The Monkey Cheeks Toolkit:
Design Strategies for Mitigating Flood Impacts in the Bangkok Metropolitan Area

by

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ABSTRACT

Bangkok, the capital of Thailand, has been facing frequent and destructive floods due to the recent decades of urban expansion and inadequate public drainage infrastructure. Although the Bangkok Metropolitan Administration (BMA) has actively improved the flood drainage network as the city expanded, its developed capacity and configuration have not kept pace with its population growth and rapid urbanization. Additionally, due to the escalating impact of climate change, Bangkok is expected to face more severe flooding, as well as the potential for greater water supply challenges, over the course of this century.

Rather than solely depending on flood protection via large-scale infrastructure, this thesis proposes a decentralized approach to stormwater management, in which rain is captured where it falls through a local flood control measure called “Monkey Cheeks.” Although this measure concept is commonly utilized in large water retention areas, the thesis applies this retention system to an ultra-urban environment such as the Bangkok Metropolitan Area, where the availability of land is limited. The main objective is to embrace water as a valuable resource and seize the opportunity to incorporate it into the fabric of the city. The outcome of this research is presented in the form of a Design Toolkit, a set of strategies for implementing Monkey Cheeks across various scales of urban conditions, ranging from small individual property-level to large-scale publicly owned spaces. The Toolkit concludes with case studies illustrating how these strategies can be applied to existing conditions of Bangkok’s urban fabric, and how they can be combined to alleviate flooding throughout the city at large. Together, a network of Monkey Cheeks within the city can play a critical role in mitigating flood risk by slowing down runoff that could otherwise overwhelm public sewage systems, storing rainwater to tackle water supply challenges, and restoring the hydrologic function of the urban landscape by releasing water back to the aquifer. As such, the research contributes to the advancement of sustainable urban water management practices and highlights the importance of integrating traditional knowledge with modern urban areas.

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THE MONKEY CHEEKS TOOLKIT

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Pimpakarn Rattanathumawat
SMArchS Urbanism 2023

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Introduction

The Bangkok Metropolitan Area, home to over 15 million people[1], is one of the largest and most populous metropolitan regions in Southeast Asia. The area has undergone rapid urbanization over the past few decades, and whenever it rains, the classic perennial problem for Bangkok residents is "flooding."

The city has experienced several devastating floods throughout its history, and the problem of flooding has been a central issue in every election for the city's governor. Since the Great Flood in 2011, the Bangkok Metropolitan Administration (BMA) and the central government tended to focus on trying to keep the water out. Money has been invested in mega-scale projects such as water tunnels, floodgates, and data technology to deal with the city's flooding issues. Although these infrastructures are vital to control and mitigate floods at a certain level, the floods of the past decade have proven that these existing measures are still insufficient.

The problem stems from an imbalanced ecology in the city, primarily due to a lack of natural flood-catchment spaces. In the past, Bangkok had many canals, marshes, rivers, and vacant areas. People used water as a part of their daily life. However, as the city expanded, more settlements were constructed on wetlands and floodplain areas, causing a reduction in permeable surfaces and water storage capacity.

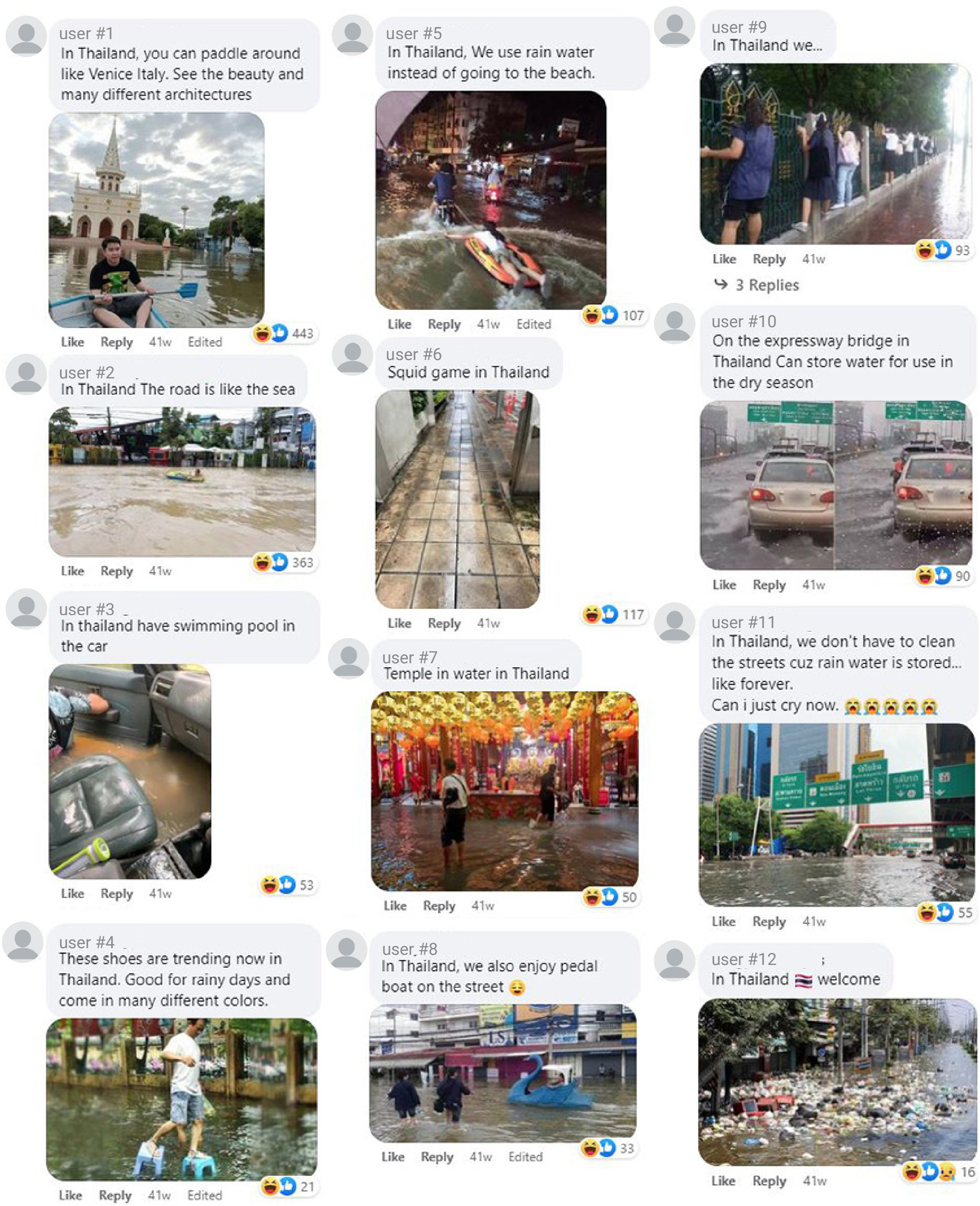
In Thailand, the concept of flood retention area became famous under the initiative of King Bhumibol Adulyadej in 1995. The idea was to store flood water in the detention area and later release those water into the sea in relation to the tide levels. During the dry season, the conserved water can also be used to prevent saltwater intrusion and support other activities around the area. The concept was popularized under the name "Monkey Cheeks."

Over the past decade, the BMA has tried to create more Monkey Cheeks projects, but the efforts to reclaim or purchase land stopped over the last five years due to land purchasing issues. With exponential urban growth coupled with planning law gaps and enforcement, the BMA would continue struggling to rent or purchase land from the private sector.

This thesis explores the opportunities to invest more in finding smaller-pocket storage locations for water at various points in Bangkok to accommodate rainwater until the canals are ready to drain it. Together, this network of Monkey Cheeks could grow with the city and serve as a runoff catchment system at large.

[1] Including unregistered residents. According to the Ministry of Interior, the total number of registered population in Bangkok Metropolitan Area is 10,863,917 people in 2021.

Figure 1.1 Shows how the Thais used self-deprecating humor on social media to point out Bangkok flooding issues.



user #13
in thailand.Public health official are receive the car wash service for free totally.that one of our welfares some policy hospital.
if you would like to get your new convenient,your new contentment, and your new car,come with us.PPK hos.

Like Reply 41w 14K

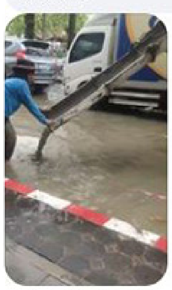
62 Replies

user #14
In Thailand, we have...

Like Reply 41w 7.9K

50 Replies

user #15
In Thailand, we have super higher technology which we can repair the road while it's flooding in the rainy season!



Like Reply 41w 9.8K

80 Replies

user #16
In thailand, we can do car wash at the parking lot

Like Reply 41w 17K

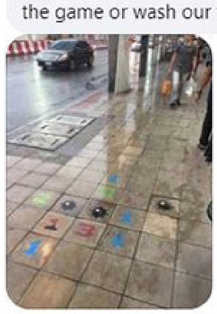
38 Replies

user #17
in my lovely country Thailand, We've got own swimming pool everywhere. and we can transform our vehicle from Motorcycle to Jet Ski
Cr.Pic from Thairath news

Like Reply 41w Edited 13K

90 Replies

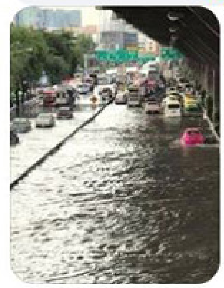
user #18
In Thailand, we store water under the footpath blocks. We can enjoy the game or wash our feet.



Like Reply 41w Edited 23K

228 Replies

user #19
How ridiculous, Koreans use water resources without value. you look at my thailand We will use the water from the end of the rainy season. Come to clean the roads with a deep clean once a year, 2 weeks to 1 month each time. 😂😆😂



Like Reply 41w 5.8K

32 Replies

user #20
In Thailand, our prime Minister ordered us to pray holy things to stop the rain and feed the fish during the flood

Like Reply 41w Edited 20K

194 Replies

user #21
would you like some Thai-tea ?

Like Reply 41w 1.3K

11 Replies

CHAPTER 1: Bangkok and Water

The proximity to water has been a key factor in the development and growth of many cities around the world. Most major cities, including Mumbai, Shanghai, London, Boston, and New York City, are situated near bodies of water. In Southeast Asia, many cities of importance are located along the Chao Phraya and the Mekong River. Throughout history, capital cities and major urban centers in the region have shifted their locations closer to the sea, such as the move from Angkor to Phnom Penh, Hue to Ho Chi Minh, and Ayutthaya to Bangkok.

Thai people have long recognized the importance of water, and their culture reflects this. The waterways of Bangkok have played a significant role in shaping the city's development, from its early days as a trading center to its emergence as a modern metropolis. The city's inhabitants have traditionally relied on water transportation to get around, and many still do.

The waterways have also influenced the city's architecture and urban design. Houses and buildings in Bangkok have traditionally been built on stilts, allowing them to stay above the water during floods. The city's streets were designed to accommodate the ebb and flow of the river, with many of them running parallel to the water. However, with the modernization and development of the city, there has been a shift towards more Western-style architecture that often does not take into account the city's water-related challenges.

While many of the city's inhabitants still rely on water for their livelihoods, many of these waterways have been degraded and polluted in recent years. As Bangkok continues to grow and develop, the challenges of managing its water resources become more complex and multifaceted. The challenges of managing water resources in an urban context are significant and require ongoing attention and investment, with implications for the city's ecological, economic, and social sustainability.

The first chapter of this thesis covers the historical development of Bangkok in association with the causes of flooding and current flood management issues, as well as supports the arguments for why there is a need for more Monkey Cheeks.

1.1 Geographical Context

Bangkok is located in the central region of Thailand on the deltaic plain of the Chao Phraya River. The urban area of Bangkok spans over 1,568.74 square kilometers[2] and is managed as part of the Bangkok Metropolitan Region (BMR), comprising not only the city itself but also five surrounding provinces (Nonthaburi, Samut Prakan, Pathum Thani, Samut Sakhon, and Nakhon Pathom). In total, the BMR encompasses an area of 7,761.50 square kilometers.[3]

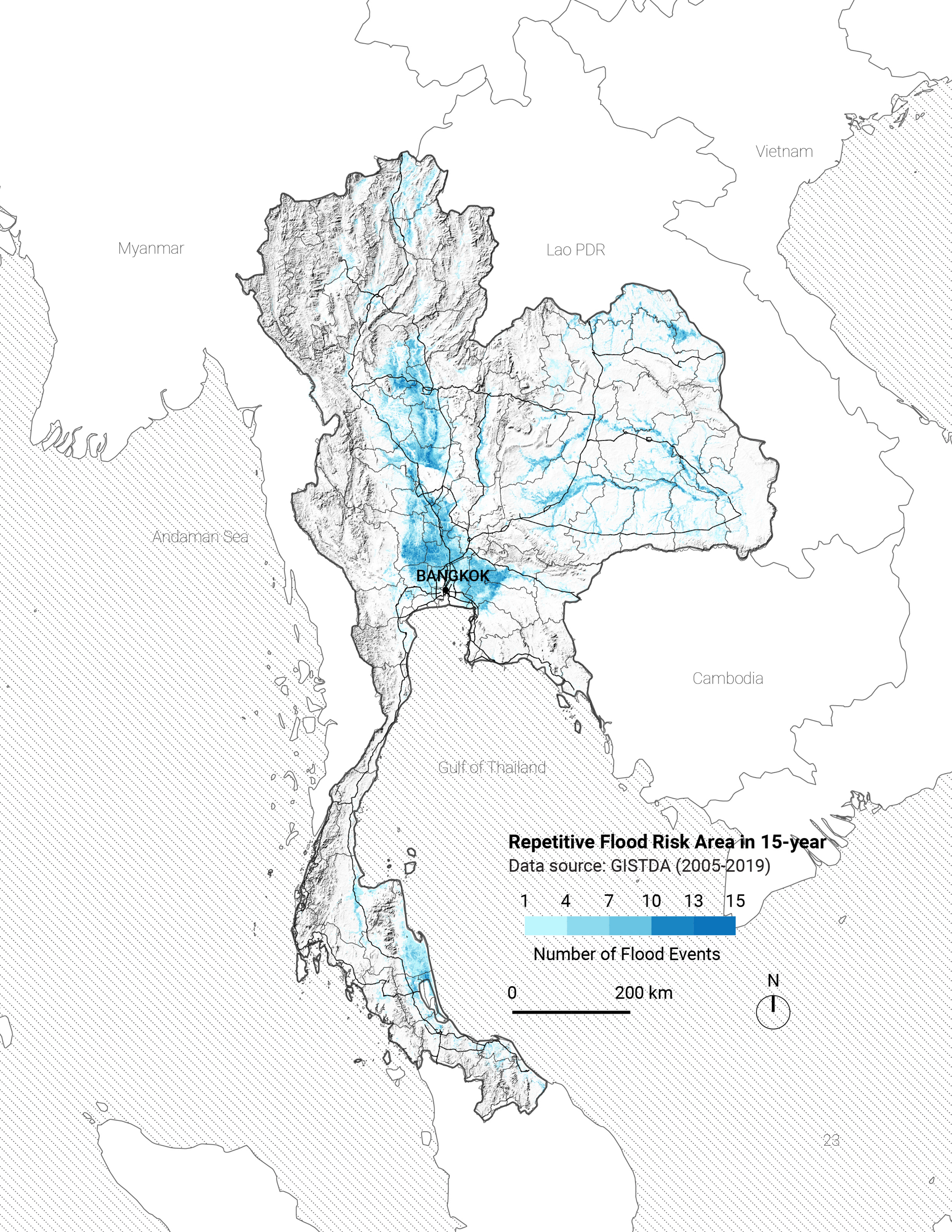
The Chao Phraya River starts at the confluence of the Ping and Nan tributaries at Nakhon Sawan province, then flows south through the Central Plain to Bangkok and discharges into the Gulf of Thailand. The Chao Phraya basin is Thailand's largest river basin covering 160,000 square kilometers (equivalent to 30% of the country's total land area).[4] The area is flat and low-lying, with an average elevation of only 1.5 meters (4 ft 11 in) above sea level.[5] Most of the area was originally swampland, which makes the location perfect for agriculture but also naturally prone to flooding.

Thailand experiences two monsoonal seasons. the southwest monsoon which occurs from May and brings warm and humid weather along with heavy rainfall from the Indian Ocean, and the northeast monsoon which starts from around October (more recently in November) and brings colder and drier conditions along with abundant rainfall. Tropical cyclones can be expected from May onwards. In addition, different parts of the country may experience local storms (also known as summer storms) during February to March. Localized storms can occur in the southern region from March to November and in the northern region between April and October. Within the climate related factors, flooding can occur from river overflow, tidal surges, and heavy localized rainfall.[6] Bangkok, especially during the monsoon season, can cause low-lying areas to be inundated without sufficient pumping stations to drain the water out of the city. The annual average rainfall in Bangkok (between 1991 to 2020) is up to 1,600 millimeters, however, as these rainfalls are often concentrated during September and October, precipitation in these two months alone can reach up to 200 to 400 millimeters.[7] Additionally, past records of precipitation levels indicate that over the coming century, total annual rainfall will increase, with the volume and number of days with heavy/very heavy rainfall also increasing. In comparison to the past period (1980–2009), over the long-term (2070–2098) the total monthly heavy/very heavy precipitation during October is projected to increase by 100–120% over Pathum Thani province and 80–100% over the remainder of the BMR.[8]

[2] Bangkok Metropolitan Administration (BMA), 2021
[3] United Nations Department of Economic and Social Affairs, 2021
[4] The Working Group of the Office of Natural Water Resources Committee of Thailand, 2003
[5] Thammano et al., 2015
[6] Milliman & Haq, 1996
[7] Department of Drainage and Sewerage BMA, 2022
[8] Cooper, 2019


THAILAND


Myanmar
Lao PDR
Vietnam
Andaman Sea
Cambodia
Gulf of Thailand
Ping
Wang
Yom
Nan
Pa Sak
Sakae Krang
Chao Phraya
Tha Chin
BANGKOK
Chao Phraya River Drainage Basin
Major Tributaries
Chao Phraya River
0
200 km
N


Myanmar
Lao PDR
Vietnam
Andaman Sea
BANGKOK
Cambodia
Gulf of Thailand
Repetitive Flood Risk Area in 15-year
Data source: GISTDA (2005-2019)
1 4 7 10 13 15
Number of Flood Events
0 200 km
N

1.2 Historical Urban Development

The origins of Bangkok can be traced back to the 15th century when it was a small trading outpost on the Chao Phraya River. The city's modern history began in 1782 when King Rama I moved the capital from Thonburi to Bangkok and founded the Chakri Dynasty.[9]

Bangkok grew slowly through the 18th and early 19th centuries, despite being the capital since 1782. In 1822, the population was estimated at 50,000 or less.[10] The population began to grow as the city became more industrialized in the 1960s.

Bangkok's economy gradually expanded through international trade, initially with China and subsequently with Western merchants who returned to the region during the early-to-mid 19th century.[11] Given its status as the capital of Siam, Bangkok played a central role in the country's modernization efforts in response to the increasing pressure exerted by Western powers during the late 19th century.[12] The Western powers also brought with them new technologies and infrastructure, including railways, telegraphs, and modern ports. These developments had a significant impact on the urban development of Bangkok.

1.2.1 Venice of the East

Bangkok has once been called the "Venice of the East" due to its complex intervening network of waterways developed over the past centuries. The nickname was given to Bangkok in the late 19th century, during the reign of King Rama V. During this period, Bangkok was a thriving city with a network of canals (or khlongs), running throughout the city as they played a significant role in the city's economic, social, and cultural development.

As the city was built in a swampy area, the network of canals played a vital role in the agricultural economy of the area. The canals were used to bring water to the rice fields for irrigation and allowed for the cultivation of fruit and vegetable crops in the low-lying areas surrounding the city.[13]

BoatsThe nickname "Venice of the East" was not just a fanciful comparison, but a testament to the city's beauty and ingenuity. The canals were lined with shops, homes, and temples, giving the city a unique charm and character. Boats were the main form of transportation, and people used

[9] Wyatt, 2003
[10] Baker and Phongpaichit, 2009
[11] Baker and Phongpaichit, 2009
[12] Chakrabarty, 2000
[13] Jiarakul, 2015

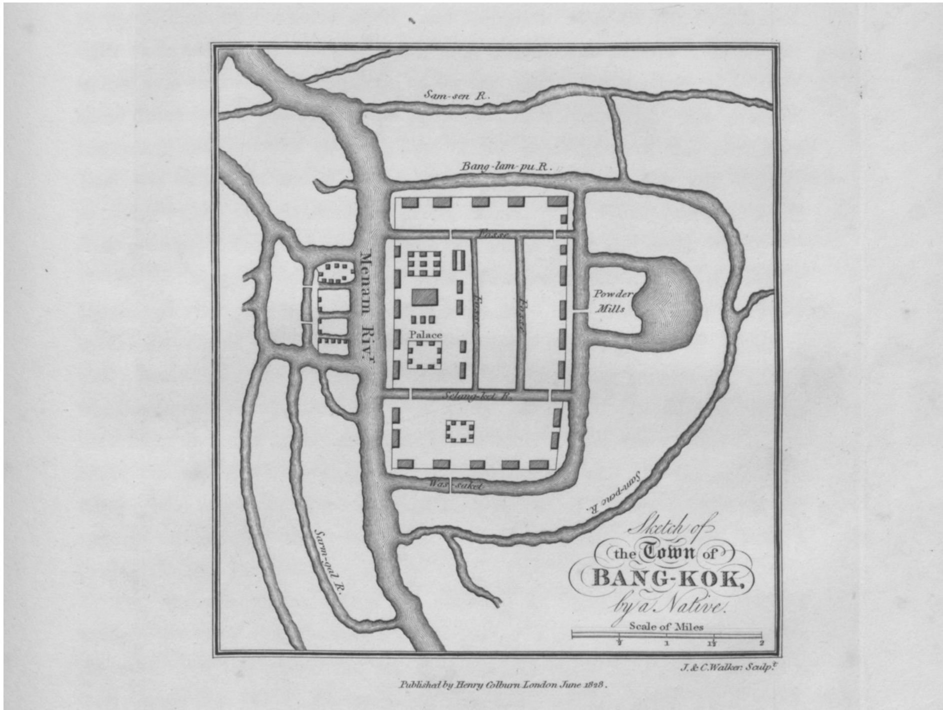


Figure 1.5 Map of Bangkok in 1822
(Source: Crawfurd, 1828)

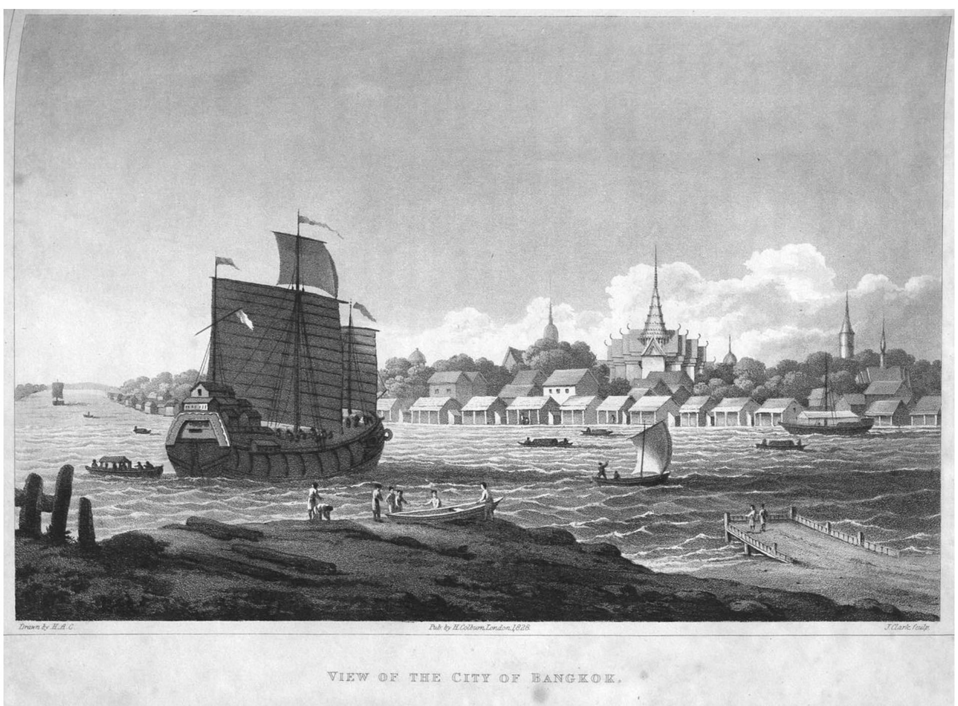


Figure 1.6 Engraving of the City from British Diplomat in 1822
(Source: Crawfurd, 1828)

neighbourhood is occupied by a colony of the people of Pegue and Lao, refugees from the territory disputed between the Burmans and Siamese. A flag was hoisted from both forts, and we were serenaded by a Peguan band of music as we passed. A well dressed chief, in the Burman or Pegue costume, came on board here, bringing us two boat loads of fruits and other refreshment.

Close to the river, and at least for twelve miles up, the land appears to be unfit for culture, owing to the saltness of the water, which occasionally overflows it. All this tract is occupied by rhizophoras, and by the cocos-nypa, the leaf of which is so abundantly used by the inhabitants of tropical India as thatch. Beyond this again, and all the way to the capital, the banks of the river are more elevated, and the country as far as we could observe it, presented every where a rich extent of cultivation, consisting of rice-fields, interspersed with numerous villages, surrounded by orchards of palm and fruit-trees. The rice stubble was on the ground, for the crop had been reaped two months before, and among it were grazing numerous herds of buffaloes, the only description of cattle which were to be seen. This appearance of fertility and industry formed a pleasing contrast to the waste of rocks, mountains, and impenetrable and unprofitable forests, to which we had been accustomed for the last three months.

At four o'clock we came to an anchor for a couple of hours, waiting for the flood-tide, and took this opportunity to land. The fields afforded a great number of birds of different descriptions, and we were successful in adding several specimens to our collection. The natives, wherever we met them, received us with kindness, and betrayed no symptoms of distrust or timidity. As soon as the flood-tide had made, we weighed, and at twelve o'clock at night reached the town of Bang-kok.

March 29.—The morning presented to us a very novel spectacle—the capital of Siam, situated on both sides of the Menam. Numerous temples of Buddha, with tall spires attached to them, frequently glittering with gilding, were conspicuous among the mean huts and hovels of the natives,

Figure 1.7 'Journal of an Embassy from the Governor-General of India to the Courts of Siam and Cochin-China', page 78 provides a description of how agriculture was the primary land use in Bangkok in the past. (Source: Crawfurd, 1828)

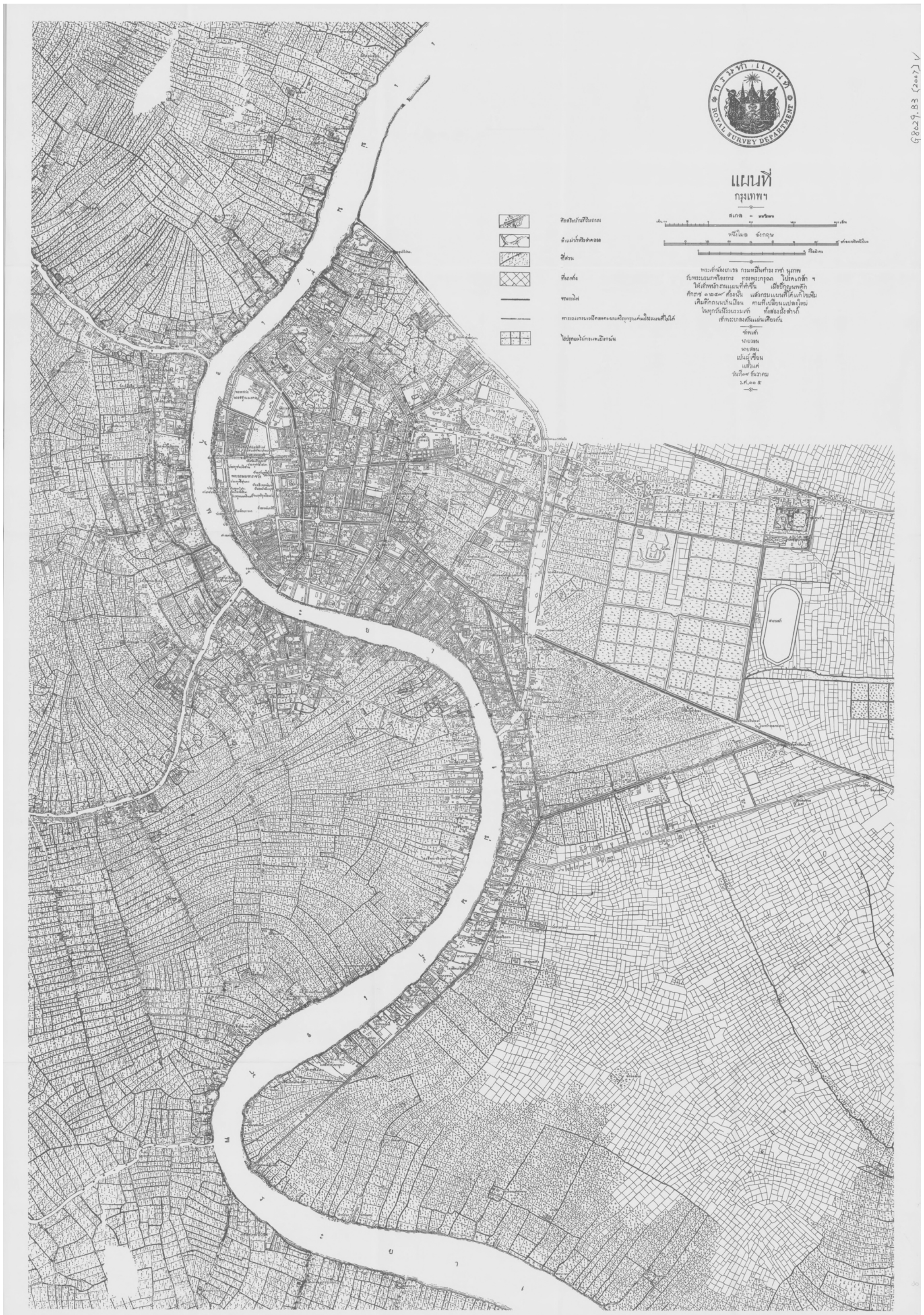


Figure 1.8 Map of Bangkok in 1896
(Source: Faculty of Architecture, Chulalongkorn University, 2007)

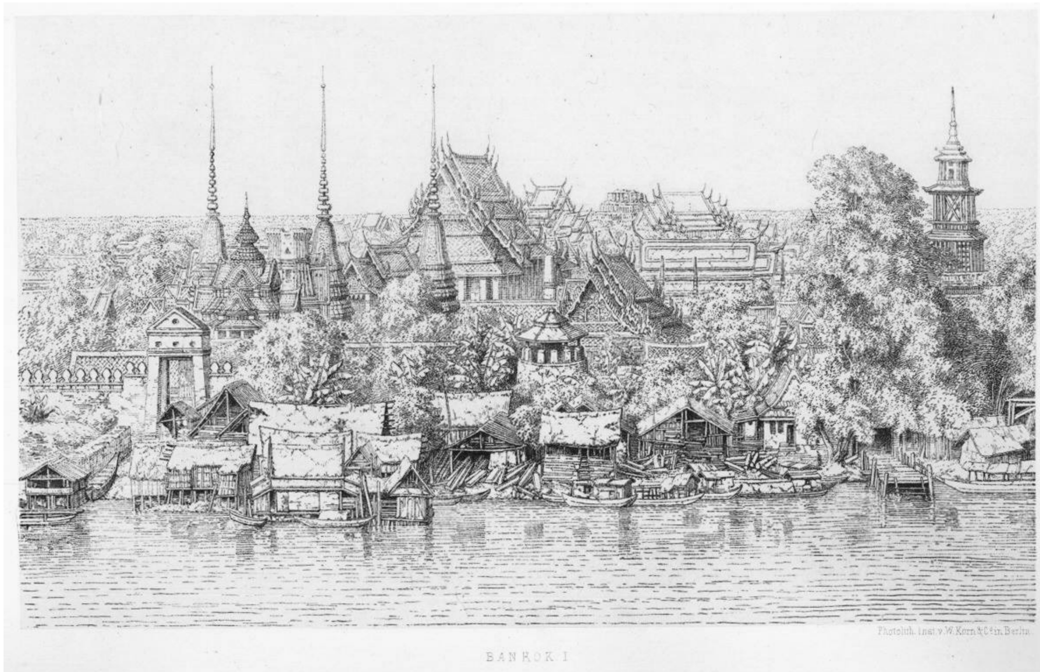


Figure 1.9 One of the scenes of Bangkok among the 32 prints which were included in the official report of the Prussian expedition to the Far East (1860-1862). (Source: Martin, 1990)

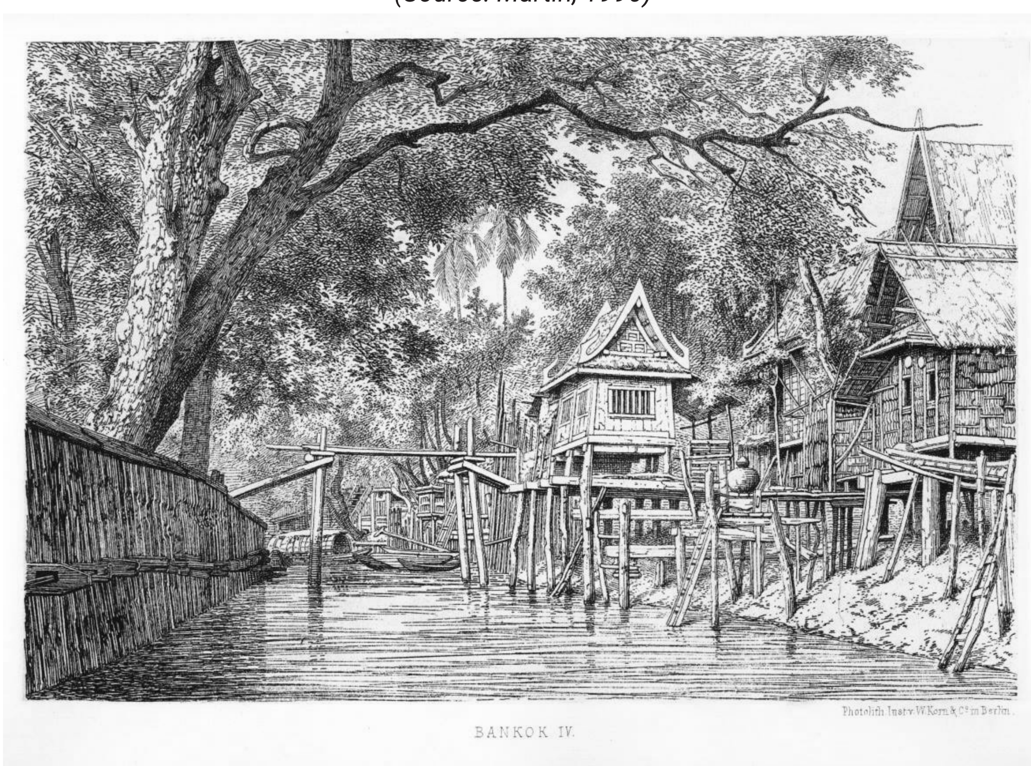


Figure 1.10 Another of the prints of Bangkok which were included in the official report of the Prussian expedition to the Far East (1860-1862). (Source: Martin, 1990)

them to commute to work, transport goods, and visit friends and family. The canals also played a significant role in trade and commerce, as they connected the city's various markets and ports. Bangkok was a major trading hub in Southeast Asia, and the canals facilitated the exchange of goods and services between different regions of the city and beyond.[14]

In addition to being a part of the city's history and legacy, these waterways networks play a significant role in flood prevention, mitigation, and control. During the reigns of King Rama the IV and the V, the government imposed a number of laws to protect the canals for efficient use and to develop traffic rules for the waterways. Nevertheless, despite their importance, the canals have been neglected by local citizens and the Thai government from the reign of King Rama VI onwards.[15] The long neglect of the responsible institution has brought about the decline of the canals and today's environmental issues.

