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# Case Studies of Management and Maintenance of Sustainable Urban Drainage Systems in Extreme Weather

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**Abstract:**

Since 1997, Sustainable Urban Drainage Systems (SUDS) have been promoted globally to manage urban stormwater and wastewater. Approaching the third decade of the development of SUDS, this paper explores the management and maintenance of SUDS under extreme weather conditions, focusing on case studies in Singapore and Australia, respectively. Active, Beautiful, Clean (ABC) Waters Program of Singapore integrates blue-green infrastructure to manage stormwater, enhance water quality, and provide social and ecological benefits. In Australia, Water Sensitive Urban Design (WSUD) incorporates natural systems to handle stormwater and reduce urban heat. The study investigates how each region has developed effective SUDS strategies tailored to their distinct climates. While Singapore focuses on managing rapid vegetation growth and maintaining water quality, Australia adapts to challenges like drought, variable rainfall, and fire risks. This research underscores the importance of innovative, site-specific solutions in enhancing urban resilience and offers valuable insights for sustainable urban water management worldwide.

**Keywords:** Sustainable urban drainage systems; urban water management; ABC water program; Water sensitive urban design.

## 1. Introduction

Water is a renewable resource that is self-purified through hydrologic or water cycle, which is critical to human beings and the development of society. Even if there is a shortage of water in many places, urbanization in established areas causes the soil to become impermeable, which can result in flooding. Since 1997, there has been a push to address stormwater and wastewater treatment in cities by implementing sustainable urban drainage systems (SUDS), which are intended to decrease the natural dumping of water [1]. The goals are: quantitative control of surface runoff, improvement in the quality of water from surface runoff, conservation of the natural characteristics of bodies of water, and balance of hydro-

logical variables in watersheds. SUDS are critical in urban environments where traditional drainage systems are often overwhelmed by extreme weather events.

SUDS developed and act as part of the city's infrastructure that collects and convey rainwater and wastewater after the introduction of sustainable urban water management [2]. The primary design goal of the conventional drainage system is water quantity control, making it a single-objective system. Today's drainage solutions further emphasize the need for other key elements in urban water management [3]. Over the past few decades, SUDS development has been utilized broadly worldwide [4]. Distinct countries use distinct terminology, yet their design concepts are similar. Specifically in Singapore, the sustainable stormwater management strategy is known as Active, Beautiful, Clean (ABC) water program launched in 2006. There are three parts to the ABC Waters Program. In addition to encouraging environmental responsibility among residents, the active component builds new community spaces around waterbodies. This stunning element transforms reservoirs and waterways into eye-catching, colorful areas. The Clean component seeks to reduce water pollution by educating the public and enhancing the quality of the water. [5]. In Australia, the Water Sensitive Urban Design (WSUD) is an approach that integrates water management into the urban planning and design process. It emphasizes the use of natural systems to manage stormwater, enhance water quality, and reduce urban heat islands. WSUD practices include swales, wetlands, rainwater harvesting, and the incorporation of vegetation in urban spaces to manage stormwater sustainably. Further approaches such as Low Impact Development (LID) and Best Management Practices (BMP) are used in the United States and Canada. This paper explores various case studies of SUDS management and maintenance under extreme weather conditions, highlighting the challenges and solutions implemented in different regions, particularly Singapore and Australia.

## 2. Rainfall-Rich Region

### 2.1 Urban Context and Regional Characteristics

The selection of SUDS in rainfall rich regions needs to consider and favor the maximum capacity of the system, as dealing the more intensive and frequent rainfall events in tropical and subtropical regions is challenging [6].

Singapore is a maritime Southeast Asian city-state and island nation. Situated 137 kilometers (85 miles) or one degree latitude north of the equator, Singapore experiences abundant rainfall throughout the year in a tropical rainforest climate. The consistent and substantial rainfall in Singapore fosters lush greenery and a vibrant ecosystem, which the city has seamlessly integrated into its urban planning and architecture. The juxtaposition of dense urban developments with expansive green spaces is a defining feature of Singapore's urban texture. The cityscape is punctuated by numerous parks, gardens, and nature reserves, earning it the nickname "Garden City."

