STORMWATER MANAGEMENT SYSTEM IN BANGKOK METROPOLITAN

BY

TASSAWAN WINYUCHONCHAROEN

AN INDEPENDENT STUDY SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (ENGINEERING TECHNOLOGY)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY

ACADEMIC YEAR 2023

THAMMASAT UNIVERSITY
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

INDEPENDENT STUDY

BY

TASSAWAN WINYUCHONCHAROEN

ENTITLED

STORMWATER MANAGEMENT SYSTEM IN BANGKOK METROPOLITAN

was approved as partial fulfillment of the requirements for
the degree of Master of Engineering (Engineering Technology)

on June 26, 2024

Member and Advisor ______________________________
(Assistant Professor Amin Eisazadeh Otaghsaraei, Ph.D.)

Member ______________________________
(Associate Professor Kriengsak Panuwatwanich, Ph.D.)

Director ______________________________
(Professor Pruettha Nanakorn, D.Eng.)

Independent Study Title	STORMWATER MANAGEMENT SYSTEM IN BANGKOK METROPOLITAN
Author	Tassawan Winyuchoncharoen
Degree	Master of Engineering (Engineering Technology)
Faculty/University	Sirindhorn International Institute of Technology/ Thammasat University
Advisor	Assistant Professor Amin Eisazadeh Otaghsaraei, Ph.D.
Academic Years	2023

ABSTRACT

Effective stormwater management is crucial for urban sustainability, especially in cities facing increased urbanization and climate change impacts. Low Impact Development (LID) practices offer sustainable solutions by mimicking natural hydrological processes to reduce runoff and improve water quality. This report evaluates LID practices such as green roofs, permeable pavements, bioretention areas, retention ponds/wetlands, community rainwater harvesting, underground reservoirs, and SMART tunnels. Each practice is assessed based on costs, maintenance, benefits, limitations, performance, and environmental impacts. The findings highlight that green roofs and permeable pavements are effective in reducing runoff and enhancing urban aesthetics, while retention ponds and wetlands provide valuable flood storage and biodiversity benefits. Community rainwater harvesting offers localized water conservation benefits. The suitability of each LID practice for implementation in Bangkok is discussed, considering the city's unique urban challenges. This report provides insights into selecting appropriate LID strategies for urban contexts, facilitating informed decision-making for sustainable stormwater management in Bangkok and similar urban environments.

Keywords: Stormwater management, Sustainable drainage system, Urban flooding

ACKNOWLEDGEMENTS

I am deeply thankful to my advisor, Assistant Professor Amin Eisazadeh Otaghsaraei, Ph.D., and Associate Professor Kriengsak Panuwatwanich, Ph.D. for their invaluable guidance, support, and encouragement throughout this research journey. Their expertise and mentorship have been instrumental in shaping the direction of this study. I extend my appreciation to the faculty members of Civil Engineering and Technology for their insightful feedback and constructive criticism during the development of this project. My heartfelt thanks to my family and friends for their unwavering encouragement, understanding, and belief in my abilities. Their constant support has been a source of strength and motivation. Additionally, I acknowledge any other individuals, organizations, or resources that have contributed to this study in any capacity.

Tassawan Winyuchoncharoen

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	Terms
BMPs	Best Management Practices
DID	Department of Irrigation and Drainage
GI	Green Infrastructure
LID	Low Impact Development
PUB	Public Utilities Board
SWMS	Stormwater Management System
BMA	Bangkok Metropolitan Administration

CHAPTER 1
INTRODUCTION

Bangkok, the vibrant capital of Thailand, stands as a testament to urban growth and development, evolving into a bustling hub of commerce, culture, and innovation over the years. However, with urbanization come challenges, and one of Bangkok's most pressing concerns is stormwater management. The Bangkok Metropolitan Region, due to its low-lying geography, rapid urban expansion, and inadequate infrastructure, is particularly susceptible to the adverse impacts of heavy rainfall and flooding. Recurrent inundations during the monsoon season disrupt daily life, jeopardize public safety, harm the environment, and threaten economic stability. In response to these challenges, the urgent need for an effective stormwater management system in Bangkok has become a top priority, one that takes a holistic approach addressing flood control, water quality, sustainability, and resilience in the face of climate change.

Stormwater management is a crucial aspect of urban planning and environmental stewardship. It encompasses the practices and systems designed to control the flow and quality of rainwater runoff in urban areas. Its significance lies in its ability to mitigate flooding, reduce water pollution, and protect the overall health of ecosystems and communities. In rapidly growing urban centers like Bangkok, effective stormwater management is essential to minimize the risks of urban flooding and waterborne diseases, safeguard critical infrastructure, and promote sustainable urban development. As climate change intensifies weather patterns, the importance of robust stormwater management becomes increasingly evident, highlighting the need for innovative and comprehensive solutions to address the challenges posed by urbanization and changing environmental conditions.

1.1 Problem statement

Frequent flooding in Bangkok disrupts daily life, damages infrastructure, and poses health risks. The current stormwater management system struggles to cope with the increasing demands of a growing population and changing climate patterns.

Addressing these challenges requires a comprehensive understanding of the existing system and exploration of innovative solutions.

1.2 Objective

This report aims to analyze the current stormwater management practices in Bangkok, focusing on identifying existing challenges and assessing the effectiveness of current measures. By examining the unique characteristics of Watthana District, a densely built area, and Minburi District, which has more vacant land, the report seeks to recommend tailored stormwater management strategies for these distinct urban environments. Additionally, it provides insights and actionable recommendations for enhancing Bangkok's overall stormwater management system, aiming to improve flood resilience and sustainable water management across the city.

1.3 Scope

The study's scope encompasses a comprehensive analysis of stormwater management at the district level in Bangkok, with a specific focus on Watthana District, known for its commercial and residential developments, and Min Buri District, characterized by its peri-urban landscape.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Geographical of Bangkok

Understanding Bangkok's geological features is crucial in comprehending its susceptibility to flooding and stormwater management challenges. The city's soil composition and elevation profile significantly influence water drainage patterns and retention capabilities. According to the Department of Mineral Resources, Bangkok is situated on a vast clay layer covering the central plains of Thailand, extending up to 30 meters deep in some areas. This clay layer, influenced by a mixture of seawater and alluvial water, particularly in tidal zones, plays a critical role in water infiltration and permeability.

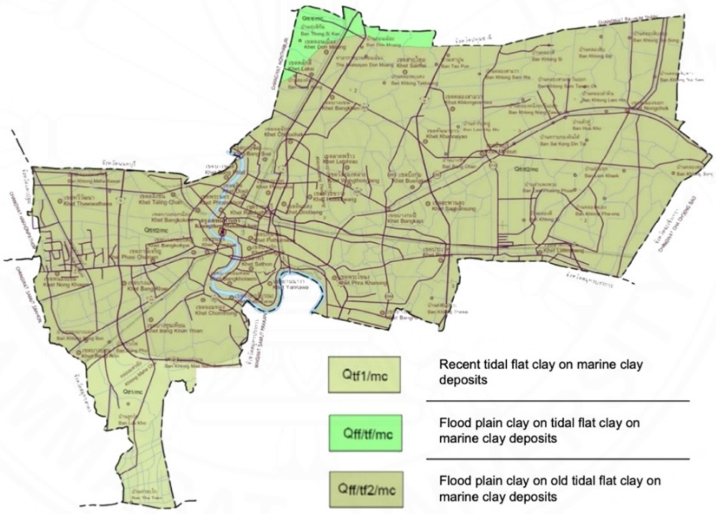


Figure 2.1 Soil characteristics of Bangkok
(Department of Mineral Resources)

The elevation of Bangkok varies widely, ranging from below 0 meters to over 3.5 meters, with an average elevation of approximately 1.50 to 2.0 meters, as reported by the Royal Thai Survey Department. This variation in elevation impacts surface runoff dynamics, flood risk zones, and the effectiveness of drainage infrastructure across different parts of the city.

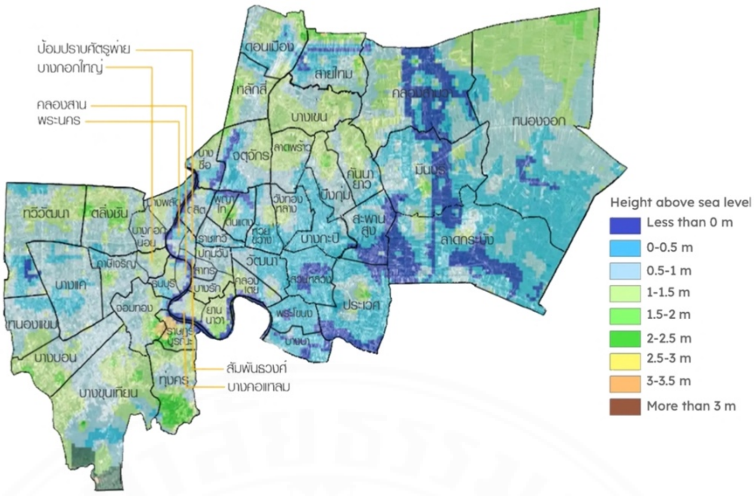


Figure 2.2 Elevation of Bangkok
(DDproperty, 2021)

2.2 Stormwater management in Bangkok

Bangkok's water management system operates on a polder model, characterized by the use of embankments and pumps to manage water flow. When rain falls onto the streets, it drains into the roadside stormwater drains. These drains then channel the water into canals, which eventually lead to the Chao Phraya River and out to the sea. However, the current water management at all levels faces significant challenges. For instance, water draining into the pipes can be obstructed by debris, blocking the flow because there is no space left for the water to exit. This obstruction is often a result of human activities.

2.3 Factors contributing to stormwater management issues in Bangkok

Currently, Bangkok has become an overcrowded city with significant economic expansion, leading to changes in water absorption areas and more frequent and severe flooding. This situation is a consequence of urban development that may have overlooked the limitations related to water-related disasters. Despite ongoing efforts by the Bangkok Metropolitan Administration (BMA) to manage the situation, such as waste removal, dredging, and constructing drainage tunnels, many problems remain unresolved and numerous factors are difficult to address. According to the BMA, the causes of flooding can be categorized into two main groups: natural causes and physical causes.