1.2.2 Disappearing of Canals

By the 1890s, Bangkok had become wealthier from centralized taxes collected from the growing rice trade and the influx of more Chinese immigrants. This expansion of the city had its physical expression in the construction of more roads, and for the first time, Bangkok began to shift away from its connection with water and become a land-based city.[16]

Another major turning point for Bangkok was during the implementation of the National Economic Development Plan in 1961 (B.E. 2504) by the government at that time. The government placed great importance on economic growth and stability as the main objectives for developing the country. This was achieved through various investments in infrastructure projects such as transportation, highways, dams, power plants, and public utilities. During this time, the construction of roads was seen as a symbol of progress, while the development of canals and waterways was neglected and viewed as a hindrance to land transportation. As a result, many canals were filled in, embankments were leveled, roads were cut, and buildings were erected, resulting in significant changes to the city's original landscape. Since then, Bangkok's economic development plans have gone through many revisions, with the current plan being the 12th version. Despite these changes, the significance of water transportation systems has been greatly reduced and neglected, resulting in a decline in importance.[17]

[14] Jiarakul, 2015
[15] Sirirat, 2013
[16] Sternstein, 1987
[17] Srisamai & Wajeetongratana, 2012

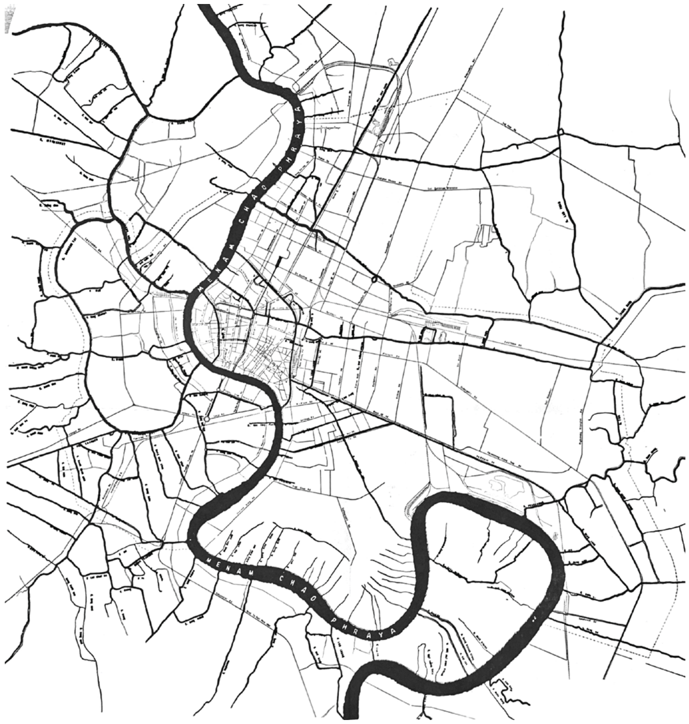


Figure 1.11 Canals Network in 1960
(Source: Litchfield Whiting Bowne and Associates, 1960)

Figure 1.12 Canals Network in 2022
(Source: Image by Author, Data from GISTDA)

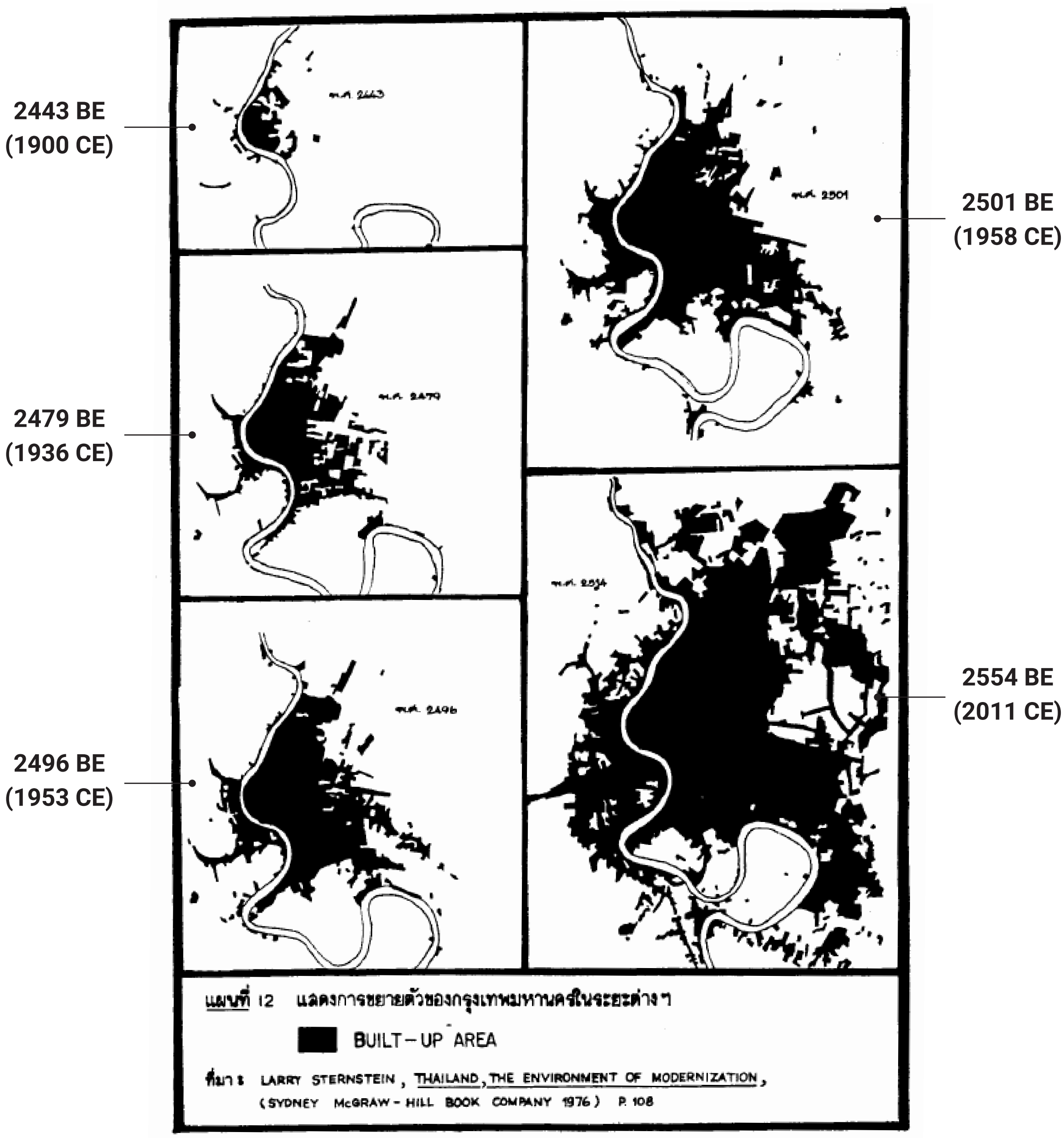


Figure 1.13 Bangkok Built-Up Area Network Between 1900 - 2011
(Source: Sternstein, 1976)

1.2.3 The Evolving Metropolitan Area

Bangkok continued to evolve and underwent a considerable expansion between 1991 - 1996, with the key contributing factors being real estate development, business growth, and the manufacturing industry. The initial phase of this expansion was characterized by horizontal growth up until 1991, which later shifted towards vertical expansion, particularly in the inner and urban areas.[18] This transformation led to a high concentration of population in the inner zones, while suburban areas experienced urban sprawls as a result of the expansion of road networks that connected Bangkok to surrounding provinces. Between 1986 and 2002, residential areas in Bangkok increased, more than double from 181 to 366 square kilometers, and commercial areas increased from 18 to 61 square kilometers During the same period, agricultural land decreased by 31%, and vacant land decreased by 39%.[19]

Urban areas in Bangkok have increased every year. From 2000 to 2010, more than 46% of Bangkok's fertile agricultural land was replaced by urban areas.[20] Furthermore, the transformation of urban areas has brought the city's growth rate from 2000 to 2020 as high as 368%.[21] Without proper land use planning to limit urban growth, suburban farmland will continue to be converted into impervious areas as the city continues to grow in all directions.

The 2021-2022 annual report on the Bangkok flood prevention and remediation plan by the Department of Drainage and Sewerage states that the uncontrolled city plan has resulted in a lack of water retention areas and an insufficient drainage system.[22] In contradiction, the upcoming new Bangkok city plan that will take effect in 2024 aims to further promote the city center with midtown and suburban areas. According to the BMA, The new plan will be the fourth revision to the Bangkok city plan that will replace the current version that has been used since 2013. The upcoming plan is still in the process of revision but some proposed key changes have been revealed to the public, including the modified land zoning controls of the floodplain area that has been dramatically reduced to open up more development opportunities. The new plan proposed to convert 94,424 rai (151 square kilometers) of floodway (rural and agricultural conservation zone) into "brown area," allowing for low to medium-density housing to be developed.[23]

[18] Padon, 2021
[19] Klongvessa and Chotpantarat, 2015
[20] Iamtrakul et al., 2022
[21] Iamtrakul et al., 2022
[22] Department of Drainage and Sewerage BMA, 2021
[23] Department of City Planning BMA, 2022

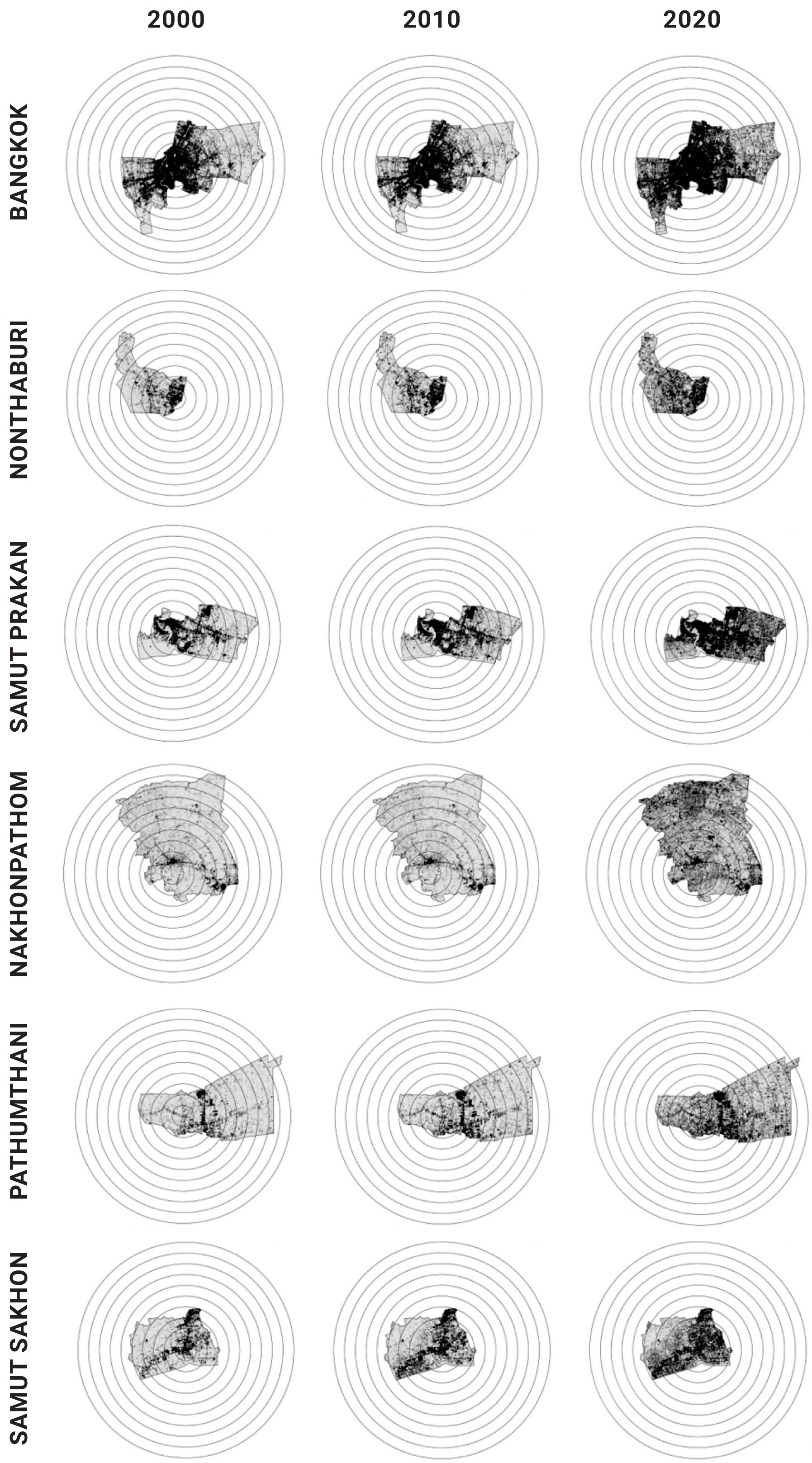
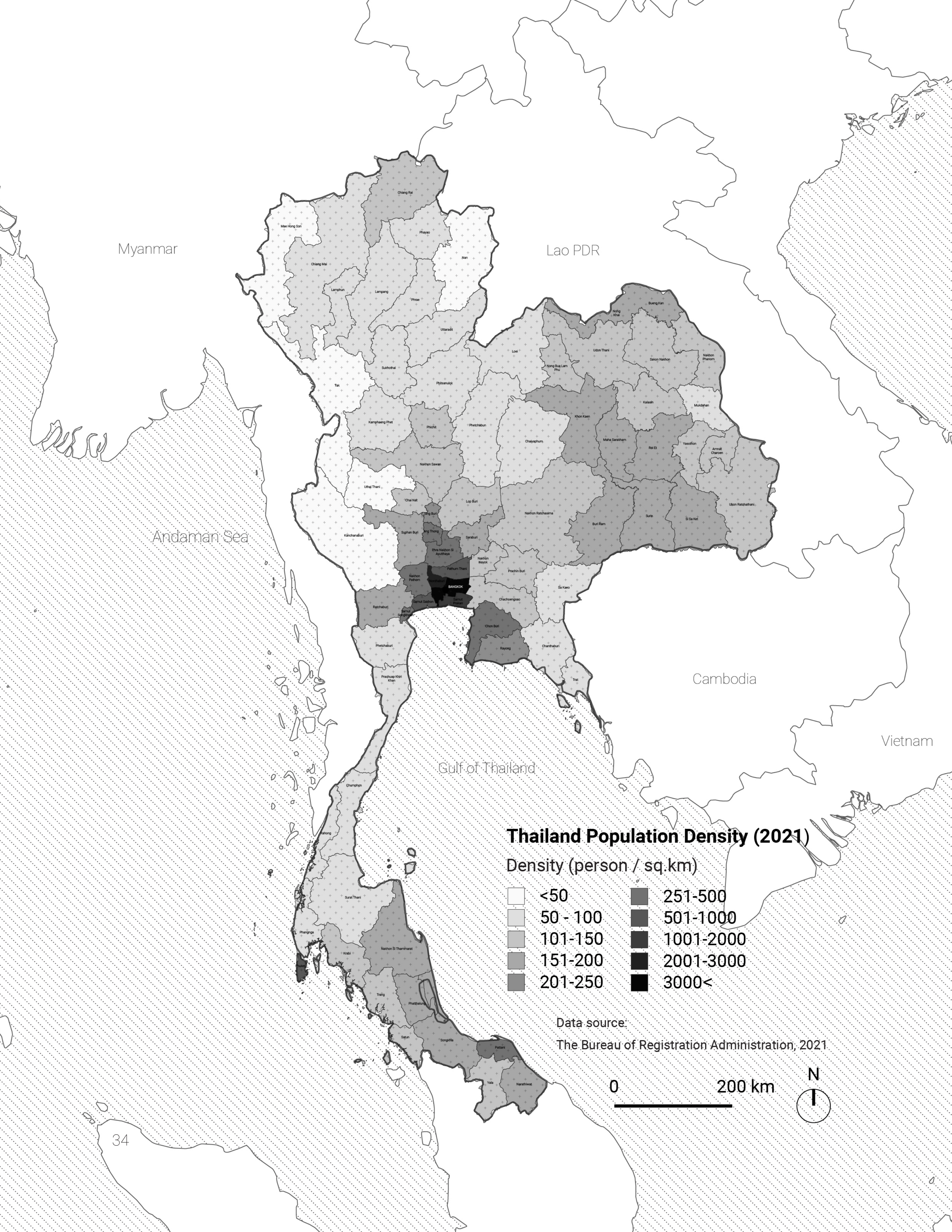
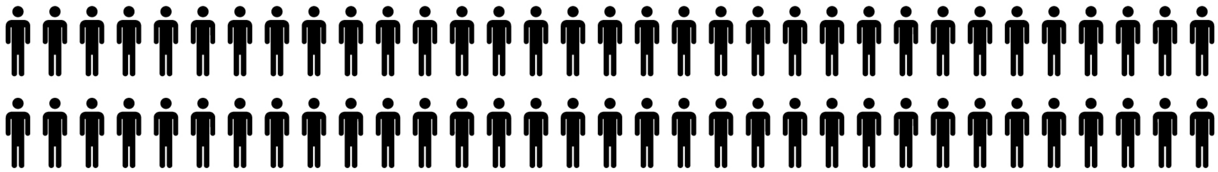


Figure 1.14 Maps showing built-up and non-built-up areas in the BMR for the years; 2000, 2010, and 2020. (Source: Image by Author, Adapted from Fig. 4. Iamtrakul et al., 2022)


Myanmar
Lao PDR
Andaman Sea
Cambodia
Gulf of Thailand
Vietnam
BANGKOK
Thailand Population Density (2021)
Density (person / sq.km)
<50
50 - 100
101-150
151-200
201-250
251-500
501-1000
1001-2000
2001-3000
3000<
Data source:
The Bureau of Registration Administration, 2021
0
200 km
N

Thailand Registered Population

66,200,000



Thailand Non-Registered Population

8,300,000

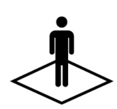
#1 Most Populous Provinces

BANGKOK

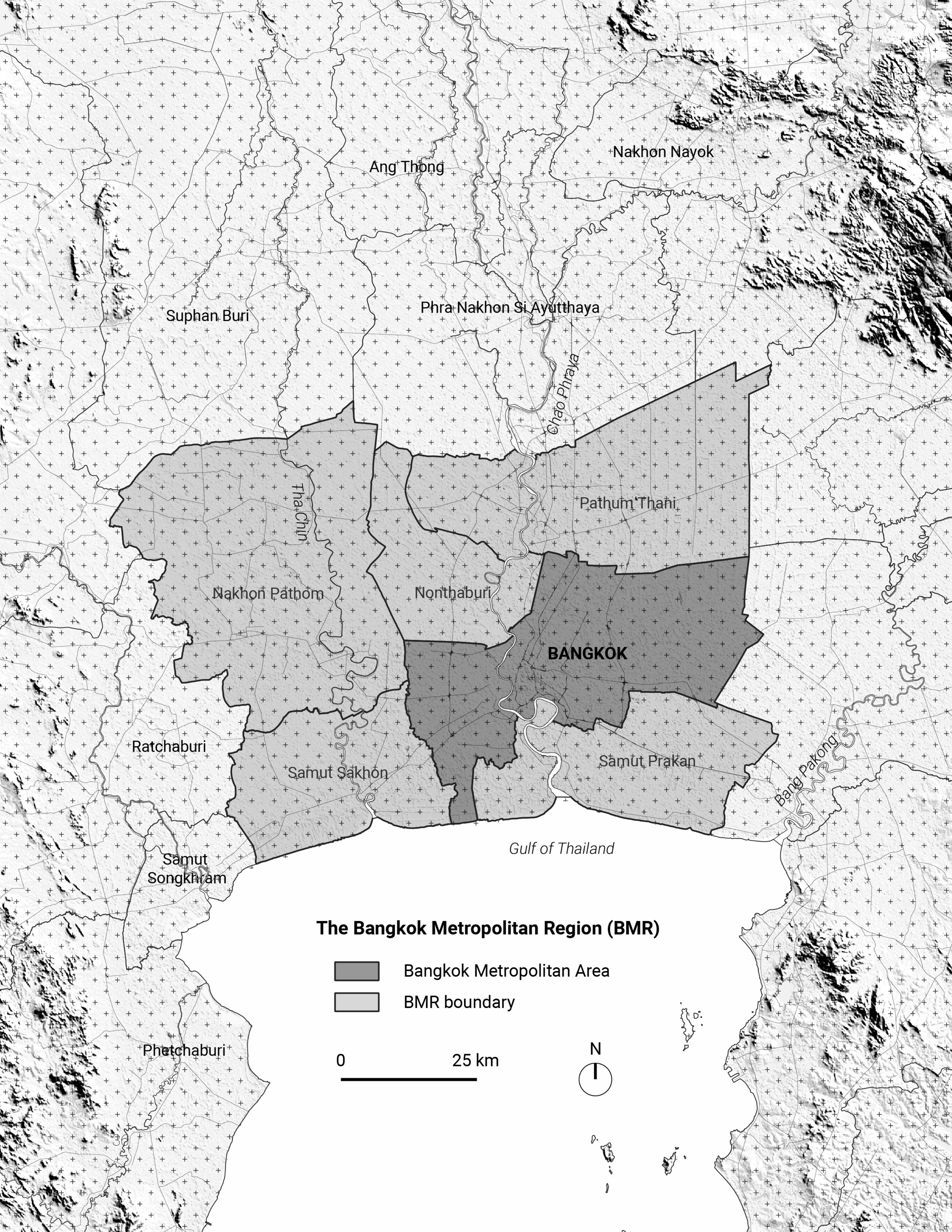
5,495,000 (Registered Population) **+** **2,325,000** (Non-Registered Population)

BANGKOK Population Density

5,660 person / sq.km



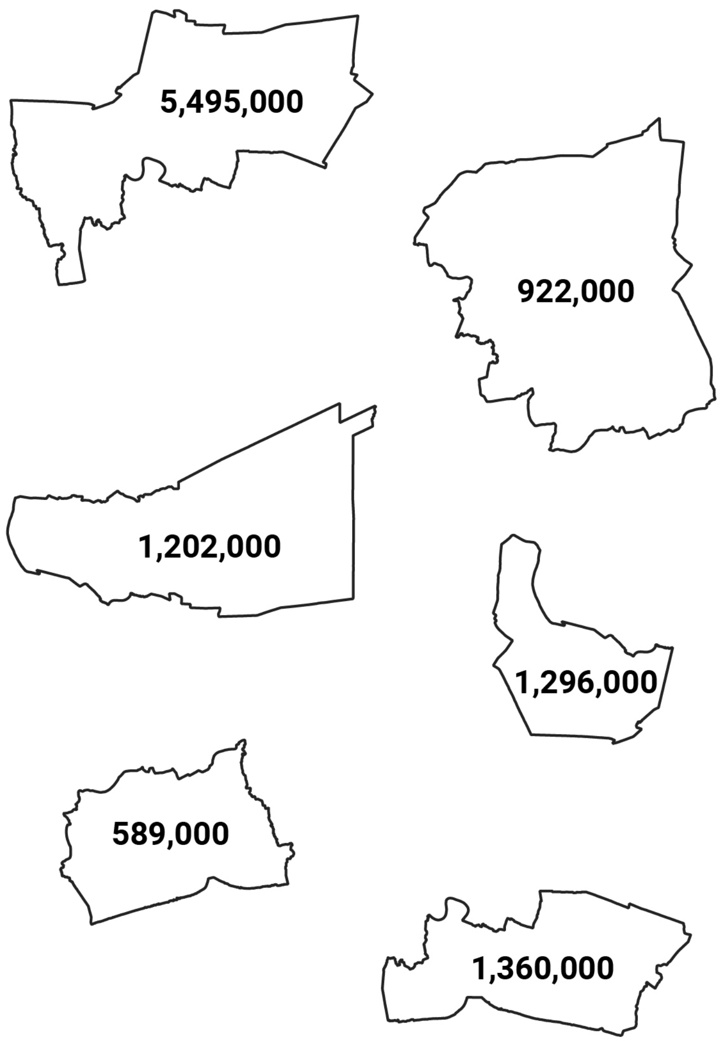
Data source: National Statistical Office of Thailand, 2021



Nakhon Nayok
Ang Thong
Suphan Buri
Phra Nakhon Si Ayutthaya
Chao Phraya
Tha Chin
Pathum Thani
Nakhon Pathom
Nonthaburi
BANGKOK
Ratchaburi
Samut Sakhon
Samut Prakan
Bang Pakong
Gulf of Thailand
Samut Songkhram
Phetchaburi
The Bangkok Metropolitan Region (BMR)
Bangkok Metropolitan Area
BMR boundary
0
25 km
N

