 Waters 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

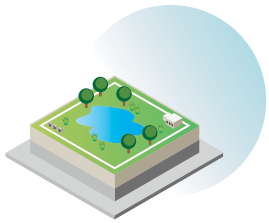
1. Smaller structures interspersed throughout the site, affording no large open space, but a network of interstitial spaces

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 common features in Singapore's urban landscape, particularly in commercial and retail spaces where large crowds gather, such as Orchard Road and Shenton Way. The following are common but unsustainable approaches 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.

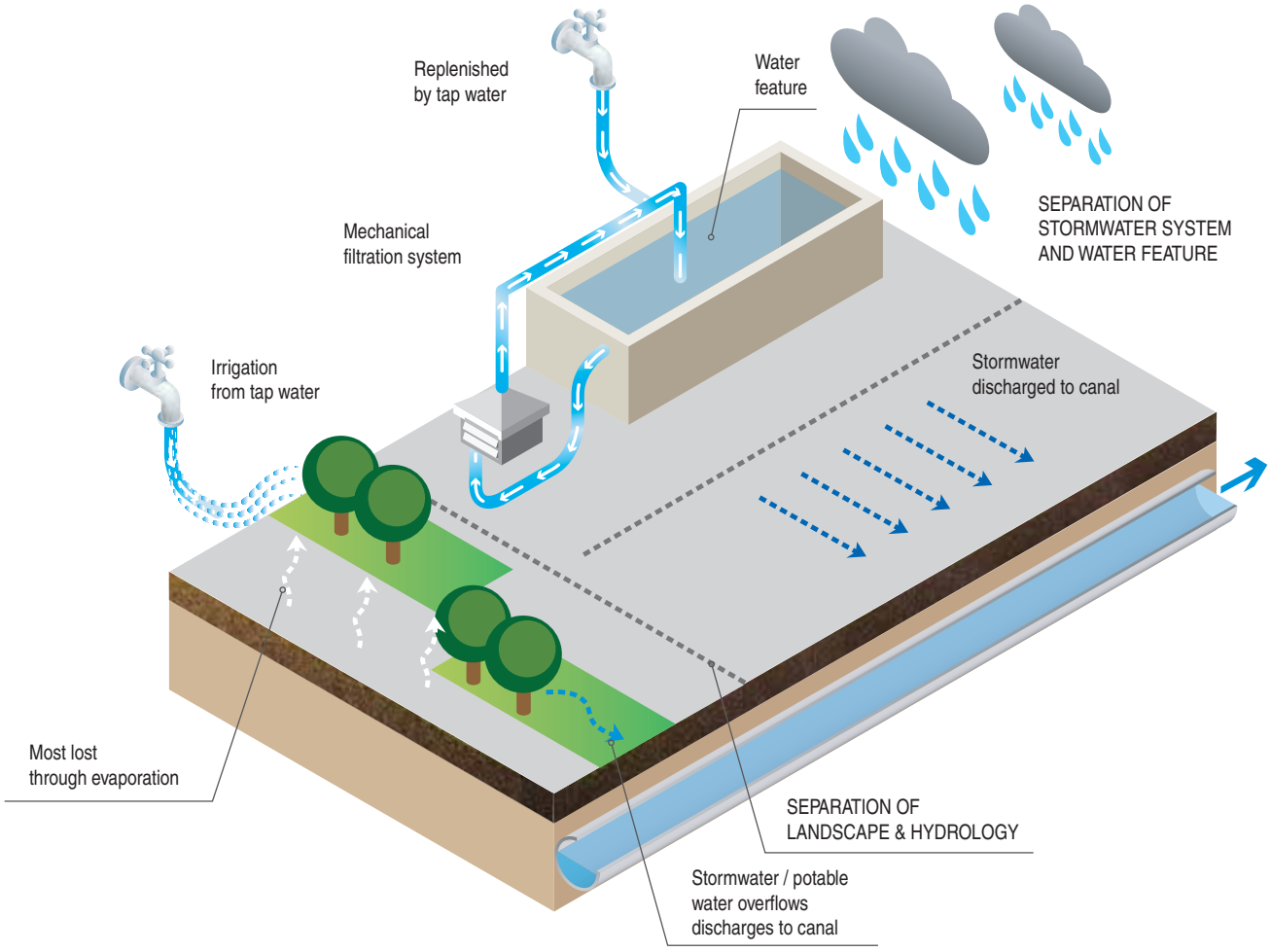


Fig. 4.1 Existing situation of a typical plaza (not sustainable)

4.1.3 AN INTEGRATED PLAZA WITH ABC WATERS DESIGN FEATURES

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

i) Cleansing

The plants take on a cleansing 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 and enhanced biodiversity.

ABC Waters Concept — integration of environment, waterbodies and community

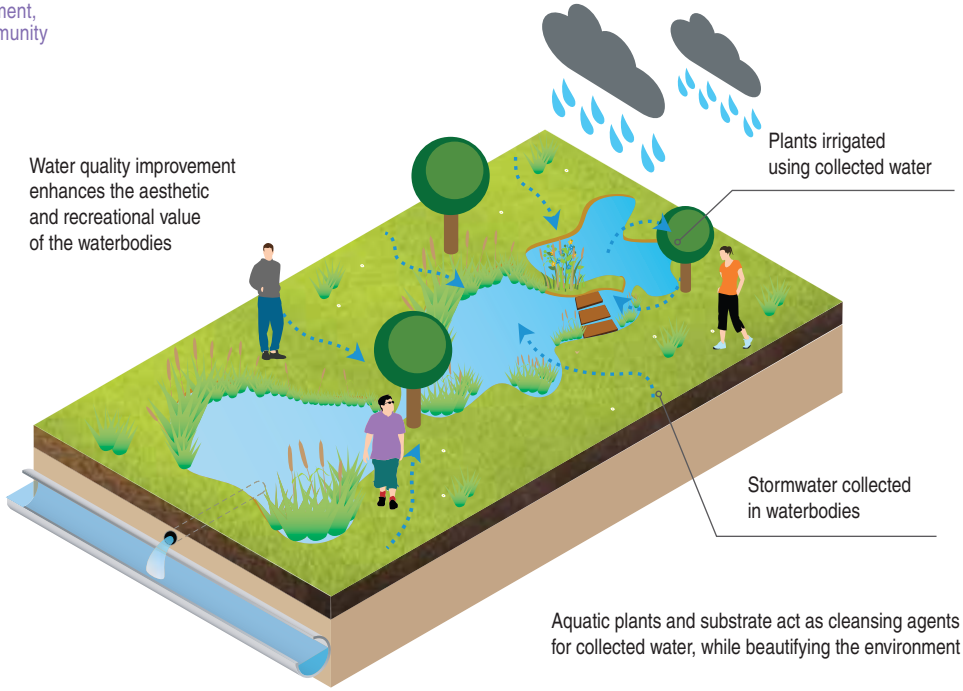


Fig. 4.2 ABC Waters design features in a plaza can be both cleansing features and public amenities

Fig. 4.3 Water feature and stepping stones at a plaza area in Yale-NUS College

Fig. 4.4 Cleansing biotopes installed at the Central Plaza in Jurong Eco-Garden

4.1.4 ARCHITECTURAL STRUCTURES

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

- Rooftop
- Sky garden or terrace
- Balcony
- Planter box
- Ground level greenery

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.

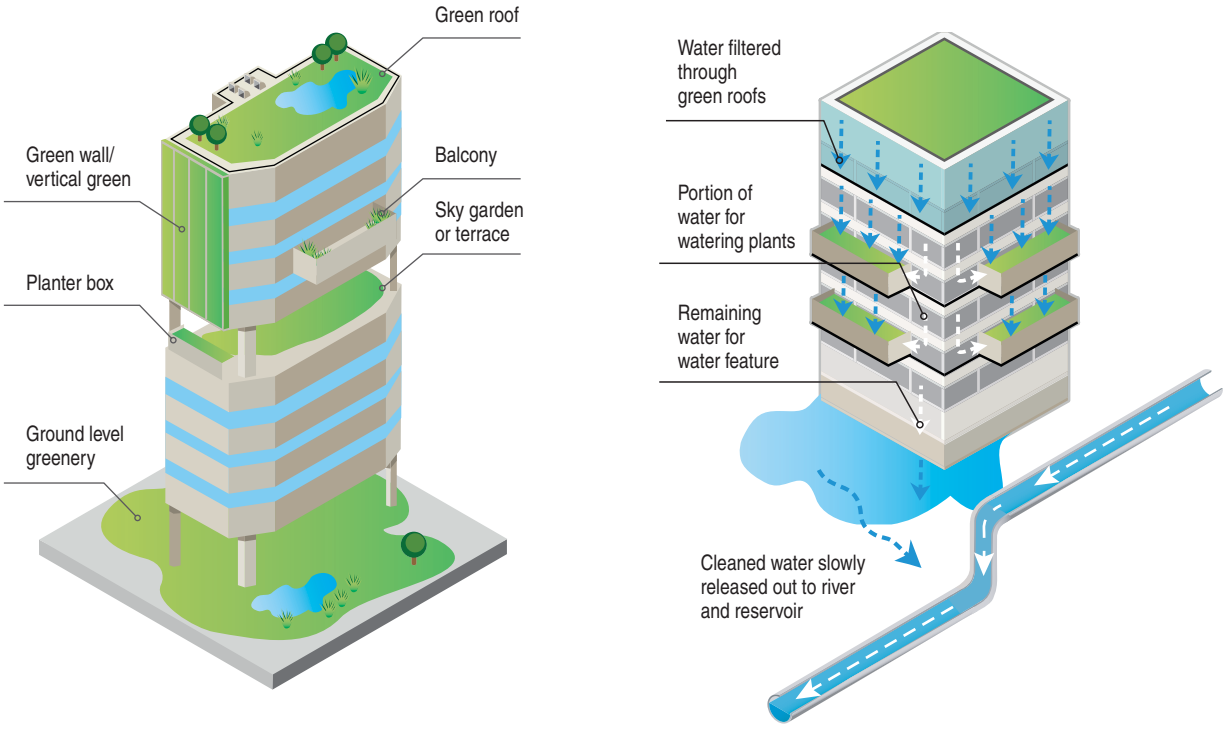


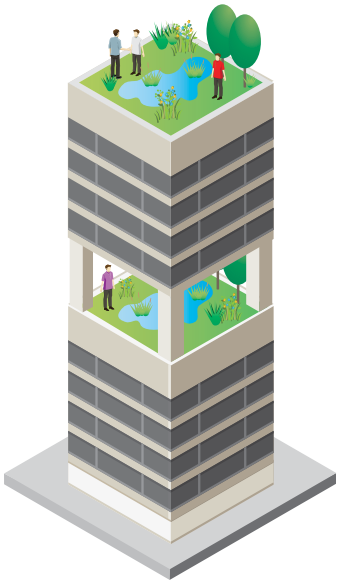
Fig. 4.5 Treatment features located at various levels of the building elements in Kampung Admiralty

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 Orchard Central, 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.

Rainwater runoff can first be collected and cleansed (using rain gardens or cleansing biotopes) on the roof, then channelled to the various water features on lower levels. Alternatively, the cleansed water can be used to irrigate the plants on the planters and balconies, or for the washing of pavements and walkways.



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

Fig. 4.6 Intensive green roof at a multi-storey carpark in Whampoa Dew

Fig. 4.7 Green roof at Orchard Central

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 rainwater that could be supplied to plants when there is no rain. It is not designed as a recreational space.

As a result, less water 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. 4.8 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 rainwater runoff.

Fig. 4.9 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 high purification standards.

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

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

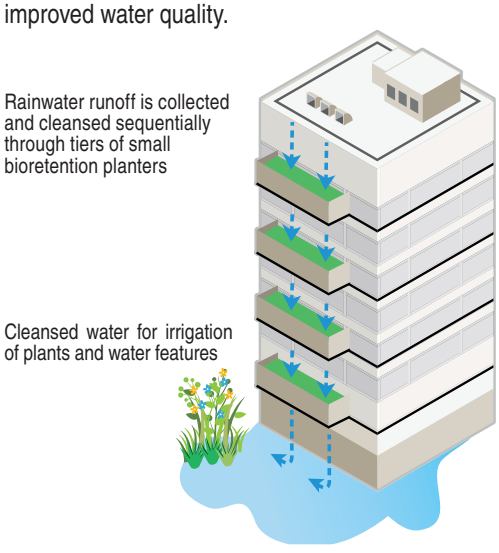


Fig. 4.10 Vertical greeneries commonly utilised in public as well as private developments in Singapore (South Beach Development & Tree House Condominium)

The following is an example taken from Kampung Admiralty, where multi-level planters of bioretention basins cleanse runoff from the roof while creating a pleasant atmosphere in the building all year round. The cleansed water is stored in the rainwater harvesting tank that provides irrigation water.

Overflow from the harvesting tank is channelled to ABC Waters design features (such as vegetated swales, cleansing biotope) at ground level, which are integrated with the plaza. Details of this project can be found in Section 10 Case Studies.