The two monsoon seasons and the inter-monsoon months that separate them define Singapore's climate. The southwest monsoon lasts from June to September, while the northeast monsoon lasts from December to early March. Singapore has a lot of rain, with an average of 171 days a year, and Fig. 1 shows the average number of rainy days per month. The long-term average annual rainfall for the period 1991-2020 is 2113.3 mm and Fig. 2 shows the monthly rainfall in Singapore.

The idea of using natural processes to control stormwater is at the core of the ABC Waters Program. In order to slow down and treat stormwater runoff, this method involves the construction of engineered wetlands, rain gardens, and bio-retention swales that imitate natural hydrological processes. These features not only improve water quality by filtering out pollutants but also mitigate flooding by enhancing the infiltration and storage capacity of urban landscapes. For instance, the Bishan-Ang Mo Kio Park, one of the flagship projects of the ABC Waters Program, has transformed a concrete canal into a naturalized riverine park. This project not only provides flood protection but also creates a thriving ecosystem and a recreational space for the community. Technological innovation and stringent regulatory frameworks support the implementation of the ABC Waters Program. The ABC Waters Certification Scheme, for example, sets out clear guidelines and standards for incorporating ABC design features in new developments and redevelopment projects. This certification ensures that projects adhere to best practices in sustainable stormwater management, contributing to the overall resilience and environmental quality of the city.

In addition to enhancing flood resilience and water quality, the ABC Waters Program significantly contributes to the aesthetic and social dimensions of urban life in Singapore. By integrating blue-green infrastructure into the urban fabric, the program creates attractive and accessible public spaces that encourage outdoor activities and foster a sense of community. These green corridors and water bodies provide habitats for biodiversity, contributing to the ecological richness of the urban environment.

Moreover, the ABC Waters Program aligns with Singapore's broader sustainability goals and its vision of becoming a City of Gardens and Water. The program exemplifies how urban infrastructure can be designed to deliver

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multiple benefits, enhancing environmental sustainability, public health, and social well-being. By transforming traditional drainage systems into dynamic, multifunctional spaces, the ABC Waters Program sets a benchmark for urban water management and showcases the potential for cities to adapt to climate challenges through innovative and holistic approaches. An analysis of certification items on PUB's website from 2010 to 2014 found that the most used design element in ABC building integrated protection systems is the biological retention system. As shown in Fig. 3, the number of projects using bioretention swale and bioretention basins/rain garden is 41, the number of projects using green roofs is 27, and the number of projects using green walls is 18.