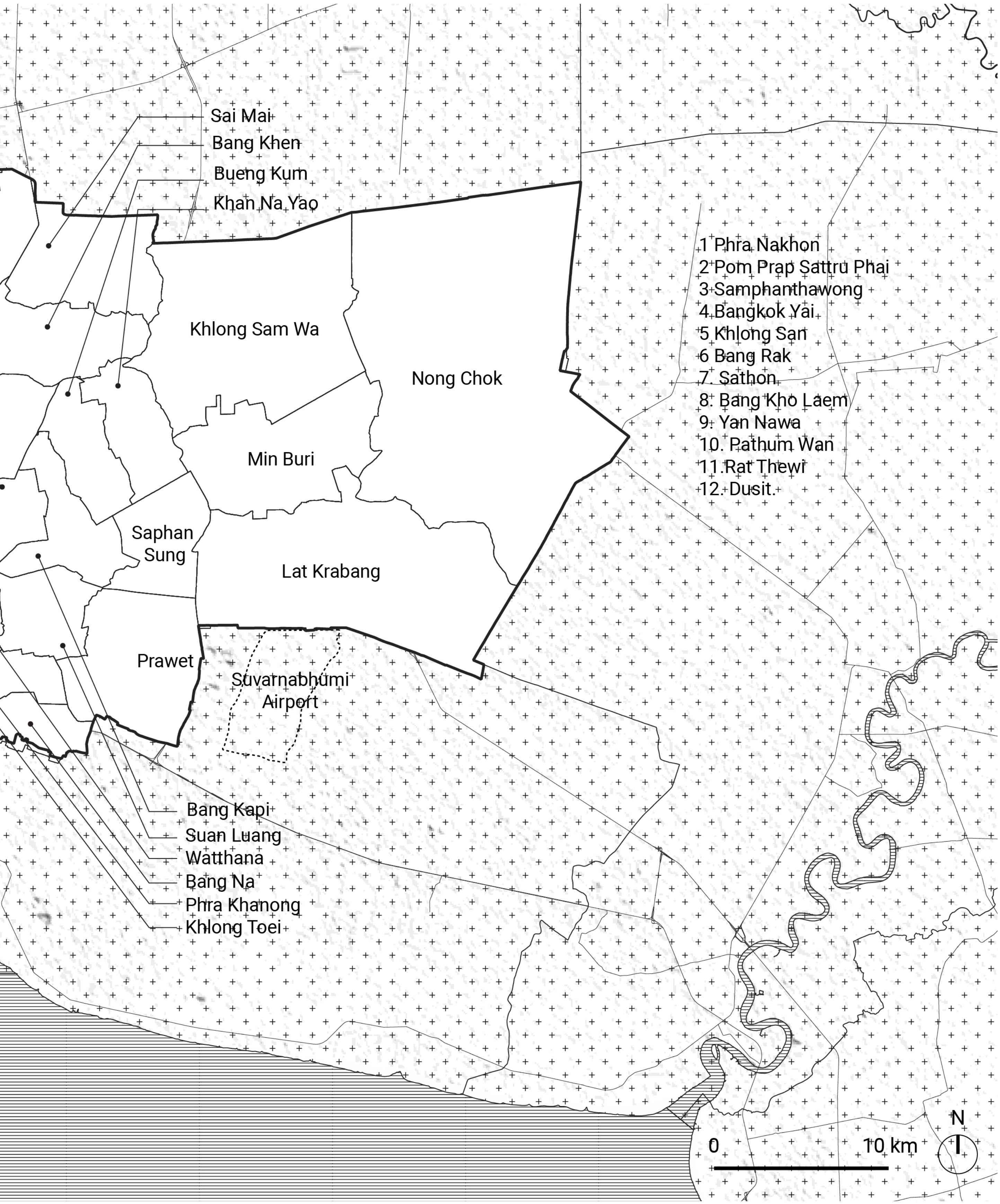
Total BMR Registered Population

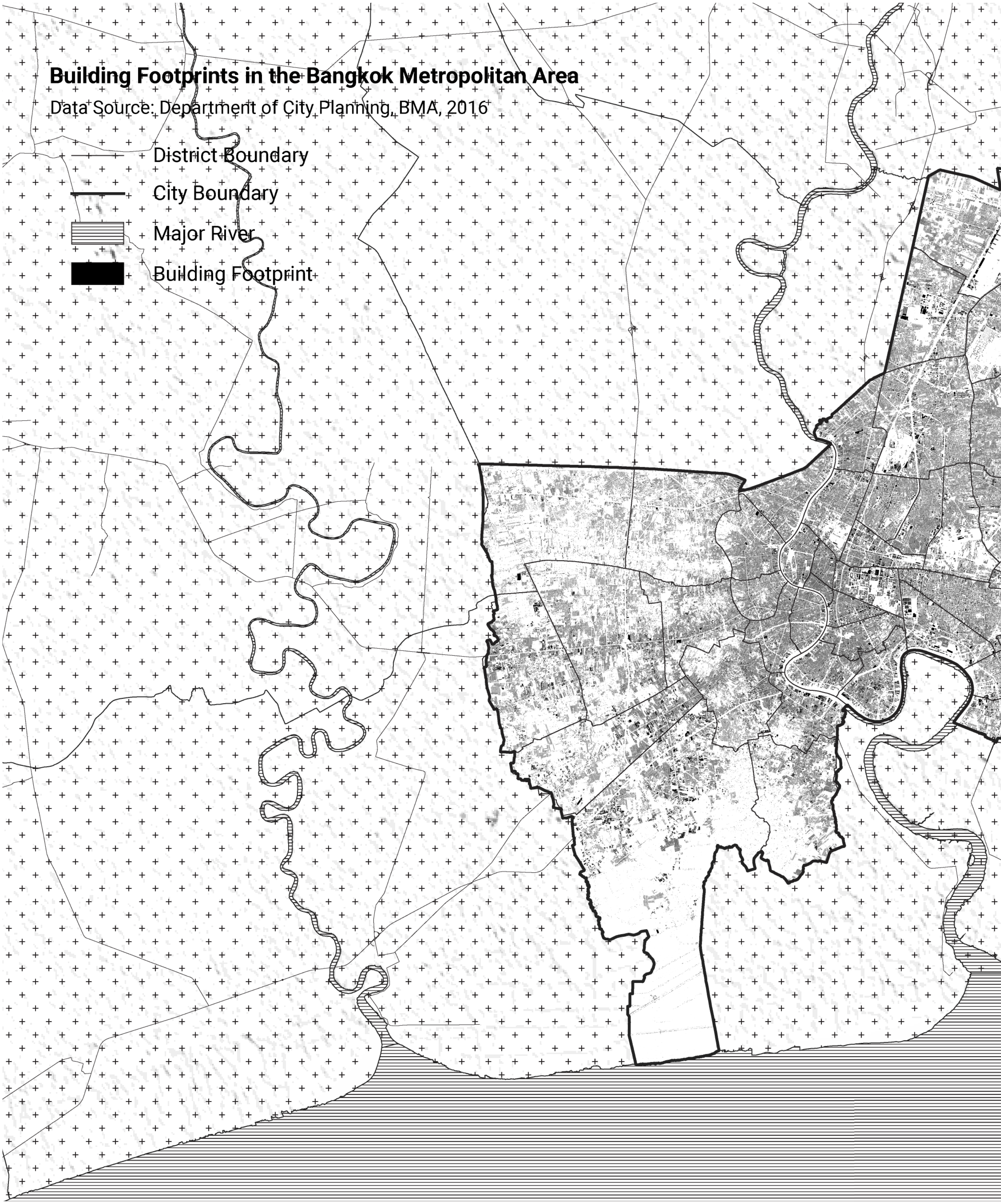
10,864,000



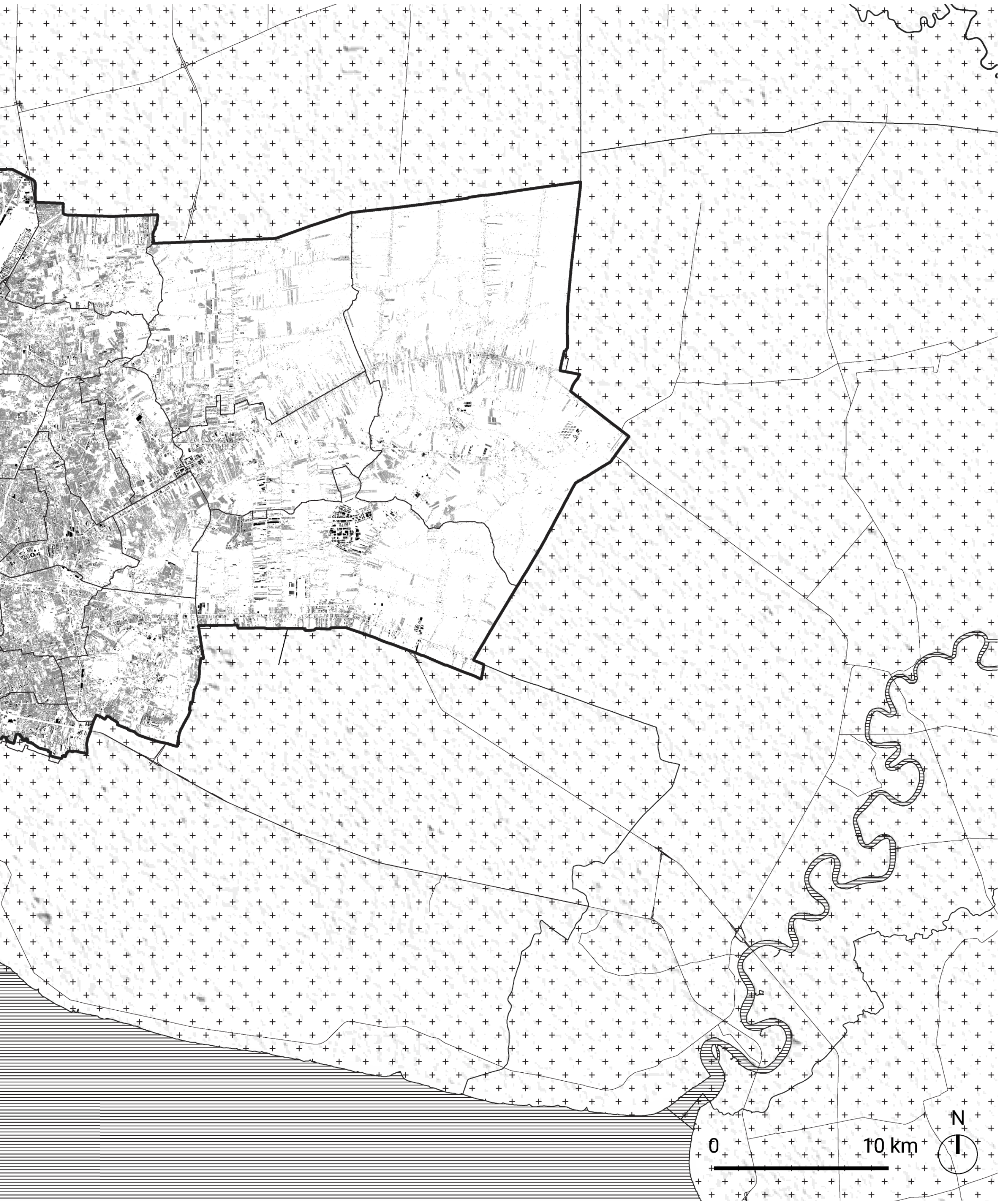
Data source: The Bureau of Registration Administration (BORA), 2021

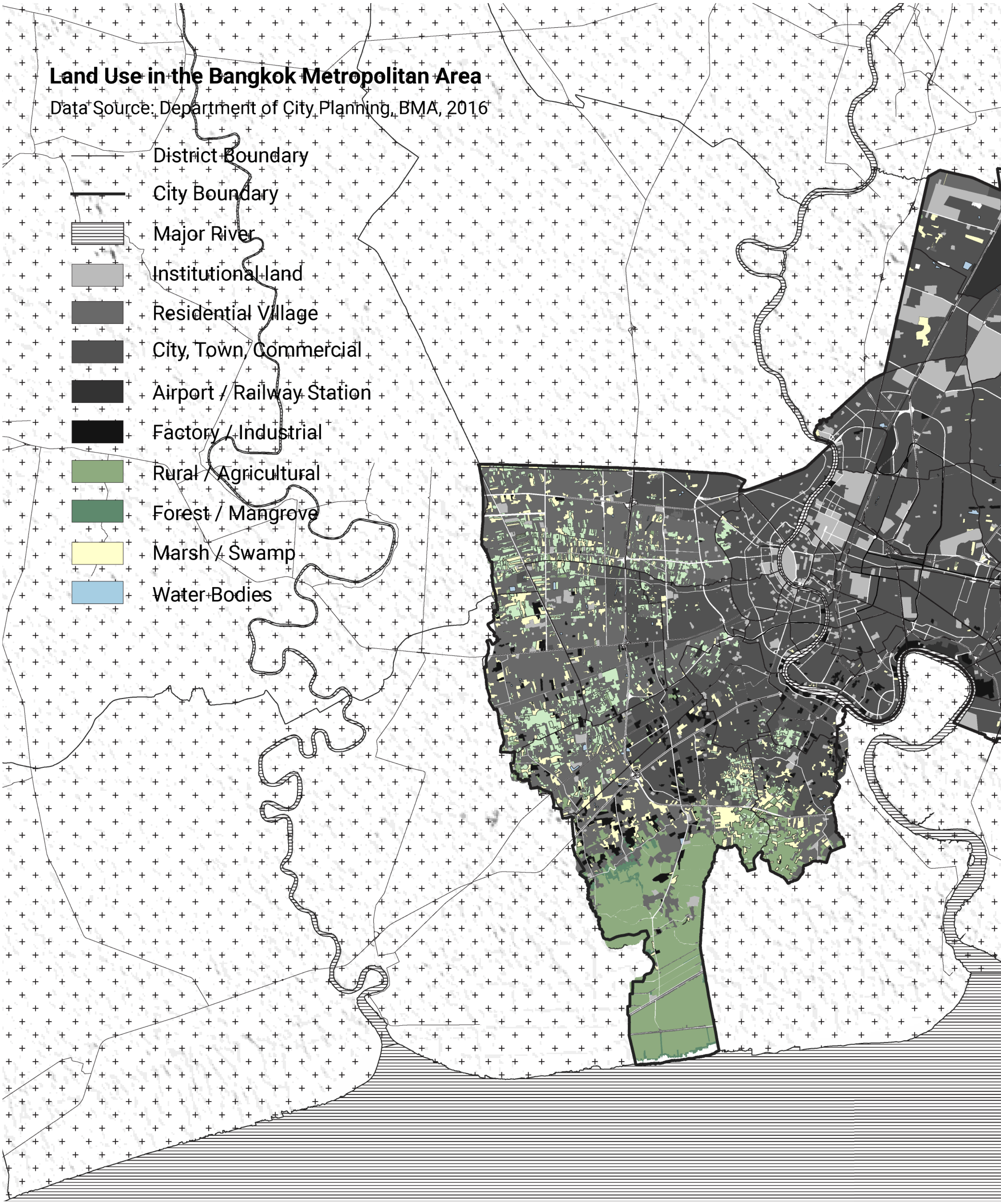

50 Administrative Districts in the Bangkok Metropolitan Area
Total area: 1,569 km² (606 mi²)
District Boundary
City Boundary
Major River
Don Maung
Lak Si
Lat Phrao
Chatuchak
Wang Thong Lang
Huai Khwang
Din Daeng
Bang Sue
Phaya Thai
Thawi Watthana
Taling Chan
Bang Phlat
12
Bangkok Noi
1
2
11
10
3
4
5
6
7
8
9
Phasi Charoen
Thon Buri
Bang Khae
Nong Khaem
Chom Thong
Rat Burana
Bang Bon
Thung Khu
Bang Khun Thian

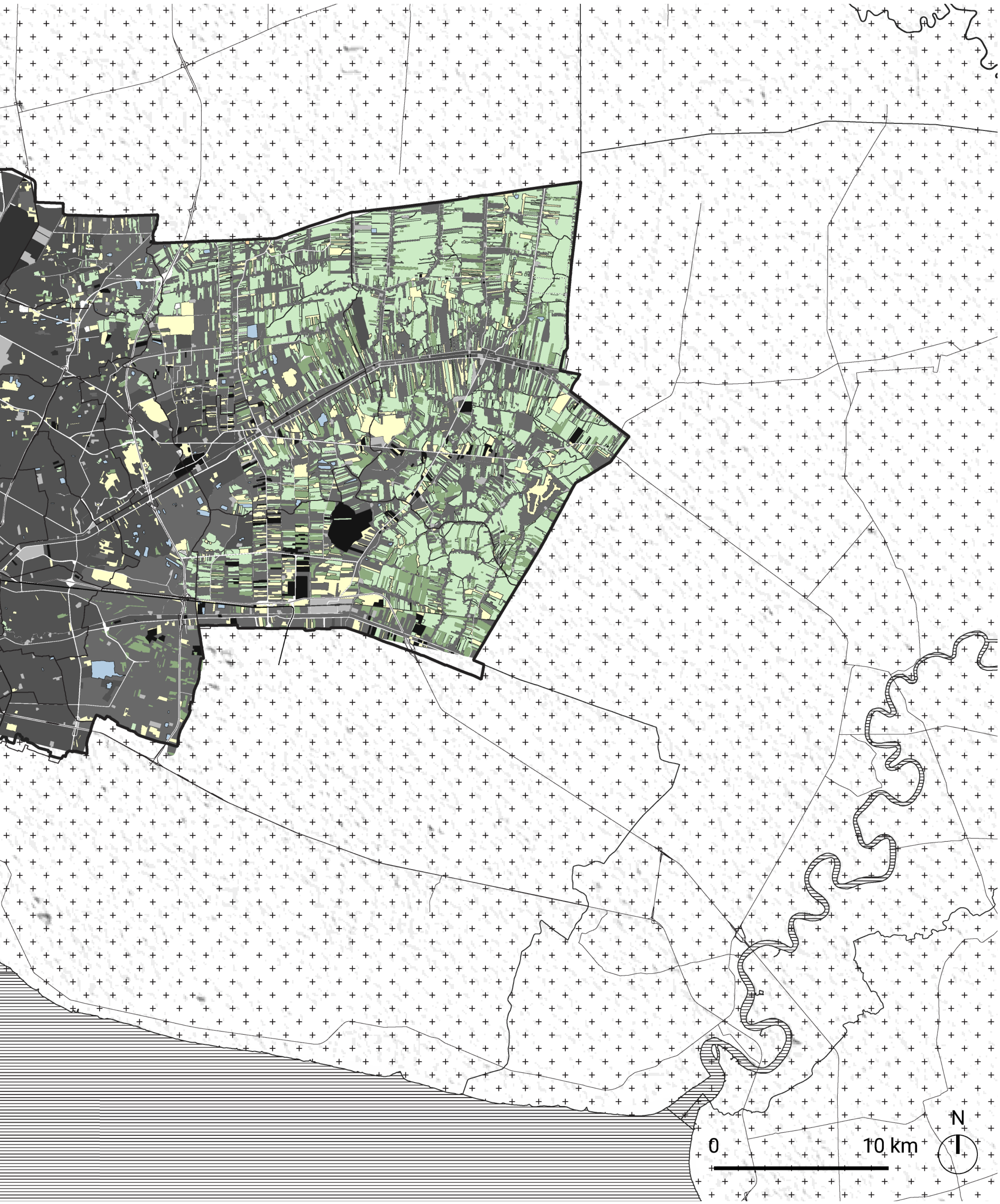

Sai Mai
Bang Khen
Bueng Kum
Khan Na Yao
Khlong Sam Wa
Nong Chok
Min Buri
Saphan Sung
Lat Krabang
Prawet
Suvarnabhumi Airport
Bang Kapi
Suan Luang
Watthana
Bang Na
Phra Khanong
Khlong Toei
1 Phra Nakhon
2 Pom Prap Sattru Phai
3 Samphanthawong
4 Bangkok Yai
5 Khlong San
6 Bang Rak
7. Sathon
8. Bang Kho Laem
9. Yan Nawa
10. Pathum Wan
11 Rat Thewi
12. Dusit
0
10 km
N



Building Footprints in the Bangkok Metropolitan Area
Data Source: Department of City Planning, BMA, 2016
District Boundary
City Boundary
Major River
Building Footprint


0
10 km
N


Land Use in the Bangkok Metropolitan Area
Data Source: Department of City Planning, BMA, 2016
District Boundary
City Boundary
Major River
Institutional land
Residential Village
City, Town, Commercial
Airport / Railway Station
Factory / Industrial
Rural / Agricultural
Forest / Mangrove
Marsh / Swamp
Water Bodies


N
0
10 km

1.3 Causes of Flooding

Flooding is a complex and multifaceted problem in Bangkok, with numerous interrelated issues. The causes of flooding can occur from various factors, but they can be divided mainly into natural causes and physical causes. In Bangkok, flooding is often the result of one or more of the following causes combined:

1.3.1 Natural Causes

Intense local rainfall

Bangkok is located in a tropical monsoon climate. The rainy season starts from May to October and the dry season from November to April. Bangkok experiences its highest rainfall amount and frequency during the period from mid-August to October, which is also the time when there is a chance for the occurrence of a tropical cyclone moving towards Thailand and near Bangkok. The annual average rainfall in Bangkok (between 1991 to 2020) is approximately 1,600 millimeters, however, as these rainfalls are often concentrated during September and October, precipitation in these two months alone can reach up to 200 to 400 millimeters. Rainfall rates such as these usually overwhelm the drainage system as the current drainage pipes were designed to handle rainwater amounts up to 60 millimeters per hour only.[24]

High Tides from the Gulf of Thailand

The water level in the Chao Phraya River corresponds to the tides along the Gulf of Thailand. Since the capital is located near the sea, high tides often overwhelm drainage capacity. The natural rise and fall of the sea level significantly affects the water levels in the Chao Phraya River basin. High tides from the Gulf of Thailand appear to surge mainly between October and December and strongly influence the water level in the lower portion of the Chao Phraya to rise.[25] The backwater flow at high tides can overflow the banks of the Chao Phraya delta during tidal surges, and in the event of heavy runoff from upstream, high tides can block the draining of flood water through the Chao Phraya River.

[24] Department of Drainage and Sewerage BMA, 2022
[25] Tomkratoke, 2015.

Water from upstream catchments

Rainfall in the Chao Phraya River basin is distributed over an area of more than 160,000 square kilometers, covering various cultivated areas and other regions. Some of it is stored in dams and reservoirs while the remaining 70% flows through Bangkok. This results in the Chao Phraya River having its highest water levels from October to November. The amount of northern water flowing through Bangkok in a year ranges from approximately 1,000-2,000 cubic meters per second during drier years up to 4,000-5,500 cubic meters per second during wetter years. The Chao Phraya River around Bangkok can only accommodate up to around 2,500-3,000 cubic meters per second of northern water without overflowing.[26]

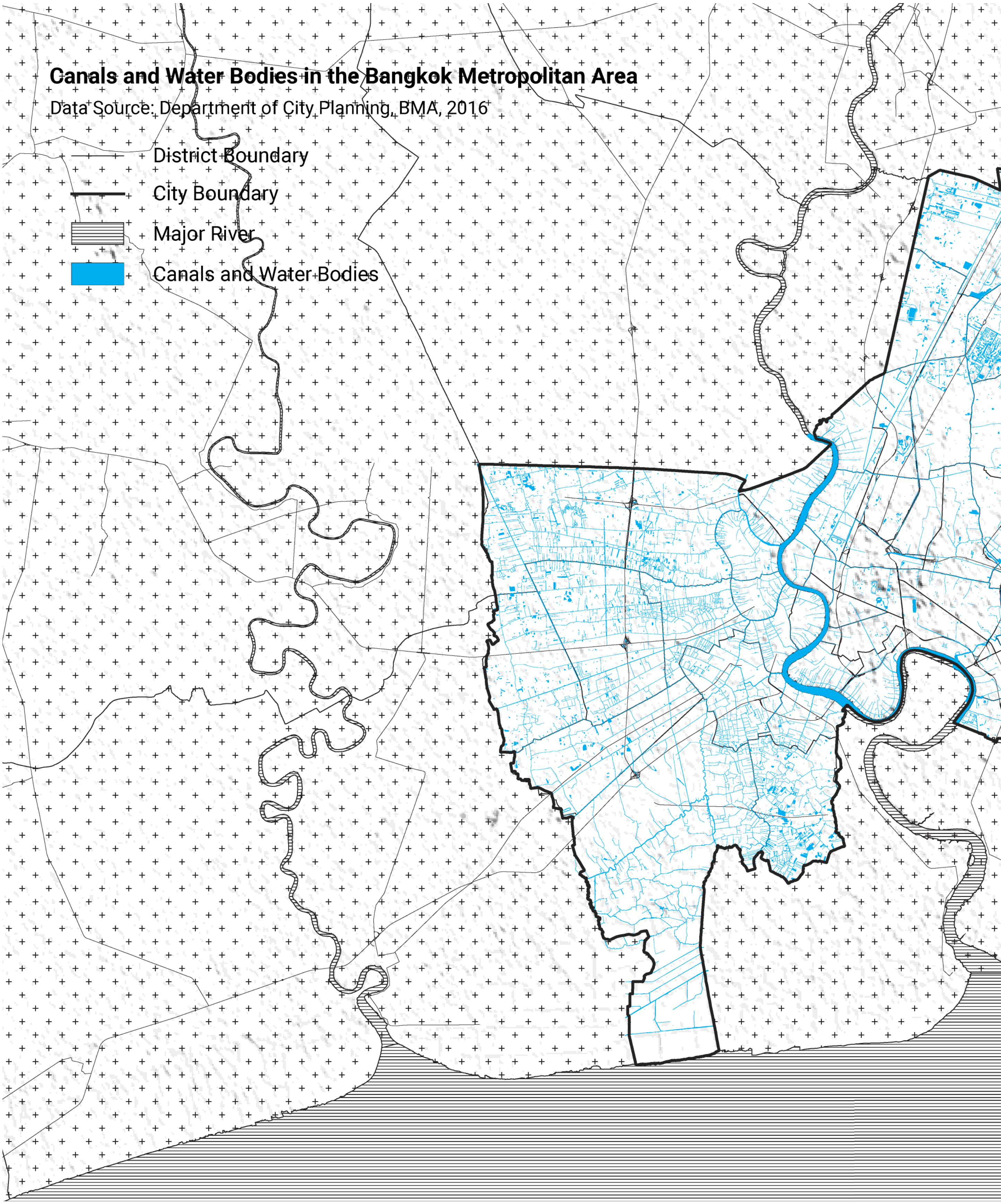
Regional Climate Occurrences

A naturally occurring climate pattern known as the El Niño-Southern Oscillation (ENSO) also lead to changes in atmospheric circulation patterns that affect patterns of temperature, rainfall rates, and other weather variables such as the frequency of tropical storms in Bangkok.[27] Higher than normal rainfall tends to occur during a La Niña event as sea surface temperatures in the central and eastern Pacific Ocean become cooler than normal. El Niño event, on another hand, brings drier weather in general and the overall rainfall tends to be lower than average, however, it can cause heavy rain in some areas which usually affects urban areas such as Bangkok.[28]

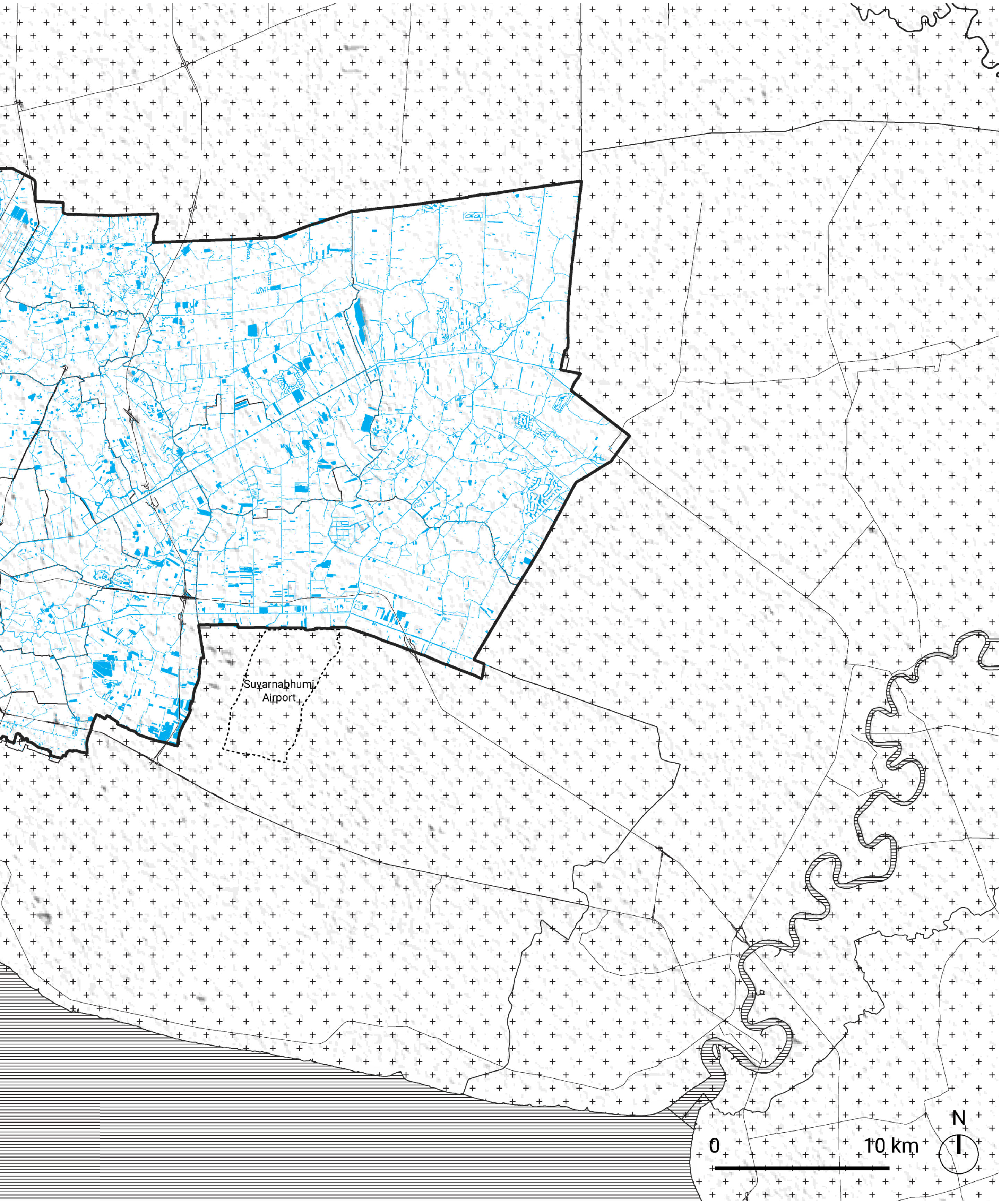
Climate change

Climate change on a global scale is one of the largest contributors to flood vulnerability. Climate change also contributes to more extreme weather events and repetitive flood risk in the Chao Phraya River basin. According to a study,[29] the frequency of heavy rainfall events in the region has increased in recent years, which has resulted in more frequent and severe floods. The study also notes that the projected increase in global temperature is likely to exacerbate this trend in the future.

[26] Department of Drainage and Sewerage BMA, 2022
[27] National Oceanic and Atmospheric Administration, 2023
[28] Department of Drainage and Sewerage BMA, 2022
[29] Supharatid, 2016



Canals and Water Bodies in the Bangkok Metropolitan Area
Data Source: Department of City Planning, BMA, 2016
District Boundary
City Boundary
Major River
Canals and Water Bodies


Suvarnabhumi
Airport
0
10 km
N

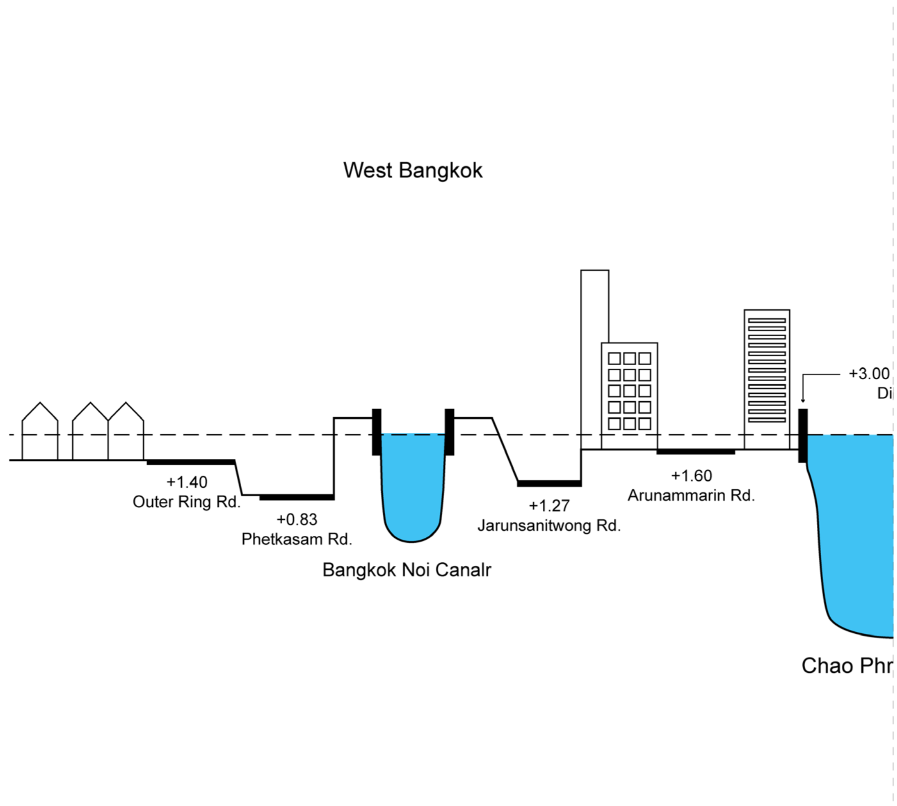
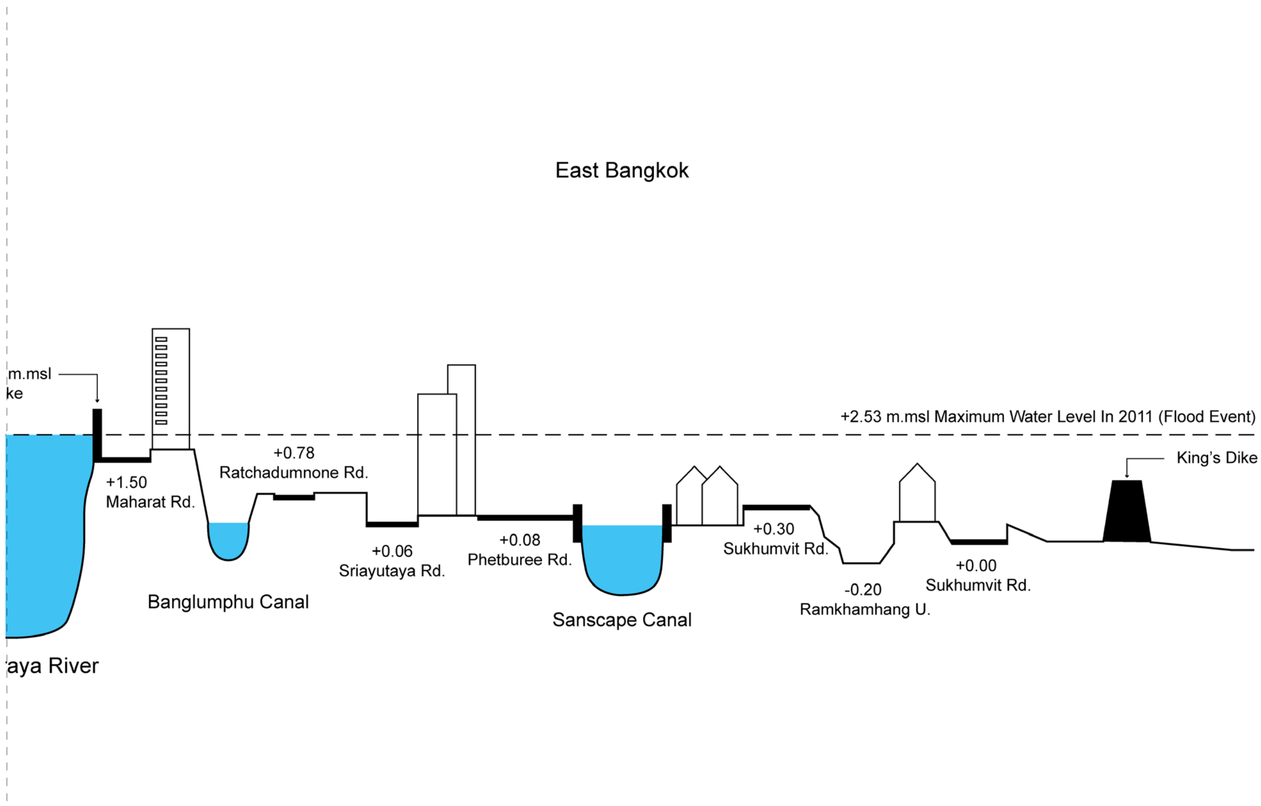


Figure 1.21 Bangkok's Section
(Source: Diagram by the author, Data from Department of Drainage, BMA, 2010)



East Bangkok
m.msl
ke
+2.53 m.msl Maximum Water Level In 2011 (Flood Event)
King's Dike
+1.50
Maharat Rd.
+0.78
Ratchadumnone Rd.
+0.06
Sriayutaya Rd.
+0.08
Phetburee Rd.
+0.30
Sukhumvit Rd.
-0.20
Ramkhamhang U.
+0.00
Sukhumvit Rd.
Banglumphu Canal
Sanscape Canal
aya River

1.3.2 Man-Made Cause

While global climate trends are strong influencers of sea-level rise, local and human-induced changes can play an even larger role. In the past, Bangkok adapted to work with nature, nowadays, the city tries to 'control' and work 'against' nature.

Urbanization

Since the 1960s, rapid urbanization in Bangkok and surrounding provincial cities has increased the risk of flood damage. The population has grown, and the Bangkok metropolitan area, which was only 51 square kilometers in the 1950s,[30] has now expanded to over 1,568.7 square kilometers. As a result, the potential for flood damage has increased, and floods have become more severe due to a decrease in run-off detention capacity. The floodplains (green belt) on the east and west banks of the Chao Phraya River have traditionally served as water conservation areas to protect Bangkok from extreme floods. However, due to rapid urban sprawl, a residential area and industrial estate were built on the green belt resulting in ineffective water drainage and flood control function that no longer works as originally intended.

Associate Professor Dr. Panit Phujinda, a faculty member in the Department of Urban Planning, Faculty of Architecture, Chulalongkorn University, stated that the floodway area in the eastern region is an area where the law prohibits the allocation of land for residential purposes. However, it is evident that there are over 400 large-scale housing projects in that area, each consisting of more than 500 households.[31] Moreover, the upcoming new Bangkok city plan that will take effect in 2024 aims to further support these horizontal developments. According to the BMA, the modified land zoning controls of the floodplain area will be dramatically reduced from 150,203 rai (240 square kilometers) to 53,779 rai (86 square kilometers) to open up more development opportunities and accommodate the expansion of the city. The plan would allow for low to medium-density housing to be developed in the floodplain and argues that they would expand the existing canals in order to make up for the missing floodways.[32] However, it is questionable whether the proposed plan to expand the existing canals in order to compensate for the loss of floodway area will suffice. This plan may lead to further urbanization in Bangkok and potentially exacerbate the issue of insufficient green areas in the city.