2.3.1 Natural causes

2.3.1.1 Rainfall

Bangkok's monthly cumulative rainfall comparison graph are shown below. The rainy season begins in May and ends in October, between mid-August and mid-October it will have the highest amount and frequency of rain. In addition, this is a period where there is a chance of tropical cyclones moving into Thailand and approaching Bangkok.

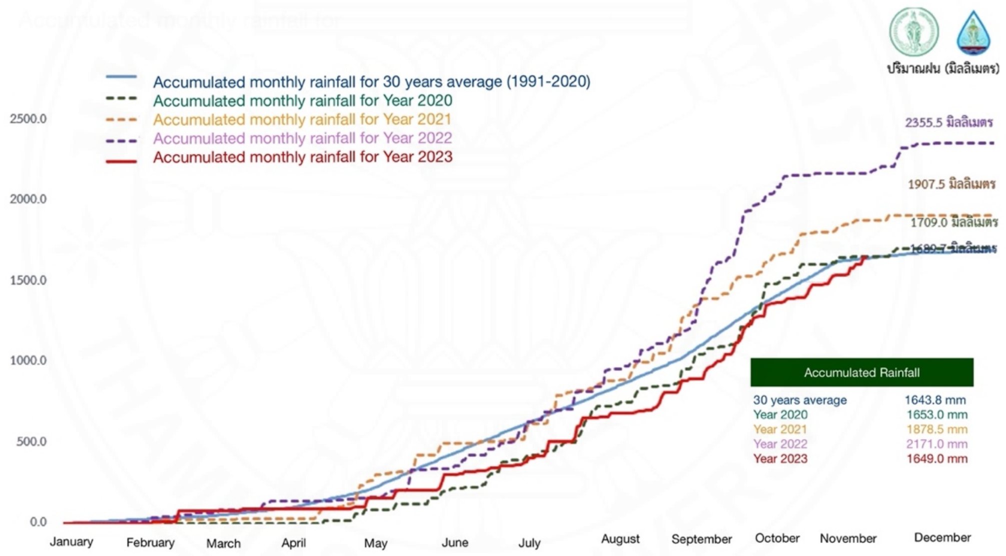


Figure 2.3 Monthly Cumulative Rainfall Comparison Graph (Department of Drainage and Sewerage, 2023)

2.3.1.2 Rising tide

When the sea level naturally rises and falls, it has a consequential impact on the water levels in the Chao Phraya River area near Bangkok. There is a gradual fluctuation with the highest high tides occurring from October to December. This fluctuation directly affects stormwater runoff.

2.3.2 Physical conditions

2.3.2.1 Urbanization

Bangkok was once filled with canals, ponds, and open spaces capable of accommodating a significant amount of water. However, rapid urbanization and poor urban planning have led to the replacement of these absorbent areas with buildings and concrete. As a result, the city's ability to retain rainwater has significantly diminished. The changes in land use, driven by development and lacking enforceable regulations, have reduced water retention areas. Since the integration of Bangkok's urban plan in 2013, there have been significant alterations in land use without effective controls. These changes highlight the urgent need for the enforcement of urban planning laws to mitigate the risks associated with rapid urbanization.

2.3.2.2 Drainage system

The absence of comprehensive drainage plans, following urban planning issues, has led to inadequate primary drainage systems. Canals and channels have been filled to make way for roads, and the size of drainage pipes is insufficient. The drainage pipes were constructed a long time ago, with some having a small diameter of approximately 30-60 cm, while the largest pipes have a diameter of about 80 cm. Originally, they were designed to handle rainfall of no more than 60 mm per hour. However, current rainfall exceeds 100 mm per hour, making it impossible for the pipes to drain the water in time, resulting in flooding.

The Drainage and Sewerage Department has plans to construct ten drainage tunnels throughout Bangkok. However, currently, only four drainage tunnels are operational:

The Pracharat Sai 2 drainage tunnel that channels water along the Prem Prachakorn Canal, facilitating drainage in the Bang Sue, Chatuchak, Lak Si, and Don Mueang districts, covering an area of approximately 3.50 square kilometers.

The Bueng Makkasan tunnel that facilitates the drainage of water from the swamp into the Chao Phraya River, serving the Wattana, Pathum Wan, Ratchathewi, Phaya Thai, Huai Khwang, and Din Daeng districts, covering approximately 26 square kilometers.

Khlong Saen Saep drainage tunnel and Khlong Lat Phrao that drain water in the districts of Huai Khwang, Bang Kapi, Bueng Kum, Wattana, Wang Thonglang, and Lat Phrao, covering approximately 50 square kilometers.

Drainage tunnel beneath Bang Sue Canal that facilitates the drainage of water from the areas of Huai Khwang, Din Daeng, Phaya Thai, Chatuchak, Lat Phrao, Wang Thonglang, Bang Sue, and Dusit. This drainage system encompasses an area of 56 square kilometers.

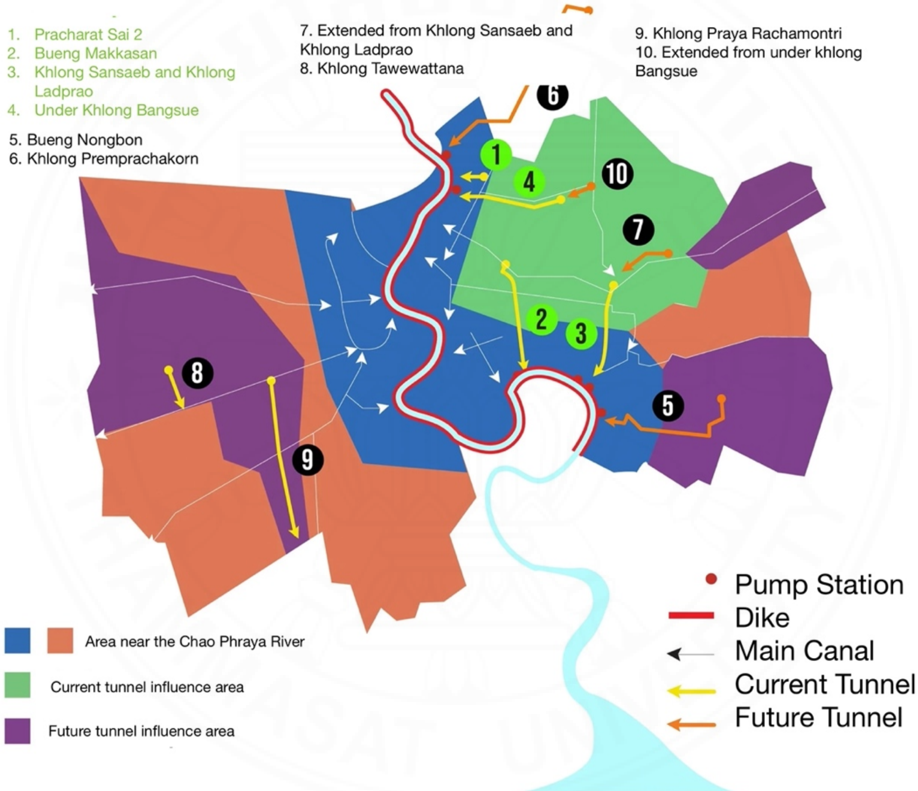


Figure 2.4 Drainage Map

(Thairath Plus, 2022)

2.3.2.3 Soil subsidence

The problem of land subsidence is the most concerning problem. This is because it causes flood prevention and drainage systems that have already been invested and will be invested again in the future to fail or reduce their efficiency as long as there is no adequate measure to stop or slow down the rate of subsidence.

2.4 Challenges associated with Stormwater Management

2.4.1 Water Pollution

Stormwater runoff can accumulate pollutants from various sources such as roads, parking lots, and other surfaces, transporting contaminants like oil, heavy metals, pesticides, and sediments into water bodies. This influx can degrade water quality and pose threats to aquatic ecosystems.

2.4.2 Flooding

In urban areas characterized by extensive impervious surfaces such as roads and pavement, stormwater runoff can overwhelm drainage systems, leading to flash floods and heightened risks of property damage and public safety concerns.

2.4.3 Erosion and Sedimentation

Intense stormwater runoff has the potential to cause soil erosion, resulting in the loss of fertile topsoil and sedimentation in water bodies. These processes can disrupt habitats, ecosystems, and water quality.

2.4.4 Infrastructure Strain

Inadequate management of stormwater can strain drainage systems and other infrastructure, causing degradation of pipes, culverts, and related components. This necessitates increased maintenance costs and the need for infrastructure upgrades.

2.4.5 Public Health Concerns

Contaminated stormwater poses health risks to individuals who encounter it directly or indirectly through contaminated water sources. Pathogens, chemicals, and other pollutants present in stormwater can be detrimental to human health.

2.4.6 Ecological Impact

Changes in water flow patterns and heightened pollutants in stormwater runoff can adversely impact both aquatic and terrestrial ecosystems, resulting in harm to fish, plants, wildlife, and ultimately leading to a decline in biodiversity.

2.4.7 Urban Heat Island Effect

Impermeable surfaces in urban areas hinder natural water absorption, contributing to the urban heat island effect where city temperatures are higher than those in surrounding rural areas. This phenomenon has implications for energy usage and public health.

2.5 Comparative analysis of different types of LID for stormwater management

The adoption of Low Impact Development (LID) principles, advocating for the localized management of rainwater runoff, marks a departure from conventional end-of-pipe strategies and has garnered support among professionals and public authorities (Sage et al., 2015). The LID approach encompasses site planning, hydrologic analysis, comprehensive management practices, erosion and sediment control, as well as public outreach initiatives (Prince George's County, 1999). Examples of LID technologies include green roofs, permeable pavement, retention cells, and treatment swales.

Based on the findings of Arya and Kumar (2023), Jotte et al. (2017), (Gogate et al., 2017), and RTI International and Geosyntec Consultants. (2015), a summary of the comparative analysis, including cost, performance, environmental impact, benefits, and limitations, is presented in the table below.

2.5.1 Cost comparison

The cost comparison for different types of LID stormwater management system is shown in the table below.