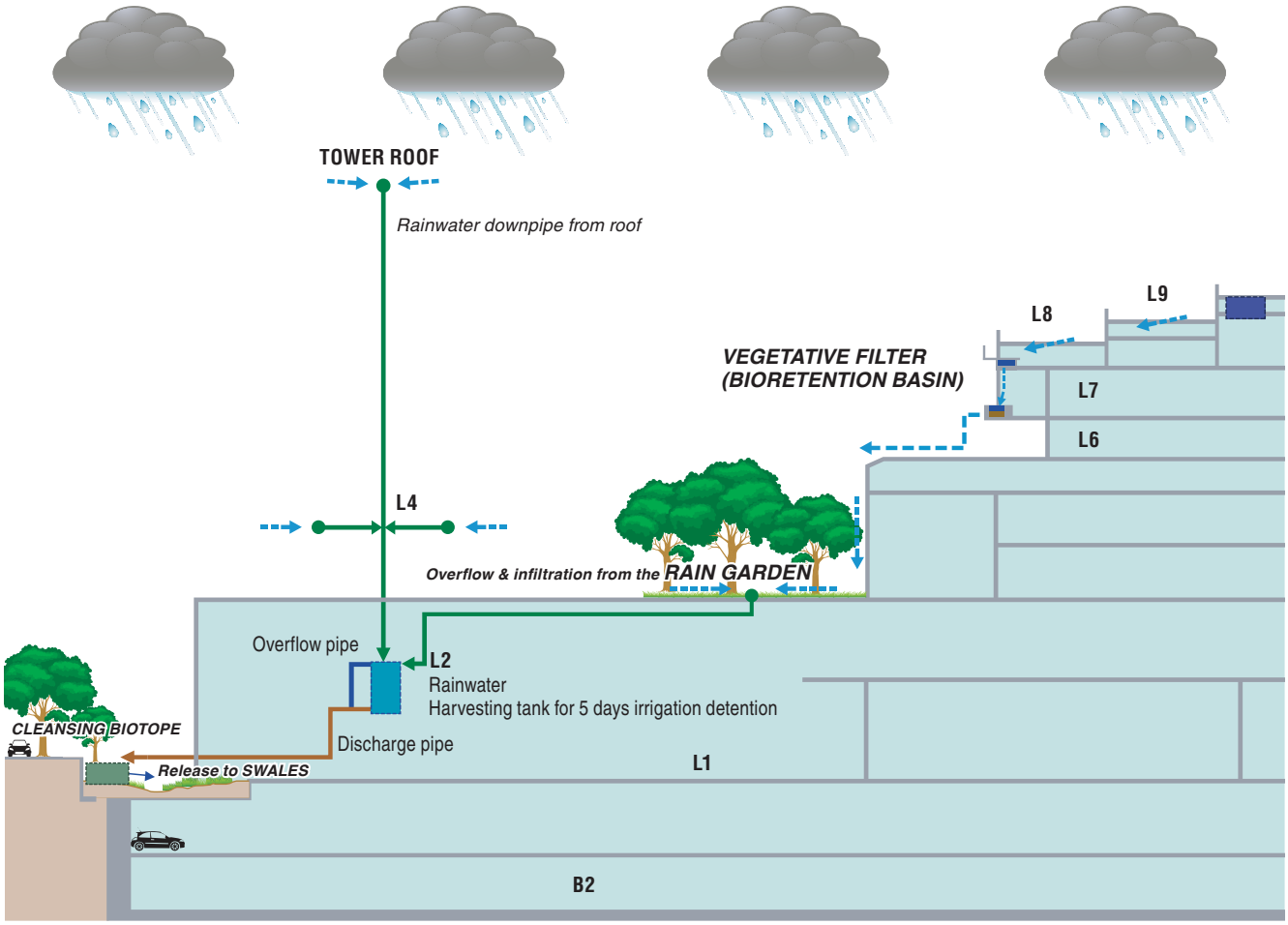


Fig. 4.11 Section of Kampung Admiralty showing the application of tiered bioretention planters and its integration with rainwater harvesting system and treatment systems

Fig. 4.12 Exterior façade of Kampung Admiralty with multi-functional greeneries

Fig. 4.13 Cleansing biotope, an ABC Waters design feature, located at ground level helps to cleanse runoff

4.1.5 VEHICULAR ROADS AND PEDESTRIAN WALKWAYS

The typical road in Singapore comprises carriageways that are sloped towards either the roadside kerbs 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 cleansing stormwater runoff before it is discharged to roadside drains.

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
Bioretention swale along a road with standard kerbs (with slots) in Faber Hills Estate

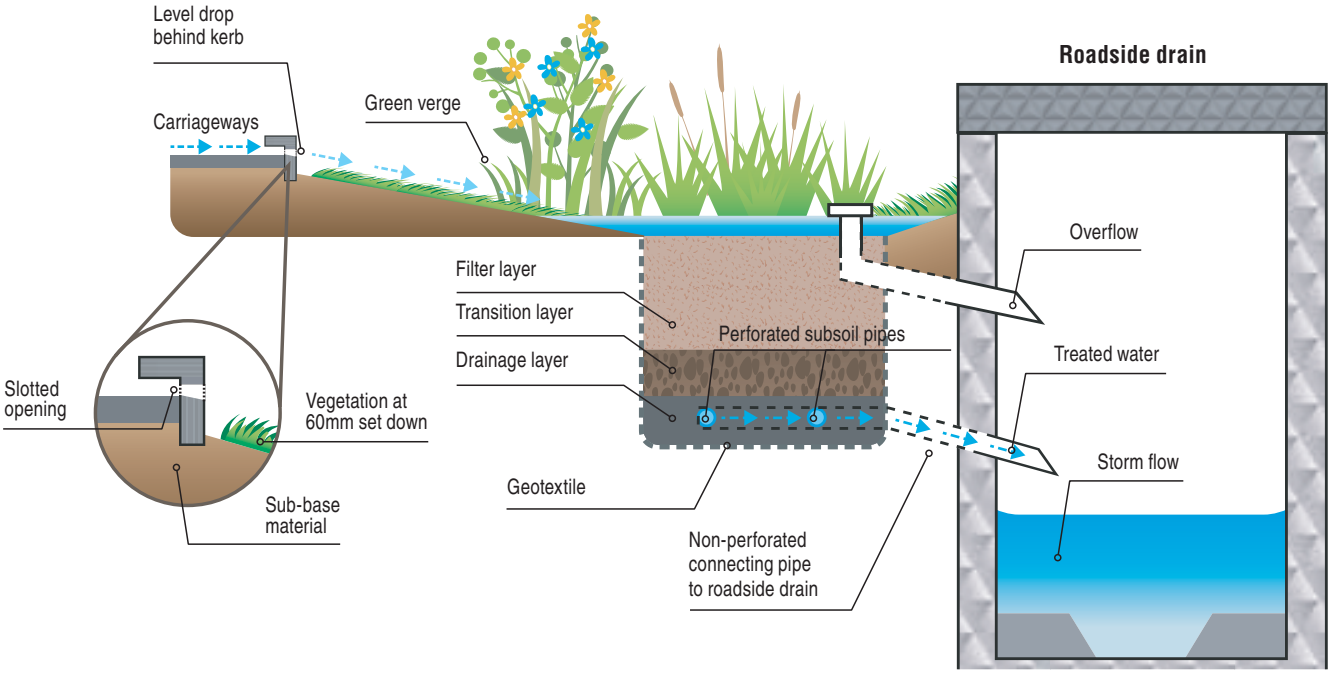
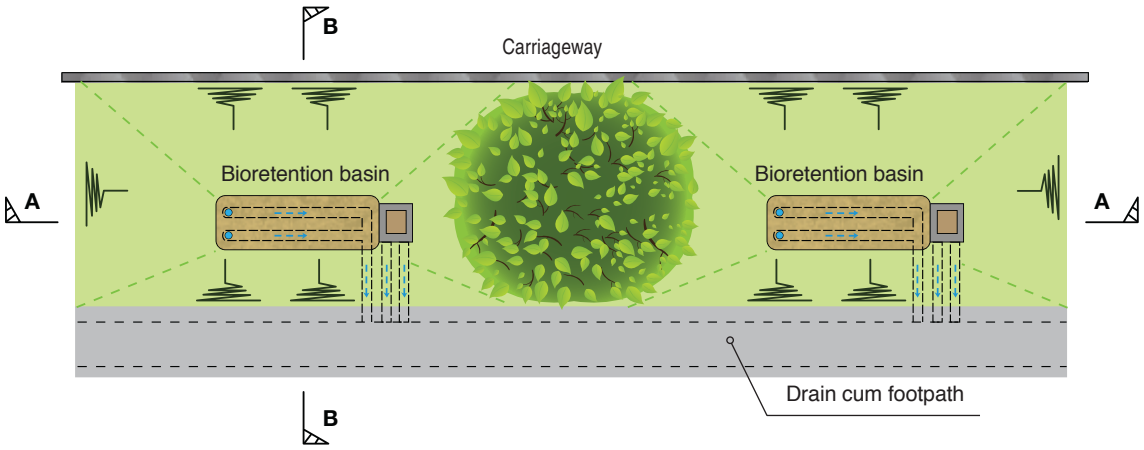
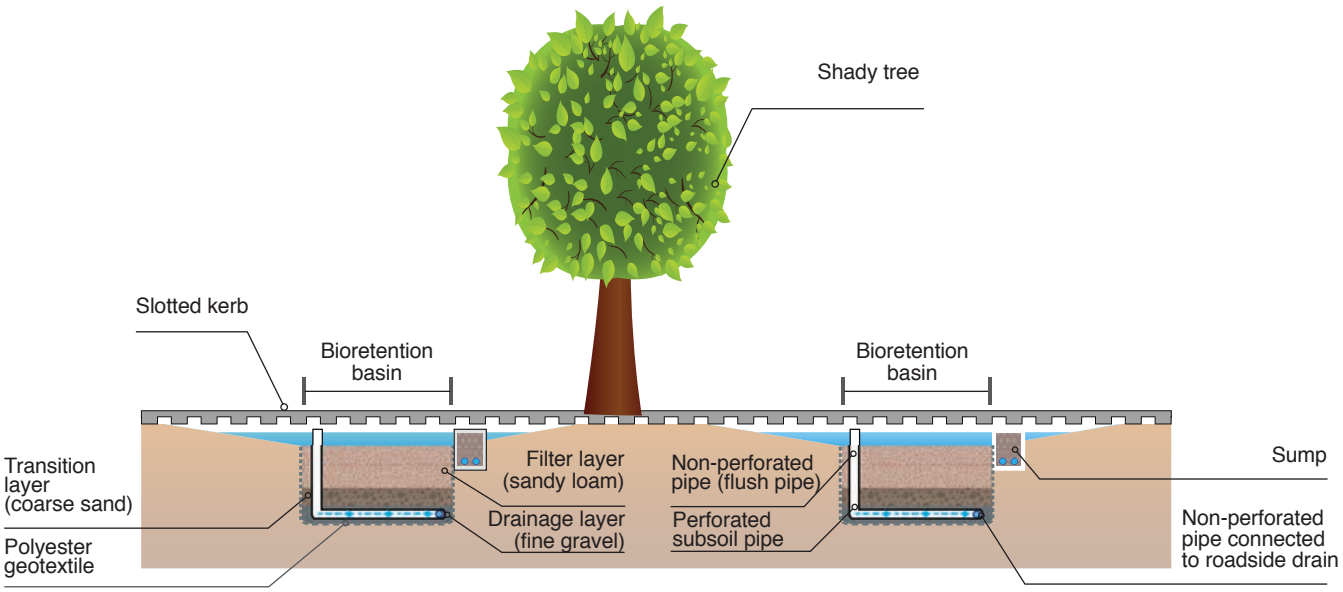


Fig. 4.15 Application of a bioretention system within a road verge with standard kerbs (with slots) and a set-down behind the kerb to facilitate ingress of road runoff

PLAN



SECTION A-A



SECTION B-B

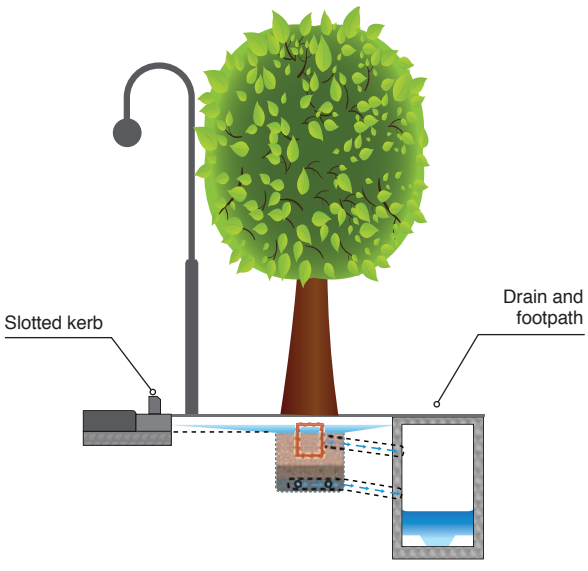


Fig. 4.16 Plan & sections of bioretention basin application in a roadside verge.

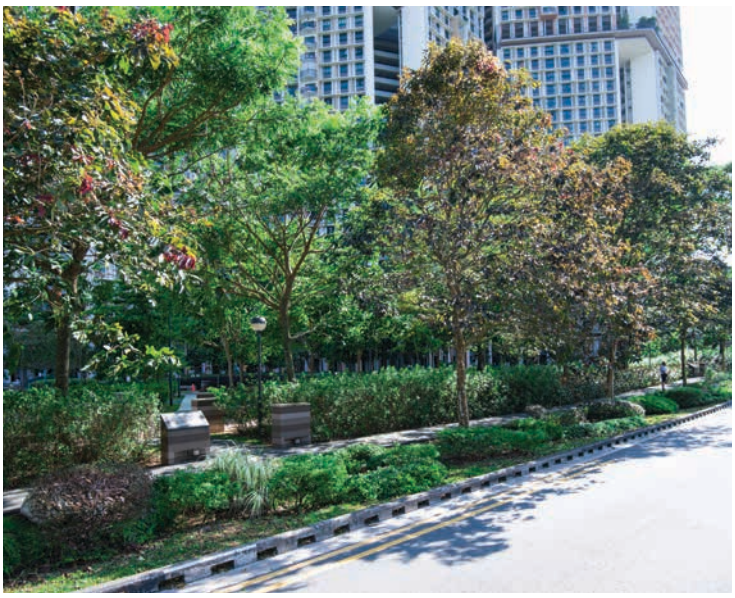
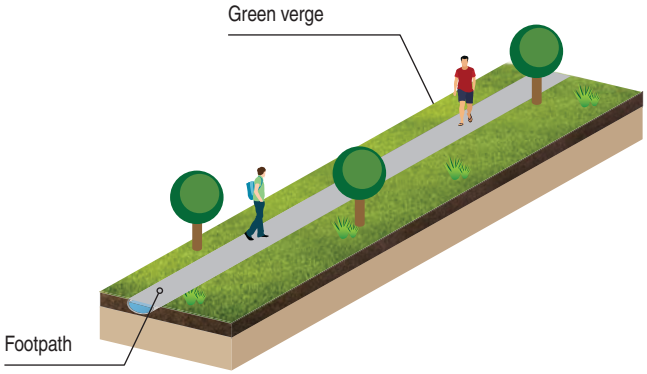


Fig. 4.17 Bioretention basins along Margaret Drive

Existing roads (including side verges) 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

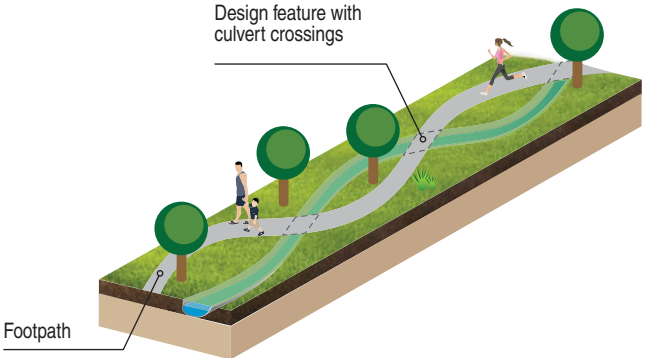


Fig 4.18 Typical car-parking facilities with concrete drains (above), Fig. 4.19 Typical roads with pedestrian pathways (top right) and Fig 4.20 Expressways with green verges and roadside drains in Singapore (right)

Fig. 4.21 Carpark at the Singapore Botanic Gardens with a vegetated swale to treat carpark runoff

Fig. 4.22 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. 4.23 Vegetated swale integrated with footpaths and timber deck in Greenwood Sanctuary

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 cleansing it.

They are cost-effective, natural and environment-friendly green features for sustainable 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 generic maintenance requirements. The document also gives guidance on selection and sizing of the treatment elements with worked examples and checklists.