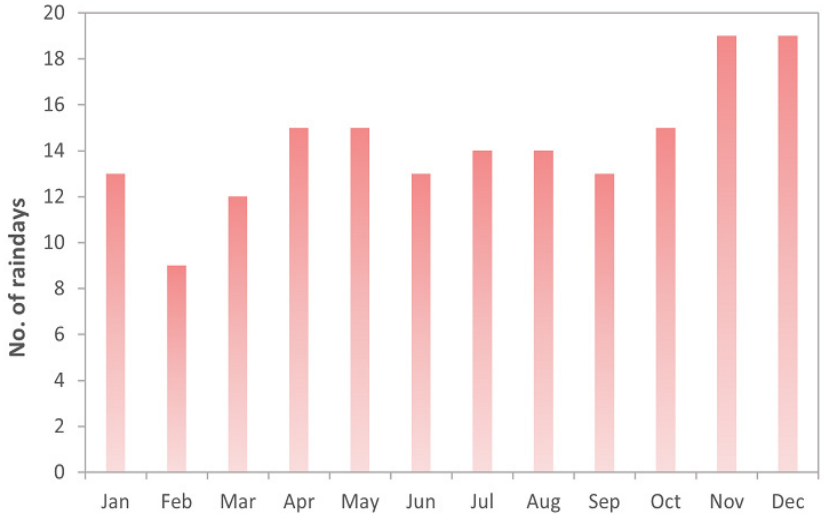


**Fig. 1 Rain days each month [7]**

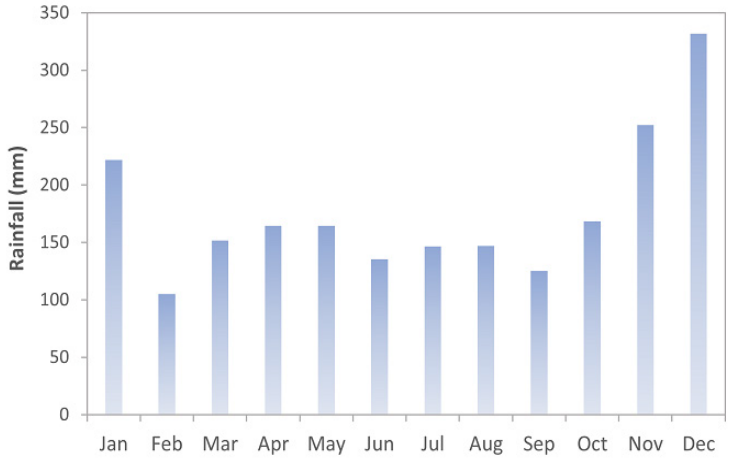


**Fig.2 Rainfall amount each month [7]**

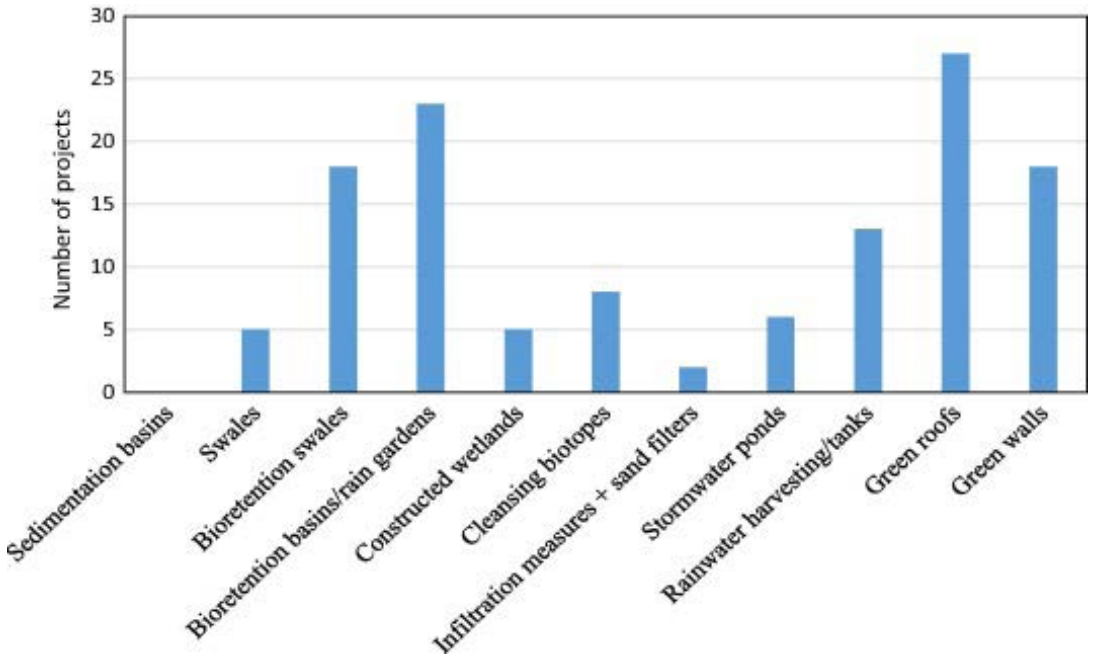


**Fig. 3 SUDS projects in Singapore [5]**

### 2.2 Case of Bishan-Ang Mo Kio Park

Bishan-Ang Mo Kio Park is known for its lush greenery and the integration of naturalistic landscapes with urban environments [8]. The park features a wide variety of plant species, as shown in Table 1 [9].