In 1991, Built-up areas in Bangkok were approximately 30%, it was sharply increasing to nearly 55% of the total area in 2016. In contrast, green areas and bare land were continually decreasing

[30] Phienwej et al., 2005
[31] Bangkokbiznews, 2020
[32] Department of City Planning BMA, 2022

Figure 1.22
Historic Maps Bangkok in 1910
(Source: Central Library, Office of Academic Resources, Chulalongkorn University)

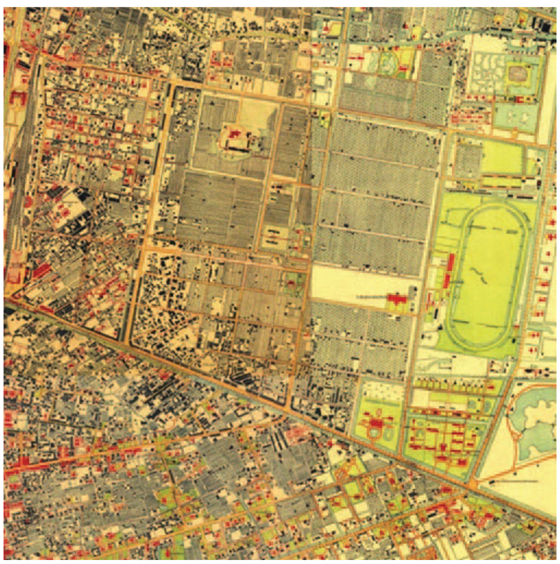
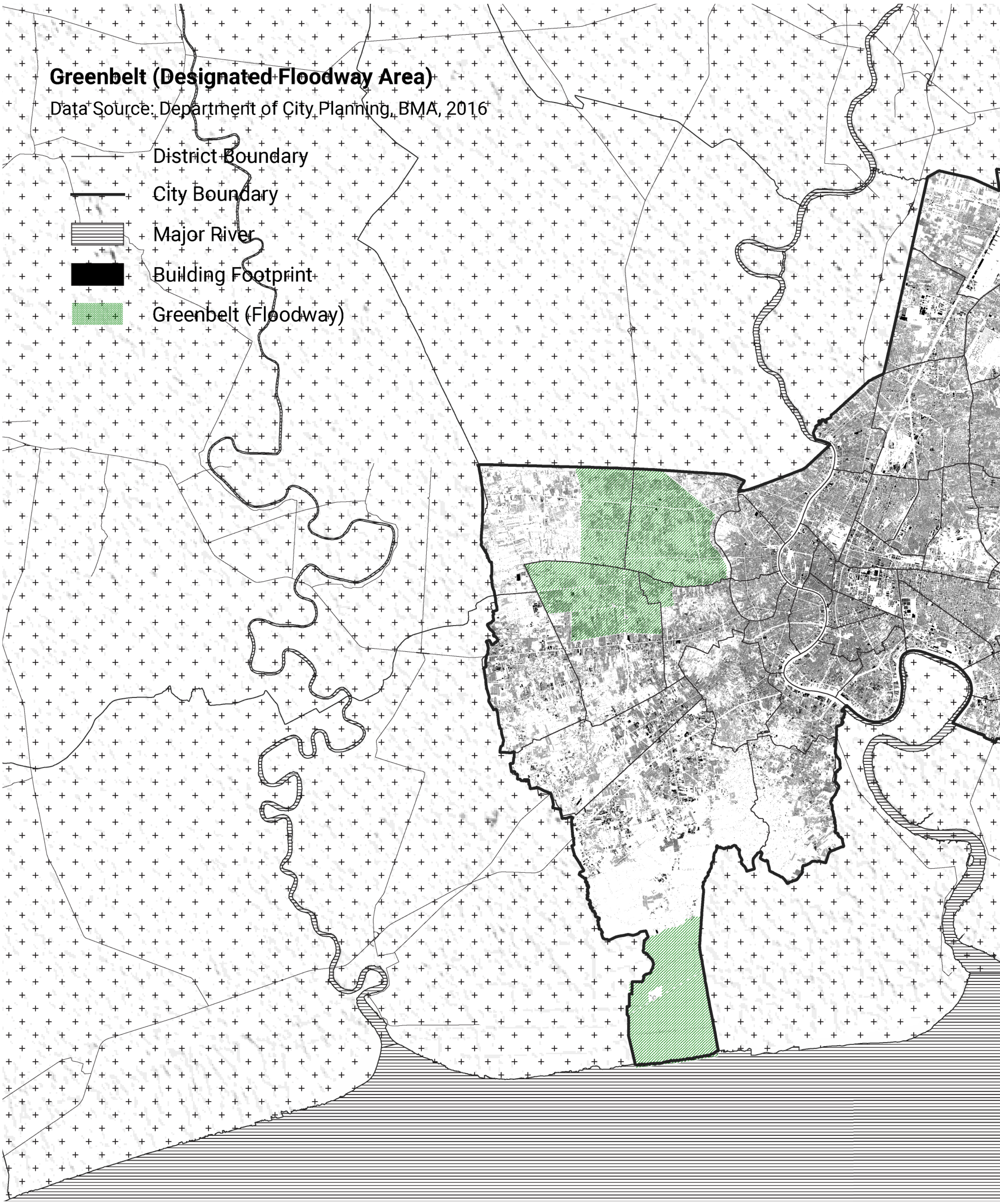
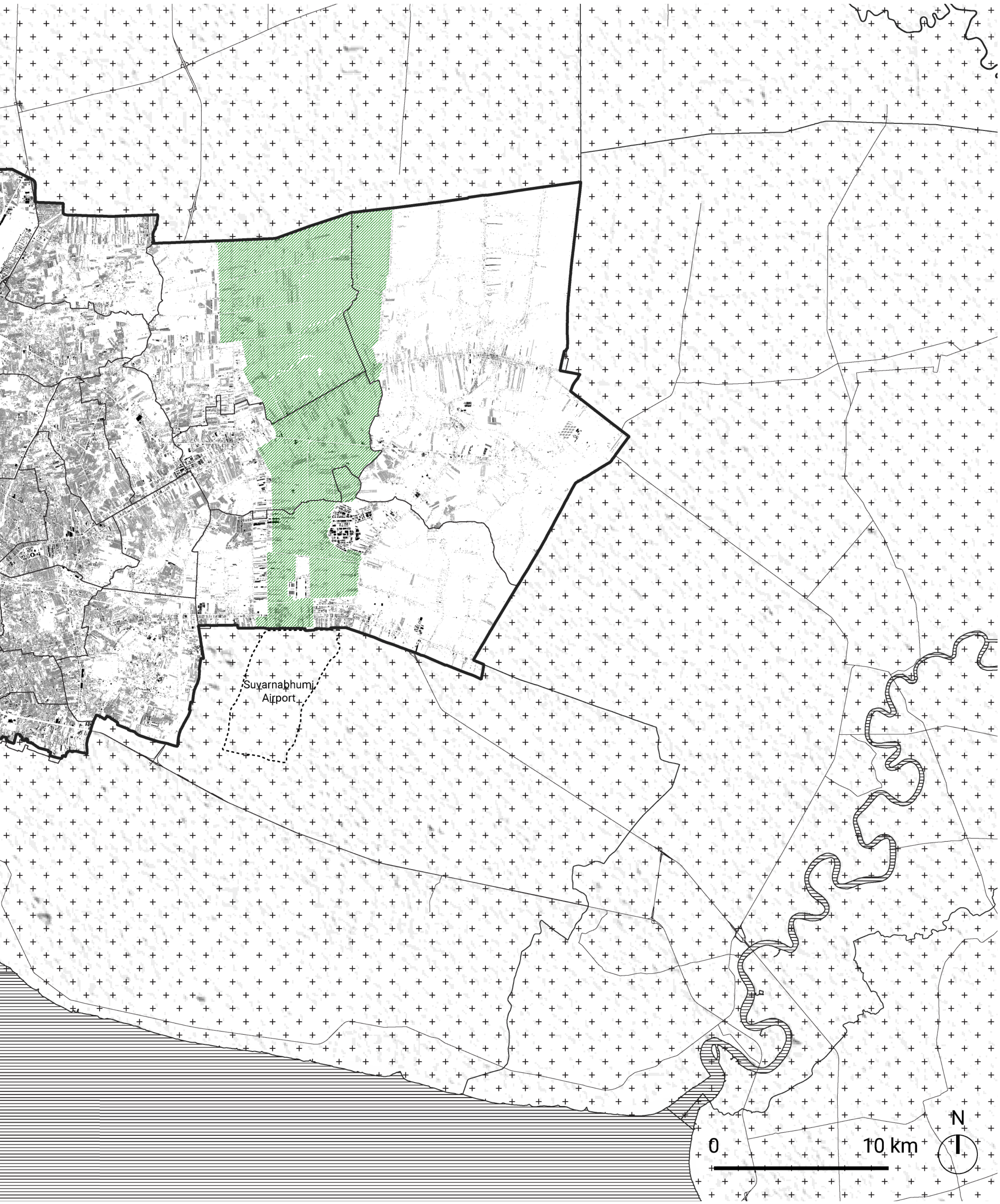


Figure 1.23
Historic Maps Bangkok in 1952
(Source: Pinit Phra Nakhon Book 1932-2002)

Figure 1.24
Historic Maps Bangkok in 2002
(Source: Pinit Phra Nakhon Book 1932-2002)


Greenbelt (Designated Floodway Area)
Data Source: Department of City Planning, BMA, 2016
District Boundary
City Boundary
Major River
Building Footprint
Greenbelt (Floodway)



Suvarnabhumi Airport
0
10 km
N

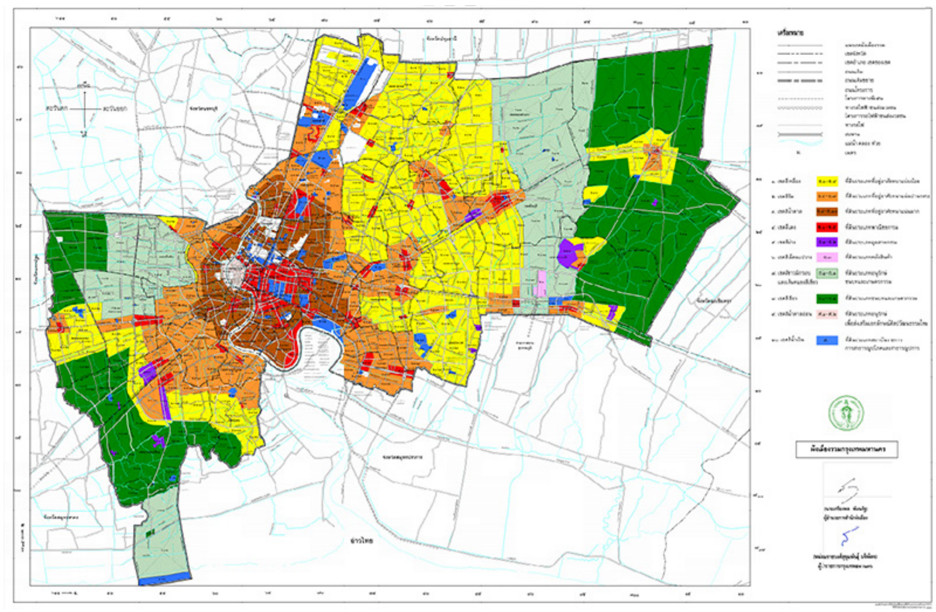


Figure 1.26 Current Bangkok City Plan
(Source: Department of City Planning, BMA, 2022)

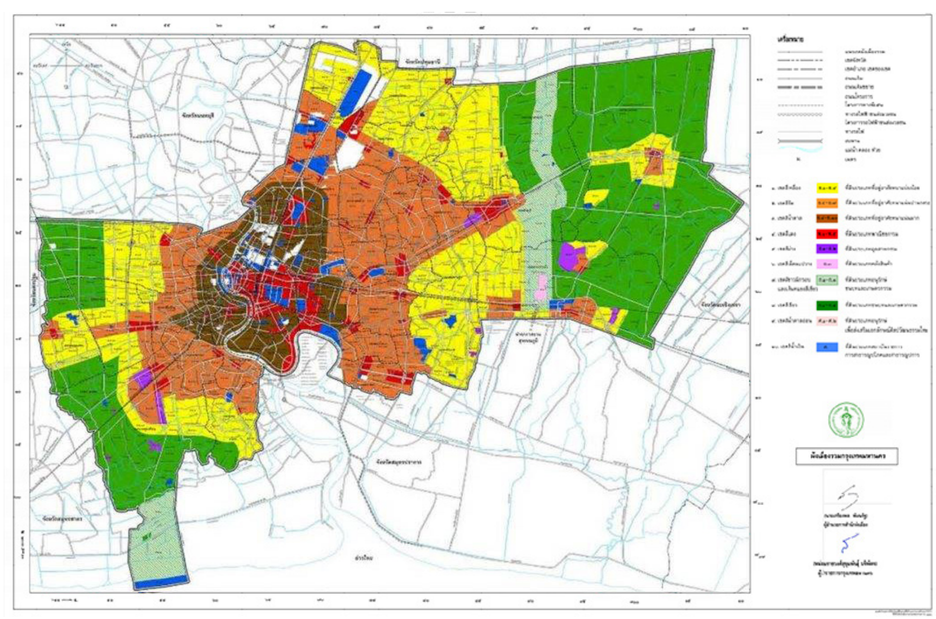


Figure 1.27 Latest Draft of the New Bangkok City Plan
(Source: Department of City Planning, BMA, 2022)

from roughly 38% in 1991 to 33% in 2016 and 25% in 1991 to 7% in 2016.[33]

The current national policy and regulation are overlapping and failing to control the expansion of urban areas and rapid urbanization in recent decades. This has meant changes in land use which have affected long-existing watercourses, canals, and retention ponds. Without water retention areas, Bangkok will inevitably continue to face flooding problems.

Inadequate Drainage System

Bangkok's sewer system is outdated and was constructed many years ago. The pipes vary in size, with some as small as 30-60 centimeters in diameter and the largest being approximately 80 centimeters. Originally, these pipes were intended to handle rainwater up to 60 mm per hour, but the city now receives rainfall amounts exceeding 100 mm per hour which causes runoff to overflow the drainage system.[34]

The canal network in Bangkok that was originally constructed to serve as a major drainage channel is currently in a state of disrepair, heavily polluted, and often blocked by waste and rubbish. The pollution of the canal network is a consequence of various human activities such as discharging untreated wastewater and solid waste dumping. Furthermore, the problem is often exacerbated by a lack of proper waste management systems in the city, leading to an accumulation of garbage in the canals. The pollution and blockage of the canals pose a significant threat to the city's drainage system and exacerbate flooding problems during periods of heavy rainfall.

Land Subsidence

The low ground surface elevation of Bangkok, ranging from +0 to +2 meters above sea level, exacerbates the city's flood risk during the rainy season when water levels in the Chao Phraya River often exceed +2 meters above sea level. The overuse of groundwater for the city and surrounding provinces, combined with rapid population growth and ineffective urban land use, have worsened the problem of land subsidence, which has a critical role in increasing flood risks. Land subsidence affects drainage, pumping efficiency, and the effectiveness of flood protection measures. Currently, the greatest subsidence occurs in the southeastern and southwestern industrial zones on the outskirts of Bangkok, with an alarming rate of 30 mm per year.[35] Despite a cabinet resolution in 1983 to regulate groundwater abstraction, overpumping continues to be a leading cause of land subsidence.

[33] Khamchiangta, 2020
[34] Department of City Planning BMA, 2022
[35] Phien-wej, 2006

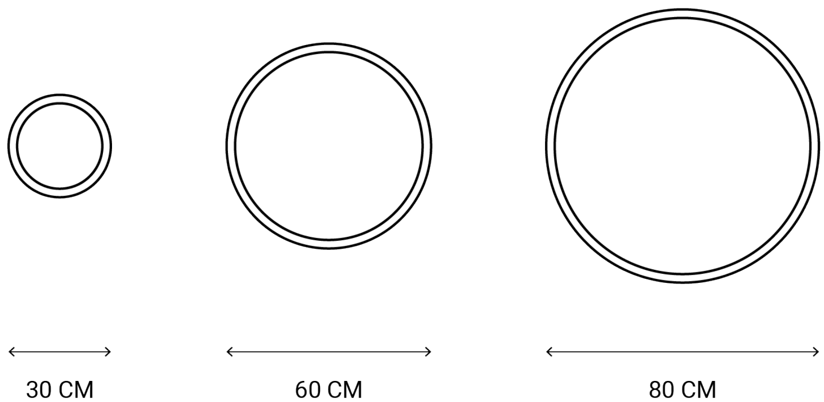


Figure 1.28 Pipes size were designed to handle up to 60 mm/hour of rainfall (Diagram by the author)

Figure 1.29 A civil service officer named Mr. Boonrueang dove into the drain to collect garbage that was blocking the waterway. (Source: Bangkhen District Official Facebook Page, 2022)

1.4 Flood Timeline: History, Present, and Future Trend

Floods have long been a natural part of life in Bangkok, but over the last century, the city has faced increasingly severe flooding due to a combination of factors. Development within the floodplain has reduced the area available for flood retention, while large-scale deforestation has exacerbated the problem.

Prior to 1996, most recorded flood events were a result of upstream flooding[36] that exceeded the carrying capacity of the Chao Phraya River. While these floods typically took several days to reach the city, they could last for several weeks and have depths of up to 2 meters above the low alluvial plain.The typical frequency of these previous floods was once every 3-5 years on average. To address this issue, the Bangkok Metropolitan Administration (BMA) constructed five polder systems on the west and twelve on the east of the river in 1983. The existing infrastructure such as roadways and railways were utilized to enclose the polders, while additional levees were built as necessary. These polders were equipped with apparent drainage structures like pipes, water gates, natural and man-made canal networks, and pumping stations. In tandem with these measures, King Rama IX issued a royal decree that called for the construction of levees on the east polders in order to contain upstream floods. Since 1997, these polder systems and associated levees have been successful in protecting the city from upstream floods, with local extreme rainfall being the only source of flooding in the city since 1997.[37]

Over time, flood characteristics in Bangkok have shifted from high-depth, long-duration events to more frequent flash floods with shallower depths (less than 0.5 m) and durations shorter than 1 day.[41] To mitigate the negative effects of flash floods, the BMA has improved the capacity of existing drainage systems by constructing seven detention tunnels. These tunnels have been effective in handling local floods with maximum intensities of 60 mm/hr lasting between 5 minutes to 4 hours since their construction in 2011.[38] However, there has been an increase in the frequency of flooding in recent years, leading to concerns about the effectiveness of current mitigation measures. While several factors could contribute to changes in precipitation patterns, experts generally agree that rising global temperatures result in a larger capacity for storing atmospheric moisture, leading to larger, more intense downpours when they occur.[39]

[36] Worawiwat et al., 2021
[37] Worawiwat et al., 2021
[38] Kiguchi et al., 2021
[39] BMA, 2020
[40] Lee et al., 2020

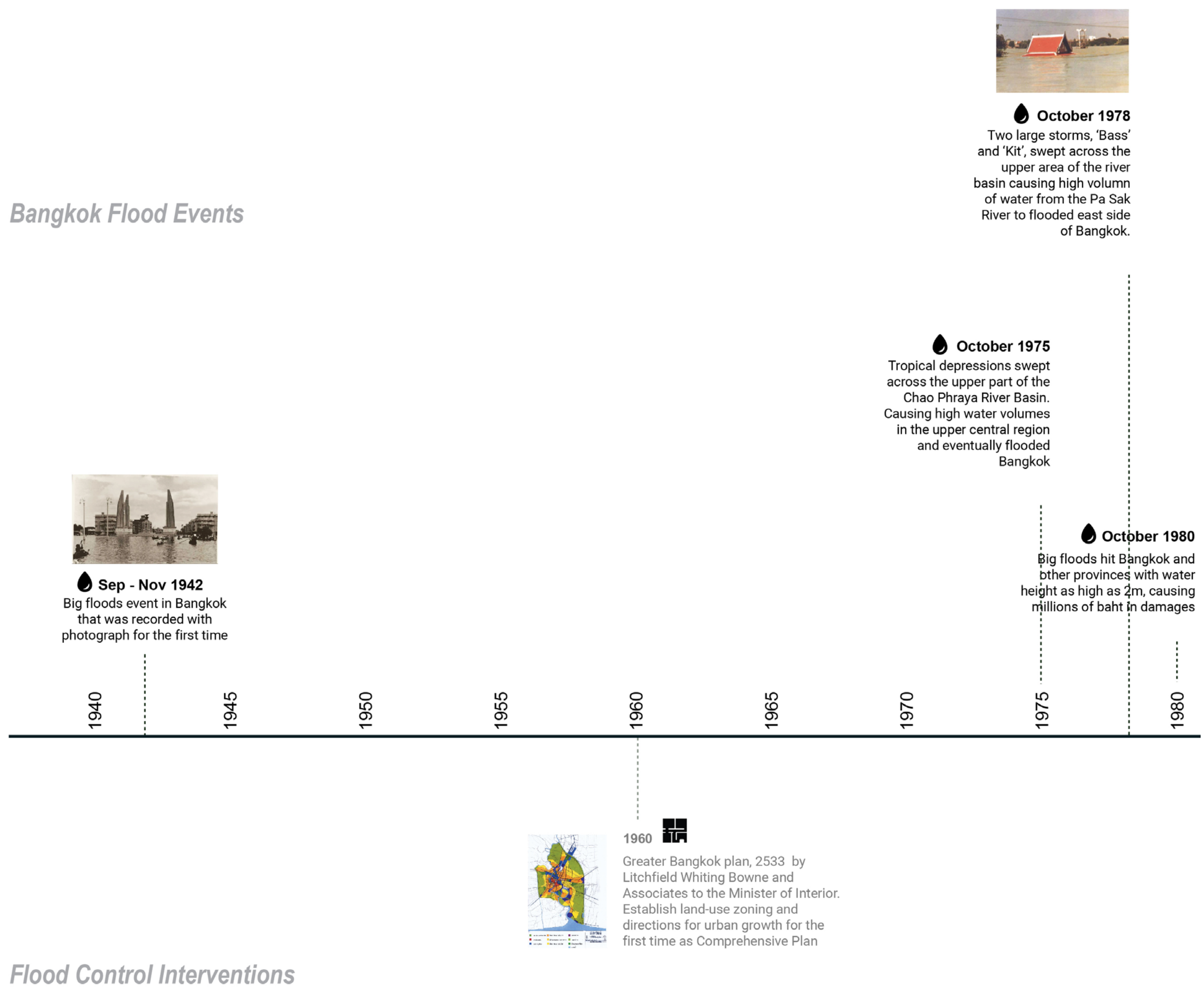


Figure 1.30 The timeline of Bangkok's historical flood events and flood control interventions that took place between 1940 and 2022

Oct- Nov 1983
Tropical depressions 'Herbert' and 'Kim' left a trail of destruction, big flood and death in Bangkok and 42 other provinces

1983
The first underground Drain Tunnel began it's operation. The tunnel diameter is 1 meter to solve the problem on Sukhumvit Road between Soi Sukhumvit 22-28.

1985
The king's dike was constructed as a 72 km polder system located at the northern and eastern boundaries to protect the inner city of Bangkok from flood water.

May 1986
Summer storm brought heavy rainfall of 250 - 275 mm per hour causing flash floods in some areas

October 1990
Tropical storms Era and Lola swept through the Northeast of Thailand, causing heavy rain recorded highest at 617 mm.

1991
Another two tunnels was completed and began it's operation: Drainage tunnels and water diversion systems at Khlong Prem Prachakorn and Sukhumvit 36

May 1994
Summer storm hit Bangkok, the highest amount of rainfall was measured at 458 mm and on average of 200 mm causing flash floods in many areas

Aug - Oct 1995
Many storms blew through the country since May and heavy rain during August to October due to the storm 'Olis' causing excessive water in the Chao Phraya River to overflow. The flood height was as recorded high as 2.27m

1995 - 1996
The Royal-initiated Kaem Ling (Monkey Cheeks) Project began on both east and west bank of the Chao Phaya River

May 1986
Minor flash floods in Bangkok with water height around 20-40cm

2002
Pumping Station and the Drain Tunnel in Soi Sukhumvit 42 was completed

2003
Completion of 5th Drain Tunnel in Phayathai area

October 2006
Remnants of Typhoon Xangsane passed over Thailand. Bangkok experience 80 mm of rainfall and 110 mm in some area causing floods in the east side of the city.

2010
The 6th Drain Tunnel was completed in the Makkasan swamp area

October 2010
A series of flash floods hit 38 provinces including 7 districks of Bangkok, due to tropical depression incombination with La Niña monsoon rains

July 2011 - Jan 2012
The worst flooding in five decades spread over 65 provinces, mainly in the North and Central regions, including a large part of Bangkok

2011
Completion of 5th Drain Tunnel between Rama 9 - Ramkhamhaeng Road

Sept 2013
Floods out east of Bangkok, mainly in 4 districts: Min Buri, Nong Chok, Lat Krabang and Khlong Sam Wa.

June 2016
Heavy rain caused flooding in 36 areas of Bangkok. Although the rain was short lived, the rainfall was as much as 200 mm, the highest level for over 25 years.

October 2017
Another big floods hit Bangkok and 68 other provinces.

October 2022
Heavy rainfall recorded at 800 mm, 5 times higher than average, flooded mainly in 6 districts: Laksi, Bang Khen, Don Mueang, Phra Khanong, Prawet, Lat Krabang

1985 1990 1995 2000 2005 2010 2015 2020

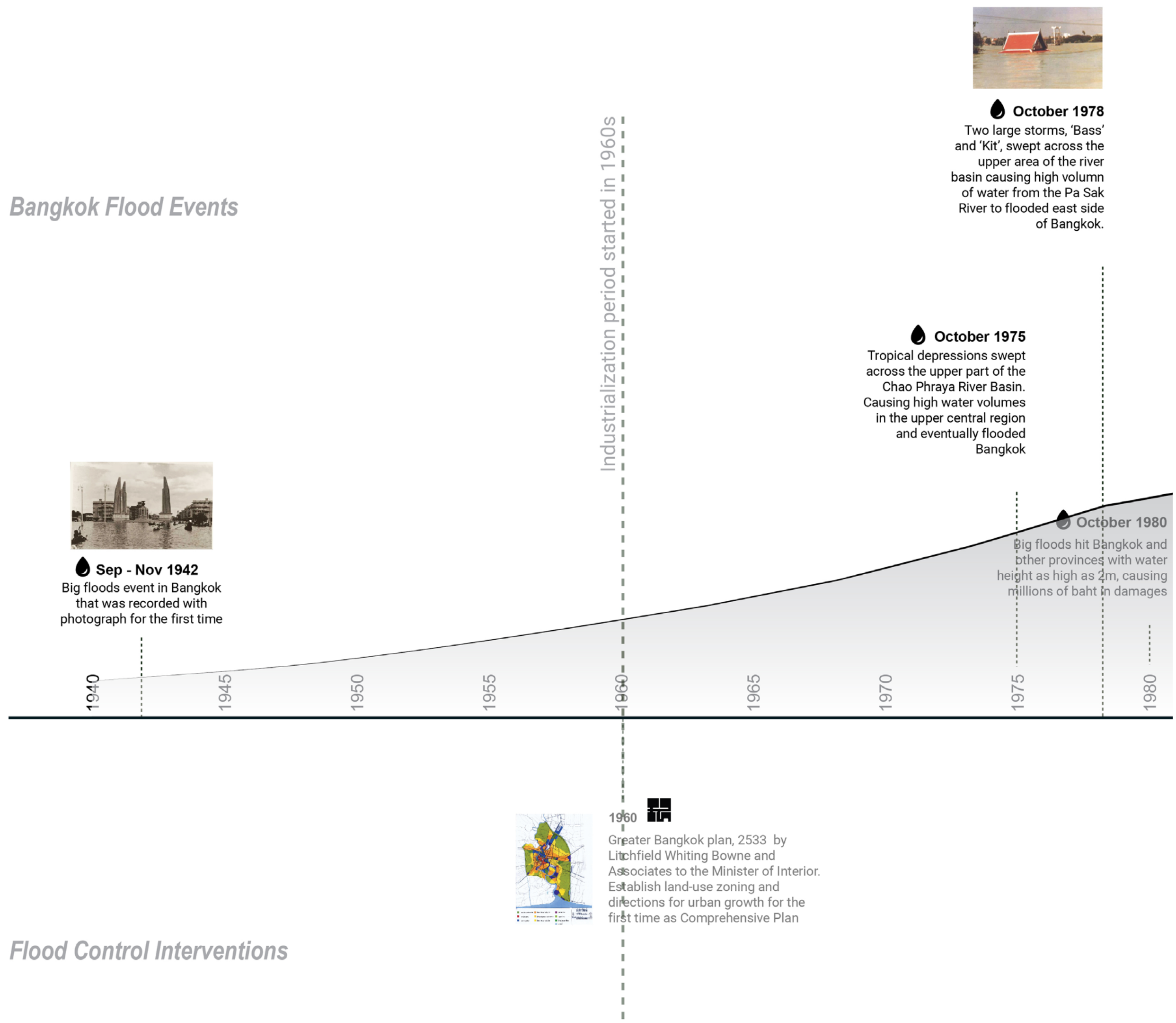
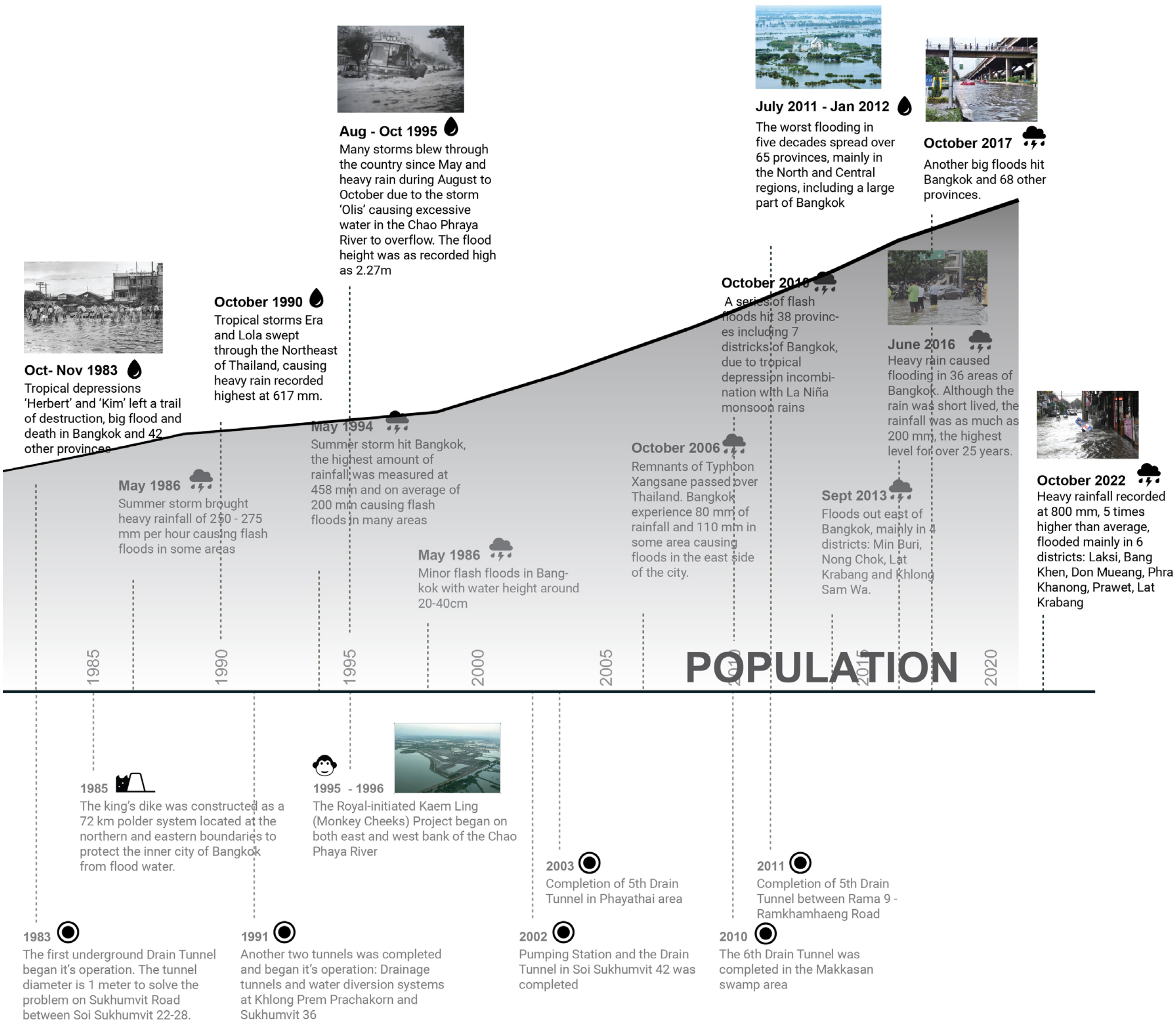


Figure 1.31 The timeline of Bangkok's historical flood events in relation to the population increase after industrialization that started in the 1960s


Oct- Nov 1983
Tropical depressions 'Herbert' and 'Kim' left a trail of destruction, big flood and death in Bangkok and 42 other provinces
May 1986
Summer storm brought heavy rainfall of 250 - 275 mm per hour causing flash floods in some areas
October 1990
Tropical storms Era and Lola swept through the Northeast of Thailand, causing heavy rain recorded highest at 617 mm.
May 1994
Summer storm hit Bangkok, the highest amount of rainfall was measured at 458 mm and on average of 200 mm causing flash floods in many areas
Aug - Oct 1995
Many storms blew through the country since May and heavy rain during August to October due to the storm 'Olis' causing excessive water in the Chao Phraya River to overflow. The flood height was as recorded high as 2.27m
May 1986
Minor flash floods in Bangkok with water height around 20-40cm
October 2006
Remnants of Typhoon Xangsane passed over Thailand. Bangkok experience 80 mm of rainfall and 110 mm in some area causing floods in the east side of the city.
October 2010
A series of flash floods hit 38 provinces including 7 districks of Bangkok, due to tropical depression incombination with La Niña monsoon rains
July 2011 - Jan 2012
The worst flooding in five decades spread over 65 provinces, mainly in the North and Central regions, including a large part of Bangkok
Sept 2013
Floods out east of Bangkok, mainly in 4 districts: Min Buri, Nong Chok, Lat Krabang and Khlong Sam Wa.
June 2016
Heavy rain caused flooding in 36 areas of Bangkok. Although the rain was short lived, the rainfall was as much as 200 mm, the highest level for over 25 years.
October 2017
Another big floods hit Bangkok and 68 other provinces.
October 2022
Heavy rainfall recorded at 800 mm, 5 times higher than average, flooded mainly in 6 districts: Laksi, Bang Khen, Don Mueang, Phra Khanong, Prawet, Lat Krabang
1985
1990
1995
2000
2005
2010
2015
2020
POPULATION
1983
The first underground Drain Tunnel began it's operation. The tunnel diameter is 1 meter to solve the problem on Sukhumvit Road between Soi Sukhumvit 22-28.
1985
The king's dike was constructed as a 72 km polder system located at the northern and eastern boundaries to protect the inner city of Bangkok from flood water.
1991
Another two tunnels was completed and began it's operation: Drainage tunnels and water diversion systems at Khlong Prem Prachakorn and Sukhumvit 36
1995 - 1996
The Royal-initiated Kaem Ling (Monkey Cheeks) Project began on both east and west bank of the Chao Phaya River
2002
Pumping Station and the Drain Tunnel in Soi Sukhumvit 42 was completed
2003
Completion of 5th Drain Tunnel in Phayathai area
2010
The 6th Drain Tunnel was completed in the Makkasan swamp area
2011
Completion of 5th Drain Tunnel between Rama 9 - Ramkhamhaeng Road

1.5 Current Flood Management and Issues

Bangkok uses a flood control and mitigation system called the "polder system", which was first implemented after a major flood event in 1995.[41] The system is divided into two main operations: protection and mitigation. The flood protection system was designed to prevent fluvial flooding from the Chao Phraya River during the high tide period as well as when there is an inflow from the release of water from the dam in the northern part of the country. The flood mitigation system, on the other hand, is used to manage stormwater runoff caused by local heavy rainfall.