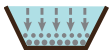
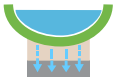
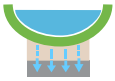
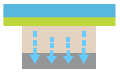
Stormwater Management Functions	Purification	Detention
Purpose	 Clean stormwater runoff so that cleaner and clearer water enters our reservoirs. This also beautifies the waterbodies so people can enjoy them. Stormwater runoff can be purified through one or a combination of the following: ◆ Sedimentation  ◆ 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.
Treatment Elements	◆ Vegetated swales  ◆ Bioretention swales  ◆ Bioretention basins  ◆ Cleansing biotopes  ◆ Constructed wetlands  ◆ Sedimentation basins 	◆ Vegetated swales  ◆ Bioretention swales  ◆ Bioretention basins  ◆ Cleansing biotopes  ◆ Constructed wetlands  ◆ Sedimentation basins 

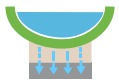
Table 4.1 Roles of ABC Waters design features in stormwater management

Every treatment element covered in this chapter has different water treatment or cleansing capabilities. They cleanse 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 is its primary stormwater management function (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 cleansed as it percolates down. The cleaned water is collected by subsoil pipes or allowed to soak away into in-situ soil. Plants with suitable root systems are used to keep the filter media porous.
◆ Constructed wetlands  ◆ Sedimentation basins 	◆ Vegetated swales  ◆ Bioretention swales 	◆ Bioretention swales  ◆ Bioretention basins 

4.2.1 VEGETATED SWALES

Introduction

Vegetated swales are natural drainage channels with mild slope. They are used to convey stormwater via overland flow at a slower speed to allow settlement of sediments. 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 perimeter or compound drains, park 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 the settlement and detention of coarse to medium-sized solids in the rainwater runoff. 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.

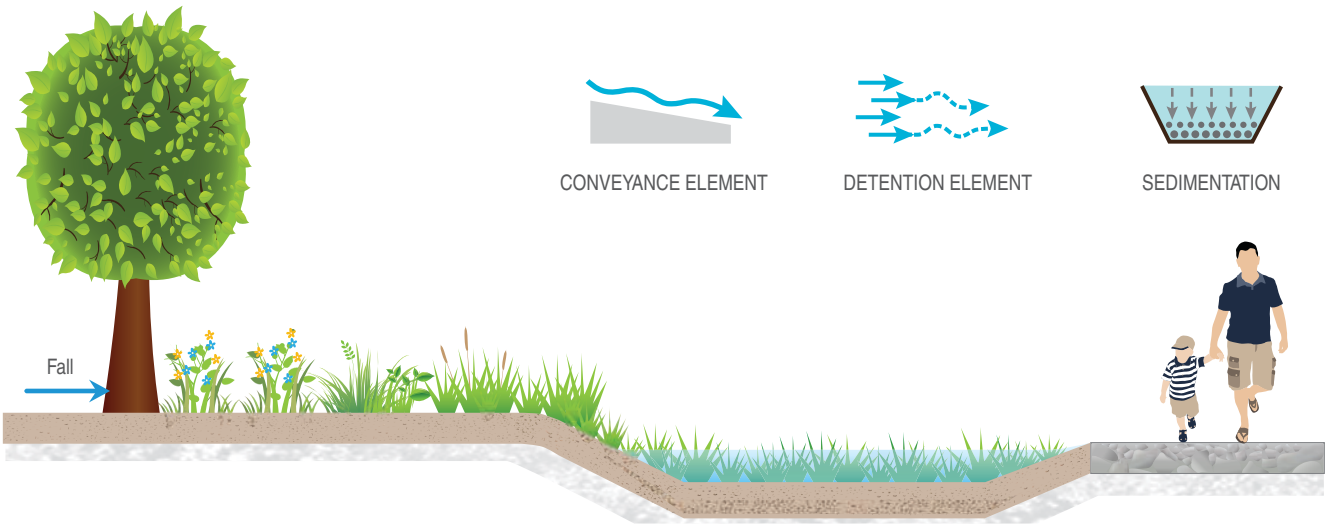


Fig. 4.24 Typical section of a vegetated swale

Benefits

- Reduces flow velocities and remove solids like stones and other particles to protect downstream waterways from erosive flows during storms.
- Provides effective pre-treatment for downstream ABC Waters design features like bioretention swales, rain gardens or constructed wetlands.
- Beautifies the surrounding landscape, integrates well with green area and provides drainage.
- 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 and longitudinal profile of the vegetated swale are maintained and that it is not subjected to erosion or excessive deposition of debris and sediments 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
- Maintain the height of vegetation within the flow channel
- 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. 4.25 Vegetated swales at Bishan-Ang Mo Kio Park

4.2.2 BIORETENTION SWALES

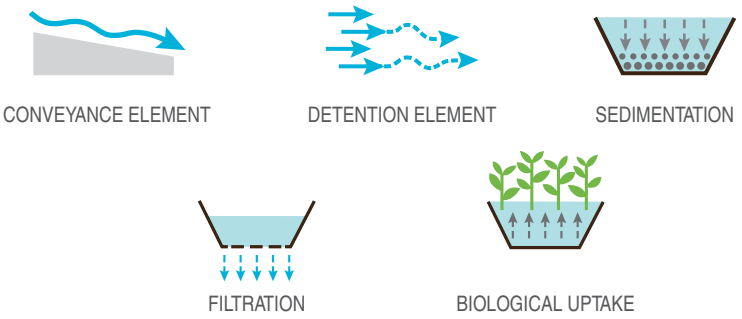
Introduction

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 cleansed 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, carparks, residential, commercial, industrial areas and parklands, etc. They could 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 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.



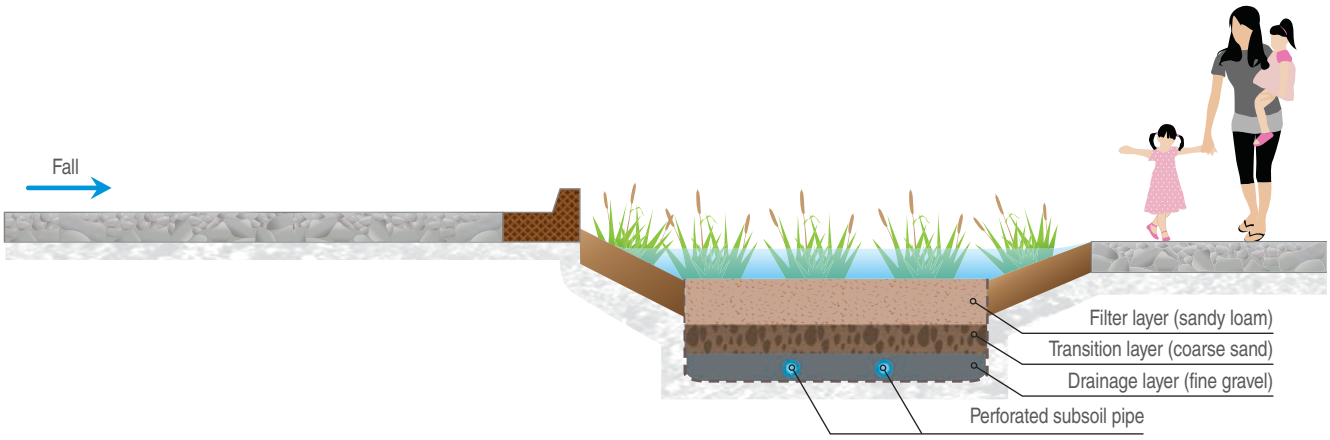


Fig. 4.26 Typical section of a bioretention swale

Benefits

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

Operation & 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 and slope of the bioretention swale are maintained and that it is not subjected to erosion or excessive deposition of debris and sediments that may impede the passage of stormwater. The inlet points and overflow points or pits have to be kept clear.

Maintenance of bioretention swales primarily consists of:

- Routine inspection and repair of the bioretention swale cross-section and longitudinal profile
- Routine inspection of inlet and overflow points to clear any blockage and repair any damage.
- Routine removal of litter, debris and sediments
- Maintain the height of vegetation within the flow channel
- 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. 4.27 Bioretention swale along Kallang River at Potong Pasir

To facilitate ease of construction at tight sites, a modular bioretention swale can be used. A modular bioretention swale consists of three basic modules: an inlet module, middle modules and an outlet or overflow module. The inlet module contains an inlet pipe to direct stormwater runoff from the catchment area into the bioretention facility. The middle modules are connecting modules to join the inlet module to the outlet module. The number of middle modules added depends on the size of catchment area and the desired length of the swale. The outlet or overflow module allows stormwater runoff to overflow when the influent stormwater runoff exceeds the designed capacity of the swale. The subsoil drainage pipe runs through all the modules installed and discharges at the outlet module.

Such a design facilitates easy construction as the system can be manufactured offsite and assembled on-site to shorten construction time. Fig 4.28 shows the typical cross-section of a modular bioretention swale system.

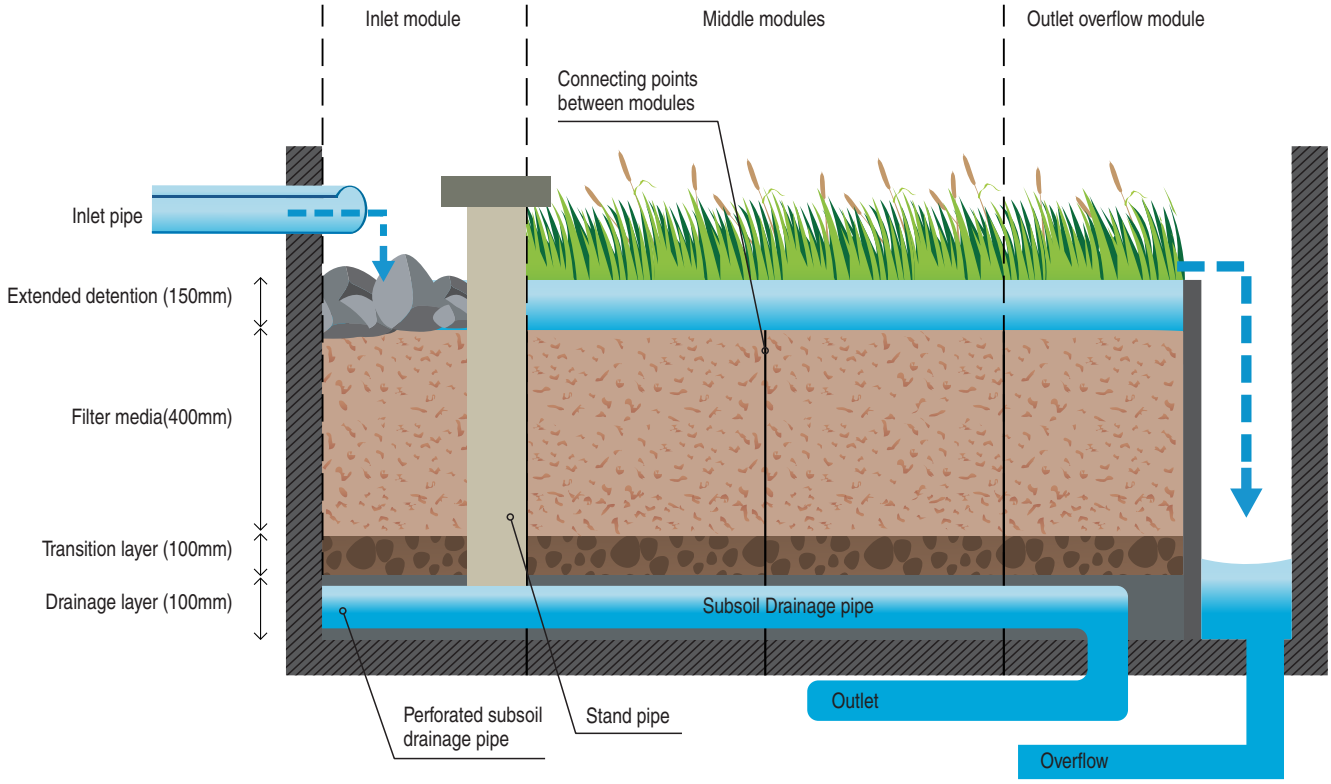


Fig. 4.28 Sectional view of a modular bioretention swale

Fig. 4.29 A modular bioretention swale at NUS High School

4.2.3 BIORETENTION BASINS (RAIN GARDENS)

Bioretention basins or rain gardens 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 layers). 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 uptake (by plants, bacteria, etc). Rain gardens can be installed in 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 small sedimentation basin (refer to section 4.2.4) or a vegetated swale 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.

Soak Away Rain Garden

Typically, subsoil 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 as it only has one filter layer and no subsoil pipe. It is suitable for small developments like schools or even private homes. Test-bedding of soak away rain garden has been carried out in a few local schools (see case study in Section 10).

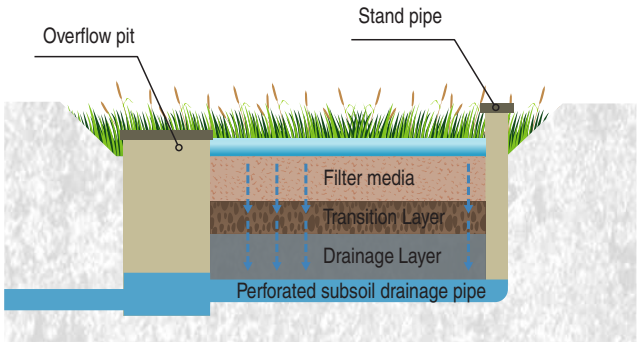


Fig. 4.30 Typical cross-section of a conventional rain garden

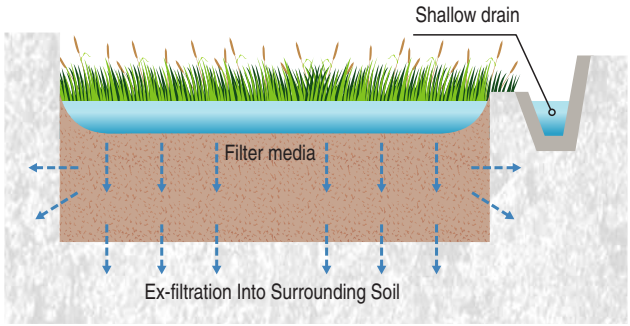


Fig. 4.31 Typical cross-section of a soak away rain garden

Benefits

- Ease of design
- Encourages habitat creation and promotes biodiversity
- Beautifies surrounding landscape
- Filters and cleanses 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 well-covered healthy growth of vegetation is critical to its performance.

Maintenance of bioretention basins primarily consists of:

- 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 sediments from the forebay
- 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. It is good to use a variety of plants to control plant damage by pest.

Fig. 4.32 Bioretention basin at Lower Seletar Reservoir Park

Fig. 4.33 Soak away rain garden in Anglo-Chinese Junior College

4.2.4 SEDIMENTATION BASINS

Introduction

Sedimentation basins are ponds that provide temporary detention or longer time retention of stormwater runoff as well as reduction of the flow velocity to promote the settling of particles by gravity. They are designed to capture 70 to 90% of coarse to medium-sized sediments (typically above 125µm). The settled sediments can then be removed periodically. Sedimentation basins are used as pre-treatment features for constructed wetlands and bioretention basins. Larger sedimentation ponds can be used as water storage ponds or pre-treatment upstream of aesthetic water features 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 like irrigation.