Table2.1 Cost comparison compiled in collaboration with RTI International and Geosyntec Consultants (2015)

	SIMPLE	COMPLEX
Permeable Pavements	**$2/ft2, $7/ft3 (volume of water captured)**	**$16/ft2, $27/ft3 (volume of water captured)**
Rainwater Harvesting Barrels	**$0.50/gal of storage**	**$8/gal of storge**
Detention Ponds	**N/A**	**N/A**
Infiltration Basins	**$1.30/ft2**	**$11/ft2**
Retention Ponds	**N/A**	**N/A**
Filter Strips	**N/A**	**N/A**
Wetlands	**N/A**	**N/A**
Grass Swales	**$5/LF**	**$50/LF**
Rain Gardedns and Bioswales	**$3/ft2**	**$40/ft2**
Green Roofs	**$9.60/ft2**	**$40/ft2**

2.5.2 Performance comparison

The performance comparison for different types of LID stormwater management system is shown in the table below.

Table 2.2 Comparative performance as per Arya and Kumar (2023)

	Runoff reduction (%)
Permeable Pavements	82.5
Rainwater Harvesting Barrels	47.3
Detention Ponds	34.5
Infiltration Basins	54.2
Retention Ponds	20.3
Filter Strips	67.9
Wetlands	66.1
Grass Swales	59.4
Rain Gardedns and Bioswales	26.5
Green Roofs	43.5

2.5.3 Environmental impact comparison

The environmental impact comparison for different types of LID stormwater management system is shown in the table below.

Table 2.3 Environmental impact comparison based on Arya and Kumar (2023), Jotte et al. (2017), and (Gogate et al., 2017)

Permeable Pavements	• Water quality improvement by efficient trapping of suspended solids and pollutants
Rainwater Harvesting Barrels	• Water conservation
Detention Ponds	• Help remove pollutants
Infiltration Basins	• Contribute to groundwater recharge and quality improvement
Retention Ponds	• Favor wildlife
Filter Strips	• Effective at controlling pollution
Wetlands	• Support biodiversity
Grass Swales	• Encourages infiltration
Rain Gardedns and Bioswales	• Filter pollutants
Green Roofs	• Favor wildlife (ex. birds) • Absorbing pollutants

2.5.4 Benefits comparison

The benefits comparison for different types of LID stormwater management system is shown in the table below.

Table 2.4 Comparative analysis of benefits according to Arya and Kumar (2023), Jotte et al. (2017), and (Gogate et al., 2017)

Permeable Pavements	• Significantly reduces runoff rates and volumes • Reduces impervious surface area
Rainwater Harvesting Barrels	• Simple, easy to set up and operate
Detention Ponds	• Easy to design and less maintenance needed
Infiltration Basins	• Reduction of peak flow rate, erosion and scouring • Maintain base flow of nearby streams, contribute to reduction of local flooding • Simple and cost effective
Retention Ponds	• Add an aesthetic value
Filter Strips	• Remove sediments along with pollutants
Wetlands	• Good aesthetic • Positive public perception
Grass Swales	• Easily adaptable to different geographical conditions • Flexible design and cheaper than conventional approaches
Rain Gardedns and Bioswales	• Work in restricted space • Less maintenance needed • Aesthetically appealing
Green Roofs	• Slow stormwater runoff due to reduction in impervious area for the property • Aesthetically pleasing • Good insulation

2.5.5 Limitations comparison

The limitations comparison for different types of LID stormwater management system is shown in the table below.

Table 2.5 Limitations comparison according to Arya and Kumar (2023) and Jotte et al. (2017)

Permeable Pavements	• Higher construction and maintenance costs than conventional pavements • Application has mostly been restricted to parking spaces and low-volume roads
Rainwater Harvesting Barrels	• The quality of water stored gets deteriorated after a prolonged period of time
Detention Ponds	• Require a considerable amount of spaces, making it unsuitable for densely populated area
Infiltration Basins	• May fail in places with steeper slopes and soils possessing low hydraulic conductivity
Retention Ponds	• Safety and health concerns
Filter Strips	• May fail in case of higher pollutant loads • Demand maintenance
Wetlands	• Demand constant inspection and removal of collected debris along with other remains from its inlet and outlet structures
Grass Swales	• Maintenance costs vary from moderate to high
Rain Gardedns and Bioswales	• Installation is expensive becauase of the high investment cost of labour • Sediment clogging may occur
Green Roofs	• Limited research at a local level to find suitable native plants for the optimum performance • Initial high construction cost and require constant maintenance • Improper installation increase the probability of leakage and can lead to structural failure of buildings

2.6 Case study in Malaysia

In Malaysia, the predominant drainage method for addressing urban flash floods has historically been the open channel or open drainage system. This approach, outlined in the 1975 manual "Planning and Design Procedure No.1: Urban Drainage Design Standard and Procedure for Malaysia," aimed to mitigate flash flood issues. However, observations by researchers suggest that this solution may not be optimal for the future, potentially leading to downstream flash floods. Some recent developments in Malaysia have opted for pipe conduits as an alternative to open drainage systems to channel stormwater runoff to watercourses. However, these systems contribute to river pollution and pose significant public health concerns.

Recognizing the limitations of existing practices, the Department of Irrigation and Drainage (DID) Malaysia, as the government representative, introduced a comprehensive approach through the "Stormwater Management Manual for Malaysia" (Manual Saliran Mesra Alam or MASMA), effective from January 2001. MASMA promotes a new philosophy for Malaysia, emphasizing "source control techniques" to minimize runoff flow rates from contributing areas, departing from the previous concept of "rapid runoff discharge". The manual advocates the application of Best Management Practices (BMPs) to control both the quantity and quality of stormwater runoff, aiming for zero development impact contribution. The primary objectives of these guidelines are to provide direction to regulators, planners, and designers involved in stormwater management, establishing a new direction for urban stormwater management in Malaysia.

2.6.1 Runoff quantity management strategies

2.6.1.1 Conveyance-oriented approaches

In Malaysia, stormwater management has traditionally prioritized addressing flooding impacts through a conveyance-oriented approach. This approach involves swiftly collecting and conveying stormwater from the collection area to the discharge point to minimize damage and disruptions. The focus is on rapidly disposing of stormwater as it is perceived as a nuisance. The advantages include the quick removal of stormwater, maximizing land availability for development by minimizing drainage-related land requirements, and employing established analysis and design procedures.

However, this approach has notable drawbacks, including the need to size conveyance systems for the total increase in flows resulting from urbanization. Downstream conveyance systems often lack the capacity to handle these increased flow peaks and durations, leading to potential new or exacerbated flooding, erosion, and sedimentation issues. Additionally, traditional open conveyance systems with hard linings pose hazards to the public during and after rain due to high flow velocities, and they contribute to the transport of urban pollutants to downstream areas. (DID, 2012)

2.6.1.2 Storage-oriented approaches

The evolution of stormwater management in Malaysia has led to two distinct approaches in controlling the quantity, and to some extent, the quality of stormwater runoff. In addition to the traditional conveyance-oriented approach, an effective and preferable alternative is the storage-oriented approach. This approach focuses on temporarily storing stormwater runoff at or near its origin, followed by slow release to the downstream stormwater system or infiltration into the surrounding soil.

The storage-oriented approach minimizes flood damage within and downstream of the collection area and allows for potential reuse of stored runoff for irrigation and domestic purposes. Key elements of this approach include stormwater detention facilities and retention facilities.

Detention facilities encompass on-site storage, community storage, and regional storage. On-site detention is designed to reduce nuisance flooding locally, while larger community and regional facilities enhance public safety and minimize downstream property damage, channel erosion, and disturbance of aquatic habitat. Techniques involve temporary storage in tanks, basins, ponds, wetlands, flood reservoirs, and urban lakes.

Retention facilities primarily aim to reduce the volume of stormwater runoff from small frequent storm events by storing and allowing infiltration into the surrounding soil. Techniques include dispersion trenches, pits, wells, grassed swales, pervious stormwater pipes, porous pavements, and infiltration trenches. Stormwater re-use is also considered at both individual and community levels.

The advantages of a storage-oriented approach include potential cost savings in the overall life cycle of the stormwater system. This approach may reduce the required size of downstream conveyance systems and allows for multi-use integration with open space systems, recreational areas, and wildlife corridors. Additional benefits include improved public safety, an aesthetically pleasing urban landscape, increased property values near open water bodies, enhanced flora and fauna habitats, and groundwater recharge. While concerns about land take exist, they can be addressed through proper design, incorporating multi-purpose facilities, and reviewing planning regulations.

The conveyance-oriented and storage-oriented approaches are not mutually exclusive; instead, their integrated use is encouraged for a more optimal stormwater drainage system. For instance, conveyance-oriented facilities can address minor drainage systems, while storage-oriented facilities can manage major drainage systems. However, retrofitting storage in existing built-up areas with high land values may present challenges and necessitate costly conveyance system enlargements. (DID, 2012)

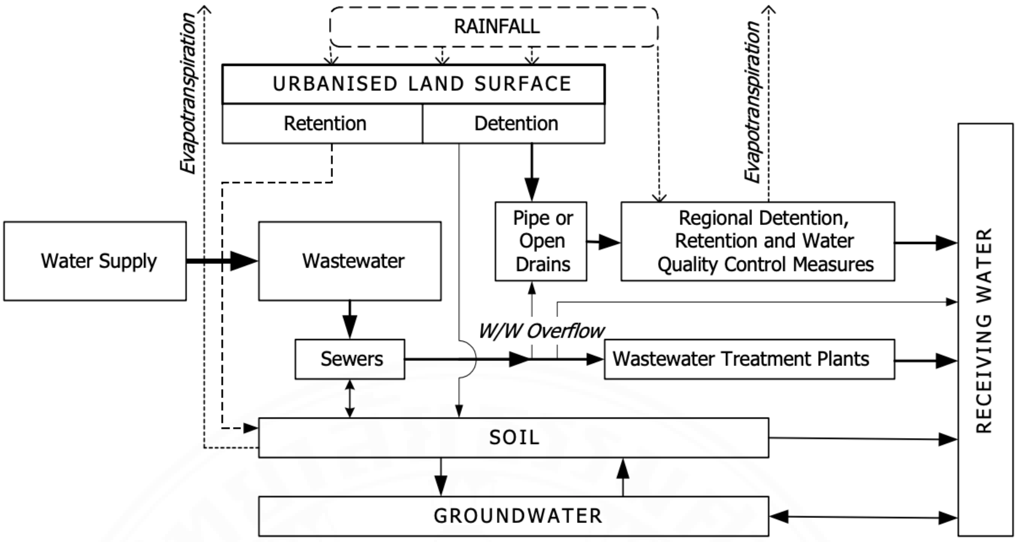


Figure 2.5 Urban Water System of Malaysia

(Department of Irrigation and Drainage, 2012)

2.6.2 The Stormwater Management and Road Tunnel (SMART Tunnel)

The tunnel is located in Kuala Lumpur, is a pioneering infrastructure project designed to address both traffic congestion and urban flooding issues in the city. Officially inaugurated in 2007, the SMART Tunnel serves a dual purpose: it operates as a traffic tunnel during normal weather conditions and as a stormwater diversion tunnel during periods of heavy rainfall or flooding.