1.5.1 Current Protection System

The protection system is intended to prevent water from the river and tidal surges by constructing barriers to prevent water from flooding into the area. The Royal Irrigation Department constructed levees along both sides of the Chao Phraya River from Chainat through Ayutthaya. These levees protect rice fields from small and medium floods and serve as a buffer for flood control. Floodgates are used to divert large floods into the rice fields, which are connected to the floodplain through water channels. This approach helps prevent unexpected dike breaks that could cause significant damage and controls the flow of floodwaters into the Bangkok Metropolitan Area. This method was first used after the major flood in 1981, with the construction of a 72-kilometer, 3-meter-high embankment completed in 1985.[42] However, the embankment has since deteriorated and was reinforced with additional barriers after the 2011 floods. Additionally, more flood protection measures were constructed in the Khlong Sam Wa district and five more flood walls were built.

Currently, the flood protection system is located along the Chao Phraya River, Khlong Bang Kho Laem, Khlong Maha Sawat, Khlong Chak Phra, and Khlong Phra Khanong, with a total length of embankments of 87.93 kilometers. The system provides self-protection for 9 kilometers, while the water management office has constructed an additional 78.93 kilometers of flood protection measures.[43] However, the existing flood protection system does not completely eliminate the risk of flooding, as the area still needs to be monitored for tidal surges. Moreover, there are still houses and buildings located outside the embankment area that require temporary flood protection using sandbags during periods of high water levels.

[41] Department of Drainage and Sewerage BMA, 2021
[42] Department of Drainage and Sewerage BMA, 2021
[43] Department of Drainage and Sewerage BMA, 2021

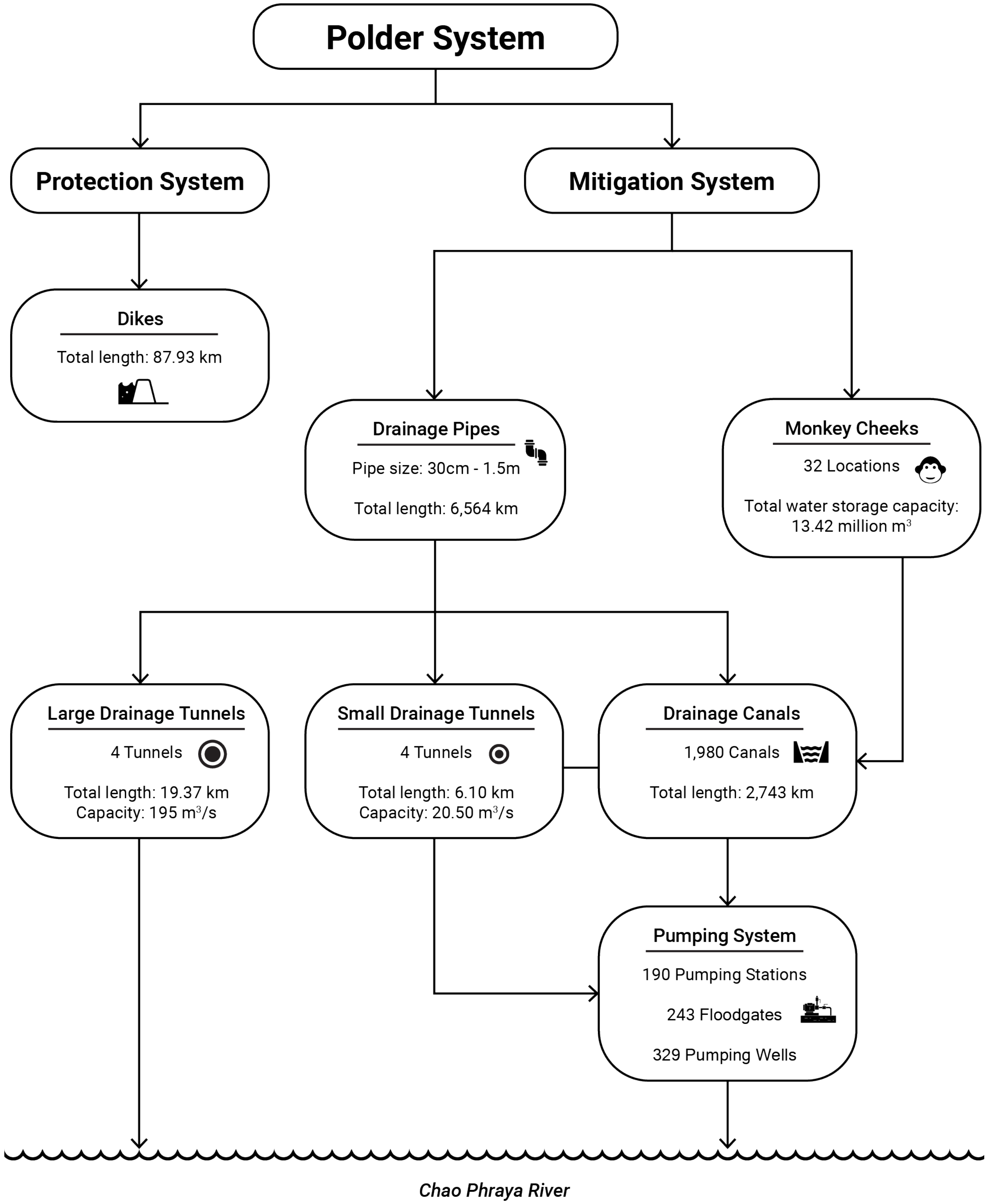


Figure 1.32 Bangkok's Current Flood Control and Mitigation System
(Source: Diagram by the author, Data from Department of Drainage, BMA, 2021)

1.5.2 Current Mitigation System

The mitigation system (or drainage system) is designed to address the problem of flooding caused by rainwater. Currently, the system has the capacity to handle an accumulated rainfall of no more than 60 millimeters within a day (considering it rains for about 3 hours in a day on average) or a rainfall intensity of no more than 58.7 millimeters per hour.[44] The drainage system disposes runoff into the Chao Phraya River and the Gulf of Thailand through one or more of the following channels:

Drainage pipes

The drainage system of Bangkok has a total length of 6,564 kilometers, divided into 2,050 kilometers underneath the main roads and 4,514 kilometers underneath the alleys (known in Thai as Soi). The pipes are standardized and range in size from 30 centimeters to 1.50 meters. Pipes smaller than about 30 or 60 centimeters in size are part of the old pipe system, even though the city has since demolished and expanded the new pipes to 1.20-1.50 meters, the water still drains inefficiently because the drainage pipes for rainwater and wastewater from households are combined into a single pipe system.[45] This inefficiency occurs because, in practice, these two pipes should not be combined. Wastewater from households should be kept in a separate, closed system to allow for proper treatment and prevent the spread of disease-causing organisms carried by animals. This would also prevent the water from becoming contaminated and clogging the pipes. Right now the BMA can only temporarily improve the drainage system by excavating the drainage pipes which is extremely inefficient to maintain and requires a lot of time and budget.

The issue of flooding and drainage pipe excavation has been a recurring problem throughout history. In particular, the accumulation of debris in the pipes hinders efficient water drainage. Additionally, the size and number of pipes do not correlate with the growing number of buildings and homes, and policies regarding pipe excavation vary.

The issue at hand, aside from the accumulation of blockages in drainage pipes, is that each district in Bangkok is unable to fully excavate all of the pipes within a single fiscal year due to budget constraints. For instance, in the case of the Bangkok Yai district, when looking at the action plan report[46] to clean 44 alleys, only roughly one-third of the pipes were cleaned.

[44] Department of Drainage and Sewerage BMA, 2021
[45] Department of Drainage and Sewerage BMA, 2021
[46] Department of Drainage and Sewerage BMA, 2021

Currently, every district office has an annual drainage pipe excavation project, with each district receiving a different budget depending on the length and size of the pipes in that area. Data from the Department of Drainage and Sewerage in 2021 indicates that pipe cleaning is carried out throughout the year, starting from December 2020 to May 2021, but only 493 kilometers or 7.51% of the total length of pipes in Bangkok were cleaned.[47]

Drainage canals

Currently, Bangkok has 1,980 drainage canals with a total length of 2,743 kilometers.[48] The canal system is another method employed to alleviate the issue of flooding in Bangkok. Aside from excavation similar to that of drainage pipes, a key problem with canals is their inability to expand their capacity like drainage pipes. As a result, even areas situated in zones with water drainage systems may still be susceptible to flooding, particularly in areas with high levels of rainfall and a limited number of canals to accommodate water discharge. This factor may contribute to the occurrence of flooding in areas such as Ratchathewi and Phaya Thai.

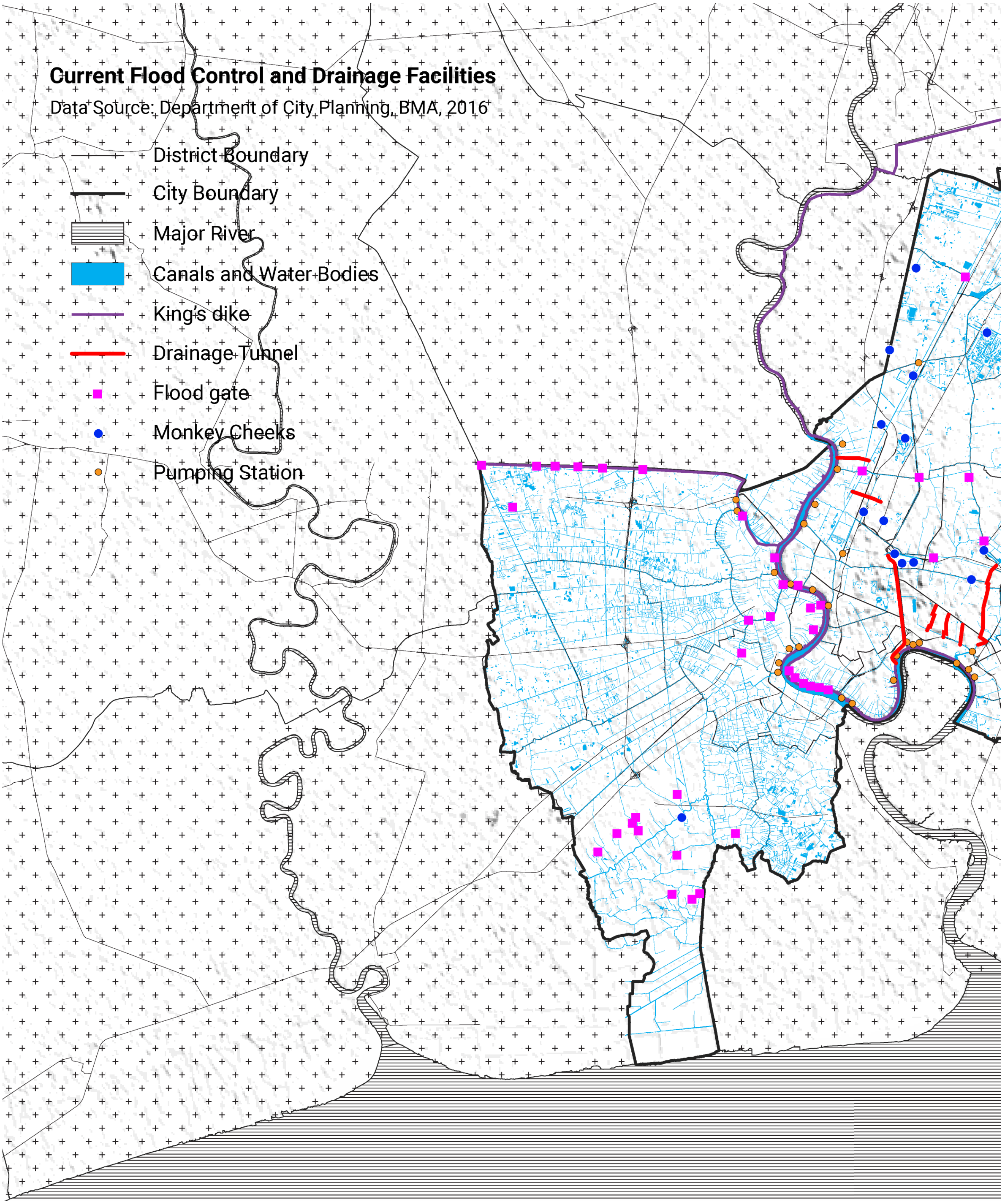
Drainage tunnels

Large and small drainage tunnels help increase water drainage efficiency and alleviate flooding in low-lying areas. They are particularly useful in cases where drainage pipes and canals cannot drain water effectively because they are at the same level. Even if the roads are not flooded, the communities near the canals may still experience flooding, as the canal's water level remains the same as the Chao Phraya River. Therefore, the construction of drainage tunnels directly helps alleviate this problem, as the tunnels accelerate the drainage of water into the river without going through the canal system.

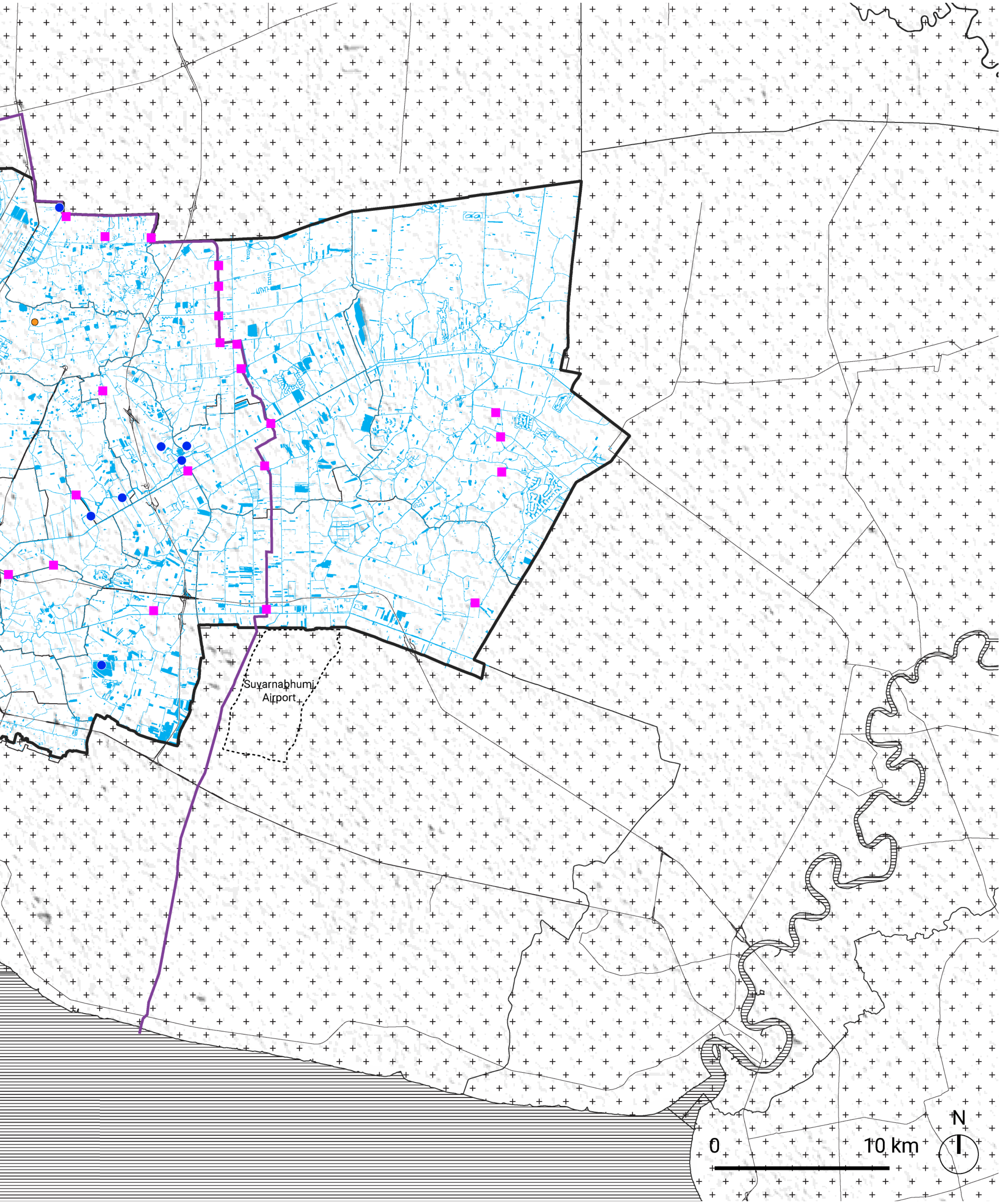
Currently, there are four completed drainage tunnels with a total length of 19.37 kilometers and a drainage capacity of 195 cubic meters per second. Additionally, six more drainage tunnels are under construction, with a total length of 39.625 kilometers and a drainage capacity of 238 cubic meters per second.[49]

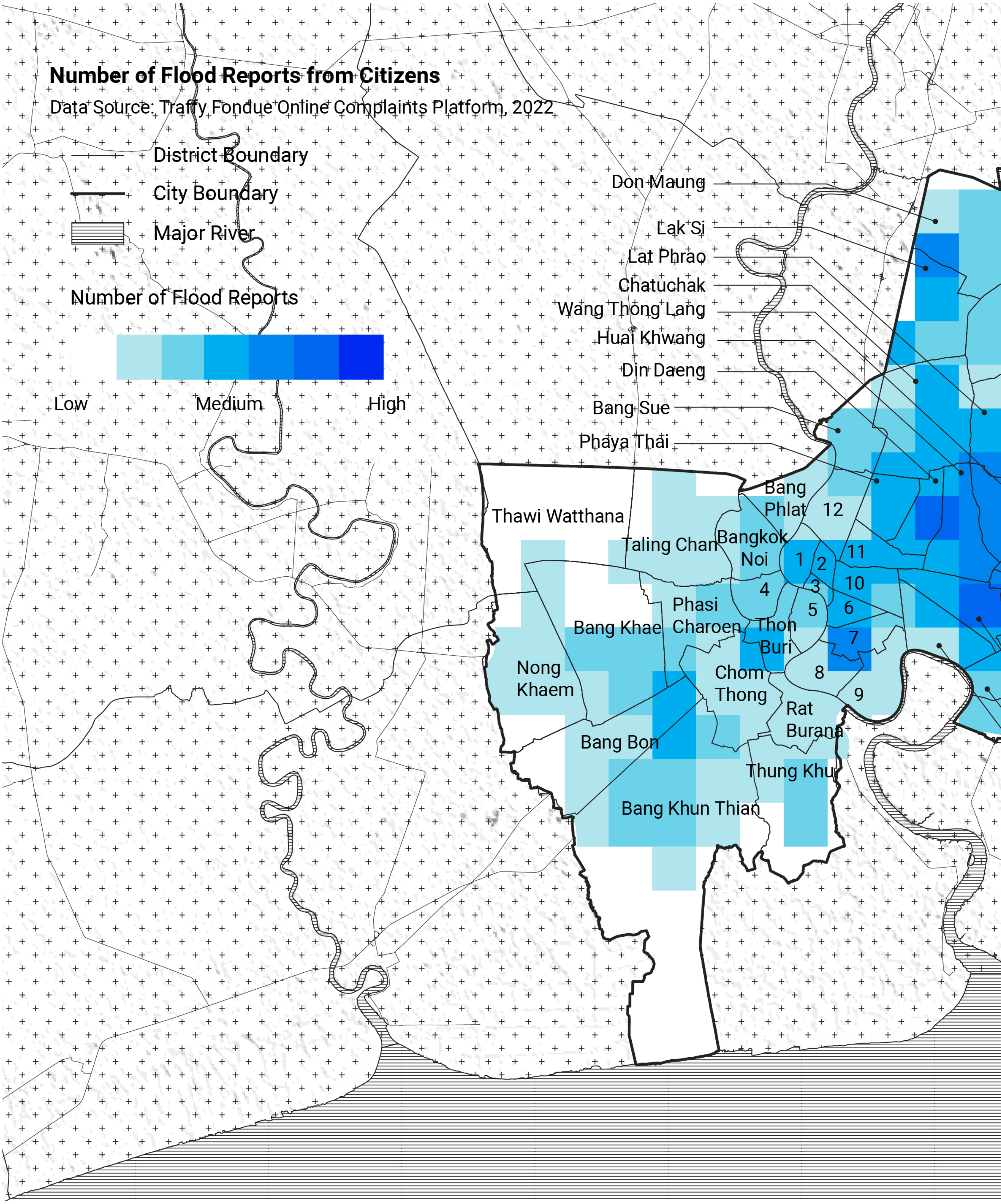
As for the small drainage tunnels, they are built to address the flooding risk in high-risk areas on main roads. These tunnels receive water from drainage pipes on the road, drain it through the tunnel into the canal, and then send it to the pumping station for release into the Chao Phraya River.

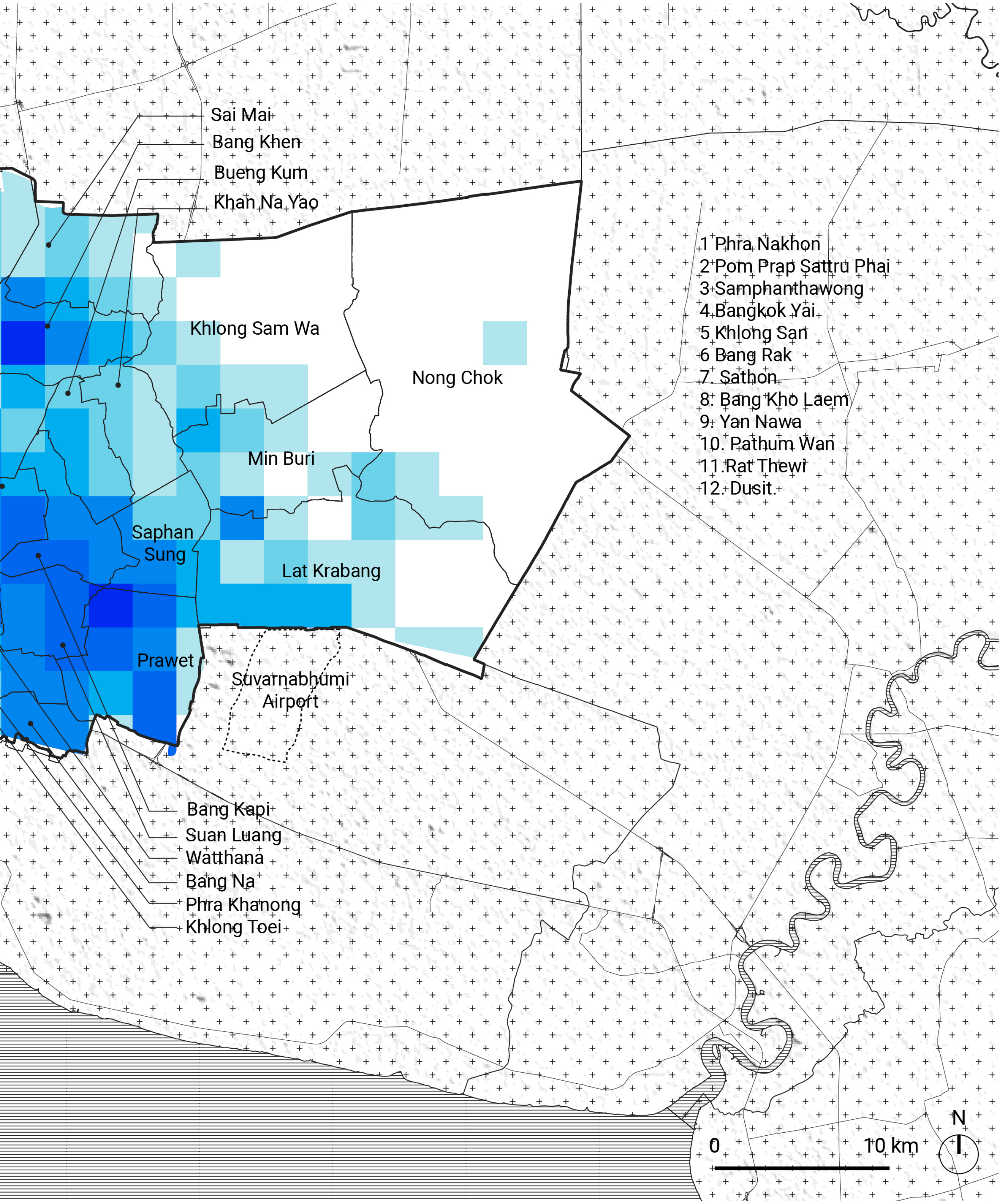
[47] Department of Drainage and Sewerage BMA, 2021
[48] Department of Drainage and Sewerage BMA, 2021
[49] Department of Drainage and Sewerage BMA, 2021



Current Flood Control and Drainage Facilities
Data Source: Department of City Planning, BMA, 2016
District Boundary
City Boundary
Major River
Canals and Water Bodies
King's dike
Drainage Tunnel
Flood gate
Monkey Cheeks
Pumping Station


Suvarnabhumi Airport
0
10 km
N


Number of Flood Reports from Citizens
Data Source: Traffy Fondue Online Complaints Platform, 2022
District Boundary
City Boundary
Major River
Number of Flood Reports
Low
Medium
High
Don Maung
Lak Si
Lat Phrao
Chatuchak
Wang Thong Lang
Huai Khwang
Din Daeng
Bang Sue
Phaya Thai
Bang Phlat
12
Thawi Watthana
Taling Chan
Bangkok Noi
1
2
11
10
3
4
6
5
Phasi Charoen
Bang Khae
Thon Buri
7
Nong Khaem
Chom Thong
8
9
Rat Burana
Bang Bon
Thung Khu
Bang Khun Thian


Sai Mai
Bang Khen
Bueng Kum
Khan Na Yao
Khlong Sam Wa
Nong Chok
Min Buri
Saphan Sung
Lat Krabang
Prawet
Suvarnabhumi Airport
Bang Kapi
Suan Luang
Watthana
Bang Na
Phra Khanong
Khlong Toei
1 Phra Nakhon
2 Pom Prap Sattru Phai
3 Samphanthawong
4 Bangkok Yai
5 Khlong San
6 Bang Rak
7 Sathon
8 Bang Kho Laem
9 Yan Nawa
10 Pathum Wan
11 Rat Thewi
12 Dusit
0
10 km
N

Currently, there are four small drainage tunnels with a length of 6.10 kilometers and a drainage capacity of 20.50 cubic meters per second.[50]

The issue of drainage tunnels is always discussed whenever there is flooding in Bangkok, especially how heavy rainfall will affect the flow of water into the drainage tunnels. The problem of drainage pipes and the drainage system is also a concern, as it can cause water to back up and flood the surrounding areas.

Dumping stations and water gates

The water pumping station system, water gates, and water pumping ponds are installed in Bangkok to discharge floodwaters into the Chao Phraya River. Currently, there are 190 water pumping stations, 243 water gates, and 329 water pumping ponds. Additionally, there are 483 electric and engine water pumps in use throughout the city, with a total of 1,121 machines.[51]

Some water gates still rely on manual labor to open and close, which can result in delays during emergencies.In cases where human error is the cause of the problem, the readiness of government agencies to coordinate with each other can be a factor. For example, during the flooding in the Bang Khen area in 2018, the water pumps in the affected area could not be operated as the contractor responsible for the construction of the underground water retention pond did not provide the key required to access the area.[52] Furthermore, the contractor was not on-site at the time, leading to delays in resolving the issue.

Monkey Cheeks

Currently, the “Monkey Cheeks” project involves the acquisition of ponds and reservoirs to store water (including underground water banks, as they are called in Bangkok) to serve as temporary water storage during periods of heavy rainfall. The water is then released from the Monkey Cheeks into canals, rivers, and ultimately into water pumping stations for discharge into the Chao Phraya River. Presently, there are 32 Monkey Cheeks with a storage capacity of 13.42 million cubic meters, including two newly constructed water banks located in the Bang Khen community and Soi Sutthiporn 2.[53]

[50] Department of Drainage and Sewerage BMA, 2021
[51] Department of Drainage and Sewerage BMA, 2021
[52] Matichon Online, 2018
[53] Department of Drainage and Sewerage BMA, 2021

The idea of using monkey cheeks to solve the problem of flooding in Bangkok is not new. However, finding vacant space to create monkey cheeks is currently difficult due to insufficient state-owned land and rising land prices. Negotiating with private developers to rent or purchase land for creating monkey cheeks is also challenging.

1.5.3 Flood-prone Areas and Reports from Citizens

According to the data from the Department of Drainage and Sewerage in 2021, there are 12 high-risk flood-prone areas and 51 watch-out flood-prone areas in Bangkok, even with rainfall of less than 60 millimeters. However, these areas are all located on the main roads, not taking into account the alleys and smaller lanes. Flood-prone areas inside alleys and smaller lanes under the responsibility of BMA, consists of 142 high-risk spots and 132 watch-out spots. In total, there are 337 flood-prone spots, including those on main roads. The statistics from the Department of Drainage and Sewerage showed that in 2020, the number of rainy days throughout the year is 230 days, causing floods to occur in 153 spots.[54]

Based on the data,[55] the district with the highest number of flood-prone spots is Sathorn district, with 3 spots, followed by Ratchathewi and Bang Khae with 2 spots each. Meanwhile, the district with the highest number of watch-out spots is Chatuchak district, with 7 spots, followed by Din Daeng with 7 spots, and Phaya Thai with 5 spots. If we consider the amount of rainfall, it can be observed that these districts with a high number of flood-prone areas are also the areas with high rainfall volume compared to other districts in Bangkok.

Although the BMA has made progress in reducing the number of flood-prone areas every year, the truth is that there are still more flood-prone areas than what is currently being reported. For example, in the Huai Khwang district, according to the report, there is only one watch-out point, but local news and citizen reports both on social media and BMA's official complaints filing platform such as "Traffy Fondue" often show that there are more than one flooded areas, such as Pracha Uthit Road, Pracharat Bamphen Road, and several locations on Ratchadaphisek Road, especially the Huai Khwang Tunnel, among others.

Moreover, areas that do not have flood-prone areas on the official report do not mean that there is no flooding problem. For instance, the Lat Phrao district has no flood-prone areas under the BMA data, but news reports show that flooding occurs almost every time there is heavy rainfall.