Application and Principles

Sedimentation basins can be permanent water features in an urban setting or temporary measures to control sediment discharge during construction. Its primary function is to capture coarse to medium-sized sediments 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. It can also be used as a stormwater detention pond.

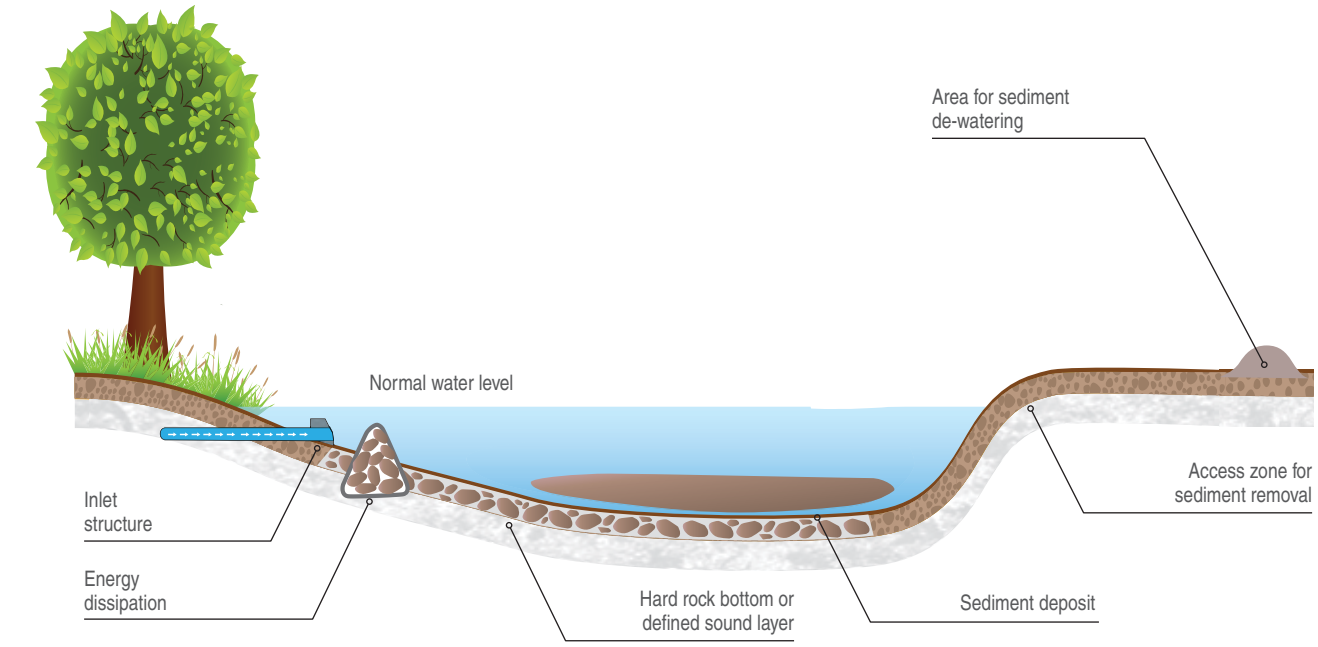


Fig. 4.34 Typical section of a sedimentation basin

Benefits

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

Operation and 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. 4.35 Sedimentation basin at Jurong Eco-Garden

Fig. 4.36 Sedimentation forebay at Grove Drive wetland

4.2.5 CONSTRUCTED WETLANDS

Introduction

The use of constructed wetlands for stormwater management is widely adopted in many urban and rural areas. Constructed wetland systems are shallow and extensively vegetated waterbodies 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 provide significant habitats for wildlife.

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

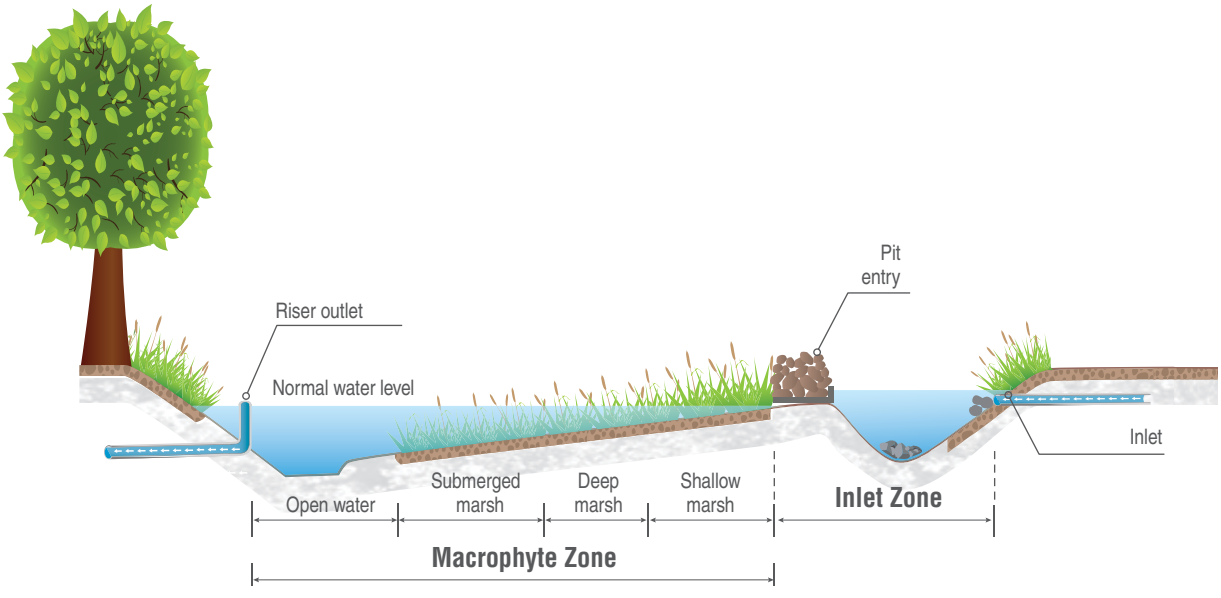


Fig. 4.37 Typical section of a surface wetland system

Fig. 4.38 Grove Drive surface flow wetland

Fig. 4.39 Lorong Halus sub-surface flow wetland

Fig. 4.40 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 promote biodiversity.

i) Surface Flow Wetland

A small scale surface flow 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 cleanse 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 cleanses water naturally without the use of any chemicals
- Encourages habitat creation and promotes biodiversity
- Beautifies surrounding landscape

Operation and 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, removal of dead plants and harvest of overgrown 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

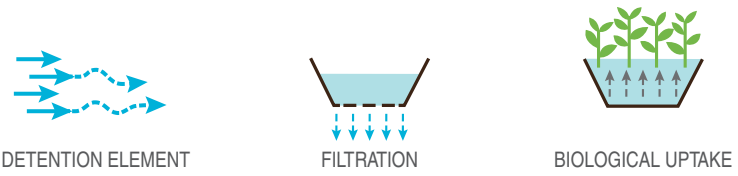
Introduction

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 cleansing capacity.

Application and Principles

Cleansing biotopes can be implemented in a variety of situations, such as in the revitalisation of lakes and the cleansing of urban waterbodies. They can also be added in outdoor areas such as parks, open fields, ponds and lakes. Areas such as rooftop gardens, gardens in building interiors, open plazas next to buildings or even under elevated structures can also be integrated with such features. The cleansing biotope can be subdivided into smaller areas (such as small sky gardens and planters) that work together in sequence for incremental cleansing.

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 nutrients in the water. If higher water quality is needed, the cleansed water is often recirculated for another pass through the cleansing biotope.



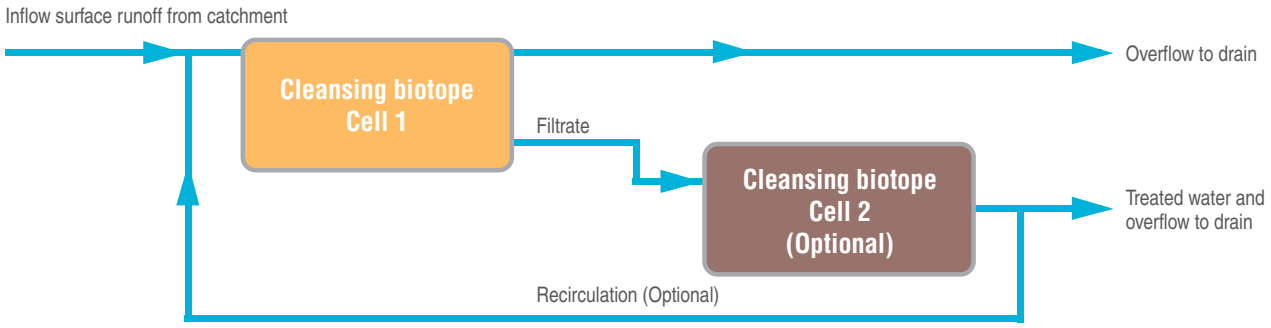


Fig. 4.41 Typical schematic of a cleansing biotope system

Benefits

- Filters and cleanses water naturally without the use of any chemicals
- Encourages habitat creation and promotes biodiversity
- Beautifies surrounding landscape
- Achieves high water quality by multiple passes

Operation & Maintenance

- Routine weeding, removal of dead plants and harvest of overgrown plants.
- Routine removal of litter, debris and sediments.
- 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 regularly 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

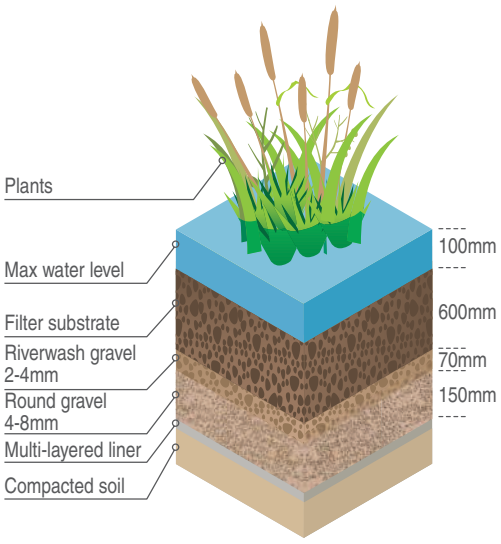


Fig. 4.42 Cleansing biotope at Bishan-Ang Mo Kio Park

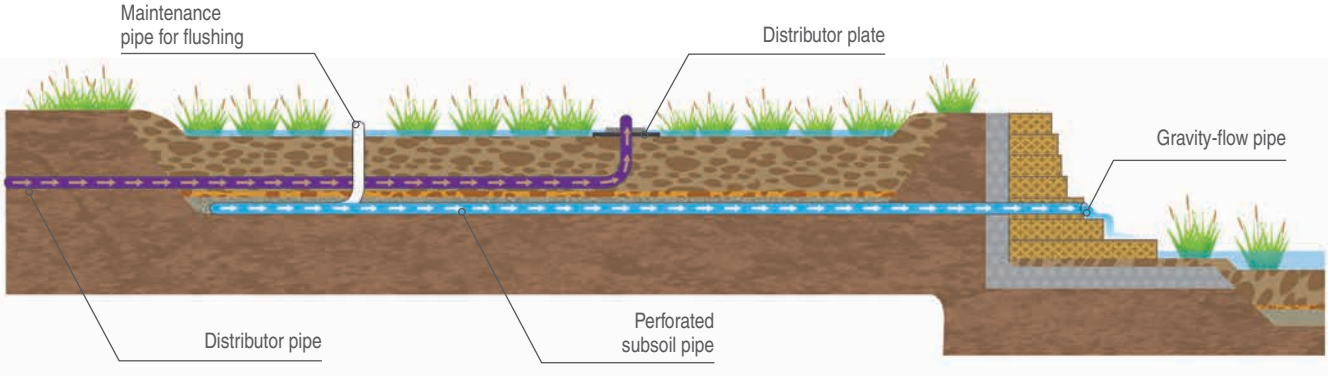


Fig. 4.43 Typical section through a cleansing biotope

4.3 CONVEYANCE AND STORAGE

WATERBODIES WATERWAYS

Singapore's extensive stormwater network comprises some 17 reservoirs 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 waterbodies.

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

i) Land Use

- Affects the kind of pollutants
  Stormwater pollutants from urban development 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, organics, 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. 4.44 Submerged boardwalk at MacRitchie Reservoir

- Affects quantity of runoff
  The high density of buildings and paved areas has an inverse effect on stormwater infiltration levels, and increase the runoff rates. Detention of stormwater on-site is necessary for urban developments and ABC Waters design features can be used as detention measures.

ii) Soil and Geological Condition

The composition of soil has an effect on a variety of properties. 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. 4.45 Careful design of waterway can help to preserve biodiversity

4.3.1 ENHANCING WATERWAYS

i) Incorporating Amenities to Bring People Closer to Water

Areas next to waterways can be transformed into attractive promenade spaces to encourage the community to enjoy our waterways. Amenities such as benches, pavilions, look-out decks and other outdoor facilities can be added to bring people closer to the water edge. These amenities can also be used to improve connectivity and accessibility to the water.

ii) 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 and shrubs. These have been implemented by PUB at some of the canals in Singapore and an example is shown below.

Another method to green our waterways and improve aesthetics is via the use of gabions, which can be integrated into canal walls that are partially removed. The combination of a natural material (e.g. stones in the gabions) and the lush creepers enhance the overall look and feel of the waterway. This is illustrated in the picture shown below.

Where there are space limitations, a full naturalisation of a waterway with bioengineering techniques (see item iv) like Kallang River @ Bishan-Ang Mo Kio Park is difficult to achieve. An option could be a partial naturalisation on one side of the waterway (where space permits). Naturalisation of the base of the waterway with rocks and/or planting will also improve the aesthetics of the waterway, particularly in waterways that are mainly dry. Hydraulic checks should be done to ensure that there is adequate capacity after taking these into consideration.

Fig. 4.46
Greening of canal wall at Sg Whampoa-St George's Lane

Fig. 4.47
Gabions and creepers at Kallang River @ Bishan-Ang Mo Kio Park

iii) Creating a Permanent Waterbody

Sometimes, there is little or no dry weather flow available in the canal. To provide a permanent pool of water in the waterway, weirs or dams can be constructed downstream to allow a buildup of water, thus creating a permanent waterbody in the waterway. This can help to improve the aesthetics and invite biodiversity into the waterway. The design of weir or dam, however, has to take into consideration hydraulic and maintenance requirements.

iv) 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 to stabilise 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.

Application and Principles

The suitability of specific techniques depends on site conditions such as the gradient of slope banks, soil type as well as the water velocity along the waterway. 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. As bioengineered banks have higher roughness coefficient, hydraulic capacity of the waterways also need to be checked for compliance.