Constructed at a cost of approximately $1 billion, the SMART Tunnel spans 9.7 kilometers and incorporates technologically advanced features such as a unique double-deck structure. The upper deck serves as a roadway for vehicles, providing an additional route to alleviate traffic congestion in the city center. During heavy rains, the lower deck is transformed into a stormwater tunnel, capable of diverting excess water from the Klang River and other urban catchments to prevent flooding in low-lying areas of Kuala Lumpur.

The SMART Tunnel represents a significant engineering achievement, integrating flood management and transportation infrastructure to enhance urban resilience and sustainability. By effectively managing stormwater runoff and reducing traffic congestion, the tunnel contributes to improving the overall quality of life for residents and businesses in Kuala Lumpur.

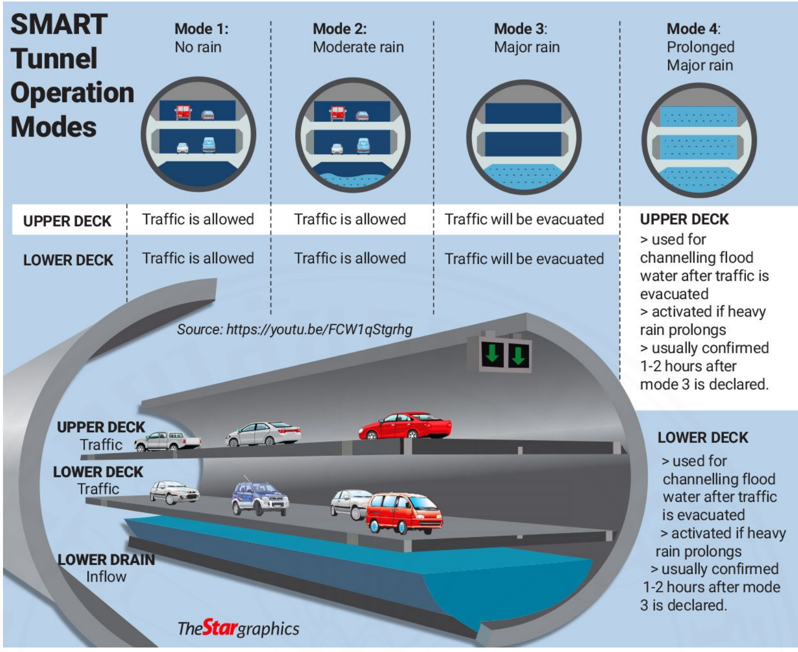


Figure 2.6 SMART Tunnel

(The Star, 2022)

2.7 Case study in Singapore

Singapore, a small island-state located 137 km north of the Equator with an area of 716 km2, is recognized for its successful urban water management despite facing environmental challenges. The country experiences high rainfall of 2338.5 mm/year occurring throughout the year, influenced by the monsoon system. Despite abundant rainfall, Singapore is classified as water-scarce due to a high population and limited water resources.

In addressing address stormwater management, Singapore has developed dense networks of drains and canals that transport stormwater into reservoirs and the sea. Earlier practices involved lining, straightening, and enlarging natural drainage pathways. Low Impact Development (LID) practices, such as stormwater retention ponds for greenery irrigation, date back to the 1970s. The ABC Waters program signifies a shift toward widespread LID practices for sustainable stormwater management, aiming to integrate waterways with the urban landscape.

The ABC Waters Program follows a source-pathway-receptor approach, constructing Best Management Practices (BMPs) throughout the country. BMPs treat stormwater at its source, enhance the stormwater drainage network (pathway), and include protective measures like flood barriers at flood-prone locations (receptor). This approach aligns with PUB's goal of creating a water-sensitive city by recognizing natural hydrological processes in urban stormwater management.

2.7.1 Stormwater management system map

Inspired by the vision of pristine rivers with landscaped shores and serene lakes, Singapore has embraced the challenge of evolving into a City of Gardens and Water. Since the initiation of the Active, Beautiful, Clean Waters (ABC Waters) Program in 2006 by PUB, an extensive network of approximately 8,000 km of waterways and 17 reservoirs has been developed. This strategic initiative is dedicated to enhancing water quality and overall quality of life by unlocking the full potential of Singapore's waterbodies. Through a holistic approach that seamlessly integrates drains, canals, and reservoirs with their surrounding environments, the ABC Waters Program strives to craft aesthetically pleasing and pristine streams, rivers, and lakes. The goal is to create community spaces that are not only visually appealing but also contribute to a cleaner and more enjoyable environment for everyone.

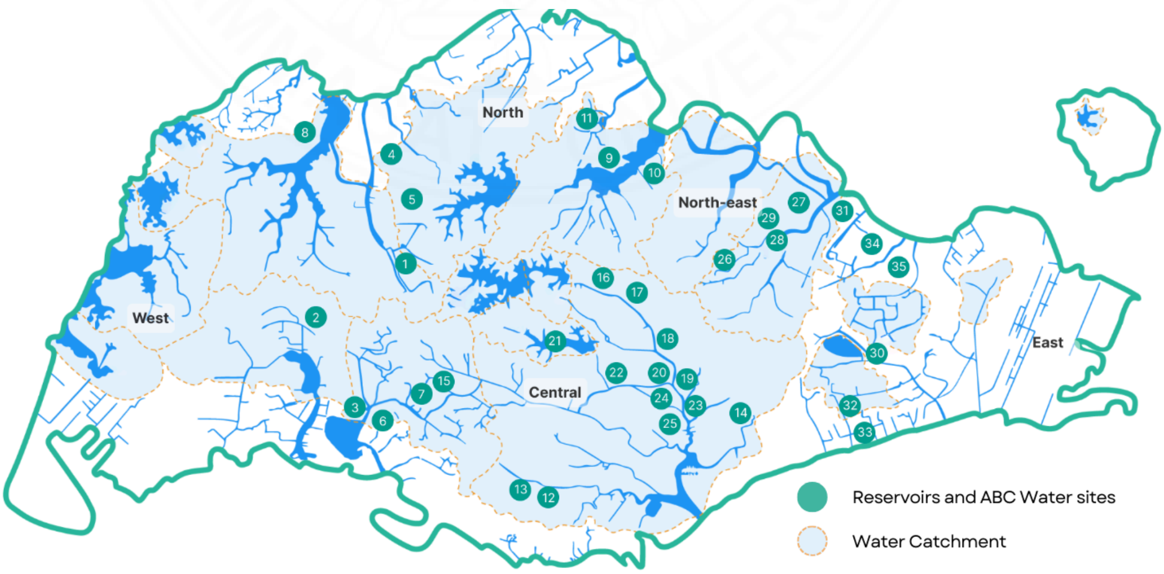


Figure 2.7 Reservoirs and ABC Water sites across Singapore
(PUB, Singapore's National Water Agency)

2.7.2 The source-pathway-receptor approach

2.7.2.1 Source

The goal of source solutions seek to slow down the amount of runoff that enters the public drainage system from developing zones. These options include wetland ponds, bioretention basins, and detention tanks (sometimes called rain gardens). Source solutions, which are implemented by both public and private developments, complement pathway solutions to improve the catchment's flood protection. (PUB, 2014)

2.7.2.2 Pathway

Expanding or deepening already-existing canals, as well as creating new canals or diversion canals, are examples of pathway solutions. It is difficult to extend drains and canals in heavily populated regions without upsetting the public, particularly when waterways are near roadways and private property. A different course of action in these situations is to direct extra runoff from public canals or drains to a centralized pond or detention tank for short-term storage. After the storm has passed, the runoff is subsequently dumped into the same canal in preparation for the following one. (PUB, 2014)

2.7.2.3 Receptor

Receptor solutions, which fall into two main categories: structural and non-structural, shield infrastructure from flooding.

Raising road levels, development platform levels, basement and subterranean facility entrance levels (also known as crest levels) and putting in mechanical flood protection devices like flood barriers are examples of structural measures.

Preventive flood monitoring through heavy rain warning subscriptions and updates on water levels in Singapore's drains and canals are examples of non-structural interventions. (PUB, 2014)

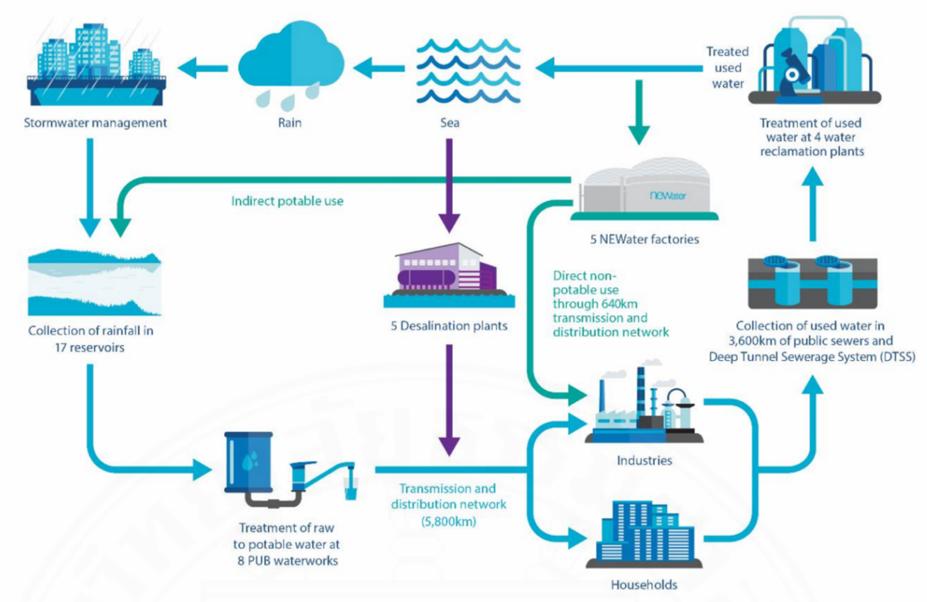


Figure 2.8 Singapore's ABC water program approach
(PUB, Singapore's National Water Agency)

2.7.3 Underground Reservoir

The underground reservoir in Singapore is a key component of the country's water management infrastructure, designed to enhance water security and resilience in the face of limited land availability and vulnerability to droughts. Officially known as the Marina Barrage Reservoir, it is located in Marina Bay and serves multiple functions beyond water storage.