[54] Department of Drainage and Sewerage BMA, 2021
[55] Department of Drainage and Sewerage BMA, 2021

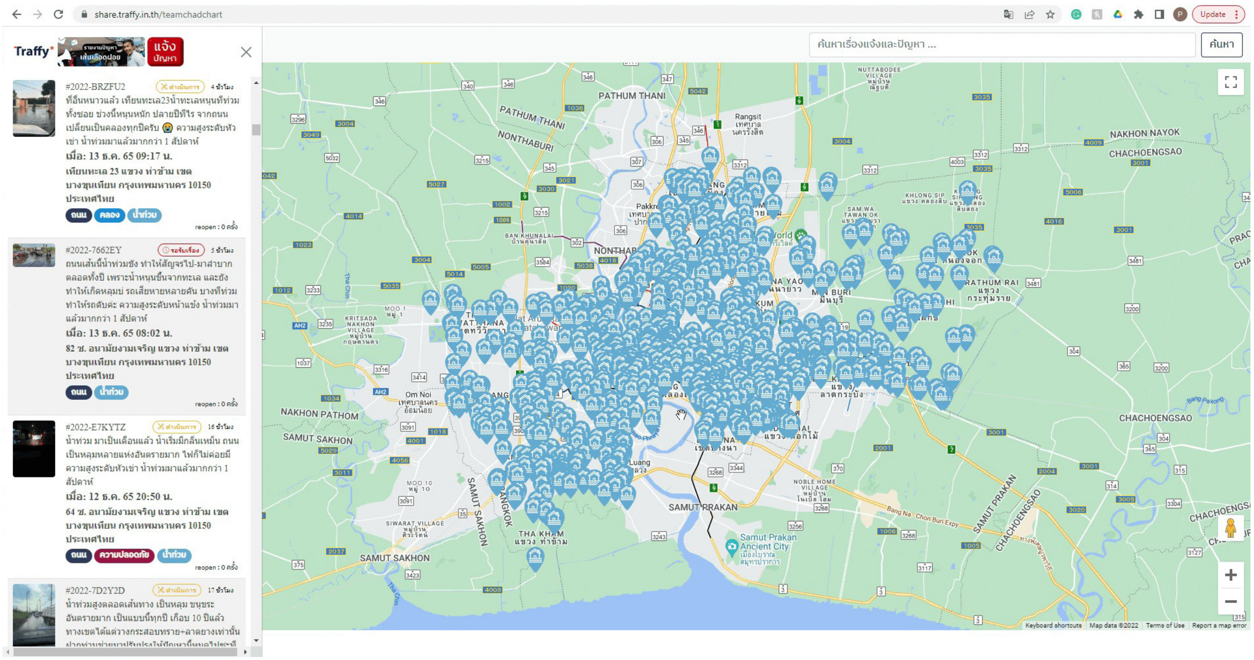


Figure 1.35 Official real-time crowdsourced flood complaints platform, showing flooded area all over Bangkok
(Source: Traffy Fondue Website, Accessed on December 13, 2022)

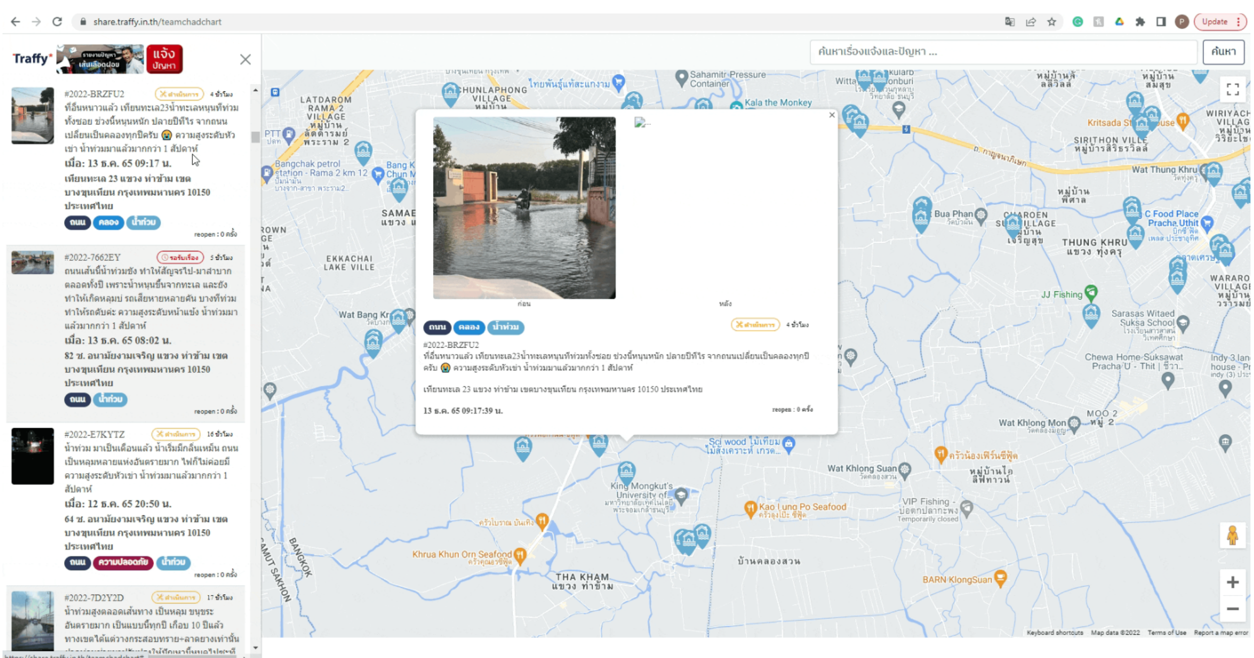


Figure 1.36 Example of a flood complaint submitted by a citizen
(Source: Traffy Fondue Website, Accessed on December 13, 2022)

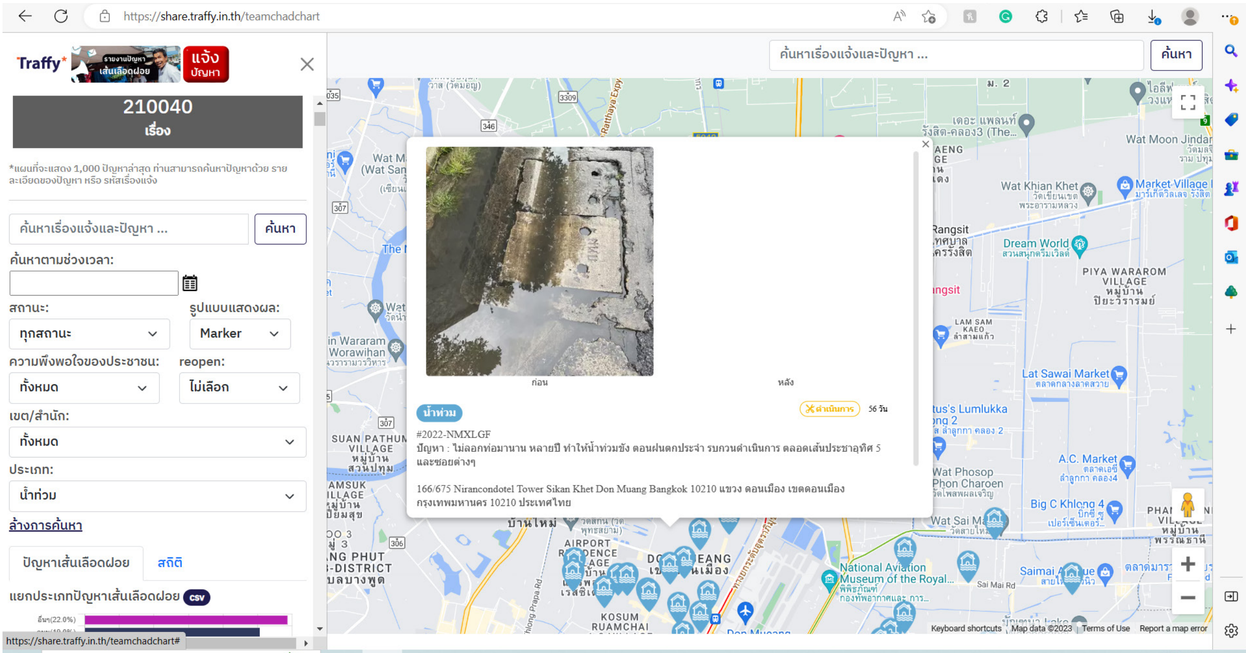


Figure 1.37 Example of a flood complaint submitted by a citizen (Source: Traffy Fondue Website, Accessed on January 23, 2023)

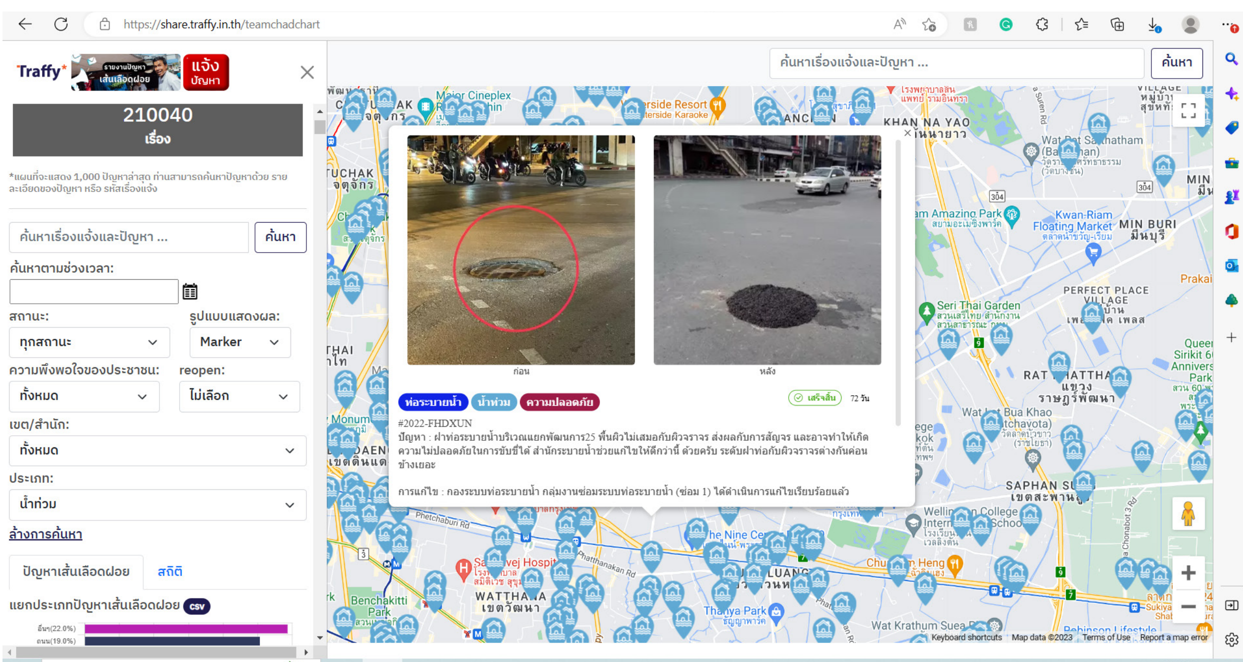


Figure 1.38 Example of how city officials fixed the issue (Source: Traffy Fondue Website, Accessed on January 23, 2023)

1.5.4 Additional Issues

In 2011, Thailand experienced its worst floods in half a century, leading to the loss of over 800 lives and 1.425 trillion baht in economic damage. This catastrophic event raised expectations that the country would take necessary measures to improve its preparedness for future deluges. Despite these expectations, it appears that progress has been slow, and little improvement has been made toward building adequate flood defenses and systems to manage floods.

According to Sitang Pilailar,[56] a lecturer at the Department of Water Resources Engineering, Kasetsart University, despite the establishment of multiple agencies, such as the National Water Resources Act, the Office of the National Water Resources, and the National River Basin Committee, among others, since the major floods in 2011, little progress has been made in managing water resources during crises. The existing agencies continue to manage flood risks and problems in the same manner, with resources being mainly allocated for temporary solutions to recurring problems. As a result, Thailand's flood defenses are lacking in long-term measures, and preparations have failed to keep pace with urbanization and climate change

Dr. Panit Pujinda, Associate Professor at the Department of Urban Planning, Chulalongkorn University, stated in an interview[57] that the floods happening nowadays are not the same as those in 2011. The problem now is that the drainage system is unable to cope with the volume of water due to an inadequate water drainage system that cannot keep up with the expansion of the city. The country's flood defenses are also lacking long-term planning and investment. For instance, the road elevation levels in Bangkok are not standardized, which means that when one section is raised, water may flow to lower areas that lack proper drainage.

A number of measures are being implemented as stand-alone interventions without considering implications to flood management. This is because there is no systematic coordination among departments in the BMA.[58] In Thailand, flood planning and management challenges are complicated by inter-agency fragmentation, political polarization, a lack of local administrative capacity, public communication, and community mistrust.[59] Additionally, Bangkok's water-drainage system is not functioning at its full capacity. At present, only four drainage tunnels are in operation, one is under construction and others are in the planning stage.[60] The normal capacity for the drainage

[56] Thai PBS World, 2022
[57] Bangkokbiznews, 2020
[58] Saito, 2014
[59] Lebel, 2011
[60] Thai PBS World, 2022

Figure 1.39 Informal settlement and trash in the Lat Phrao canal
(Image taken by the author)

Figure 1.40 Water pumps are not operating at full capacity and require manual labor (Image taken by the author)

Figure 1.41 Many private properties are not responsible for their surface runoff (Image taken by the author)

pipes can handle up to 60 millimeters per hour, however, according to the research,[61] the drainage efficiency in several districts such as Bang Khen was only 25-50%, or only 30 millimeters per hour, due to the trapped water in the system. The system is further hampered by canals that have been encroached upon by informal settlements, broken pumps and other flood-prevention measures such as flood barriers are also nowhere close to completion.

A more comprehensive and forward-thinking approach is needed to address these issues and safeguard the city against the growing threat of flooding.

1.5.5 The Demand for More Water Storage

The BMA has implemented various water management projects, including the construction of new drainage tunnels, the dredging of canals, and the installation of flood barriers. However, these projects have not been enough to prevent flooding during heavy rainfall, and there is a growing demand for more water storage and retention infrastructure.

The exponential urban growth coupled with gaps in planning law and its enforcement has resulted in much of Bangkok's natural water retention and drainage channels being lost to buildings and other urban structures. The least of what BMA could do now is increase the city's water storage and retention capacity.

Water storage and retention infrastructure such as "Monkey Cheeks" can help to mitigate the impact of floods by providing a place for excess water to be stored during heavy rainfall. This water can then be used during periods of drought or water scarcity, reducing the dependence on groundwater and surface water sources. Additionally, water retention infrastructure can help to improve the quality of water in rivers and canals by reducing the amount of pollutants that are carried into these water bodies.They also play a role in addressing the growing water scarcity issue in Bangkok. As the city continues to grow, the demand for water is increasing, and existing sources are becoming depleted. Water storage and retention infrastructure can help to reduce the dependence on these sources and ensure a reliable water supply for the future.

More Monkey Cheeks are needed to ensure a more sustainable water management system in the capital.These efforts need to scale up quickly enough to meet the enormity of the climate challenge, however, as mentioned earlier in this chapter, there are several challenges that it difficult for the BMA to create more Monkey Cheeks projects. The next chapter will discuss the challenges more in detail and the possible solutions to these issues.

[61] Udnoon, 2022

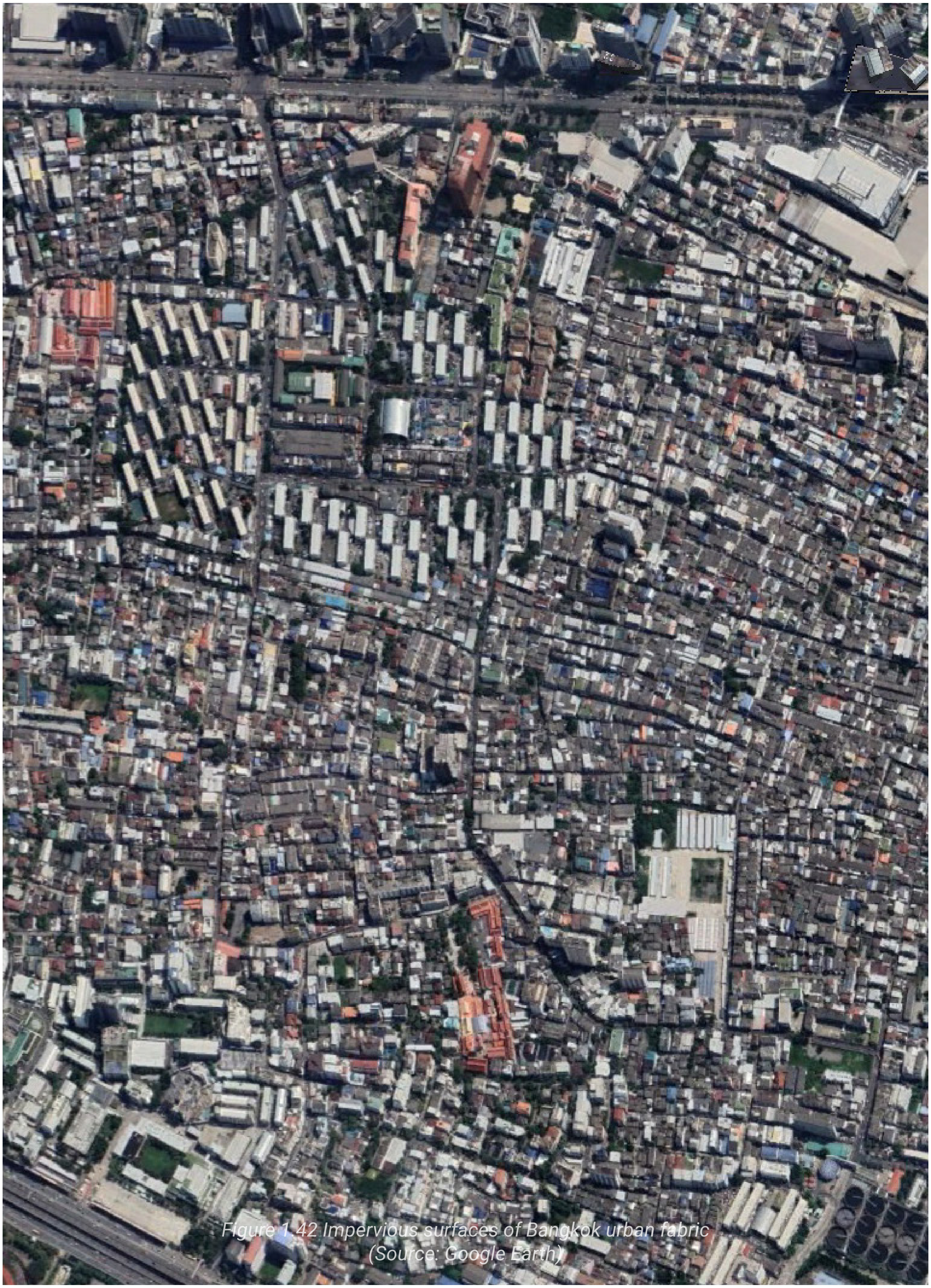
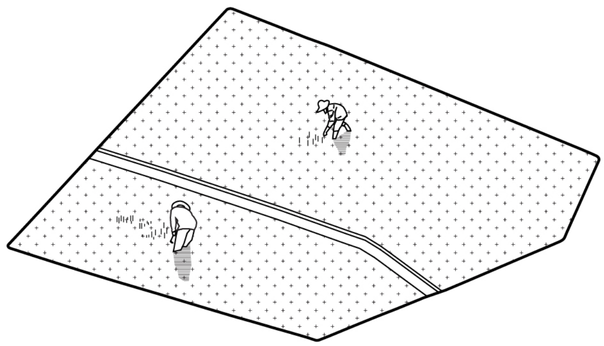


Figure 1.42 Impervious surfaces of Bangkok urban fabric
(Source: Google Earth)

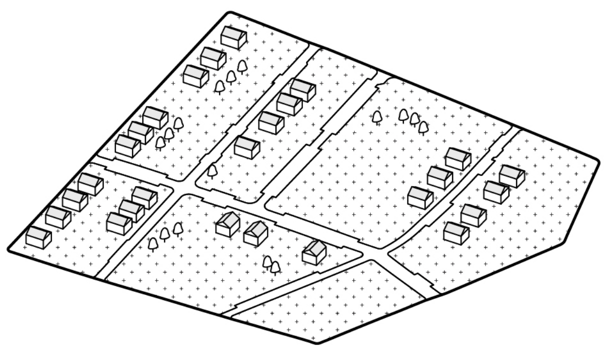
IMPERVIOUS SURFACES ASSOCIATED WITH URBANIZATION

(Souce: Diagram by the author, Data from Livingston and McCarron, 1992)



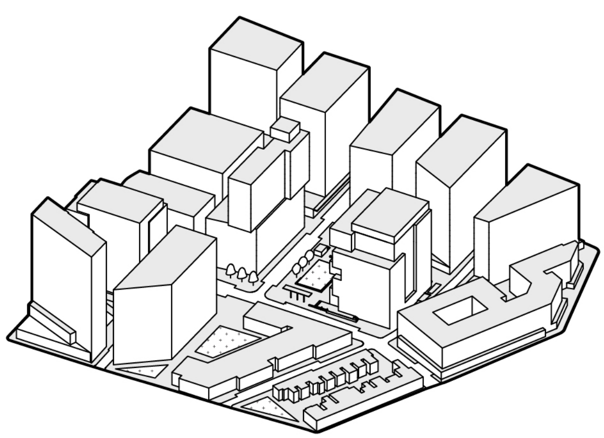
RURAL

0-10% IMPERVIOUS SURFACE



SUBURBAN

35 - 50% IMPERVIOUS SURFACE

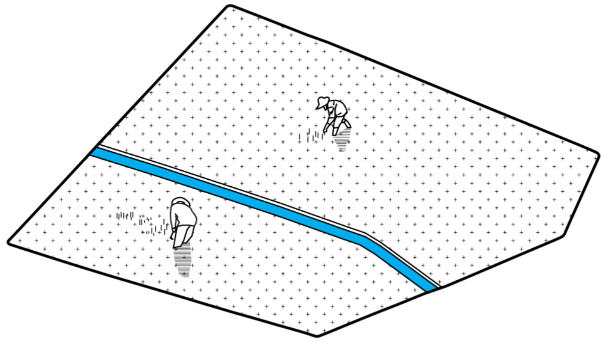


ULTRA-URBAN

75 - 100% IMPERVIOUS SURFACE

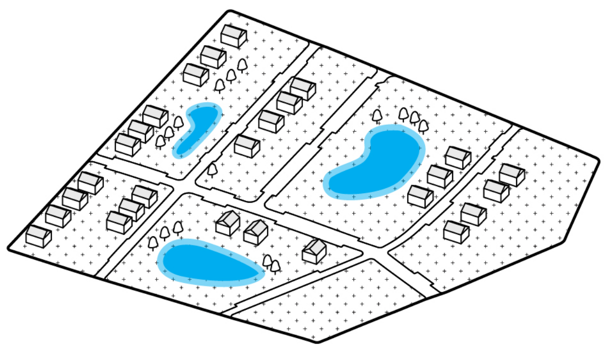
CHANGES IN RUNOFF FLOW RESULTING FROM INCREASED IMPERVIOUS AREA

(Souce: Diagram by the author, Data from Livingston and McCarron, 1992)



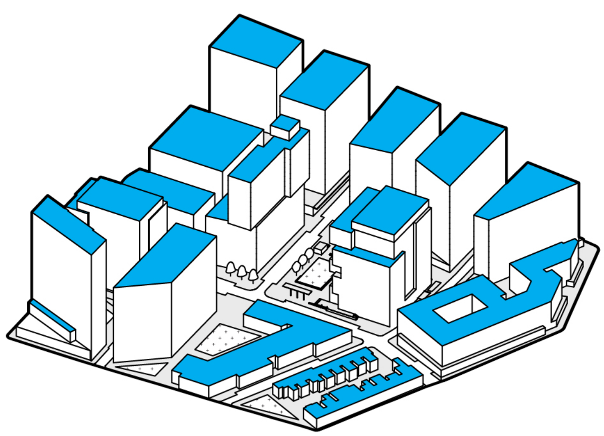
RURAL

10% RUNOFF



SUBURBAN

30% RUNOFF



ULTRA-URBAN

55% RUNOFF

CHAPTER 2: Monkey Cheeks

Monkey cheeks, or Kaem Ling (Thai: แก้มลิง), is a term coined by the late King Bhumibol Adulyadej of Thailand (also known as King Rama IX) to promote flood control measures in Bangkok. The idea stems from his observation that most monkeys, when given bananas, would first store them in their cheeks, conserving them to eat later. His Majesty applied this concept for water detention after the way monkeys eat by temporarily storing excess water during heavy rains and gradually draining it afterward.

"…When I was five years old, we had monkeys and we gave them bananas. They would munch, munch, munch, and then keep the food in their monkey cheeks. It follows that this "Monkey Cheek Project" actually originated way back when I was five years old. Five years old, that is, 63 years ago. The monkeys of that time, the ancient monkeys, already had monkey cheeks. They munched and stored their food in their cheeks. When flood waters come down, and we have no "Monkey Cheek Project", that flood would inundate all over the place, the same way it did this year, all over the central plains. We have to make a "Monkey Cheek" as a retention area to keep that water…" [62]

— His Majesty's royal speech granted on December 4, 1995.

[62] Office of the Royal Development Projects Board (ORDPB), 2023

2.1 Background of the Monkey Cheeks Project

The origin of the Monkey Cheeks Project can be traced back to the severe flood crisis in 1995 as a result of heavy rainfall in the Upper and Lower Chao Phraya River Basin areas. A large amount of water surged down to the Chao Phraya River, flooding many provinces and inevitably inundating Bangkok and surrounding areas, submerging these places for over two months. On November 14 of the same year, His Majesty advised the Bangkok Metropolitan Administration (BMA) and the Royal Irrigation Department to look for areas that can serve as water detention reservoirs to help divert flood water into.[63]

The Royal-initiated Monkey Cheeks Project was successfully undertaken by excavating the canals along the east and west bank of the Chao Phraya River to serve as a large retention basin, now called “Monkey Cheeks,” to hold water and then drain it into the sea using the natural force of gravity. These canals are located near the coastal areas in Samut Prakan Province and Samut Sakorn Province. New water gates are also constructed to release water into the sea during low tides, while the gates will be closed during high tides to prevent seawater from flowing back. In addition to easing flood problems in the Bangkok Metropolitan Region, Monkey Cheeks also serve as a barrage during drought season by conserving the water to alleviate wastewater problems, protect against saltwater intrusion, and use for agriculture and industrial purposes.

The Monkey Cheeks project has since expanded to include flood relief projects all over Thailand, especially in the lower region of the Chao Phraya River as this area is unsuitable for dam construction with ground elevation less than 20 meters above sea level. Drainage of water to the sea out of the lower sub-basin is challenging due to low transmission capacities through the main river channels and the effects of tides in the Gulf of Thailand. Monkey Cheeks project is therefore perfect for low-lying plain areas.

[63] Office of the Royal Development Projects Board (ORDPB), 2023

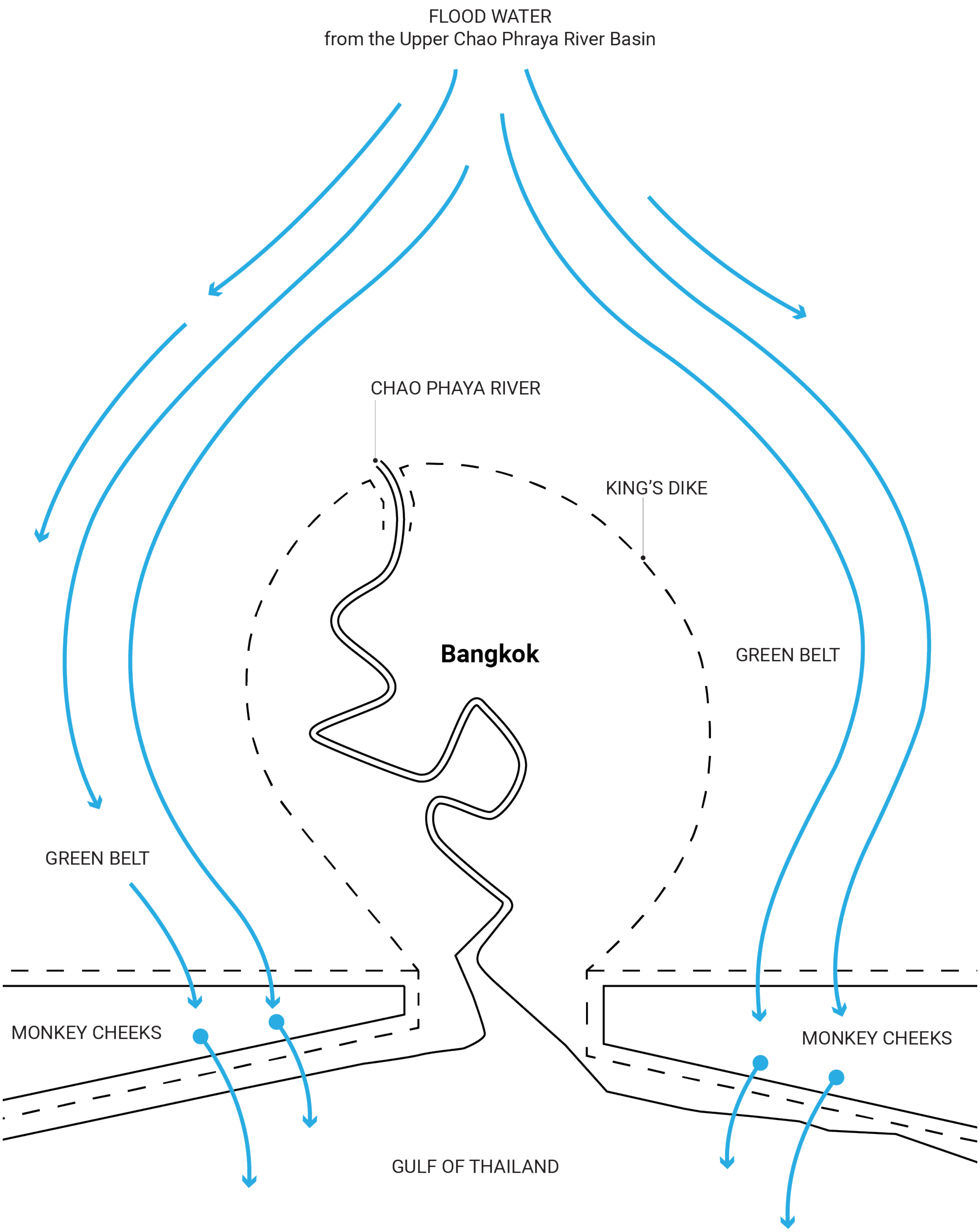
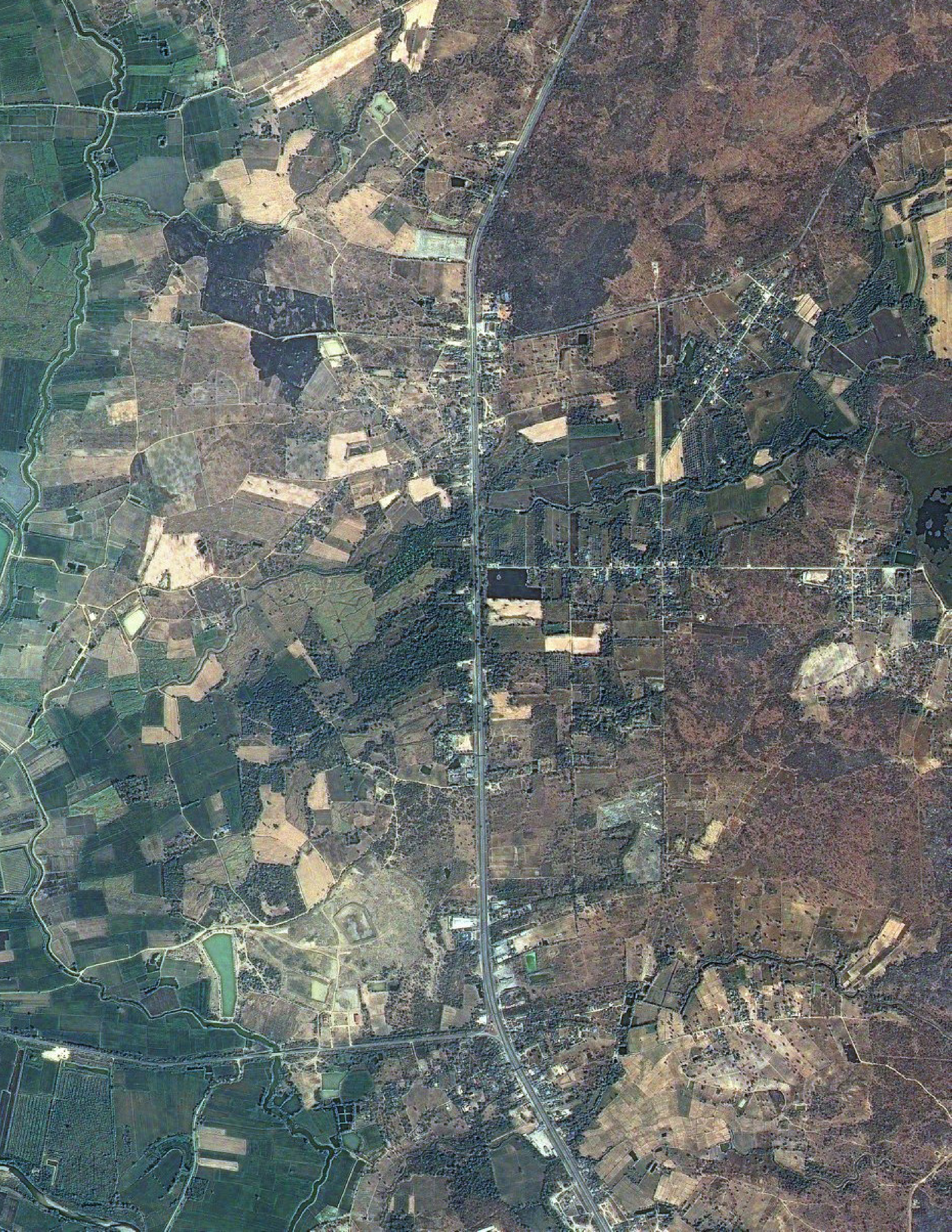

FLOOD WATER
from the Upper Chao Phraya River Basin
CHAO PHAYA RIVER
KING’S DIKE
Bangkok
GREEN BELT
GREEN BELT
MONKEY CHEEKS
MONKEY CHEEKS
GULF OF THAILAND

Figure 2.2 Nong Cham Monkey Cheeks Project in Tak Province of Thailand
(Source: Image from Thaichote Satellite, GISTDA)



2.2 Issues with Implementing More Monkey Cheeks Projects

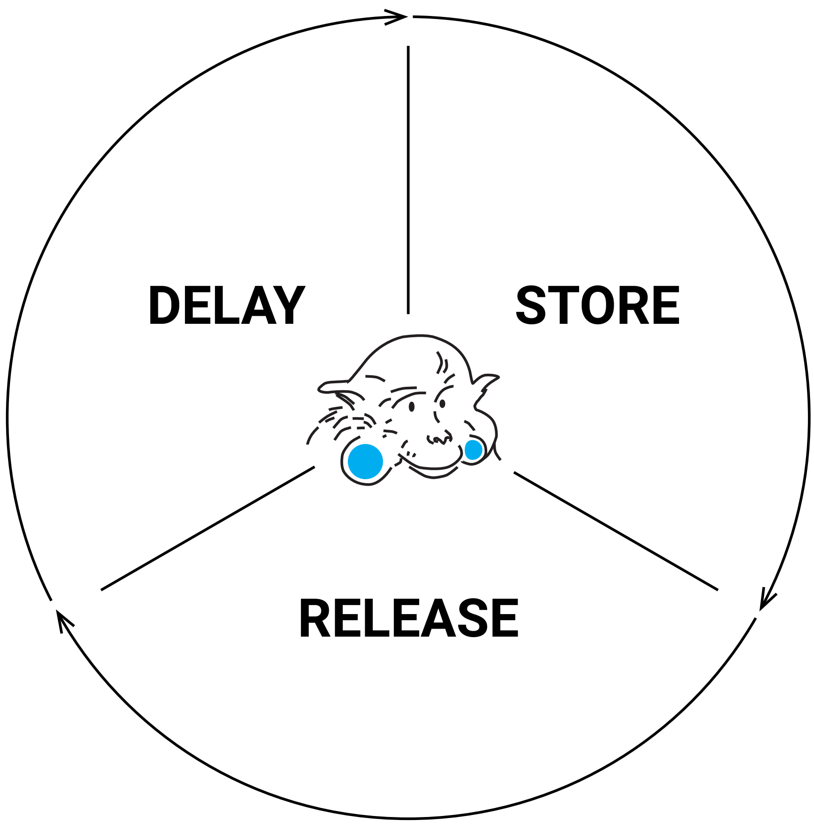
The BMA has developed several more Monkey Cheeks projects in the past, for instance, Bueng Nong Bon adjacent to King Rama IX Park, which has become a recreational center where members of the public can take part in activities such as sailing and boat rowing. It also serves as a wastewater treatment site, receiving discharge from households and buildings in that area, and a water retention site to ease flood problems.