Fig. 4.48 Soil bioengineering along Kallang River @ Bishan–Ang Mo Kio Park and riparian zone along the permanent flow channel

Benefits

Several benefits can be reaped from such bioengineering techniques. For example, bioengineering protects the soil surface from erosion caused by climatic elements (rain, wind) and increases soil integrity through establishing root networks. It also reduces the velocity of water flow, facilitates settlement and deposition of sand and silt, thus protecting the water quality of downstream waterbodies. In this way, soil fertility is enhanced through retention of nutrients. As bioengineering techniques employs only natural materials, it beautifies surrounding landscape and encourages habitat creation and promotes biodiversity.

Operation and 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 silt generated from eroded rocks, plant damage and degeneration) are natural processes along the river. Periodically but infrequently, minor maintenance works (like replacement of displaced rocks, trimming of plants to prevent breakage, etc.) are necessary.

Some of the rountine 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 @ Bishan-Ang Mo Kio Park project, completed in 2012, is an example of a naturalised waterway (refer to the case study in Section 10 for more details.)

Nevertheless, the naturalisation of waterways and waterbodies 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

CONSTRUCTION AND MAINTENANCE OF ABC WATERS DESIGN FEATURES

During construction of ABC Waters design features, site investigation, coordination, supervision, safety and erosion control are important. Maintenance is equally important to prolong the lifespan and sustain the function and benefits of the features.

5.1 CONSTRUCTION STAGE

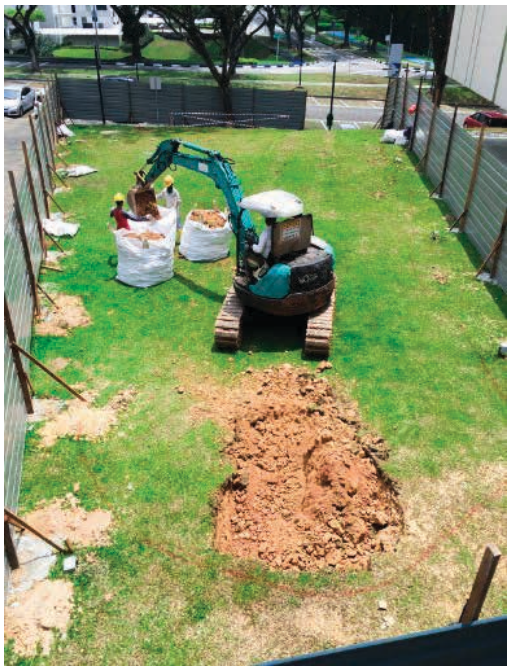


Fig. 5.1 Site is first marked out, followed by excavation

i) Site Investigation

During construction stage, site investigation works (especially soil property test and services detection), must be carried out before commencing physical works on site. Feedback should be given promptly if abnormalities or hindrances are observed during site investigation so that design can be reviewed early to suit site condition.

(ii) Site Coordination and Supervision

Holding points in construction of ABC Waters design features are important and have to be carefully coordinated. Supervision by ABC Waters Professionals is needed at the following holding points:

- **Site Setting Out** to prevent excessive excavation. For example, excessive excavation may lead to the need for safety railings (arising from a sharp drop) around the bioretention system due to proximity to pedestrian traffic.
- **Checking of catchment area** to ensure that the catchment area designed to be treated is maintained during construction stage. This must be coordinated by the different disciplines: C&S, landscape architecture, architecture & ABC Waters works.
- **Leak test** for geo-membrane liner (before the various soil layers are installed) if this is installed for the bioretention system.
- **Checking of materials** used in the different layers of the ABC Waters design features before they are installed at site. Each batch of material delivered to site should be checked.
- **Inspection of each layer** of the ABC Waters design features during installation. For example, in the installation of bioretention systems, the drainage layer, transition layer and filter media layer should always be supervised and inspected. It is a good practise to specify “hold points” for inspection after the subsoil pipes and each layer of soil media have been laid.

Fig. 5.2 Laying of membrane

Fig. 5.3 Drainage layer

Fig. 5.4 Transition layer

Fig. 5.5 Filter media

iii) Implementation of Earth Control Measures (ECM)

It is important to prevent silt and sediments 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. Silt and sediments from construction site shall be treated with ECM put in place. The specific requirements on ECM can be found in the Code of Practice on Surface Water Drainage.

The following ECM shall be taken into consideration during the construction of ABC Waters design features:

- When forming or excavating the profile of the ABC Waters design features;
- After various soil layers are installed to prevent silt getting in to clog the layers;
- Protection of ABC Waters design features shall continue until the bare areas on site have been stabilised.

The ECM implemented on site shall be checked and maintained regularly to ensure that the ECM remains effective throughout the whole duration of works.

Fig. 5.6 ECM to prevent erosion and prevent silt from entering the ABC Waters design features

iv) Construction Sequence

Laying of various soil media is to be carried out immediately after the profile of the ABC Waters design features is formed or excavated. It is to prevent slope erosion as well as to prevent the excavated area from collecting water and becoming a potential mosquito breeding ground.

No heavy vehicle movement is allowed within the ABC Waters design features after the profiles of the design features are formed. This is to prevent soil compaction which would inevitably affect the performance of the ABC Waters design features.

v) 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, contractors and the general public during the site preparation, construction and site handover phases.

vi) Mosquito and Pest Control

The ABC Waters design features should 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.

Notwithstanding the above, effective pest control measures should be adopted in construction sites and in completed premises as necessary to safeguard public health. The designer should also refer to the Code of Practice on Environmental Health, which addresses the various aspects of mosquito control.

5.2 POST-COMPLETION

i) Mosquito Control

Efforts to prevent, detect, identify and destroy any mosquito breeding spots, 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:

- Ensuring proper drainage of places that could collect water or contain water stagnation
- Removal of discarded items (litter, debris etc.)
- Clearing of choked subsoil pipes or discharge outlets
- Removal of plants with thick axils

b) Regular monitoring and maintenance of subsoil drain pipes and sumps to ensure no water stagnation.

c) Regular monitoring of the time taken for the detained runoff to infiltrate through the filter layer of bioretention systems. Prolonged detention times exceeding 1-2 days 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
- Replanting of bare patches on the filter media.

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 shall 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 shall take place periodically.

iii) Public Education

The following can be adopted to educate the public on the functions of the ABC Waters design features:

- 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 waterbodies. Where areas have been designated for water-play, parents shall 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. For naturalised river like Kallang River @ Bishan-Ang Mo Kio Park, the public should observe all safety precautions when they enter the flood plain of the river.

5.3 MAINTENANCE CONSIDERATIONS

Like any system, maintenance is a necessary and important consideration, and sufficient provision shall be given to long-term maintenance during the design stage. The facilities and features must be monitored, inspected and maintained regularly to sustain their functions and benefits. Routine inspections and maintenance programmes also help to prolong the lifespan of these facilities and features. By detecting 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, deterioration of water quality in downstream waterbodies, and flooding.

ABC Waters design features are green infrastructures that mimic natural systems. They are cost effective, sustainable, and environment friendly. These features harvest the natural cleansing capability of plants and soil to remove pollutants like nutrients and suspended solids without the need for sophisticated mechanical equipment and chemicals. As such, plant and soil (filter media) form the two main items for maintenance.

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

i) Landscape Maintenance

ABC Waters design features (e.g. bioretention systems, vegetated swales, and wetlands, etc.) rely on the establishment of good vegetation to cleanse stormwater runoff. Vegetation also plays a key role in maintaining the permeability 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 good performance of the systems. In the case of swales, overgrown vegetation is to be avoided as this may cause friction force to rise sharply and greatly reduce the flow capacity of the swales.

The most intensive period of maintenance is during the plant establishment period when replanting may be required. The use of fertilisers is to be restricted as far as possible. Replanting is necessary if there are bare patches on the filter media.

ii) Maintenance of Bioretention Filter Layer

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 permeability of the filter layer, regular monitoring of the time taken for stormwater runoff to infiltrate through the filter layer shall be undertaken. Prolonged detention times exceeding 1-2 days 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

iii) Cleaning Maintenance

Routine cleaning maintenance for ABC Waters design features is essential, 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 to identify areas of sediment accumulation and to remove the sediments are 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 a good slope so that there is no hindrance to the conveyance of stormwater runoff.

iv) Specific Checklists

The main maintenance requirements of the major types of ABC Waters design features can be found in Section 4.2. 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, Singapore's waterways and reservoirs will be enhanced aesthetically, 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. Friends of Water are made up of individuals and organisations that participate in PUB-organised activities, initiate water activities for their community or start their own initiative to educate the public. With more than 300 Friends of Water adopting ABC Waters sites, we hope more will continue to step forward as stewards of our waterways.

Fig. 6.1 Anchor Green Primary School organises learning trails for other organisations such as Brother International Singapore Pte Ltd to get to know more about their adopted ABC Waters site at Sengkang Floating Wetland

6.2 EDUCATING THE PUBLIC

Public education is essential towards ensuring that everyone uses and enjoys our water spaces responsibly. The 3P (People, Public, Private) sectors are encouraged to conduct educational activities in and around the waterbodies. They can tap on the ABC Waters sites as experiential learning venues for meaningful interactions. For example, the ABC Waters Learning Trails educate members of the public on the ABC Waters design features, the river ecology, and the impact of their action on our waterbodies. To date, over 10,000 residents have participated in the learning trails across ten ABC Waters sites as part of the Active Aging and Healthy Lifestyle programme collaborations. Several schools have also adopted the ABC Waters design features by bringing them into their school premises. One of them, Woodgrove Secondary School collaborated with PUB and CH2M Hill to incorporate two rain gardens in the school. These rain gardens not only enhance biodiversity in the school but also provide learning opportunities for students to better understand how natural materials such as soil media and plants can be used to cleanse rainwater runoff.

Fig. 6.2 CH2M Hill lends resources to help build rain gardens in Woodgrove Secondary School so that students can learn about one of the ABC Waters design features more comprehensively

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 project at Kallang River (Upper Boon Keng Road to Sims Avenue) is one of PUB's latest projects opened in 2017. To encourage community appreciation of the water space, Kolam Ayer Citizens' Consultative Committee (CCC), an adopter of this site, organised "Breakfast by the River" where residents get to bond with one other by the water.

This is in addition to the many regular activities that residents of Kolam Ayer have been enjoying by and on the waterway at the Kolam Ayer ABC Waterfront, with the CCC organising festive celebrations on the deck and the annual kayaking expedition as part of the Singapore World Water Day celebrations.

Fig. 6.3 Grassroots Adviser for Jalan Besar GRC, Professor Dr Yaacob Ibrahim joined residents for their "Breakfast by the River" sessions.

Fig. 6.4 Residents of Kolam Ayer actively use the ABC Waters site for their recreational activities

Fig. 6.5 Residents enjoy getting close to our water spaces by actively taking part in water activities

PUB also facilitates twinning and collaborative programmes between different community partners. In 2016, ITE College Central, Raffles Institution and Ricoh Singapore Pte Ltd worked together to develop the ABC Waters Learning Trail at Kallang River @ Bishan-Ang Mo Kio Park for pre-school students. The different partners contributed resources based on their areas of expertise, with Raffles Institution and ITE College Central developing the content and Ricoh Singapore Pte Ltd providing resources to produce the learning material. By infusing fun-filled activities and quests, this trail makes learning even more stimulating and engaging for our young.

Fig. 6.6 Guest-of-Honour, Mr Masagos Zulkifli, Minister for the Environment and Water Resources, then Permanent Secretary of MEWR, Mr Choi Shing Kwok and PUB Chief Executive, Mr Ng Joo Hee witnessed the launch of the learning trail for pre-school students at the Singapore World Water Day event

Fig. 6.7 Pre-schoolers enjoying their day out at Kallang River @ Bishan-Ang Mo Kio Park

6.4 A CALL FOR PARTNERSHIP

The ABC Waters Programme calls on the efforts of the public to keep our waters clean. Under the Programme, well used community spaces are created where the waters integrate seamlessly with the surrounding landscape. 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. 6.8 Various members of the public, young and old, coming together to gather at our ABC Waters sites for the annual community celebration for Singapore World Water Day

Fig. 6.9 ABC Waters sites provide great communal spaces for residents to enjoy the waterway

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. In August 2017, a new category known as the ABC Waters Certified (Gold) was added to recognise entries of exceptional standard.

7.1 APPLICATION AND ASSESSMENT

With applications open throughout the year, developers of completed projects or projects that have the detailed design finalised 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. For completed projects, site checks will be carried out to verify the information given in the application documents.

For projects before completion, applicants are to ensure that the information provided is accurate and up-to-date. Site checks will be conducted during the Temporary Occupancy Permit (TOP) stage to verify that the certified projects are executed in accordance to the design declared in the application documents.

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 https://www.pub.gov.sg/abcwaters/certification. Projects that have received ABC Waters certification are publicized on the same website.

7.2 ABOUT THE CERTIFICATION

PUB launched the ABC Waters Certification on 1 July 2010 to provide recognition to public agencies and private developers who embrace the ABC Waters concept, and incorporate ABC Waters design features in their developments.

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	10
Total : 100 Points	

In August 2017, a higher tier of certification, ABC Waters Certified (Gold), was launched to recognise entries of exceptional standards.

For a project to be ABC Waters Certified (Gold), the project needs to attain a minimum of 65 points, with at least 5 points from the Active and Beautiful categories. Under the Clean category, treatment of surface runoff from at least 40% of the total site area must be attained through the use of ABC Waters design features.

Projects which attain ABC Waters Certified (Gold) are also entitled an additional score point in the certification for BCA Green Mark for New Residential Buildings 2016 (GM RB: 2016).

7.3 CERTIFICATION CRITERIA

Active Category

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

Active Criteria	Points
1) Provision of facilities for new community spaces & public enjoyment, with possible educational values	
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	
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

Fig. 7.1 Active – Provision of facilities that bring people closer to water

Beautiful Category

This section focuses on achieving integration between water and greenery to achieve scenic waterscapes which enhances the aesthetics and biodiversity of the site.

Beautiful Criteria	Points
1) Integration of water features within site architecture	
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	
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. 7.2 Beautiful – Integration of ABC Waters design features with green facade

Clean Category

This section focuses on sustainable and holistic stormwater management through the adoption of ABC Waters design.

Clean Criteria	Points
1) Incorporation of sustainable stormwater management features	
a) Treatment or retention of runoff from more than 35% of the site area through ABC Waters design features	20
b) Treatment or retention of runoff from 11% to 35% of the site area through ABC Waters design features	15
c) Treatment or retention of runoff from up to 10% of the site area through ABC Waters design features	5
2) Holistic water management of the site	
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. 7.3 Clean – Incorporation of ABC Waters design features to treat surface runoff

Innovation Category

This section recognises creativity and innovation in incorporating ABC Waters design 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.

Innovation Criteria	Points
1) Incorporation of innovative design / device for sustainable stormwater management	Up to 10
Examples: a) Infiltration measures such as porous pavement or engineering soil b) Use of ABC Waters design features to fulfil detention requirement c) Innovative irrigation systems that conserve water d) Gross pollutant traps e) Other stormwater treatment systems eg. ultrafiltration f) Creative drain cover designs g) Other natural drainage systems	

SECTION 8

ABC WATERS PROFESSIONAL

To reap the environmental and hydrological benefits of ABC Waters design features, it is important that these features are appropriately designed, carefully constructed and properly maintained. ABC Waters Professionals are Professional Engineers, Architects and Landscape Architects trained in these aspects.