Completed in 2008, the Marina Barrage Reservoir has a storage capacity of 17 million cubic meters and spans an area of 10,000 square meters. It not only collects and stores rainwater but also acts as a freshwater reservoir, providing a sustainable water supply for Singapore's residents and industries. The reservoir is integral to Singapore's Four National Taps strategy, which includes water from local catchments, imported water, desalinated water, and reclaimed water (NEWater).

The Marina Barrage Reservoir plays a crucial role in managing Singapore's water resources by preventing flooding in low-lying areas, enhancing water quality through natural purification processes, and providing recreational spaces for the public. It also serves as a symbol of Singapore's commitment to sustainable urban development and climate resilience.

Figure 2.9 Underground Reservoir

(Straight Times, 2015)

CHAPTER 3
METHODOLOGY

3.1 Data Collection

This study begins with a comprehensive literature review and site visits to gather insights into stormwater management practices and challenges in Bangkok. The literature review involves sourcing information from academic journals, government reports, and case studies from other countries with advanced stormwater management systems. Site visits in the Watthana and Minburi districts include on-site inspections to collect primary data on existing infrastructure and flood-prone areas.

3.1.1 Site Selection Rationale

The Watthana and Minburi districts were selected for this study due to their contrasting urban characteristics and common flooding issues. Watthana is densely populated with high-rise buildings and extensive urban development, which exacerbates runoff and flooding during heavy rains. Conversely, Minburi, with its less dense population and more vacant land, presents different challenges and opportunities for stormwater management. Comparing these two districts allows for a comprehensive analysis of how urban density and land use impact stormwater management effectiveness and the types of strategies that may be most effective in different urban contexts.

3.2 Data Comparison

Data collected from the literature review and site visits are systematically analyzed and compared between the two districts. This section focuses on two main aspects:

3.2.1 Quantitative Analysis

Quantitative analysis involves evaluating the cost-performance of different stormwater management practices in both districts. This includes comparing the initial implementation costs, maintenance expenses, and overall effectiveness in reducing runoff and mitigating flooding. Statistical methods and cost-benefit analysis are used to quantify these aspects.

3.2.2 Qualitative Analysis

Qualitative analysis assesses the environmental impact, benefits, and limitations of various stormwater management practices. This involves evaluating how different strategies affect local ecosystems, water quality, and community resilience. The analysis draws on data from site visits, stakeholder interviews, and case studies to provide a comprehensive understanding of the non-monetary impacts of these practices.

3.3 Assessment of Current Solutions and Future Plans

The research assesses current strategies and future initiatives aimed at addressing stormwater management challenges in Bangkok. This involves:

3.3.1 Reviewing City Planning Documents and Government Reports

Analyzing official documents and reports to understand existing policies, regulations, and strategies related to stormwater management in Bangkok. These sources provide insights into the city's approach and planned initiatives for mitigating flooding and managing runoff.

3.3.2 Evaluating Recent Projects and Proposed Plans

Examining recently completed projects and proposed plans for stormwater management improvements. This evaluation focuses on the objectives, methodologies, and outcomes of these projects, highlighting successful practices and identifying areas that require enhancement.

3.4 Alternative Recommendations

Based on the findings from the data analysis and assessment, the study formulates practical alternative recommendations for enhancing the stormwater management system in Bangkok. These recommendations are tailored to the city's unique needs, aiming to improve resilience and effectiveness in managing urban growth and changing weather patterns. The proposed solutions consider technological advancements, cost-effectiveness, and community engagement to ensure sustainable and efficient stormwater management.

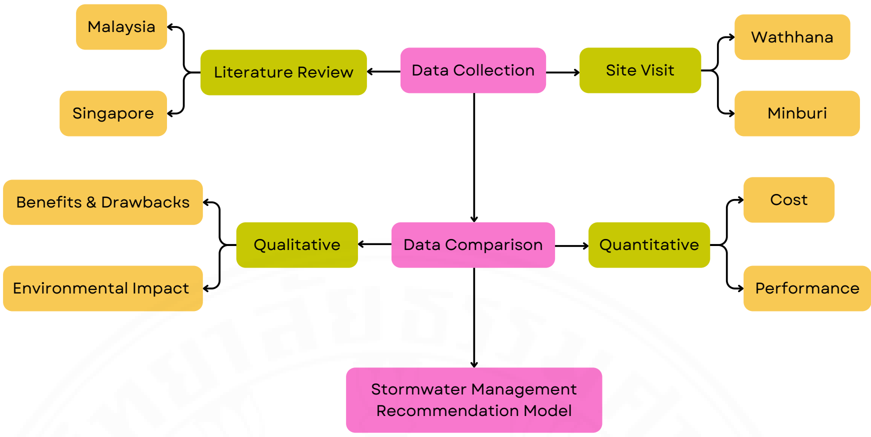


Figure 3.1 Methodology

CHAPTER 4
STORMWATER MANAGEMENT RECOMMENDATION MODEL

This chapter presents a comprehensive stormwater management recommendation model for Bangkok, specifically tailored for Watthana and Minburi districts. Additionally, it incorporates successful stormwater management strategies from Malaysia and Singapore, exploring their applicability and benefits for Bangkok. The chapter concludes with detailed calculations to support the proposed strategies.

4.1 Current Practices and Challenges

Bangkok's stormwater management currently relies on a polder system, which involves the use of canals and pumps to manage water flow and drainage. However, rapid urbanization and economic expansion have altered the city's hydrological landscape, resulting in frequent and severe flooding. The existing infrastructure struggles with issues such as clogged drainage systems due to waste accumulation and inadequate capacity to handle heavy rainfall.

4.2 Case Study in Thailand, Watthana District

Watthana District, one of the key commercial and residential areas in Bangkok, faces unique challenges in stormwater management due to its high density of buildings and limited green spaces. The drainage system in this district is a crucial component in mitigating the impact of heavy rainfall and preventing urban flooding.

As shown in Figure 2.5, Watthana District mainly consists of brown-colored areas, indicating land with high residential density, typically located in inner-city areas. This type of land can be developed for all types of residential buildings due to its high value. Given its location, this land is often used for vertical residential developments, such as various condominium projects in city centers.

The red areas indicate commercial land, focusing on large-scale business activities, with fewer restrictions on residential construction compared to other zones.

Orange areas indicate medium-density residential land, which is contiguous with inner-city zones and accommodates residential expansion, suburban community centers, and industrial zones.

Lastly, the blue areas indicate land used for government institutions, utilities, and public services.

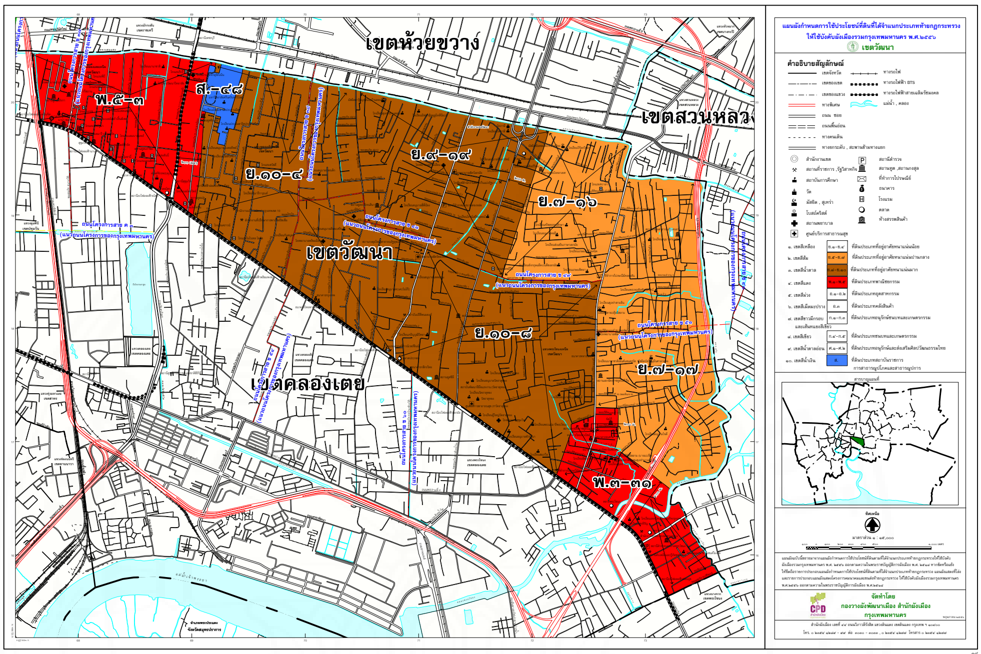


Figure 4.1 Land Use Planning Map of Watthana (Department of City Planning and Urban Development, 2024)

4.2.1 Current Infrastructure

4.2.1.1 Primary Drainage Network: The primary drainage system in Watthana District consists of underground drainage pipes that channel rainwater from streets and buildings to larger canals and drainage tunnels. These pipes vary in size and capacity, designed to handle the typical rainwater runoff during the monsoon season.

4.2.1.2 Canals and Waterways: The major canals in Watthana District include the Saen Saep Canal (Khlong Saen Saep) and the Khlong Toei Canal. These canals play a vital role in draining excess water during heavy rainfall. However, many smaller, traditional canals have been filled or narrowed due to urban development, reducing their effectiveness.

4.2.1.3 Drainage Tunnels: The Bueng Makkasan drainage tunnel is a key infrastructure element that serves parts of Watthana District. This tunnel channels excess water into the Chao Phraya River, helping to alleviate pressure on surface drainage systems during heavy rainfall.