**Table 1. Plants species in Singapore**

| Type | Description | Species |
|---|---|---|
| Riparian Plants | These plants grow along the riverbanks and help stabilize the soil, reduce erosion, and filter pollutants from stormwater. | Typha spp. (Cattails)<br>Phragmites australis (Common Reed)<br>Ludwigia spp. |
| Wetland Plants | Used in constructed wetlands to treat and filter water naturally. | Typha spp. (Cattails)<br>Phragmites australis (Common Reed)<br>Ludwigia spp. |
| Trees and Shrubs | Provide shade, improve air quality, and support local wildlife. | Ficus benjamina (Weeping Fig)<br>Syzygium spp. (Water Apple)<br>Tembusu (Fagraea fragrans) |
| Aquatic Plants | Contribute to the health of the pond ecosystems. | Nymphaea spp. (Water Lilies)<br>Hydrilla verticillata<br>Vallisneria spp. |

## 3. Arid region with Occasional Severe Storms

### 3.1 Urban Context and Regional Characteristics

Australia, particularly its southern and eastern regions, experiences long dry periods punctuated by intense, short-duration rainfall events. These can lead to flash floods, especially in urban areas. Cities like Sydney and Melbourne can experience heavy downpours during summer storms, even though overall annual rainfall is relatively low in many parts of the country.

Australia has invested heavily in developing urban stormwater management systems. These systems are designed to reduce the impact of flooding, improve water quality and improve the urban environment. Australian SUDS include permeable pavements, green roofs, rain gardens and

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constructed wetlands. Melbourne's Docklands area and the Sydney Olympic Park are notable for their extensive use of SUDS to manage stormwater sustainably [10].

### 3.2 Case Study of Melbourne's Docklands Area

Australia is known for its diverse and unique plant species, many of which are incorporated into SUDS and urban green spaces to manage stormwater, enhance biodiversity, and improve urban environments. Table 2 shows the plants species in Melbourne's Docklands area.

**Table 2. Plants species in Australia**

| Type | Description | Species |
|---|---|---|
| Eucalyptus species (Gum Trees) | These iconic Australian trees are used for their ability to thrive in various climates and soils. They provide shade, reduce urban heat, and support local wildlife. | Eucalyptus globulus (Tasmanian Blue Gum), Eucalyptus camaldulensis (River Red Gum) |
| Melaleuca species (Paperbarks) | Often used in wetlands and rain gardens, Melaleuca species are excellent for water filtration and supporting wetland ecosystems. | Melaleuca quinquenervia (Broad-leaved Paperbark), Melaleuca ericifolia (Swamp Paperbark) |
| Acacia species (Wattles) | Acacias are nitrogen-fixing plants that improve soil fertility and are commonly used in revegetation and erosion control projects. | Acacia dealbata (Silver Wattle), Acacia pycnantha (Golden Wattle |
| Banksia species | Banksias are used for their resilience to coastal conditions and are often planted in urban parks and gardens to support local bird populations. | Banksia integrifolia (Coast Banksia), Banksia serrata (Saw Banksia) |
| Lomandra species (Mat Rushes) | Lomandra is widely used in rain gardens, roadside plantings, and bio-retention systems due to its hardiness and ability to thrive in poor soils. | Lomandra longifolia (Spiny-headed Mat Rush) |
| Dianella species (Flax Lilies) | Dianella species are popular in urban landscapes for their low maintenance and ability to grow in a variety of conditions, including wet and dry areas. | Dianella caerulea (Paroo Lily) |
| Poa species (Tussock Grasses) | These grasses are used in swales and bio-retention systems for erosion control and as habitat for local fauna. | Poa labillardierei (Common Tussock-grass) |

## 4. Conclusion

This paper investigates the management and maintenance strategies of SUDS under extreme weather events in Singapore and Australia through comparative analysis of SUDS in different climatic conditions. The main conclusions are as follows:

(1) In rain-rich tropical Singapore, the ABC Waters Program integrates blue-green infrastructure such as bio interception ditches, rain gardens and constructed wetlands to sustainably manage rainwater. This approach will not only mitigate flooding, but also improve water quality and support urban biodiversity, aligning with Singapore's broader sustainable development goals.

(2) The dry areas of Australia, particularly Melbourne's Docklands, are explored. WSUD uses permeable pavements, green roofs and rain gardens to address the challenges posed by long dry periods and occasional strong storms. Australia's adaptive management practices are designed to respond to drought and heavy rainfall events and ensure the functioning of drainage systems.

(3) While this study highlights the effective practice of sustainable development systems, further research is needed on the long-term performance, cost-benefit analysis, and socio-economic impacts of sustainable development systems. Future research should also explore the combination of advanced technologies and community engagement to enhance the resilience and versatility of urban drainage systems worldwide.

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