8.1 ABC WATERS PROFESSIONAL PROGRAMME

Recognising the importance of developing the industry's competence to bring the ABC Waters design 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 five 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 Designing ABC Waters Design Features
3. Design, Construction and Maintenance of Swales and Buffer Strips
4. Design, Construction and Maintenance of Bioretention Basins and Bioretention Swales

More information on the ABC Waters Professional Programme can be found at the following link: https://www.ies.org.sg/Registries/ABC-Waters-Professional-Registry.

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. 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 registration criteria of the respective professional bodies. The Registry aims to enable the industry to recognise the quality design work of ABC Waters Professionals.

Workshops, seminars and talks related to the ABC Waters design and case study are conducted regularly to keep ABC Waters Professionals abreast on innovative design and ideas adopted in using ABC Waters design to achieve sustainable stormwater management.

As of Mar 2018, there is a pool of more than 70 registered ABC Waters Professionals in the industry to carry out work on ABC Waters design features.

With effect from 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 in their projects. 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.

8.3 PROVISIONS IN THE COP

If the ABC Waters design features are also used for detention to fulfil the requirement for peak runoff reduction, an ABC Waters Professional shall inspect the features and endorse a Certificate of Inspection on the installed ABC Waters design features annually to certify that the features have been inspected, are functional with no reduction to its designed detention volume.

8.4 DRAINAGE HANDBOOK ON MANAGING URBAN RUNOFF

The Drainage Handbook on Managing Urban Runoff was jointly developed by PUB and the IES. This book, launched in May 2013, helps 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. ABC Waters Professionals can take reference from this guidebook in their design when integrating ABC Waters design features with other drainage elements such as detention tanks.

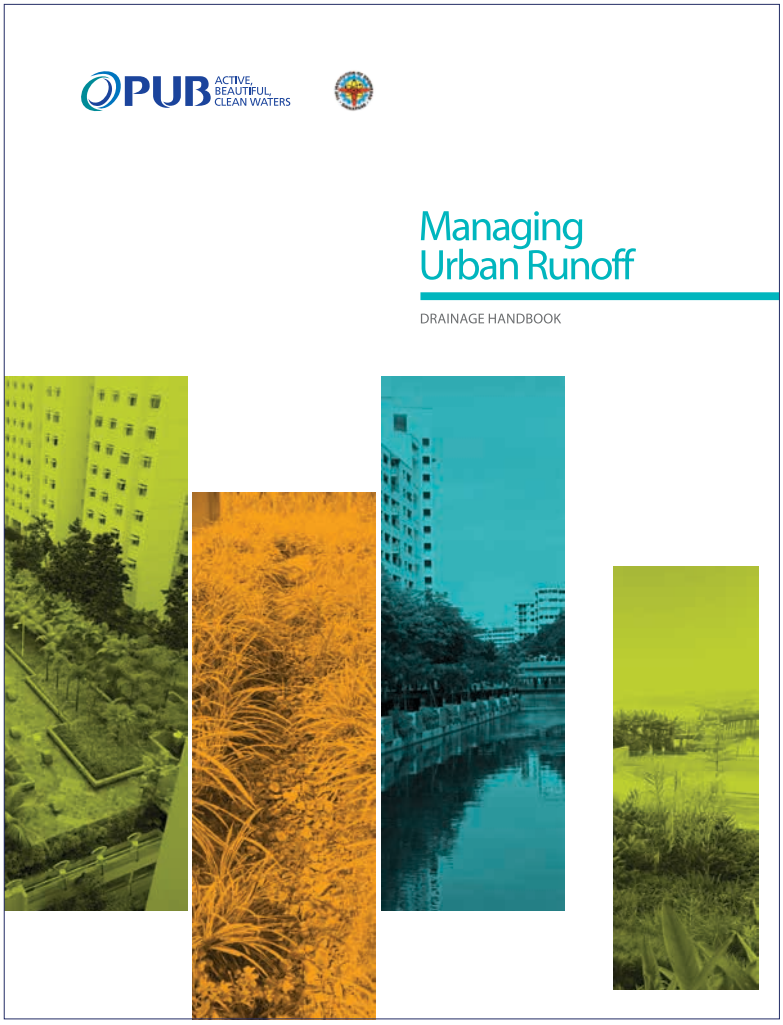


Fig. 8.1 Managing Urban Runoff Drainage Handbook

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 and 1 in 3 months.

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.

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.

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

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 waterbody) or which may be unnatural in the environment and capable of producing environmental harm (e.g. chlorinated pesticides).

Receiving Water
This is a waterbody 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
Erosion caused by flowing water.

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, carparks, 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 biological and radiological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and/or to any human need or purpose.

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

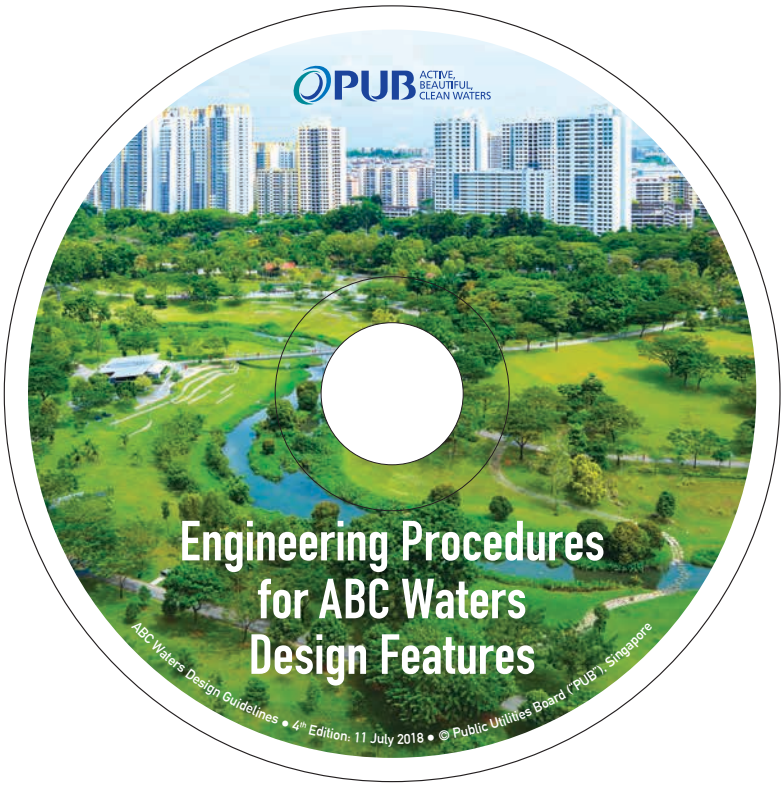
- Engineering Procedures for ABC Waters Design Features gives specific guidance on selection and sizing of the features, computational procedures with worked examples, performance charts to develop the detailed designs and checklists for construction and maintenance". A copy of the document is in the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

Code of Practice on Surface Water Drainage

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

Drainage Design Handbook on Managing Urban Runoff

- https://www.pub.gov.sg/Documents/managingUrbanRunoff.pdf



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

Sustainable Landscape

- https://www.cuge.com.sg/landscapeservices/main/landscape-weed-mgmt-and-sustainable-landscape-e-book.html

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

Adoption Guidelines for Stormwater Biofiltration Systems (Corporative Research Centres Programme for Water Sensitive Cities, Australia)

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

SECTION 10

CASE STUDIES

10.1 BUKIT TIMAH FIRST DIVERSION CANAL

The Bukit Timah First Diversion Canal was originally completed in the 1970s to alleviate flooding in the Bukit Timah area. The diversion canal, which is about 3,200m in length, diverts flow from Bukit Timah Canal into Sungei Ulu Pandan. Together with the Bukit Timah Canal, the diversion canal serves the Upper Bukit Timah Catchment.

To cater for the increase in stormwater runoff from new and intensified developments within the catchment for flood prevention, drainage improvement works were carried out to the Bukit Timah First Diversion Canal between Bukit Timah Road and Clementi Road. The drainage improvement works involve the widening of the existing canal to allow for higher conveyance capacity.

This stretch of canal located within the Holland Plain neighbourhood is envisioned to provide quality living and vibrant community spaces and sustainable green features. To tie in with this vision, ABC Waters design features would be incorporated in two main nodes, the Holland Green node where existing developments are located and the Holland Plain node where there will be upcoming developments. The main objective of these features is to complement and enhance the existing landscape and to treat stormwater runoff. The features will also provide green spaces for communal spaces and enhance connectivity.

Fig. 10.1 Location map showing Holland Plain and Holland Green Nodes

Key Features

Greening of Canal Wall and Rock Cascade

To soften the look of the concrete canal walls, additional plantings and creepers at the canal banks are added to enhance greenery. A rock cascade feature is introduced at one of the inlet drains to create a more aesthetic look for the inlet leading to the main canal.

Rain Gardens

There are three rain gardens incorporated as part of this project, one at Lasia Avenue, one at Garlick Avenue and one at Holland Plain Node. Each of these rain gardens embodies a sediment forebay designed as a pre-treatment measure to remove coarse to medium-sized sediments. The sediment forebay helps to reduce the probability of clogging within the rain garden treatment area.

At the first two locations, the rain gardens are incorporated on the decks over the canal and treat runoff from existing side drains. For the rain garden at Holland Plain node, the rain garden will treat stormwater runoff from the adjacent Holland Plain Road.

Fig. 10.2 Rain Garden at Holland Plain Node

Surface Flow Constructed Wetland with Sedimentation Basin

The area next to the waterway along Holland Green was designed as a wetland park for the enjoyment of the residents. The constructed wetland would be designed to treat dry weather flow from the upstream catchment prior to entering Bukit Timah First Diversion Canal. The proposed wetland system comprises of a sedimentation basin and a surface flow wetland module. The sedimentation basin prior to the wetland was designed to include a high flow bypass channel for direct discharge into the main canal in a storm event.

Native plants were selected, where appropriate, for the construction of the wetland. In addition to treating stormwater, constructed wetlands also provide a habitat that supports biodiversity and enhance the recreational spaces and amenities for the public to enjoy. Constructed wetlands can also provide educational opportunities for the community to learn about natural water treatment and importance of keeping our waterways clean.

Fig. 10.3 Surface flow constructed wetland at Holland Green Node

10.2 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 is designed with a holistic sustainable approach in mind. Adopting a concept of integrating 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 form 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 as a flood plain to channel stormwater to the Marina Reservoir. 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. With the natural river and existing waterbodies in the park playing an important role in promoting biodiversity, the Bishan-Ang Mo Kio Park is home to diverse flora and fauna. Completed in March 2012, the project has added more green and blue spaces for the public to enjoy in one of the most popular parks in Singapore.

Fig. 10.4 Gentle sloping river banks

Key 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 3km of the concrete canal into a natural river with landscaped banks. The naturalisation of the river has created a riverine habitat that improved the urban biodiversity within a park setting.

Soil bioengineering techniques were also utilised to stabilise the river banks and protect them from erosion. The river constantly experiences geomorphological changes, which may affect the hydraulic capacity of the river over time. Therefore, it is important to carry out post-implementation reviews to assess the effectiveness of the bioengineering techniques. This comprises periodic site walkthroughs, topography survey and hydraulic/hydrodynamic modelling.

Fig. 10.5 Riparian buffer zones are implemented along Kallang River to strengthen and improve the river banks

Cleansing Biotope

Located 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 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.

Fig. 10.6 Cleansing biotope

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. 10.7 Vegetated swales in the park

10.3 KALLANG RIVER @ POTONG PASIR

The Kallang River, approximately 10km long, begins its journey at Lower Pierce Reservoir and ends at Marina Reservoir. It serves a catchment area of about 6000 hectare comprising a myriad of land use; from public and private residential estates to industrial, commercial and educational premises. This particular project concerns the stretch of Kallang River from Potong Pasir Ave 1 to the St. Andrew's Junior School. It is situated in close proximity to St. Andrew's Village and is predominantly surrounded by Potong Pasir residential estate.

As with other ABC Waters projects, the stakeholders were consulted on the proposal from the design stage and their comments were incorporated to maximise the benefits of the project to the Potong Pasir community. St. Andrew's Village, which comprises St. Andrew's Junior School, Secondary School and the Junior College, were also consulted since the design stage. An 'outdoor classroom' concept, to engage students and provide them with the space for experiential learning on water, ABC Waters design features (rain garden, bioretention swales) and nature, was adopted.

The project was designed with the community in mind. The ABC Waters design features & the open plaza provide an outdoor classroom where students & residents can learn about rainwater runoff treatments, and use the space for community purposes. A myriad of colourful plants and water-edge planting enrich biodiversity, enliven the surroundings and enhance the water quality.

Fig. 10.8 Kallang River @ Potong Pasir - River edge planting

Key Features

Rain Gardens

Rain gardens allow stormwater to collect and progressively percolate through soil layers before being discharged into the Kallang River. During the filtering process, pollutants such as fine suspended solids and soluble nutrients are removed from the stormwater runoff. Rain gardens along the Kallang River @ Potong Pasir treat runoff from adjacent roads, footpath and community plaza space. In addition, the rain gardens enhance the biodiversity in the area.

Fig. 10.9 Rain garden treats runoff from adjacent road and plaza space

Bioretention Swales

The total length of the bioretention swales is 230m. The swales treat stormwater runoff from the adjacent footpath by removing sediments and pollutants from the runoff before channelling the water into the rain garden.

Fig. 10.10 Bioretention swales along footpath

Community Plaza and Lookout Decks

The community plaza can accommodate up to 750 people. At the community plaza, seats are provided along the pathway for residents to rest while strolling along the waterway. There are sheltered areas with notice boards for residents to catch up on the happenings within the estate. The notice boards also serve as a platform for the school to share information on students' activities with the residents. Pathways leading to lookout decks are provided for people to get up close to the water's edge. There are altogether 4 lookout decks along this stretch of the Kallang River providing good waterfront views for the public to enjoy.

Fig. 10.11 Lookout decks for visitors to get up close to the Kallang River

10.4 KAMPUNG ADMIRALTY

Kampung Admiralty is a mixed integrated development consisting of studio apartments, commercial shops, hawker centres, medical centres and a community park. Developed by the Housing & Development Board (HDB), this complex is the first of its kind to offer numerous facilities under one roof.

Fig. 10.12
Overall view of the lush facade of Kampung Admiralty

Various ABC Waters design features have been carefully designed and integrated within the development to treat and reuse rainwater runoff and to showcase the cleansed water. The development has a harvesting system which collects both rainwater and treated rainwater runoff for reuse to irrigate landscaped areas within the development. Overflow from the harvesting tank is piped to water features, consisting of a cleansing biotope, a vegetated swale and an eco-pond, located on the ground level. The rooftop terrace, which boasts an extremely lush green façade, is accessible to all residents and visitors, providing gathering spaces as well as green spaces for community farming.