4.2.2 Challenges and Issues

4.2.2.1 Limited Capacity

The existing drainage pipes in Watthana are often undersized for the volume of water they need to handle during heavy rainstorms. This leads to frequent surface flooding, especially in low-lying areas.

4.2.2.2 Blockages and Maintenance

The drainage system frequently suffers from blockages caused by debris, sediment, and waste. Regular maintenance is crucial but often inadequate, leading to reduced efficiency in water removal during critical times.

4.2.2.3 Urbanization

The rapid pace of urbanization has resulted in a significant increase in impervious surfaces, such as roads, pavements, and buildings, which prevent natural water absorption and increase runoff. This exacerbates the burden on the drainage system.

4.2.2.4 Groundwater Depletion and Subsidence

Over-extraction of groundwater has led to subsidence in parts of Watthana District, complicating drainage efforts as ground levels change and infrastructure shifts.

4.2.3 Current Solutions and Approaches

4.2.3.1 Infrastructure Upgrades

The Bangkok Metropolitan Administration (BMA) has initiated projects to increase the size and capacity of drainage pipes and tunnels. This includes ongoing work to install new, larger pipes in areas prone to frequent flooding and enhance existing infrastructure.

4.2.3.2 Green Infrastructure

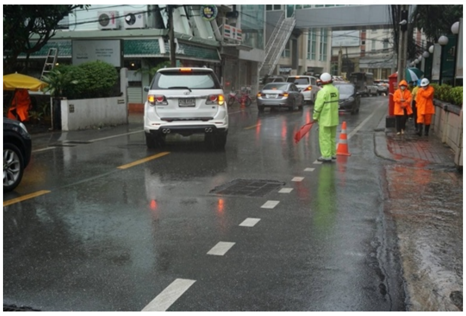
There are efforts to implement green roofs, permeable pavements, and rain gardens in new developments. These measures help absorb rainwater and reduce runoff. Additionally, the BMA is working to expand green spaces and protect remaining open areas to improve stormwater management.

4.2.3.3 Regular Maintenance

The BMA has increased the frequency of maintenance for cleaning and repairing drainage pipes and canals. This includes regular dredging of canals like Saen Saep Canal and Klong Tan Canal to prevent blockages and ensure smooth water flow.

(a) Pumping Machine

(b) Drainage Pipe



(c) Flood Prone Area

Figure 4.2 Watthana district

(Watthana District, 2020)

4.3 Recommendations for Watthana District

Watthana is a densely built area with limited green space. The following strategies are recommended to manage stormwater effectively in this urban setting:

4.3.1 Green Roofs and Vertical Gardens

Green roofs can absorb rainfall, reducing runoff. Vertical gardens on building facades can also help manage rainwater. The installation of green roofs costs approximately $200-$300 per square meter, with an annual maintenance expense of $5-$10 per square meter. Green roofs provide several benefits, including reducing runoff by up to 75%, offering insulation that lowers energy costs, and enhancing urban aesthetics and biodiversity. Although the initial cost is high, green roofs offer long-term savings through energy efficiency and reduced flood damage. Additionally, they deliver significant environmental and aesthetic advantages.

4.3.2 Permeable Pavements

Replacing traditional pavements with permeable ones allows water to infiltrate the ground, reducing surface runoff. The installation cost for permeable paving ranges from $50 to $100 per square meter, with annual maintenance costs between $2 and $5 per square meter. This paving solution offers significant benefits, including reducing surface runoff by enabling water infiltration and decreasing the load on stormwater drainage systems. Overall, permeable paving presents a moderate initial investment with low ongoing maintenance costs. It is effective in mitigating localized flooding and enhancing groundwater recharge, making it a practical choice for sustainable water management.

4.3.3 Smart Drainage Systems

Implementing smart sensors to monitor and manage water flow in drainage systems can help prevent blockages and optimize pump usage. The installation cost of advanced urban water management systems varies widely based on the technology used, typically ranging from $500,000 to $1,000,000 for a mid-sized urban area. Maintenance involves moderate costs, primarily for periodic sensor and system checks. These systems offer real-time monitoring and management of water flow, preventing blockages and optimizing pump usage. Although the initial cost is high, these systems can significantly reduce maintenance expenses and improve overall efficiency. They also enhance flood response and management capabilities, providing substantial long-term benefits.

4.4 Case Study in Thailand, Minburi District

Min Buri District, situated in the northeastern part of Bangkok, is characterized by its peri-urban landscape with a mix of residential, agricultural, and industrial areas. The district's drainage system faces challenges distinct from those in more densely built areas, due to its larger areas of vacant land and lower population density. However, effective stormwater management remains crucial to prevent flooding and ensure sustainable development.

As shown in Figure 2.6, Minburi mainly consist of green area which indicates that the land is classified as conservation and agriculture, and land classified as rural and agricultural.

The red areas indicate commercial land, focusing on large-scale business activities, with fewer restrictions on residential construction compared to other zones.

Orange areas indicate medium-density residential land, which is contiguous with inner-city zones and accommodates residential expansion, suburban community centers, and industrial zones.

Yellow areas shows that the areas have low residential density.

Lastly, Purple color shows that the land is designated for industrial purposes.

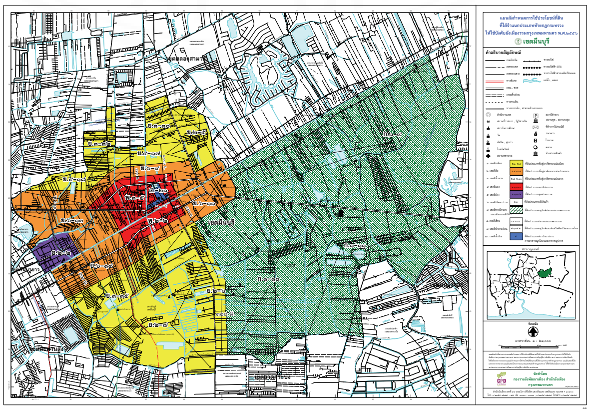


Figure 4.3 Land Use Planning Map of Minburi
(Department of City Planning and Urban Development, 2024)

4.4.1 Current Infrastructure

4.4.1.1 Primary Drainage Network

Min Buri District's primary drainage system consists of a network of underground drainage pipes that channel rainwater from streets and residential areas to larger canals and waterways. These pipes are designed to handle typical rainwater runoff, but their capacity varies across different areas.

4.4.1.2 Canals and Waterways

Major canals in Min Buri District include the Khlong Min Buri (Min Buri Canal) and Khlong Sam Wa (Sam Wa Canal). These canals are critical for draining excess water during heavy rainfall and are part of the larger Chao Phraya River Basin.

4.4.1.3 Retention Ponds and Wetlands

Min Buri benefits from several natural and artificial retention ponds and wetlands that act as temporary water storage areas during heavy rain. These areas help absorb excess water and reduce the immediate burden on the drainage system.

4.4.2 Challenges and Issues

4.4.2.1 Limited Drainage Capacity

While the district has significant open spaces, the existing drainage pipes in more developed areas can be undersized for handling heavy rainfall, leading to localized flooding.

4.4.2.2 Maintenance of Canals

The canals and waterways can become obstructed with debris, sediment, and vegetation, reducing their effectiveness in stormwater management. Regular maintenance is essential but often inconsistent.

4.4.2.3 Urbanization and Land Use Changes

As Min Buri develops, increasing impervious surfaces such as roads and buildings reduce the natural absorption of rainwater, increasing runoff and putting more pressure on the drainage system.

4.4.3 Current Solutions and Approaches

4.4.3.1 Infrastructure Upgrades

he Bangkok Metropolitan Administration (BMA) is working on upgrading drainage infrastructure in Min Buri District. This includes expanding the capacity of existing drainage pipes and constructing new ones in flood-prone areas.

4.4.3.2 Canal Maintenance and Dredging

Regular dredging and cleaning of major canals like Khlong Min Buri and Khlong Sam Wa are conducted to prevent blockages and maintain water flow. This is crucial to ensure that the canals can effectively channel excess rainwater during heavy storms.

4.4.3.3 Green Infrastructure

Projects to implement green roofs, permeable pavements, and rain gardens in new residential and commercial developments are underway. These initiatives help absorb rainwater and reduce the volume of runoff entering the drainage system.

4.4.3.4 Retention Ponds and Wetlands

The BMA is enhancing existing retention ponds and wetlands, such as the Min Buri Park's Lake and other local ponds, to improve their capacity to store stormwater temporarily. These areas are crucial for managing excess water during peak rainfall periods.

4.4.3.5 Land Use Planning

The BMA is integrating more stringent land use planning regulations to control urban development and protect natural water retention areas. This includes zoning laws that require new developments to include stormwater management solutions.

(a) Canal

(b) Drainage

(c) Minburi Area

(d) Flood Gate

Figure 4.4 Minburi district

(Site Visit, 2024)

4.5 Recommendations for Minburi District

Minburi, with more vacant land, offers different opportunities for stormwater management:

4.5.1Retention Ponds and Wetlands

Creating retention ponds and wetlands can store excess rainwater and improve water quality through natural filtration. The construction cost of flood storage facilities ranges from $5 to $10 per cubic meter of storage capacity, with annual maintenance costs between $1 and $2 per cubic meter. These facilities offer significant flood storage capacity and improve water quality through natural filtration. Overall, they present a low to moderate cost with substantial benefits in flood control and water quality improvement, making them suitable for areas with available land.

4.5.2 Green Spaces and Parks

Expanding green spaces and parks can increase water infiltration and provide recreational areas for the community. The development cost of green infrastructure ranges from $10 to $20 per square meter, with annual maintenance costs between $1 and $3 per square meter. Green infrastructure solutions increase water infiltration and reduce runoff while enhancing urban green spaces that serve as recreational areas. Overall, they offer a moderate cost with high environmental and social benefits, effectively mitigating urban heat islands and enhancing overall quality of life in urban areas.

4.5.3 Community Rainwater Harvesting

Encouraging residents to install rainwater harvesting systems can reduce runoff and provide a supplementary water source for non-potable uses. The installation cost of household water harvesting systems typically ranges from $500 to $2,000 per system, with minimal maintenance required, primarily involving cleaning and occasional repairs. These systems offer several benefits, including reducing demand on municipal water supply and providing a supplementary water source for non-potable uses. Overall, they present a low-cost solution with significant advantages in water conservation and flood reduction. Moreover, their scalability and community-driven nature make them adaptable to various residential settings, promoting sustainable water management practices effectively.