Despite the small footprint of this development (site area of Kampung Admiralty is about 0.8 hectare), runoff from about 33% of its site area is channelled to ABC Waters design features for temporary detention and treatment. The features have been innovatively designed and integrated within the landscape as well as the building elements, and hence do not take up much land area. The treated water is stored for reuse, resulting in saving of potable water.

Key Features

Rain Garden & Vegetative Filters

A comprehensive treatment system has been put in place to treat the runoff within the development. Rainwater and runoff are collected and cleansed sequentially through vegetative filters on the floor level and tiers of bioretention planters at the façade of the 6th, 7th and 8th storeys. The overflow is also channelled from the top most planters at level 8 to the planters at lower levels for further treatment. Finally, both the cleansed water and the overflow from these 3 levels of vegetative filters are channelled to the rain garden on the 3rd storey for a final round of treatment. The rain garden on level 3, while not accessible to the public, can be viewed through the full height glass windows.

Treated runoff and overflow from the level 3 rain garden eventually gets channelled to the rainwater harvesting tank situated at the mezzanine level of the development. Water is pumped from the rainwater harvesting tank to irrigate planters at the green roof. Overflow from the rainwater harvesting tank goes to the eco-pond.

Fig. 10.13 Planters located on levels 6 (left), 7 and 8 (right) form a tiered bioretention system that provides treatment of surface runoff coming from the green roof

Fig. 10.14 Rain garden on level 3

Vegetated Swale

Runoff that overflows from the rainwater harvesting tank is channelled to the ground level via rainwater downpipes, to the vegetated swales before flowing to the eco-pond.

This natural drainage channel also showcases water filtered from a cleansing biotope. It conveys the filtered runoff in a natural way to the eco-pond.

During day time, a pump maintains a small recirculation stream of water flowing from the eco-pond to the cleansing biotope in order to maintain water quality and to prevent water stagnation.

Cleansing Biotope

The cleansing biotope located at ground level of the development detains and cleanses the water, enhances biodiversity and creates aesthetically pleasing community space. Runoff is cleansed by the biotope and subsequently channelled by a vegetated swale, and discharged to the eco-pond. A circulation system that pumps water from the ecopond to the cleansing biotope for treatment keeps the water moving.

Fig. 10.15 A cleansing biotope provides natural treatment of runoff pumped up from the eco-pond

Eco-pond

Located just next to the stage at the main foyer of Kampung Admiralty, the eco-pond provides a scenic backdrop of a lush landscape and waterscape. Communal spaces and seating spaces have been created at the foyer of the mixed-use development to allow residents as well as visitors to gather, and to hold community activities such as exercise classes. Fishes are kept in the eco-pond to add biodiversity and prevent mosquito breeding.

Fig. 10.16 The eco-pond showcases cleansed runoff of the cleansing biotope as well as the raingardens and vegetative filters

Fig. 10.17 The foyer of the development offers a large space for community activities and exercise classes for the residents

Other Environmental Features

The complex also features a pneumatic waste conveyance system and solar panels on top of all residential blocks for powering of selected amenities such as common lighting.

10.5 THE LEARNING FOREST AT THE SINGAPORE BOTANIC GARDENS

Fig. 10.18 The Learning Forest at the Singapore Botanic Gardens

Fig. 10.19 The water treatment system at the 10-Hectare Learning Forest

The Learning Forest project aimed to restore an ecologically rich ecosystem and was a pioneering effort to recreate a freshwater forest wetland. The 10-hectare area, developed by the National Parks Board, is an extension of the Singapore Botanic Gardens. It is connected to the Gardens' Rainforest (a primary rain forest) by a swathe of dense vegetation and is within the new Tyersall-Gallop Core of the Singapore Botanic Gardens. The Learning Forest's network of barrier-free boardwalks and elevated walkways brings visitors through the heterogeneous landscape, comprising both lowland rain forest and freshwater wetland habitats.

At the Learning Forest, the water treatment system involves a series of vegetated swales and sedimentation basins that are connected to the freshwater wetland. These features, which have an essential role in slowing down stormwater runoff and improving runoff quality, treat about 55% of the stormwater runoff from the 10-hectare area. In addition, ABC features and educational signs are integrated into the landscape and can be viewed from the boardwalks and lookout points. This provides visitors an opportunity to learn about the ABC water systems in place and the rich biodiversity of the forest and wetland habitats.

Key Features

Vegetated Swales

Surface runoff from the northern regions, including the visitor service areas, the coach park and the carpark, flows into the vegetated swales. These swales serve as natural drainage channels for surface runoff and provide pre-treatment of water for the downstream wetland by trapping coarse particles.

Fig. 10.20 Vegetated swales surround the Learning Forest's coach park and car park, filtering and slowing down the flow of runoff that enters the wetland.

Fig. 10.21 Along the vegetated swale at the outlet of the Canarium pond, a weir (a barrier across the horizontal width of the swale) was constructed

Sedimentation Basins

Located upstream from the freshwater wetland, the Canarium Pond is a sedimentation basin that collects the stormwater runoff from Tyersall Avenue and some parts of the Bambusetum. It protects the wetland from scouring and excessive build up of sediments by providing temporary retention and reduction of stormwater flow velocity so that particles of large and medium size can settle.

Fig. 10.22 The Canarium Pond is lined with a layer of hard rock and has been planted with plant species that are tolerant of waterlogged soils. A weir at the outlet (leading to the wetlands) of the Canarium Pond increases the pond's retention capacity and its rates of sedimentation.

Fig. 10.23 The Cerbera Pond is a sedimentation basin that collects runoff from more than 2-hectares of land, including the coach park and carpark. A curve in the pond increases the length of the conveyance path, which promotes higher rates of detention, sedimentation and infiltration. The dense vegetation along the path enhances the biological removal of excess nutrients from the water.

Fig. 10.24 The freshwater forest wetland removes suspended solids and the plants help to take up the excess nutrients in the water before discharging downstream to Swan Lake in the Tanglin Core of the Botanic Gardens.

Freshwater Forest Wetlands

The wetland, which is designed to detain and treat stormwater runoff (by removing suspended particles and dissolved contaminants, such as nutrients), is also fed by a natural spring that produces up to 90 cubic metres of water per day - a quantity sufficient to fill an Olympic-sized swimming pool in a month. The cleansed runoff is then discharged into Swan Lake in Singapore Botanic Gardens.

Two key features in the wetland are the weirs and the sluice gates. The weirs increase the volume of stormwater retained, whilst the sluice gates allow water levels to be artificially controlled in order to simulate the natural water level fluctuations of freshwater swamp forests.

In order to ensure that landscape maintenance is sustainable, the water from the upper wetland is connected to a pump that brings water around the Learning Forest for irrigation. Water from Swan Lake is also used for irrigating the 20-hectare Tanglin Core of the Gardens.

As the wetland is planted with a wide variety of native plants which take up the excess nutrients in the water, it is a significant habitat for fauna such as dragonflies. More than eight species of dragonflies and damselflies have been sighted at the Learning Forest's freshwater forest wetland.

Fig. 10.25 The Crimson Dropwing (*Trithemis aurora*) is the only pink dragonfly in Singapore and can be found basking on emergent plants at the Learning Forest's wetland

Fig. 10.26 The upper portion of the wetland

10.6 NTU PIONEER AND CRESCENT HALLS

Developed by Nanyang Technological University (NTU), the picturesque Pioneer and Crescent Halls feature residential blocks innovatively integrated with the existing topography, lush greeneries and a lake, to create a campus accommodation in a nature setting.

These halls serve as a test bed for innovative green technologies and environmentally friendly features. Within the residential halls, a natural waterbody has been created by diverting stormwater runoff from upstream catchment to enhance the landscape with water elements and also to improve the water quality. A full treatment train of ABC Waters design features, consisting of a sedimentation basin, linear wetlands, bioretention basins and cleansing biotope, was integrated with the existing waterbody to cleanse the stormwater runoff before discharging it into a landscaped pond to showcase the clean water. These ABC Waters design features treat runoff from 46% of the whole development site. At the same time, the development also features boardwalks, outdoor meeting rooms, gazebos and open terraces that provide community spaces for all to enjoy the waterscape.

Fig. 10.27 Pioneer and Crescent Halls, set amidst lush greenery, waterscape and outdoor community spaces

Fig. 10.28 Recreational pond within the student hostel

Key Features

Sedimentation Basin

An old lily pond at the site was converted into a sedimentation basin. The sedimentation basin is used to settle and remove coarse to medium sized sediments from the runoff and is the first element in the treatment train. It plays an important role by protecting downstream elements from being overloaded with sediments and encourages settling of these particles.

Wetlands

The next element in the treatment train, a constructed wetland system, utilises a shallow and extensively vegetated waterbody to remove pollutants like fine particles and nutrients from stormwater runoff by enhanced sedimentation, fine filtration and pollutant uptake processes.

Bioretention Basins

There are two bioretention basins located within the development. These bioretention basins filter the runoff from impervious surfaces (such as roof runoff and pavements) through a prescribed filter media before discharging it into the wetland system or the recreational pond.

Recreational Pond

At the end of the treatment train, a recreational landscape pond showcases the cleansed runoff in the heart of the residential hall blocks. Boardwalks are built over the pond so that residents and visitors can get up close to the waterbody.

Cleansing Biotope

To provide further treatment to runoff, water from the recreational pond is re-circulated to a cleansing biotope and the cleansed water is discharged back into the pond. The cleansing biotope is in the form of an artificially constructed wetland, consisting of nutrient-poor substrates that are planted with wetland plants known for their water cleansing capacity. Runoff is filtered through the substrate layers, collected by perforation pipes before the treated effluent is channelled back to the pond.

Fig. 10.29
A bioretention basin in NTU Pioneer and Crescent Halls

10.7 PANG SUA POND

Pang Sua Pond is a 3 hectare stormwater collection pond abutting the Bukit Panjang Neighbourhood Park. In rejuvenating Pang Sua Pond, PUB worked closely with People's Association (PA) to ensure that the makeover would benefit the residents and community in the area. A boardwalk was incorporated within the pond to improve accessibility and connect residents to the various amenities around Pang Sua Pond. Care was also taken to ensure that the new features are integrated seamlessly with the nearby amenities.

Upon completion of the project, six schools and the Cashew Constituency have pledged to be adopters of the completed site.

Fig. 10.30
Pang Sua Pond is a stormwater abstraction pond rejuvenated to bring the residents of Bukit Panjang closer to water

Key Features

Elevated Boardwalk

This project features a 480m long boardwalk that offers residents a unique experience of "walking on water". Connectivity is boosted as residents can now use the boardwalk to access several facilities in the vicinity, such as the new 3G Wellness Centre, the popular Senja-Cashew Community Club and the Bukit Panjang Neighbourhood 5 Park. Two lookout decks built along the boardwalk also allow commuters to pause in their tracks to admire the picturesque waterfront. Overlooking the stunning waterfront at Pang Sua Pond, a multi-purpose stage that seats more than 250 people offers interesting possibilities for a diverse range of outdoor performances, community events and other entertainment options by the water and under the stars.

Fig. 10.31
Elevated boardwalk gives residents the opportunity to walk above the waterbody of Pang Sua Pond, and improving the access to other amenities in the vicinity

Floating Wetlands

Floating wetland is a type of ABC Waters design feature that cleanses water naturally using plants. With an area of 1,300 m^2, the floating wetlands at Pang Sua Pond is the second largest man-made floating wetland system in Singapore (after Sengkang Floating Wetland located at Punggol Reservoir, with an area of 2,400 m^2). The wetlands also encourage habitat creation, promotes biodiversity and beautifies the surrounding waterscape.

Fig. 10.32 Floating wetlands, a type of ABC Waters design feature, filter and cleanse water naturally without the use of chemicals

Floating wetlands are created by planting emergent wetland plants on buoyant mats that float on the surface of a waterbody. These mats fluctuate vertically with the water level while anchored in position by roller bracket secured to the boardwalk columns. Rooted emergents (plants that grow in water with leaves and flowers above the water surface) are selected for planting on floating wetlands. The plants used on the floating wetlands must be tolerant to water-logged conditions. It is important to choose plants with good nutrient absorption capabilities and good resistance to attacks by pests. One such plant is the Fragrant Pandan, which is a good phytoremediation plant, planted at the floating wetlands at Pang Sua Pond.

Stormwater Collection Pond

The pond has a circumference of about 770m and is 260m at its widest. With a catchment area of 425 hectare, this stormwater collection pond collects stormwater runoff from the Bukit Panjang estate, which is predominantly made up of residential estates. Water in the pond is pumped to the Upper Seletar Reservoir for storage.

There are two main stormwater canals that drain into Pang Sua Pond. Pang Sua East Canal runs along Bukit Panjang Road, joining Pang Sua Pond at the eastern end. The other canal runs through the public housing estates and enters Pang Sua Pond at the northern end. Water from the pond overflows into the downstream canal which leads to the Kranji Reservoir.

10.8 PAYA LEBAR QUARTER

Developed by Lendlease, Paya Lebar Quarter is situated at the junction between Paya Lebar Road and Sims Avenue and above a short stretch of the Geylang River.

A mixed-use development comprising office and residential towers, a retail mall and lush public spaces, Paya Lebar Quarter is a vibrant city precinct with lush landscapes, directly accessible via Paya Lebar MRT and integrated with the park connector along the Geylang River. As the first mixed-use development by a private developer that achieved ABC Waters certification, the development features three rain gardens integrated with landscape elements in the plaza and promenade. With a strong sustainability vision and plan, Paya Lebar Quarter has seamlessly integrated nature into the urban fabric of the development.

Fig. 10.33 Overall view of the site

Key Features

Fig. 10.34 A rain garden located near the outdoor refreshment area

Rain Gardens

The development features three rain gardens with easy public access, seating spaces and recreational areas such as the kids' play area and outdoor refreshment area to bring people closer to the design features. The rain gardens filter, detain and treat stormwater runoff from about 31% of the entire 4 hectare development site.

Drainage Cells for Detention

Besides detaining and treating rainwater runoff, the rain gardens are innovatively integrated with drainage cells located below. These drainage cells serve as a source measure, temporarily storing runoff and reducing the peak flow of runoff into the public drainage system during rain events. This design of integrating drainage cells with rain gardens contributes to meeting the detention requirement of a maximum allowable peak runoff stated in PUB's Code of Practice for Surface Water Drainage.

Green Roofs, Sky Gardens and Vertical Greenery

Green roofs, sky gardens and vertical greenery along the façade were incorporated to reduce the heat build-up on exposed roof surfaces while slowing down stormwater discharge. These, together with other landscape elements, further enhance aesthetics and biodiversity within the development.

Fig. 10.35 Vertical greenery is implemented throughout the exterior of the development

10.9 RAIN GARDENS IN SCHOOLS

As part of PUB's efforts to educate our younger generation and to promote a wider adoption of ABC Waters design features, PUB has worked closely with a number of schools to incorporate rain gardens (or bioretention basins) within the school premises. Upon completion, these features were handed over to the institutions for their maintenance.

Aside from their capabilities in stormwater detention and water quality improvement, ABC Waters design features can provide an immersive and experiential environment to learn about water and the importance of keeping our water catchments clean. This is beneficial in inculcating a stronger sense of stewardship of Singapore's precious water resource amongst our younger generation. These features also enhance the school environment and biodiversity. Through implementing rain gardens in these learning institutions, we can educate our young on water quality, habitat creation and the impact of human actions on our natural resources. The rain gardens serve as outdoor classrooms where students can learn about water and nature in a real-life setting.

Fig. 10.36 Rain garden in Telok Kurau Primary School

Key Features

Soak Away Rain Gardens

Amongst the schools, several adopted the soak away design for rain gardens. Unlike conventional rain gardens, soak away rain gardens can be designed with only one filter layer, without the need for subsoil drainage pipes nor connections to a sufficiently deep drain in the vicinity for the discharge of treated effluent. This innovative design facilitates easy construction and greater adoptability by the community as it is simpler to implement and more cost-effective.

Fig. 10.37 Soak away rain gardens in Pei Hwa Secondary School (right) and Nanyang Junior College (left)

Conventional Rain Gardens

The conventional design of rain gardens are adopted for some of the rain gardens in schools where there are deeper drains in the vicinity for the discharge of treated effluent and where soil condition does not support the soak away design.

Outdoor Classroom

The rain gardens in schools provide opportunities for students to understand the treatment process of design features by sampling and comparing the influent and the treated effluent. To facilitate this, a number of rain gardens were designed with two separate discharge sumps – one for overflow discharge and the other for treated effluent discharge. This way, the samples collected in the latter will not be contaminated with any overflow discharge. Students can learn about treatment by comparing the water quality of the effluent against the influent through visual inspection or lab analysis. The rain gardens can also be designed to showcase the cleansed water after treatment.

Fig. 10.38 Soak away rain garden in Anglican High School (above) and a close-up of the two separate discharge sumps (below)

Engaging the Communities

PUB works with individual schools to make use of the rain gardens as part of their teaching curriculum. Schools can use the rain gardens to teach their students about the natural processes used to cleanse runoff: sedimentation, fine filtration and biological uptake. Teachers also have the opportunity to use them for their science and geography lessons in the secondary school syllabus. They can take actual samples to see for themselves the results of treatment to the runoff. Students can also learn about biodiversity and habitat creation that have been brought about by the rain gardens.

To enhance the community education experience, some schools had their own students engaged in designing signage for the rain gardens, allowing them to better understand the functionalities of the gardens. Some teachers and students were also actively involved in monitoring plant health, water quality and hydraulic conductivity of the rain gardens. Schools also opened up these spaces for visits by the community and other school groups.

10.10 SINGAPORE SPORTS HUB

Bordering the Kallang Basin with a site area of approximately 35 hectares, the Singapore Sports Hub is a multipurpose state-of-the-art complex, integrating world-class sports, lifestyle and entertainment facility. This iconic development, jointly developed by SportsHub Pte Ltd and Sports Singapore, was completed and opened in June 2014.

Fig. 10.39 Sports Hub, an integrated sports, lifestyle and entertainment facility

The centrepiece of the project is the new National Stadium, featuring a maximum capacity of 55,000 seats and a retractable roof over the track and playing field area. Other facilities include a 3,000 seat Aquatic and Leisure Centre, a 3,000 seat Multi-Purpose Indoor Arena, a 40,000 m^2 Retail Mall, a Singapore Sports Museum, a Sports Library, a Water Sports Centre, a Leisure Water play area with external Hard Courts and Beach Volleyball Courts along the waterfront promenade. Activities organised at the waterfront bring people closer to the Kallang Basin.

In addition to being the region's premier sports, entertainment and lifestyle hub, the Sports Hub was constructed with greenery in mind. The facility is extensively landscaped with trees, shrubbery and vegetation at all levels. ABC Waters design features include a wetland, bioretention swale and vegetated swales integrated within the development to enhance the landscape and waterfront, as well as to manage stormwater runoff sustainably. These have brought about an increase in flora and fauna since completion in 2014.

Key Features

Wetlands at the Waterfront Promenade

Where there was once a gravel beach, this has been transformed into a wetland. This 200m long stretch of newly planted wetland along the Kallang Basin plays a part in the cleaning of the water and brings about a wide range of wildlife including otters, monitor lizards and various species of birds and insects.

Rainwater Harvesting

Rainwater is harvested from the giant louvres of the stadium roof, and directed into the irrigation water tanks located on level one of the stadium. The collected rainwater is treated, filtered and pressurised for irrigation through the site. Both manual irrigation and automatic drip irrigation systems are utilised to irrigate the landscape throughout the entire development.

Fig. 10.40 Vast biodiversity found around Sports Hub

Bioretention & Vegetated Swales

Bioretention and vegetated swales are constructed at one of the entrances of the Sports Hub, forming part of the visitors' arrival experience. Their main function is to slow down and cleanse the stormwater runoff from the surrounding catchment into the downstream drains, thereby allowing cleaner water to be channelled into the Marina Reservoir.

Green Roofs & Vertical Green

Green roofs in the form of raised planters are located at the retail areas (level two and three), the sports museum (level two and three) and the library (level three). Linear planters, extending over long distances along the level three sports promenade, are integrated with trees and seating areas. This provides aesthetic improvements to the site architecture.

Above the level three promenade, the 800m long continuous hanging planters at level four form a green cover around the entire stadium façade, enlivening the space for users. This greenery helps soften this large architectural structure and improves the aesthetic of the environment.

Fig. 10.41 Wetlands at the waterfront promenade

Fig. 10.42 Bioretention swales and vegetated swales help to slow down and cleanse rainwater runoff before discharging to Kallang Basin and Marina Reservoir

10.11 SKYVILLE @ DAWSON

Overlooking the old housing blocks in the Queenstown neighbourhood, SkyVille @ Dawson is one of the precincts rolled out by Housing & Development Board that embodies the "housing-in-a-park" concept where public housing is set in scenic park-like environment. At a staggering 47-storey height, this development is located within the Dawson Estate.

Key Features

Bioretention Swales

In Skyville @ Dawson, areas directly beneath the windows have been transformed into bioretention swales to keep residents away from potential killter litter. Roof runoff is channelled from the adjacent housing blocks into the bioretention swales through an innovative inlet that features scour protection -- a diamond-shaped hollow structure made from modular precast concrete that allows inflow to build up and cascade into the bioretention swales. Runoff from half of the multi-storey carpark and adjacent roads is also channelled to the swales.

The bioretention swales function as drainage conveyance channels while treating the runoff. As the water flows through the surface vegetation, coarse to medium sediments are settled along the swales. The water then percolates through a filter media where fine particles are removed and soluble nutrients taken up by the roots of the plants and soil microbes.

Seats, walkways and community spaces at the void decks are positioned in close proximity to the bioretention swales to offer views and community spaces near these features. Educational signage is provided to enhance awareness of these features.

Fig. 10.43 Top: Roof runoff is channelled into the bioretention swales through an innovative structure that allows inflow to build up and cascade into the bioretention swales.
Bottom: Bioretention swales are located next to community spaces at the void decks, allowing residents to come close to these features. Simultaneously, these plant beds would also provide a valuable habitat for suitable local wildlife.

Fig. 10.44 Skyville @ Dawson offers a refreshing injection of life into mature estates of Queenstown with its towering blocks

Sky and Roof Gardens

Each housing block incorporates naturally ventilated sky gardens on several levels. These sky gardens serve as communal spaces and provide plenty of sheltered seating areas for interaction of the residents. The roof garden on the 47th floor offers panoramic city views. These green features provide enhancements to the aesthetics of the site architecture.

Fig. 10.45 Roof gardens on top of the multi-storey carpark and the residential blocks provide a variety of community spaces for outdoor recreational activities

10.12 SKY VUE

Located in the heart of Bishan, this luxurious condominium jointly developed by CapitaLand and Mitsubishi Estate Asia offers contemporary living in the city-fringe.

Fig. 10.46 Overall view of Sky Vue

Inspired by the original Bishan landscape of gently undulating hills, the development sought to recreate a "Pavilions on the Green" concept, featuring landscaped grounds and pockets of greenery throughout the property. ABC Waters design features, lush landscape and sky terraces provide communal spaces for residents to socialise, exercise and relax while enjoying the view of the Bishan skyline.

Key Features

Bioretention Basin

A bioretention basin (or rain garden) is located on the 1st storey next to the BBQ pavilion which blends seamlessly with the landscape. Another rain garden (within a planter box) is located on the 7th storey at the e-deck next to the pool area and function room. These features provide excellent spaces for residents to enjoy the aesthetic as well as the educational values of the bioretention basins. The bioretention basins detain and treat runoff from about 10% of the 1.1 hectare development site.

Fig. 10.47 Rain garden on 1st storey

Fig. 10.48 BBQ pavilion located right next to the rain garden allowing residents to enjoy the space near the feature

Fig. 10.49 Rain garden (planter) located on 7th storey

Green Wall and Sky Terraces

A landscape deck on the 7th storey carpark podium and sky terraces on the 37th storey of the residential tower blocks allow residents to enjoy the green spaces and amenities. There is also a 7-storey green wall located along the multi-storey carpark to enhance the aesthetics of the development, softening the concrete façade of the carpark.

Fig. 10.50 Green façade incorporated at the entrance of the multi-storey carpark

Rainwater Harvesting

Rainwater from rooftops is collected and used for the irrigation of plants. Additionally, runoff overflowed from the 7th storey bioretention basin is channelled into the rainwater harvesting tank. The rainwater can be used for irrigation of greenery in the development.

10.13 WATERWAY RIDGES @ PUNGGOL EAST

A joint collaboration between 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. Bounded by the Punggol Waterway and one of its tributary drains, the precinct was conscientiously designed to relate to its unique waterfront setting, with deliberate attention on sustainable stormwater management.

Fig. 10.51
Waterway Ridges along Punggol Waterway

The development features an environmentally sustainable network of bioretention basins (rain gardens), bioretention lawns and vegetated swales that were designed to (i) integrate with the drainage system to control the peak stormwater runoff to meet the current runoff control requirements in the Code of Practice (COP) on Surface Water Drainage, and (ii) treat the collected runoff with the use of plants and layers of soil filters, before discharging cleansed runoff into the Punggol Waterway.

The bioretention basins, bioretention lawns and vegetated swales collect and treat stormwater runoff from roofs, roads, playgrounds and green areas in the precinct, by allowing the stormwater to flow through plants and filter through soil media. Sediments, nutrients and other impurities in the runoff are removed by flowing over a vegetated swale and filtering through the bioretention systems. Eventually, the cleansed water will flow into the reservoir via the nearby Punggol Waterway.

Fig. 10.52
Rain gardens are integrated within the housing precinct to enhance the aesthetics and also detains and treats rainwater runoff at the same time

ABC Waters design features form part of the natural drainage system that detains and treats stormwater runoff from about 58 per cent of the precinct area. At the same time, water is stored in thick gravel layers below the features and discharged via orifices or reduced outlets to maintain a targeted runoff coefficient of 0.55 during storms with 10-year ARI (Average Recurrence Interval). 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 be used for recreational purposes during dry days.

This pilot project has demonstrated that with a clear vision at the early stages of planning, proper design with necessary mock-up tests and close communication between all parties, it is feasible to purposefully incorporate ABC Waters design features in a holistic manner within a public housing precinct. The success of this project provides evidence that when appropriately designed, ABC Waters design features will not only cleanse stormwater runoff but also effectively reduce peak flow for storm events up to 10-year ARI. Given that two-thirds of Singapore's land area falls within water catchment, the success of this project is a milestone towards achieving catchment wide implementation of ABC Waters design features.

This project received recognition from many renowned design competitions including HDB Design Award 2016, Singapore Landscape Architecture Awards 2017, and Award of Excellence – International Federation of Landscape Architects Asia-Pacific Region Landscape Architecture Awards 2017.

Key Features

Fig. 10.53 Vegetated swale integrated with the landscape in the precinct

Vegetated Swales

Vegetated swales can replace concrete drains to convey stormwater runoff. Designed primarily to facilitate sedimentation and slowing down of stormwater, these features also improve the aesthetics and biodiversity of the surroundings. Some of the vegetated swales have incorporated gravel layers below the swales to improve their detention capabilities.

Fig. 10.54 A rain garden to showcase the cleansed water

Bioretention Basins

A comprehensive system of 21 bioretention basins form an important part of the natural drainage system in this precinct to detain and treat stormwater runoff for frequent storms (storms up to 3-month ARI). For bigger storm events, the excess runoff will overflow into the thick gravel layer below the bioretention basins for storage and then discharge via orifice at controlled discharge rates.

Bioretention Basins (Lawn Type)

Among the 21 biorentation basins incorporated on site, 3 are designed as lawn type. A lawn type bioretention basin acts as a recreational space when dry, and turns into a water collection area in the event of rain. The stormwater runoff is then ponded temporarily and filtered through the basin before being drained into the nearby Punggol Waterway.

Fig. 10.55 Bioretention basin (lawn type) which doubles as a play area on dry days

10.14 WATERWAY TERRACES

Set along both banks of the iconic Punggol Waterway, Housing & Development Board's Waterway Terraces are distinguished by their cascading block forms and unique green façades. The design of this public housing precinct is inspired by the terraced rice paddy fields of Asia, giving the project its striking identity. The terraced landscape leading down to Punggol Waterway also defines a strong relationship between the precincts and the water's edge. Lush greenery and community landscape are provided in the precincts' courtyard, green spaces and common green.

Fig. 10.56 Waterway Terraces set along both sides of Punggol Waterway

Rain Gardens Integrated with the E-deck

Rain gardens designed to treat runoff are constructed at the edges of the e-decks in both precincts. Runoff is channelled from the common green areas and e-decks to the rain gardens via downpipes. Impurities are removed through sedimentation, filtration and some biological uptake. The cleansed runoff is eventually discharged into Punggol Waterway.

The precincts also feature timber deck walkways that provide residents with connectivity to the waterway and access to the rain gardens. Signage is erected at the rain garden to explain the principles, functions and benefits of these features.

Fig. 10.57 Rain gardens are seamlessly integrated within both precincts as part of the landscape, yet provide treatment of runoff received at the e-decks

Cascading Roof Gardens at Community Spaces

The precincts also have a combination of intensive and extensive roof gardens which cascade with the blocks, providing a valley effect of vertical green. The lower tiered roof gardens are opened to the public and provides a panoramic view of the waterway. These roof gardens also have seating spaces that allow residents to relax and gather.

Fig. 10.58 Cascading roof gardens, made up of both intensive and extensive types of green roof, offer communal spaces for residents to gather

Promenade along Punggol Waterway

Fronting the precincts is a waterfront promenade, which enhances the vision of "waterfront living" for the residents. Aside from providing East-West connectivity through Punggol Town, it offers social communal spaces that are integrated seamlessly along the waterway and provide enjoyment for the residents.

Fig. 10.59 Located just next to Punggol Waterway, the precincts offer a waterfront promenade which provides connectivity as well as spaces for residents to enjoy the views of the waterway

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