4.6 Learning from Malaysia and Singapore

Malaysia and Singapore offer valuable lessons in stormwater management:

4.6.1 Singapore's Underground Reservoirs

Singapore's Marina Barrage and other underground reservoirs store stormwater for later use and flood control. Bangkok can implement similar underground reservoirs to store runoff during heavy rains. Given Bangkok's flat terrain and high-water table, careful geological studies are necessary to identify suitable locations. The construction cost of stormwater storage facilities ranges from $200 to $500 per cubic meter of storage capacity, with maintenance costs varying based on complexity and usage intensity. These facilities provide significant storage capacity for stormwater and can serve as a water supply source during dry periods. Despite a high initial cost, they offer extensive benefits in flood control and water supply resilience. With careful site selection and engineering, these solutions are feasible in urban areas like Bangkok, addressing critical water management challenges effectively.

4.6.2 Malaysia's Stormwater Management System (SMART Tunnel)

The Stormwater Management and Road Tunnel (SMART Tunnel) in Kuala Lumpur, Malaysia, is a dual-purpose infrastructure designed to manage both traffic and stormwater. During regular conditions, it functions as a typical road tunnel. However, during heavy rainfall, it transforms into a stormwater tunnel, effectively mitigating flooding in the city (Stormwater Management and Road Tunnel [SMART Tunnel], n.d.). As for Bangkok similar dual-purpose tunnel could be developed to alleviate traffic congestion and manage stormwater. The construction cost of a large-scale dual-purpose tunnel project such as the SMART Tunnel in Kuala Lumpur typically amounts to approximately $1 billion. Maintenance costs are high due to its dual-purpose functionality and technological demands. The tunnel serves both as a flood control system and a traffic management route, effectively reducing flood risks and enhancing urban mobility. Despite the very high initial cost, the project offers dual benefits in flood control and congestion reduction, making it particularly suitable for critical flood-prone and high-traffic areas like Bangkok.

4.7 Recommendations for Bangkok

To determine the best suitable model for implementation in Bangkok, we need to consider several factors such as cost-effectiveness, feasibility in urban settings, effectiveness in managing Bangkok's specific stormwater challenges (e.g., heavy rainfall, urbanization issues), and environmental benefits. The comparison of these factors is shown in Table 4.1 and Table 4.2. The following practices are what I suggest being the most suitable for Bangkok:

4.7.1 Green Roofs

Due to their ability to reduce runoff significantly, provide insulation benefits (which can be beneficial in a tropical climate like Bangkok), and enhance urban aesthetics and biodiversity. They also contribute positively to reducing the urban heat island effect, which is crucial in a city prone to heat stress.

4.7.2 Permeable Pavements

These are effective in reducing surface runoff and promoting groundwater recharge, which can help mitigate flooding and replenish groundwater resources in Bangkok's urban areas.

4.7.3 Retention Ponds/Wetlands

While requiring more space, they are effective in managing large runoff volumes and improving water quality, which can be beneficial if suitable land is available within or near urban areas.

4.7.4 Community Rainwater Harvesting

Effective for reducing household water use and peak runoff, but its impact may be limited unless widely adopted across the city.

Each of these methods has its strengths and challenges, but green roofs and permeable pavements seem particularly well-suited for urban environments like Bangkok due to their potential to integrate with existing infrastructure and provide immediate benefits in reducing stormwater runoff and improving water management.

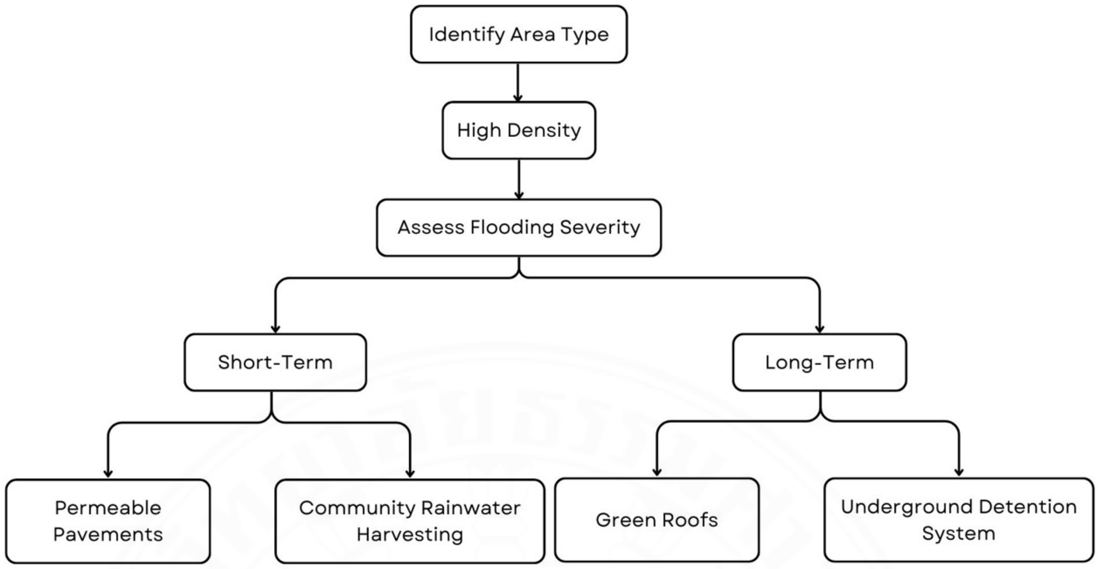


Figure 4.5 Stormwater Management Model for High Density Area

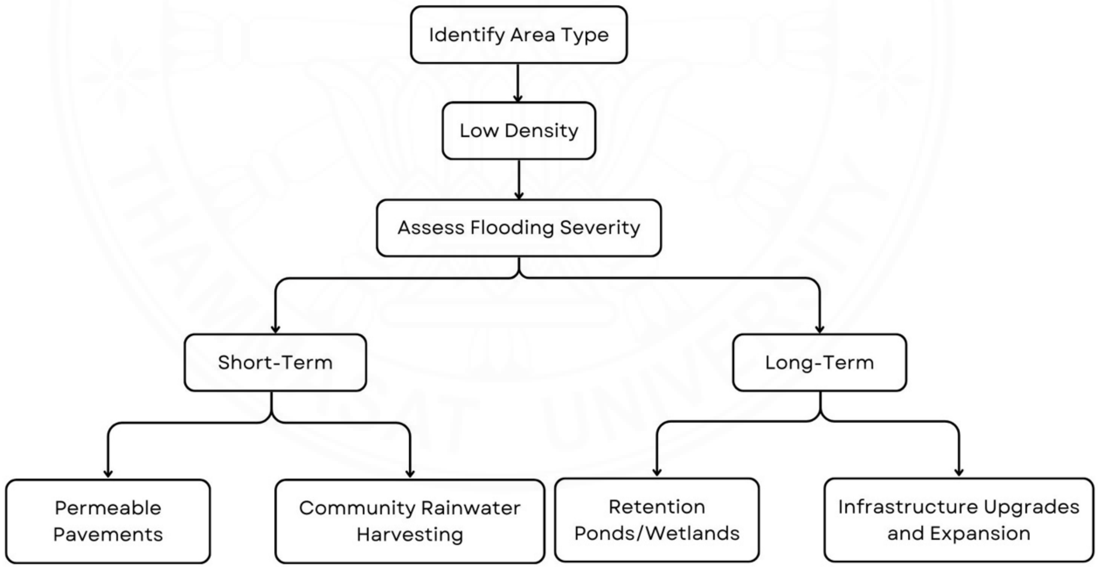


Figure 4.6 Stormwater Management Model for Low Density Area

Table 4.1 Comparison of Urban Flood Mitigation Methods: Costs and Performance

LID Practice	Installation Cost (USD)	Maintenance Cost (USD)	Performance	References
Green Roofs	\$200-\$300 per m²	\$5-\$10 per m²/year	Effective for small to moderate rainfall about 43.5% runoff reduction	Kourtis et al., 2018; The Open Water Journal, 2023
Permeable Pavements	\$50-\$100 per m²	\$2-\$5 per m²/year	Reduces runoff volume and peak discharge about 82.5%	Kourtis et al., 2018; The Open Water Journal, 2023
Bioretention Areas	\$100-\$200 per m²	Moderate	Highly effective in pollutant removal and moderate runoff reduction about 26.5%	Kourtis et al., 2018; Zhang & Chui, 2017
Retention Ponds/Wetlands	\$5-\$10 per m³	\$1-\$2 per m³/year	Manages large runoff volumes, Natural process improvement	Kourtis et al., 2018; Zhang & Chui, 2017
Community Rainwater Harvesting	\$500-\$2,000 per household	Minimal	Effective in reducing household water use, reduces peak runoff about 47.3%	Kourtis et al., 2018; The Open Water Journal, 2023

Underground Reservoirs	$200-$500 per m³	Moderate	Highly effective for large-scale storage, Manages significant runoff	Kourtis et al., 2018; The Open Water Journal, 2023
SMART Tunnel	~$1 billion	High	Highly effective for major floods, Dual purpose (flood & traffic)	Kourtis et al., 2018; The Open Water Journal, 2023

Table 4.2 Comparison of Urban Flood Mitigation Methods: Benefits & Limitations and Environmental Impact

LID Practice	Benefits	Limitations	Environmental Impact	References
Green Roofs	Provides insulation, Enhances urban aesthetics and biodiversity	High initial cost, Requires structural support	Promotes urban biodiversity, reduces urban heat island effect, Improves air quality	Kourtis et al., 2018; The Open Water Journal, 2023
Permeable Pavements	Reduces surface runoff, Promotes groundwater recharge	Potential clogging, Lower structural strength	Enhances groundwater recharge, Reduces pollutant loads	Kourtis et al., 2018; The Open Water Journal, 2023

Bioretention Areas	Effective in filtering pollutants, Enhances landscape aesthetics	Requires regular maintenance, Limited capacity for large storms	Promotes biodiversity, Improves water quality	Kourtis et al., 2018; Zhang & Chui, 2017
Retention Ponds/Wetlands	Provides flood storage, Improves water quality	Requires significant land area, Potential mosquito breeding	Enhances biodiversity, Provides wildlife habitat	Kourtis et al., 2018; Zhang & Chui, 2017
Community Rainwater Harvesting	Conserves water, Reduces runoff	High initial installation cost, Limited impact if not widely adopted	Reduces pressure on municipal supply, Minimizes erosion	Kourtis et al., 2018; The Open Water Journal, 2023
Underground Reservoirs	Provides extensive water storage, Supplies water during dry periods	High construction cost, Requires significant engineering	Reduces need for surface reservoirs, Minimizes land use	Kourtis et al., 2018; The Open Water Journal, 2023
SMART Tunnel	Combines flood control with traffic management, Handles large storm events	Extremely high cost, Complex maintenance	Reduces urban flooding, Significant build-phase impact	Kourtis et al., 2018; The Open Water Journal, 2023

CHAPTER 5
CONCLUSION AND DISCUSSION

5.1 Conclusion

This report has undertaken a comprehensive analysis of stormwater management systems in Bangkok, with a particular focus on the Watthana and Minburi districts. Through evaluating current practices, comparing them with successful international examples, and proposing tailored strategies, we have highlighted the critical challenges and potential solutions to improve stormwater management in Bangkok.

In Watthana District, characterized by dense urban development, the implementation of green roofs, permeable pavements, and underground reservoirs were recommended. These strategies aim to mitigate the adverse effects of urban runoff by enhancing infiltration and providing additional storage capacity for stormwater. Meanwhile, Minburi District, with its mix of residential and vacant land, can benefit from the development of detention basins, constructed wetlands, and better maintenance of existing canals to manage stormwater more effectively.

Additionally, the study emphasized the applicability of best practices from Singapore and Malaysia. Singapore's success with underground reservoirs and holistic water management provides a valuable blueprint for Bangkok. Malaysia's urban stormwater management manual (MSMA) offers practical guidelines that can be adapted to Bangkok's unique context.

Overall, the recommendations proposed in this report aim to create a resilient, sustainable, and effective stormwater management system for Bangkok, addressing both immediate needs and long-term challenges posed by rapid urbanization and climate change.

5.2 Discussion

The analysis and recommendations presented in this report underscore the complexity and urgency of improving stormwater management in Bangkok. Here, we discuss the broader implications, potential challenges, and opportunities associated with implementing the proposed strategies.

5.2.1 Urban Density and Infrastructure Limitations

In high-density areas like Watthana, the lack of available space poses a significant challenge for traditional stormwater management solutions. The introduction of green roofs and permeable pavements addresses this by utilizing existing infrastructure to enhance water absorption and storage capacity. However, the high initial costs and ongoing maintenance requirements for these technologies may be a barrier to widespread adoption. Incentive programs and public-private partnerships could be vital in overcoming these financial hurdles.

5.2.2 Vacant Land Utilization

Minburi's relatively lower density and availability of vacant land provide a unique opportunity for implementing large-scale detention basins and constructed wetlands. These nature-based solutions not only manage stormwater effectively but also enhance biodiversity and provide recreational spaces for the community. However, securing land for these purposes may face opposition from developers and landowners. Clear communication of the long-term benefits and potential financial compensation or incentives could facilitate cooperation.

5.2.3 Learning from International Best Practices

Singapore's advanced stormwater management system, particularly its use of underground reservoirs, offers a promising model for Bangkok. While the initial construction costs are high, the benefits in terms of flood prevention and water quality improvement are substantial. Adapting this model to Bangkok would require careful planning and significant investment, but the long-term gains in resilience and sustainability justify the effort.

Similarly, Malaysia's MSMA provides a comprehensive framework that can be tailored to Bangkok's needs. Implementing these guidelines requires strong institutional support and capacity-building among local agencies. Training programs and knowledge exchanges with Malaysian experts could facilitate this process.

5.2.4 Cost-Benefit Analysis

A detailed cost-benefit analysis (CBA) of the proposed strategies reveals that while upfront costs can be significant, the long-term benefits in terms of reduced flood damage, improved public health, and enhanced quality of life outweigh these expenses. For example, the installation of green roofs and permeable pavements in Watthana may have a high initial cost, but the reduction in flood-related damages and maintenance costs over time provides a favorable return on investment.

In Minburi, the creation of detention basins and wetlands has relatively lower upfront costs and provides immediate flood mitigation benefits. These solutions also offer ecological and recreational advantages, enhancing community well-being and property values.

5.2.5 Implementation Challenges and Opportunities

The successful implementation of these strategies requires coordinated efforts among various stakeholders, including government agencies, private developers, and the community. Policy reforms, such as stricter building codes and incentives for sustainable practices, are essential. Public awareness campaigns and community engagement can foster a culture of resilience and proactive stormwater management.

The integration of advanced technologies, such as real-time monitoring and data analytics, can further enhance the efficiency and effectiveness of stormwater management systems. Investments in research and development, coupled with international collaborations, can drive innovation and continuous improvement in this field.

REFERENCES

Berndtsson, J. C. (2010). Green roof performance towards management of runoff water quantity and quality: A review. *Ecological Engineering, 36*(4), 351-360.

Chang, N., Lu, J., Chui, T. F. M., & Hartshorn, N. (2018). Global policy analysis of low impact development for stormwater management in urban regions. *Land Use Policy*, *70*, 368–383. https://doi.org/10.1016/j.landusepol.2017.11.024

Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). *Applied Hydrology*. McGraw-Hill.

DDproperty Editorial Team. (2021, November 25). *เช็กความต้องการซื้อบ้าน-เช่าบ้าน ในพื้นที่น้ำท่วมบ่อยในกรุงเทพฯ [check the demand for buying or renting houses in flood-prone areas in Bangkok."*. DDproperty. https://shorturl.at/puUZ9

Department of Irrigation and Drainage. (2012). *Urban Stormwater Management Manual for Malaysia (MSMA)* (2nd ed.). https://shorturl.at/iGLXZ

Department of Mineral Resources. (2016). *การจำแนกเขตเพื่อการจัดการ ด้านธรณีวิทยาและทรัพยากรธรณี [classification of zones for the management of geology and mineral resources of bangkok]*. http://www.dmr.go.th/

Dunnett, N., & Kingsbury, N. (2008). *Planting Green Roofs and Living Walls*. Timber Press.

ecoDesignsd. (2021, August 30). *WHAT IS A DETENTION BASIN?* https://shorturl.at/gnO34

Gogate, N.G., Kalbar, P.P., Raval, P.M., 2017. Assessment of stormwater management options in urban contexts using multiple attribute decision-making. J. Clean. Prod. 142, 2046–2059. https://doi.org/10.1016/j.jclepro.2016.11.079.

Ismail, P., Tariq Mubarak, H. & Hyrul Izwan, M.H. (2021). *An Overview of Wetlands in Malaysia*. Forest Research Institute Malaysia. pp. 56.

Jotte, L., Raspati, G., & Azrague, K. (2017). *Klima 2050: Review of stormwater management practices* (Report No. 7). SINTEF akademisk forlag. http://hdl.handle.net/11250/2447971

Kourtis, I. M., Tsihrintzis, V. A., & Baltas, E. (2018). Simulation of low impact development (LID) practices and comparison with conventional drainage solutions. *Proceedings*, 2(11), 640. https://doi.org/10.3390/proceedings2110640

Lim, H. S., & Lu, X. (2016). Sustainable urban stormwater management in the tropics: An evaluation of Singapore's ABC Waters Program. *Journal of Hydrology*, *538*, 842–862. https://doi.org/10.1016/j.jhydrol.2016.04.063

Prince George's County. (1999). *Low-impact Development Design Strategies: An Integrated Design Approach*. Department of Environmental Resource.

Public Utilities Board. (2009). *Engineering Procedures for ABC Waters Design Features* (p. 382). PUB, Singapore.

Public Utilities Board. (2011a). *Active Beautiful Clean Waters Design Guidelines* (p. 104). PUB, Singapore.

Public Utilities Board. (2011b). *Engineering Procedures for ABC Waters Design Features* (p. 382). PUB, Singapore.

Public Utilities Board. (2013). *Managing Urban Runoff - Drainage Handbook*. Singapore, PUB.

Public Utilities Board. (2014). *Active Beautiful Clean Water Design Guidelines* (p. 114). PUB, Singapore.

Public Utilities Board (PUB), Singapore. (2018). *Managing Stormwater for a Better Environment*.

PUB, Singapore's National Water Agency. (2023). *Reservoir Locations*. https://shorturl.at/hxzN3

RTI International and Geosyntec Consultants. (2015). *Low Impact Development Stormwater Control Cost Estimation Analysis*. U.S. Environmental Protection Agency. https://shorturl.at/nstBS

Sage, J., Berthier, E., & Gromaire, M.-C. (2015). Stormwater management criteria for on-Site pollution control: a comparative assessment of international practices. *Environmental Management, 56*(1), 66-80.

Schueler, T. R., & Claytor, R. A. (2000). *Basics of Stormwater Management*. Center for Watershed Protection.

Stormwater Management and Road Tunnel (SMART Tunnel). (n.d.). Retrieved June 25, 2024, from https://www.smarttunnel.com.my.

Taemwirot, K. (2022, September 12). ฝนตกน้ำท่วมทุกวันนี้ ‘อุโมงค์ยักษ์ระบายน้ำ’ ใน กทม. มีไว้ทำไม? [Despite daily rain and flooding in Bangkok, why does the “giant drainage tunnel” exist?]. *Thairath Plus*. https://plus.thairath.co.th/topic/politics&society/102093

The Open Water Journal. (2023). Enhancing stormwater management with low impact development (LID). *Water Science and Technology*, 87(9), 2345-2357. https://iwaponline.com/wst/article/87/9/2345/94232/Enhancing-stormwater-management-with-low-impact

Virginia Department of Environmental Quality. (2000). *Stormwater Management Design Manual*.

Zhang, K., & Chui, T. F. M. (2017). Cost efficiency of low impact development (LID) stormwater management. *Journal of Hydrology*, 547, 236-245. https://doi.org/10.1016/j.jhydrol.2017.02.019

BIOGRAPHY

Name	Tassawan Winyuchoncharoen
Education	2022: Bachelor of Engineering (Civil Engineering) Sirindhorn International Institute of Technology Thammasat University