The BMA committed to expanding the concept to similar ponds across the city. However, there has not been much progress toward this commitment. A prime example is the 2012 plan to build six Monkey Cheeks in the upper and eastern parts of the city, covering about 1,000 rai of land. However, four of the six drainage basins in Bangkok did not materialize as the designated area had been sold for real estate and commercial purposes. In 2017, the BMA made an unsuccessful bid to expropriate the land but its owners turned down the offer, preferring to continue to use it for commercial purposes. Another example is the Bueng Khubon Flood Catchment project. A private firm also turned a 30-rai land plot in the designated water retention site into a commercial complex, which adversely affected the city's flood mitigation measures.

The BMA's efforts to develop more Monkey Cheek projects are hindered by the challenge of acquiring land. In the past, these projects were implemented on government-owned land, but as the supply of such land dwindles and land prices soar, it has become increasingly difficult to acquire large plots from the private sector. In the meantime, city officials also seem to be shifting their focus towards costly headline-grabbing projects such as water tunnels. Large-scale infrastructure projects required a significant investment and political instability in Thailand has led to delays in decision-making and implementation of large-scale infrastructure projects. As a result, the implementation of Monkey Cheek projects has taken a backseat, despite their effectiveness in preventing flooding.

Figure 2.3 Bueng Nong Bon Monkey Cheeks Project
(Image taken by the author)

Figure 2.4 Boat rowing activity in Bueung Nong Bon
(Image taken by the author)


DELAY
STORE
RELEASE

2.3 Broadening the Monkey Cheeks Concept

Thai people usually think about Monkey Cheeks as a massive retention basin or at the broader, regional scale, swaths of agricultural land are also perceived as Monkey Cheeks as some rice fields are designated as an area in which inundation is allowed according to administrative policy. As mentioned earlier in this chapter, due to the lack of free space and the high costs needed to free space up, increasing the number of these projects across the city to catch up with the urgency of climate change would not be possible.

However, if we consider the fundamental concept and intention of Monkey Cheeks, the project aims to delay the flow of runoff, store rainwater, and discharge the water when the drainage system can handle it. The central idea of Monkey Cheeks is based on the "DELAY, STORE, and RELEASE" concept rather than the size of the project. Therefore, the key challenge lies in integrating Monkey Cheeks into the highly urbanized environment of Bangkok, and decentralization appears to be the solution.

The urbanizing process of Bangkok reaches a state where high imperviousness and urban density are achieved. This results in the so-called ultra-urban environment. In such conditions, the range of structural flood control measures becomes restricted, so the possibilities for intervention are constrained. Therefore, instead of the large reservoirs type of Monkey Cheeks that Thai people usually perceived, smaller reservoirs or a "mini" version of the Monkey Cheeks get distributed over the urban landscape to become an on-site stormwater detention mechanism. These types of smaller Monkey Cheeks can receive and temporarily store rainwater from buildings and houses before releasing it slowly to public drainage systems or the environment.

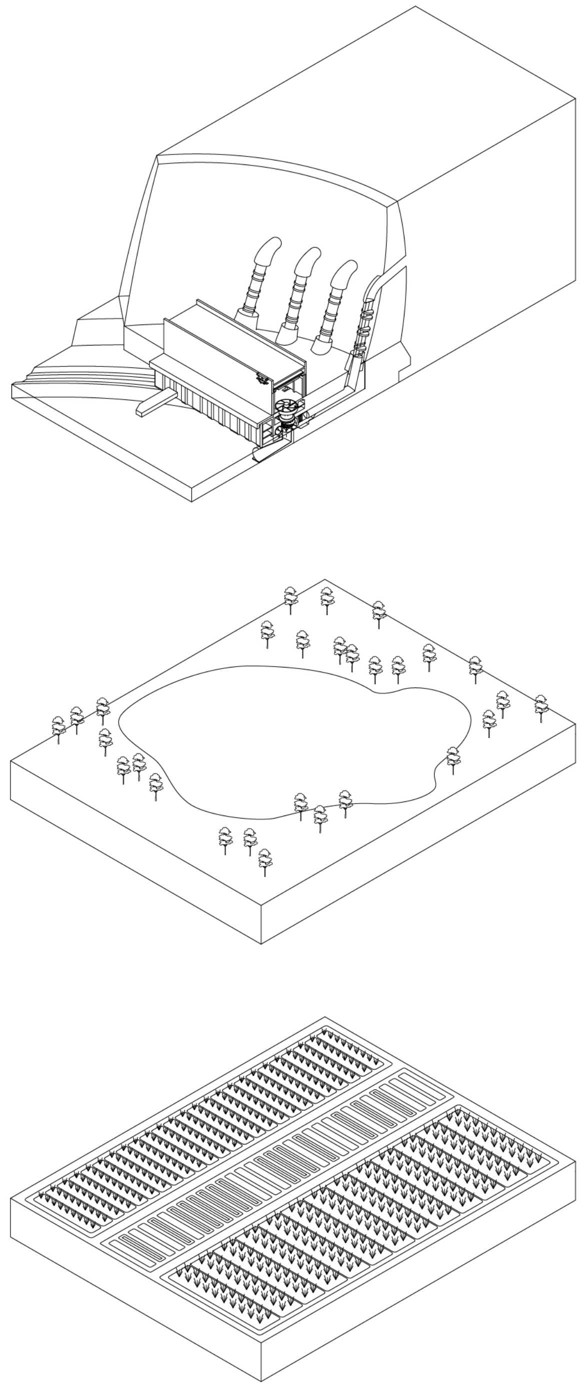
Based on a 2018 report by the BMA, there are approximately 600,000 buildings registered in Bangkok. However, only 179 of these buildings have green roofs, covering a total area of just 153.72 square kilometers,[64] which is less than 0.01% of Bangkok's total area.

By decentralizing Monkey Cheeks into smaller stormwater storage systems, the BMA could increase stormwater storage capacity and mitigate flood risk as the city continue to expand. Monkey Cheeks together with other nature-based solutions would not only reduce stormwater runoff but also improve wastewater quality[65] and improve community space which has become a major issue in Bangkok nowadays. Furthermore, given Bangkok's drinking water challenges during recent dry seasons, stormwater can become an important alternative and more sustainable source of water supply.

[64] Department of Environment BMA, 2021

[65] Kooy, 2020

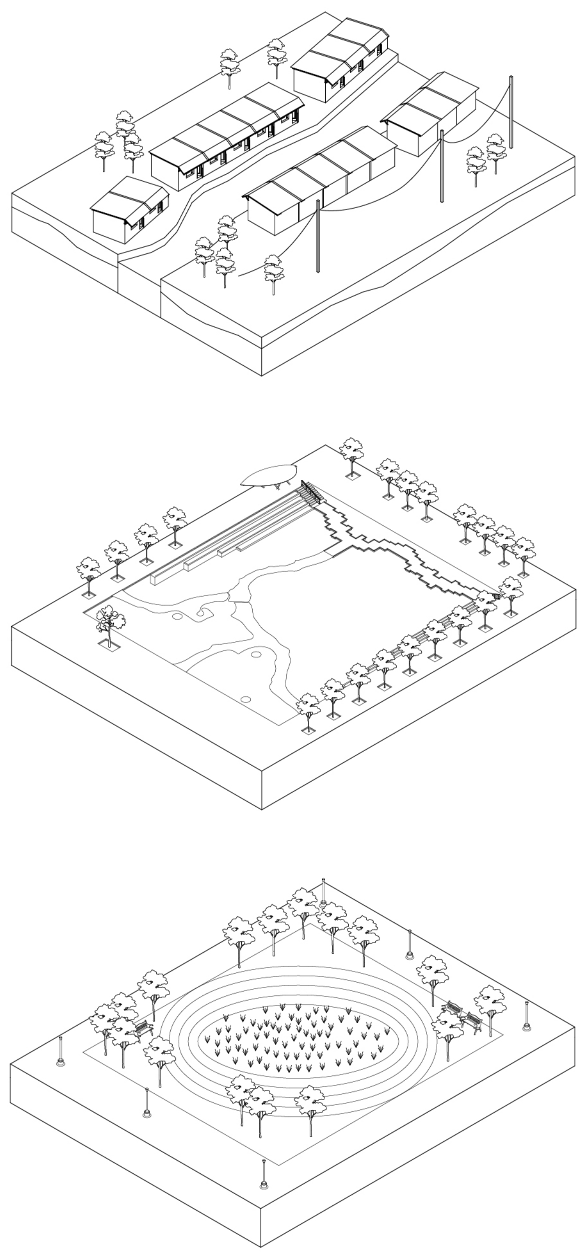
DIFFERENT SCALE OF MONKEY CHEEKS



RURAL

Large scale monkey cheeks areas that collect and store water include dams, reservoirs, agricultural fields, etc. These structures often serve other purposes as well, such as irrigation or fishing.

DIFFERENT SCALE OF MONKEY CHEEKS



SUBURBAN / URBAN

Medium scale monkey cheeks retains water at a smaller scale than a large-scale reservoir. These areas are often natural features such as ponds, marshes, or canals.

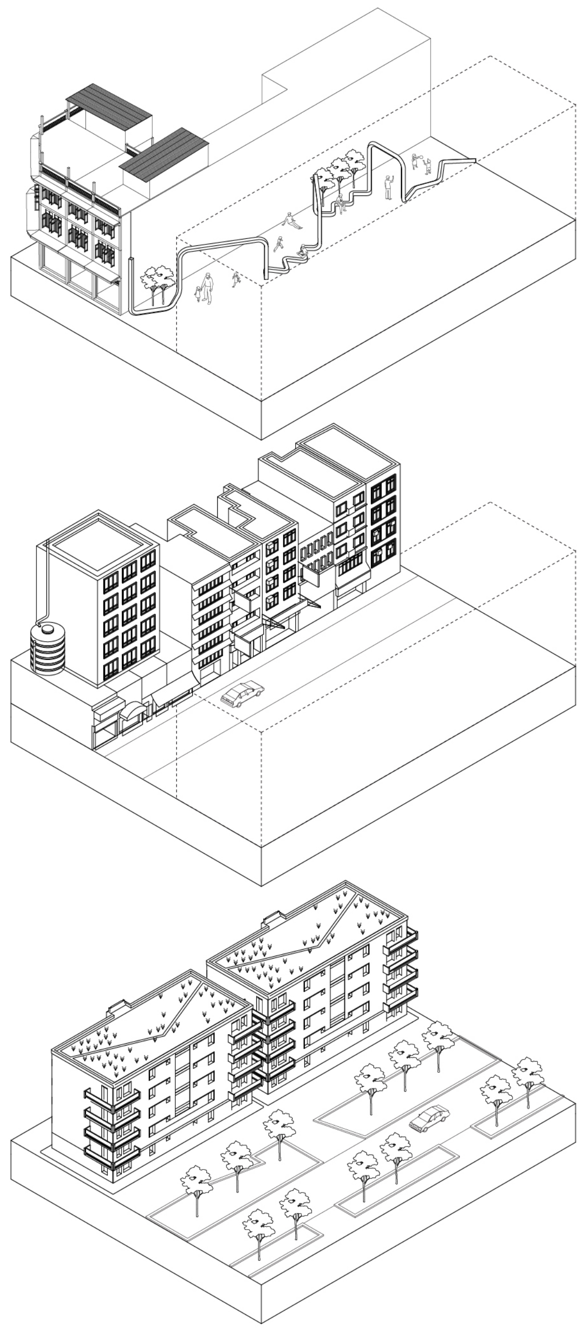
DIFFERENT SCALE OF MONKEY CHEEKS

?

ULTRA URBAN

?

DIFFERENT SCALE OF MONKEY CHEEKS



ULTRA URBAN

A small scale monkey cheeks can be a public area, playground, parking lot, yard within a house, water tank or even a small channel, anything that is connected to a drainage or canal system.

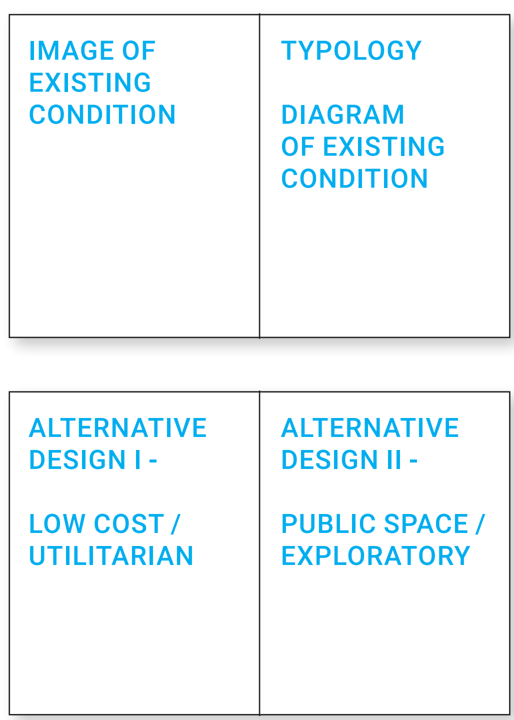
CHAPTER 3: Case Studies

Different Scale of Monkey Cheeks for the Bangkok Metropolitan Area

This Chapter presents case studies for the implementation of Monkey Cheeks, in both new development and redevelopment projects located around the Bangkok Metropolitan Area. The case studies catalog these components by type and describe them through drawings.

The design interventions are showcased along the streets, in open spaces, and atop or around buildings. They may replicate natural flows of water through a designed system that incorporates natural elements like trees, shrubs, and soil. Or they may simply offer ways to store and release water around buildings, with open spaces, or along streets. Both types help reduce the volume of runoff and encourage the replenishment of the aquifer. Additionally, these Monkey Cheeks infrastructure can be highly visible and greatly improves the experience of the public realm. It has the potential to serve as additional functions, such as furniture, seating areas, or a canopy, which can enhance the aesthetic appeal of a place while providing additional value. Monkey Cheeks infrastructure is designed to effectively delay, store, and release water during periods of overwhelmed public drainage.

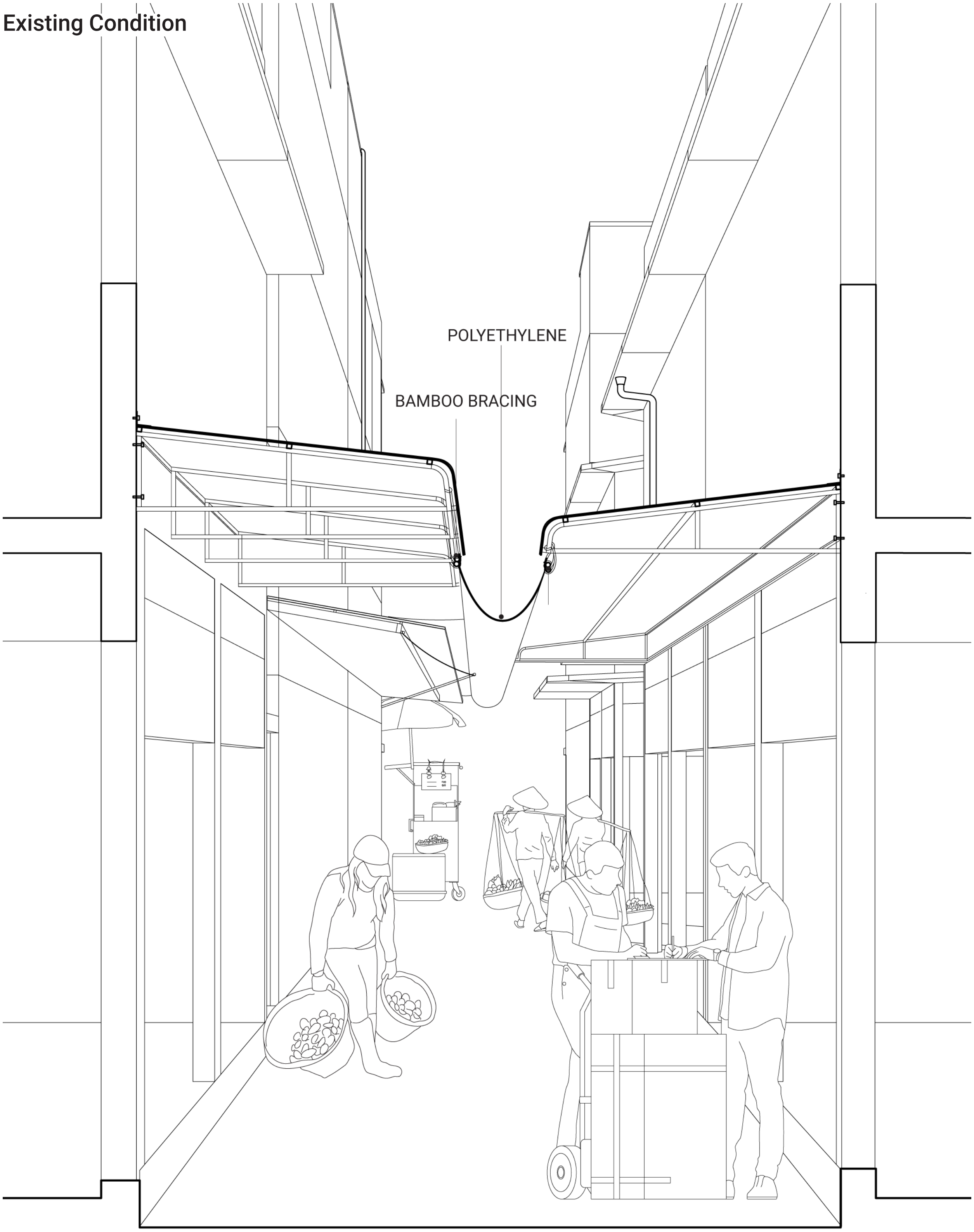
The structure of the case studies is illustrated below:




World of Professional
WORLD CAMERA

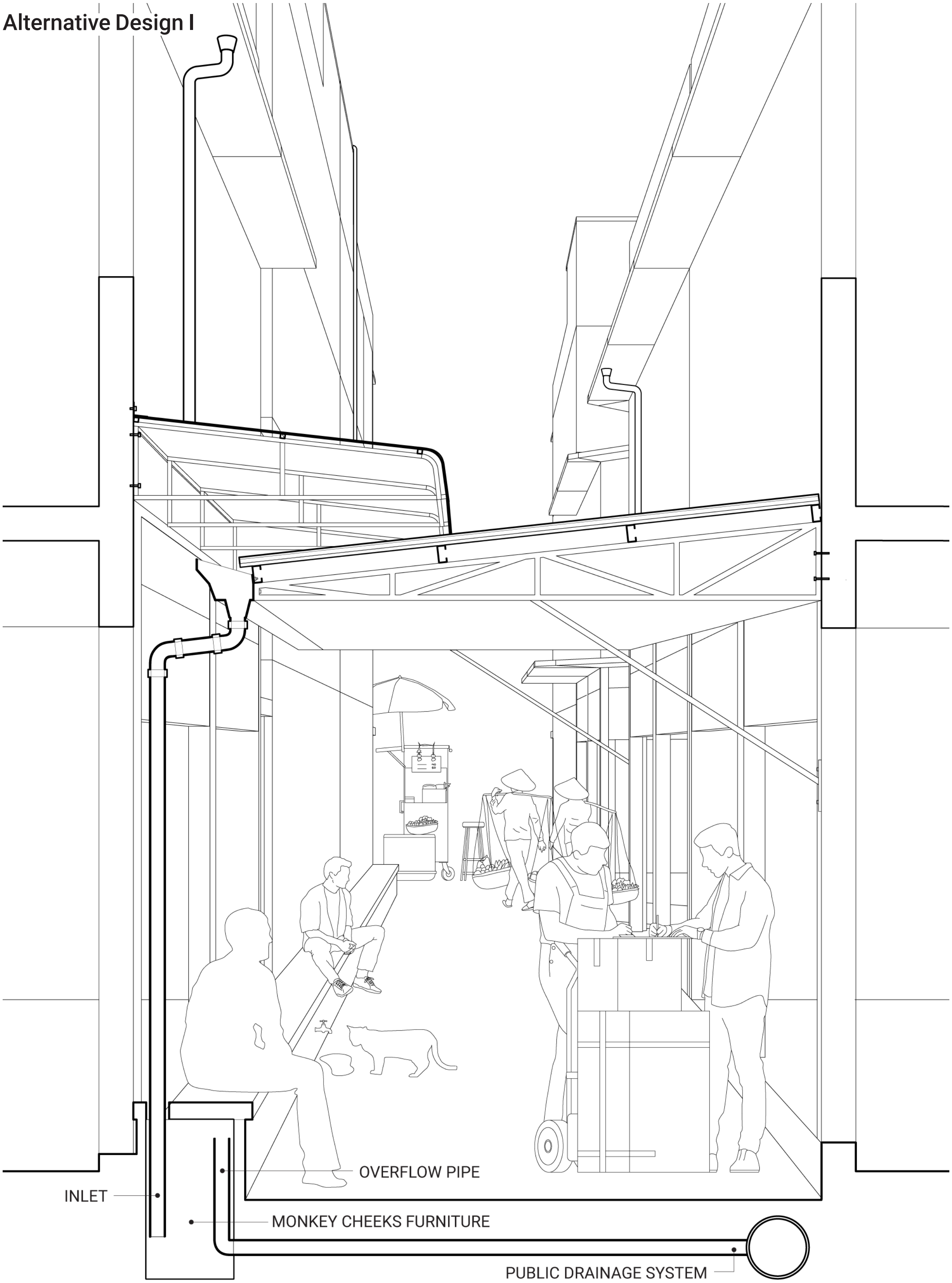
3.1 Case Study | Soi

Existing Condition



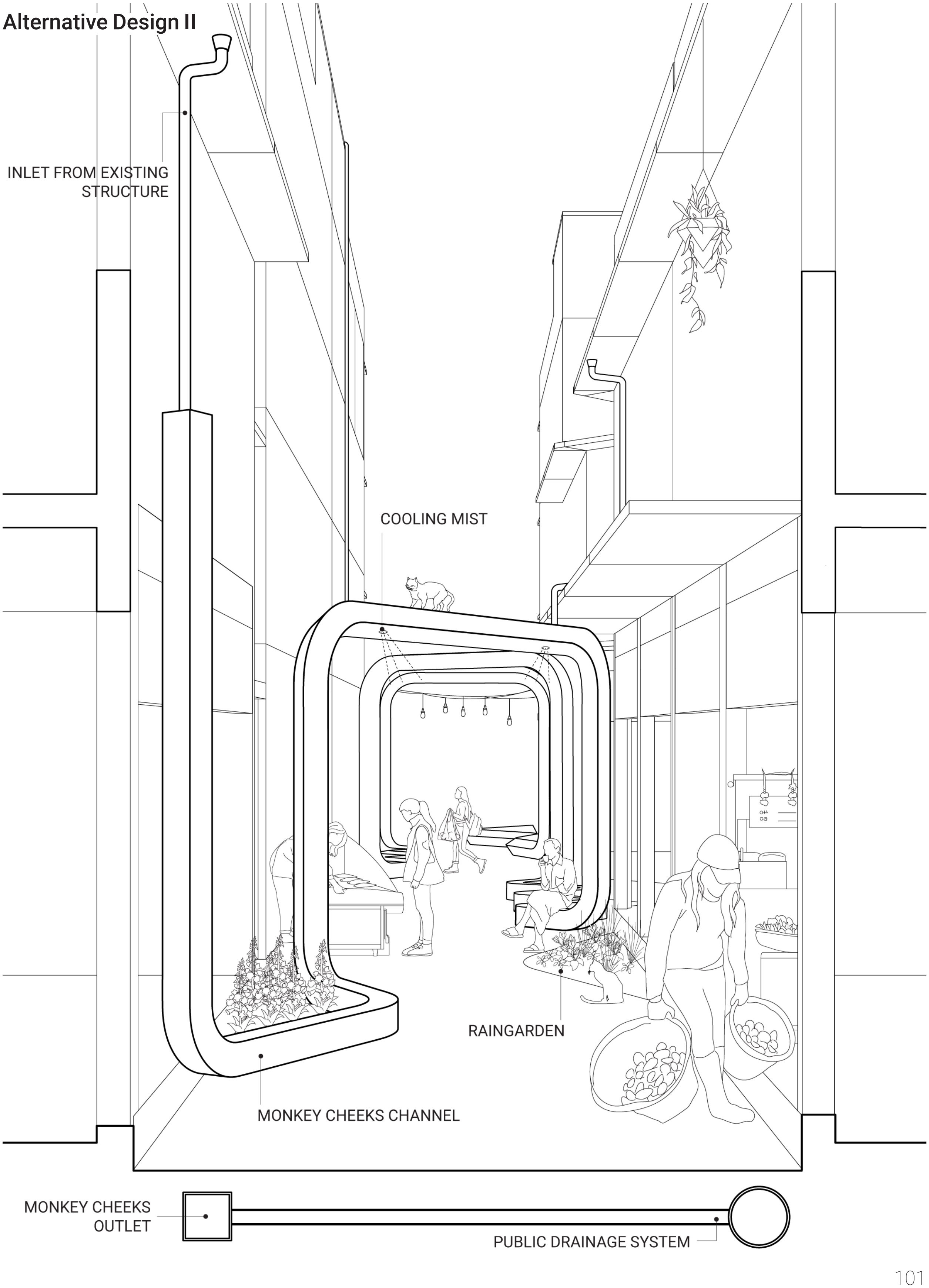
3.1 Case Study | Soi

Alternative Design I



3.1 Case Study | Soi

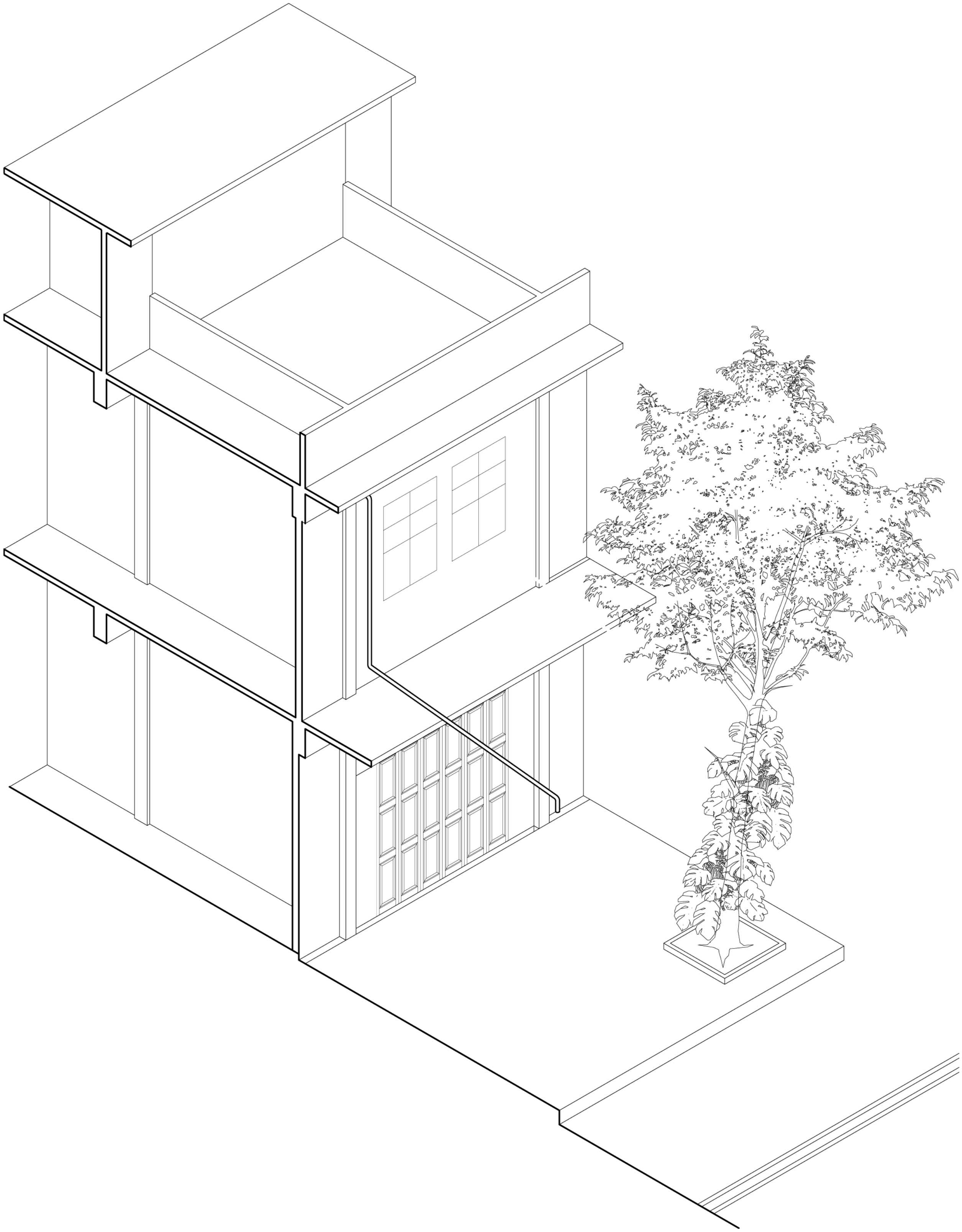
Alternative Design II




NTN

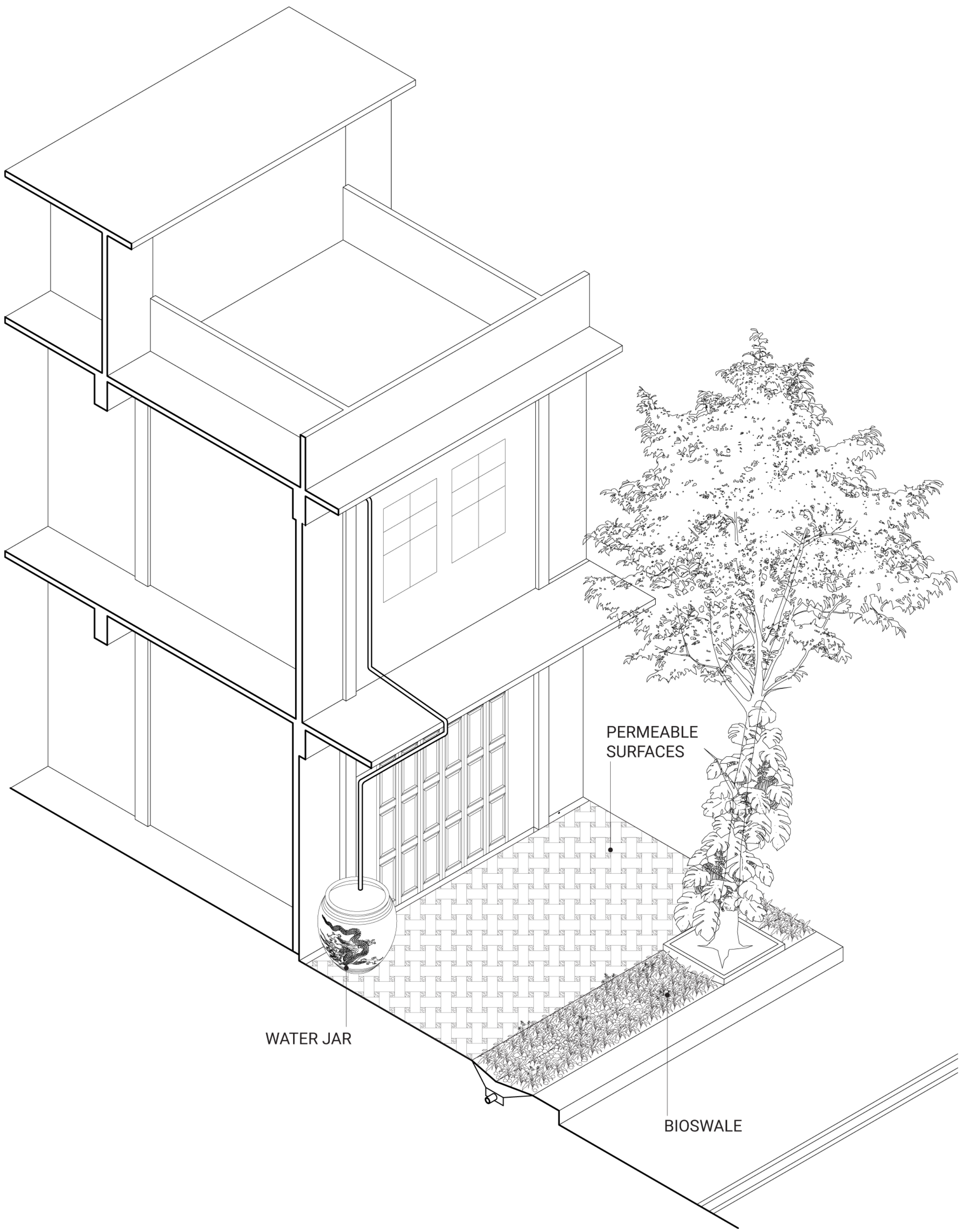
3.2 Case Study | Sidewalk

Existing Condition



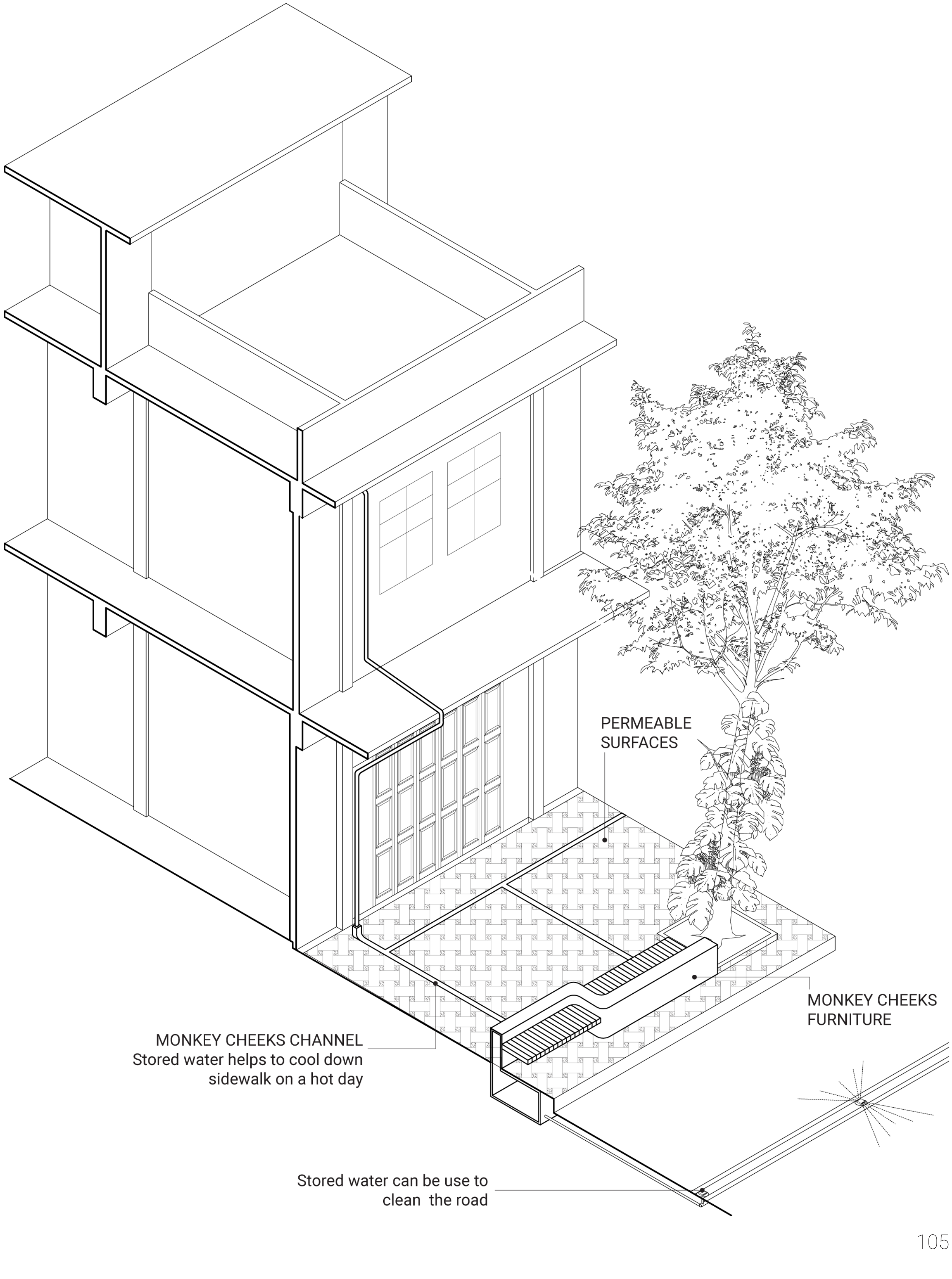
3.2 Case Study | Sidewalk

Alternative Design I



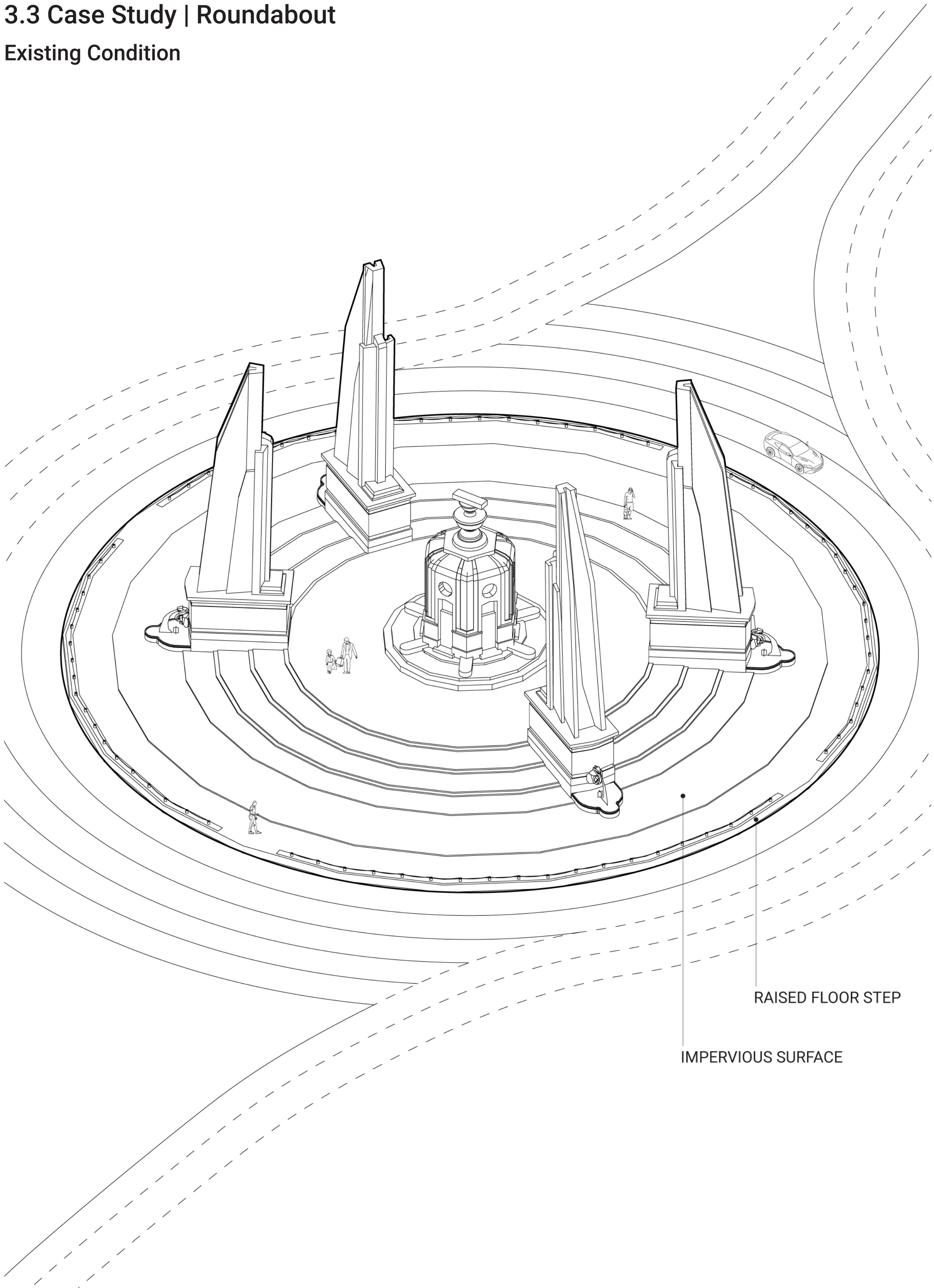
3.2 Case Study | Sidewalk

Alternative Design II



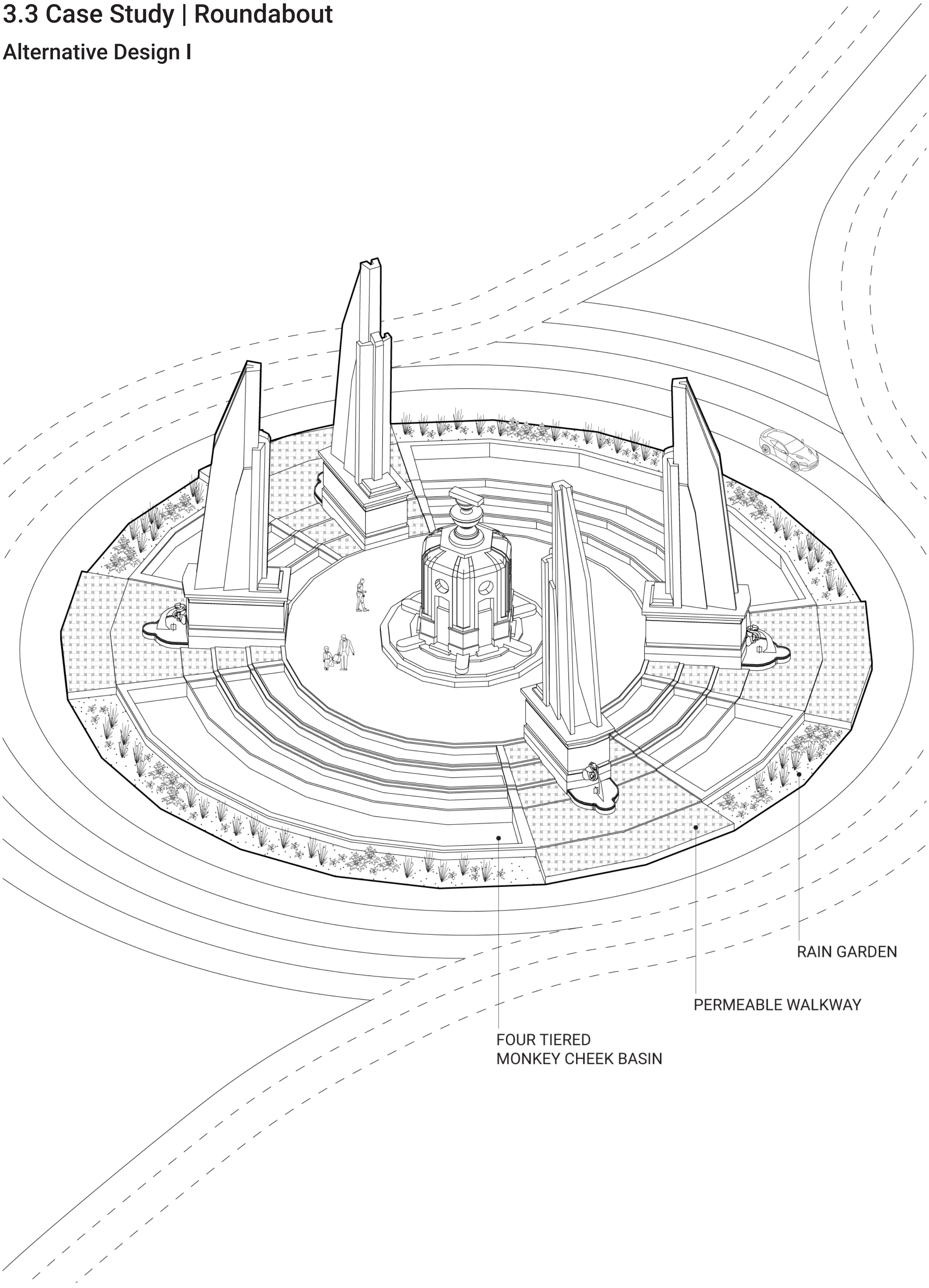
3.3 Case Study | Roundabout

Existing Condition



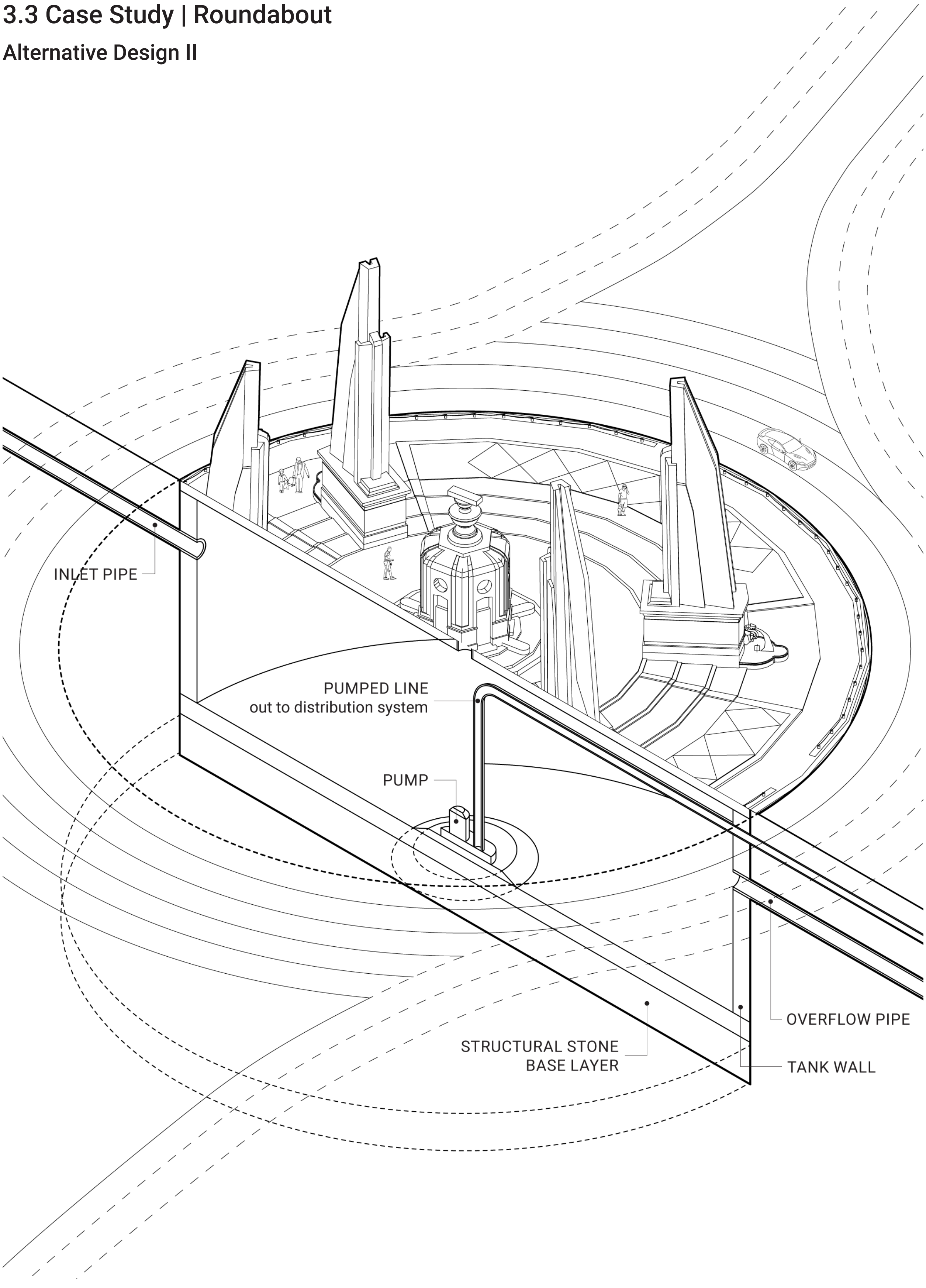
3.3 Case Study | Roundabout

Alternative Design I



3.3 Case Study | Roundabout

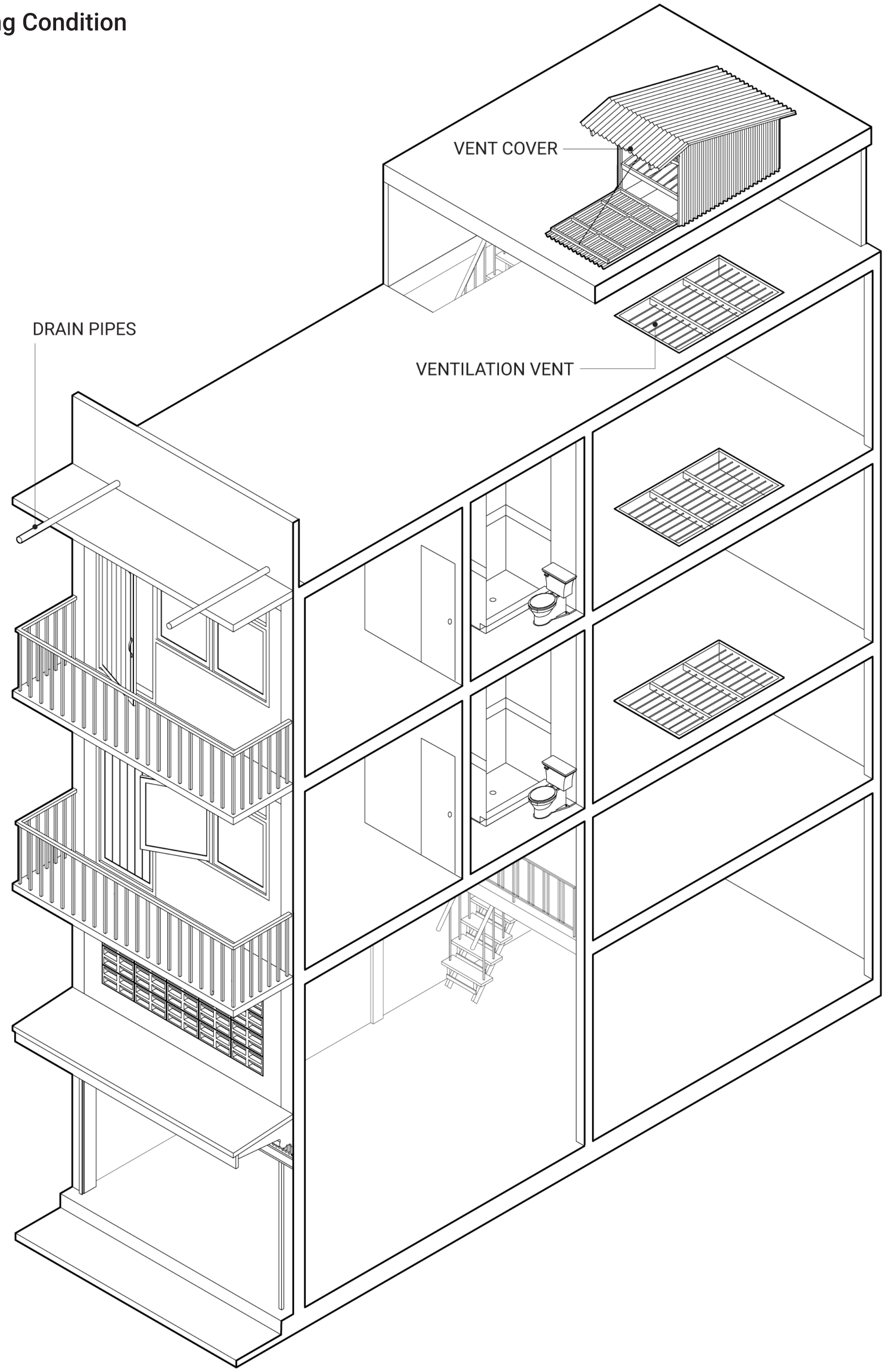
Alternative Design II




ถนนมังกร
Thanon Mangkon
PALLADIUM
bodyslam
#walkwithme
ซื้อ 1
แถม 2
BUY 1 GET 2 FREE

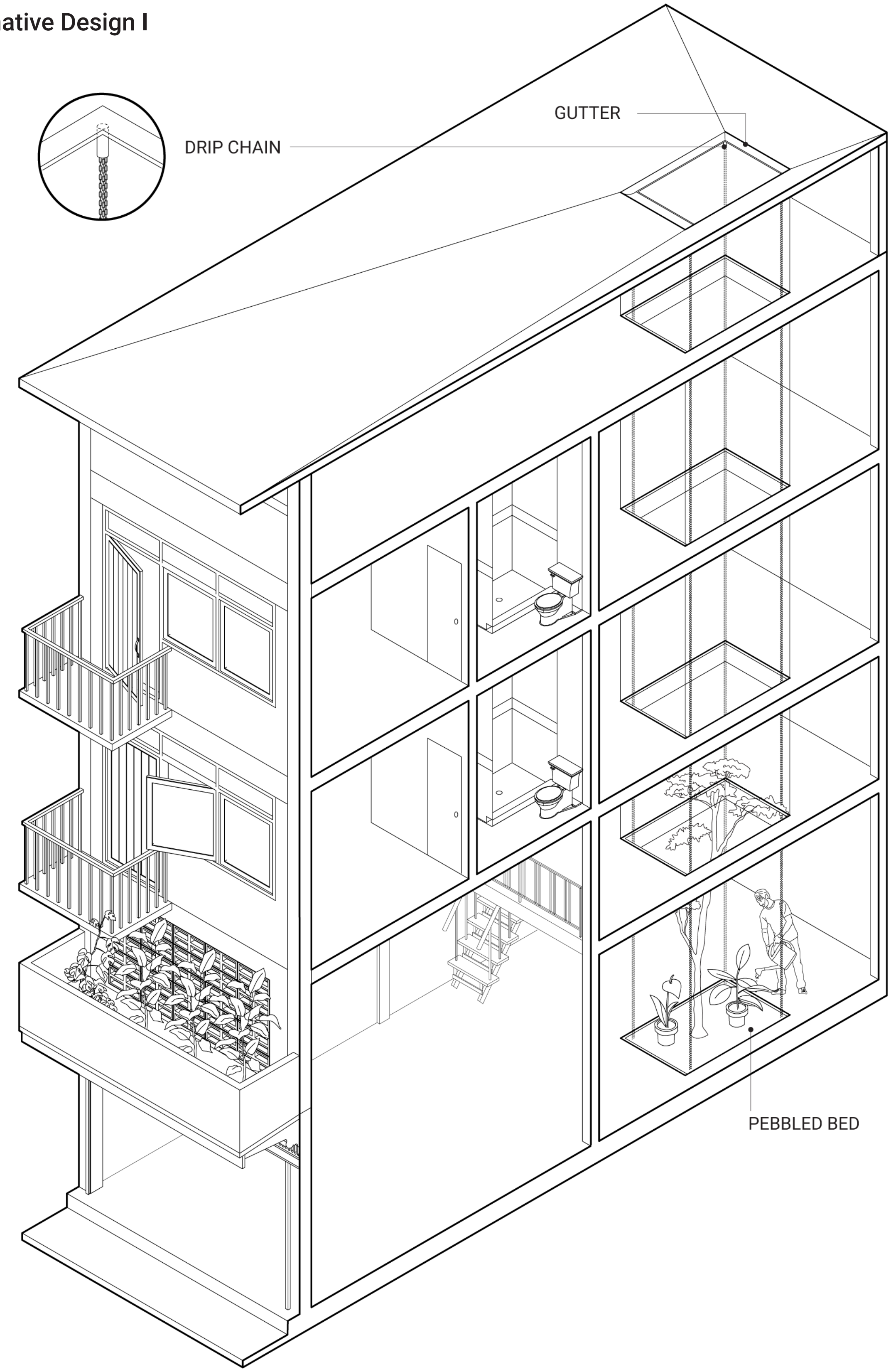
3.4 Case Study | Shophouse

Existing Condition



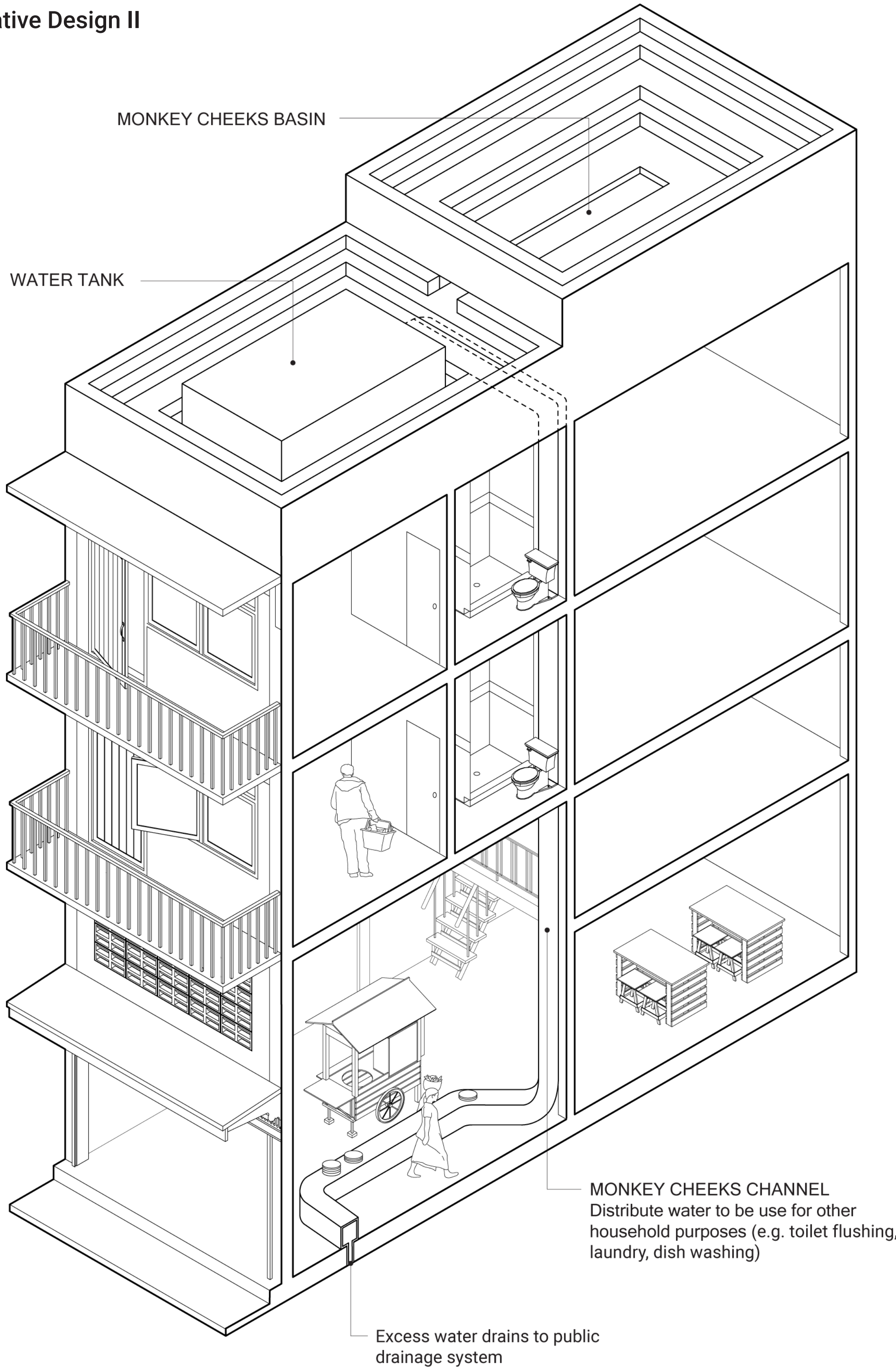
3.4 Case Study | Shophouse

Alternative Design I



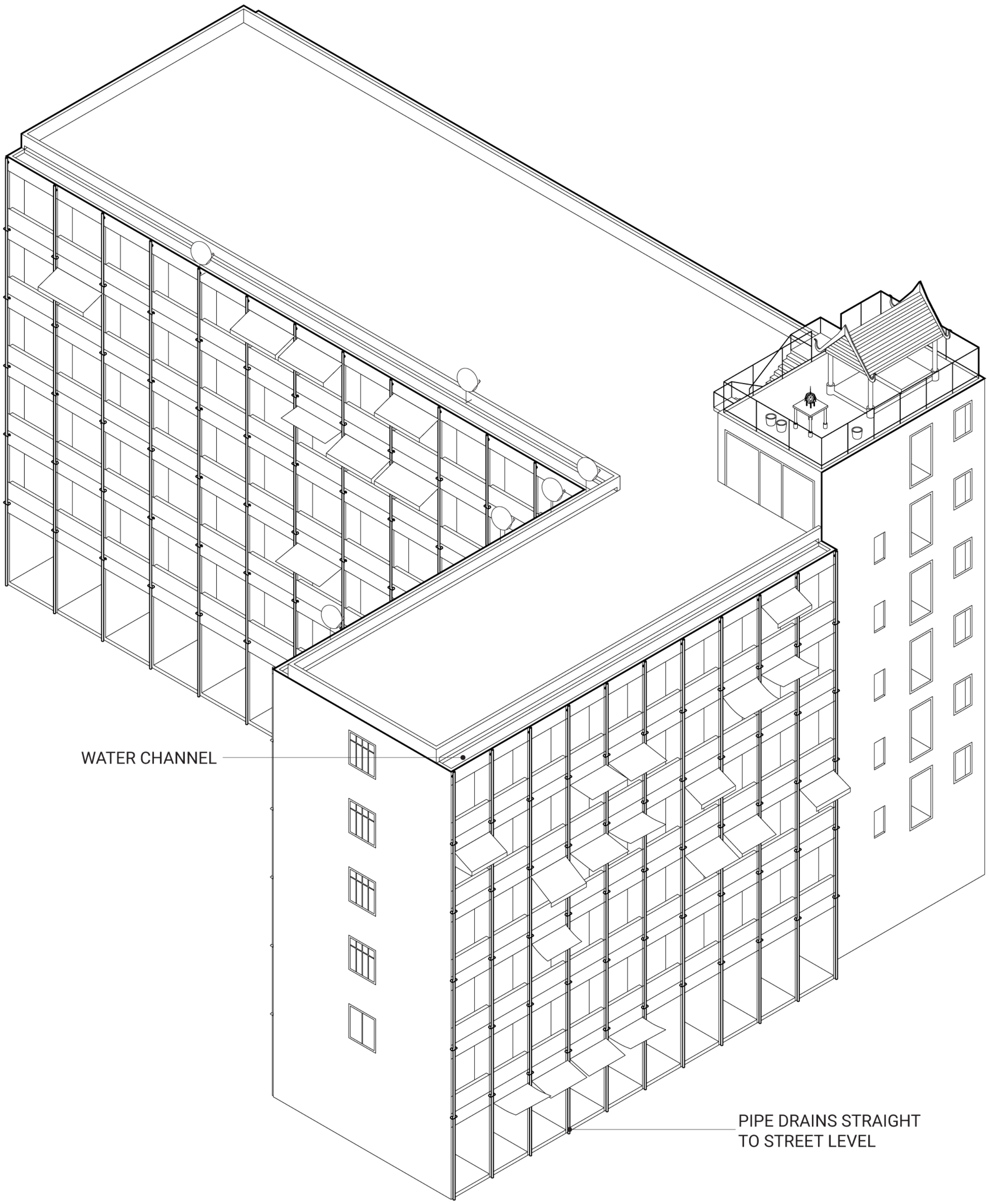
3.4 Case Study | Shophouse

Alternative Design II



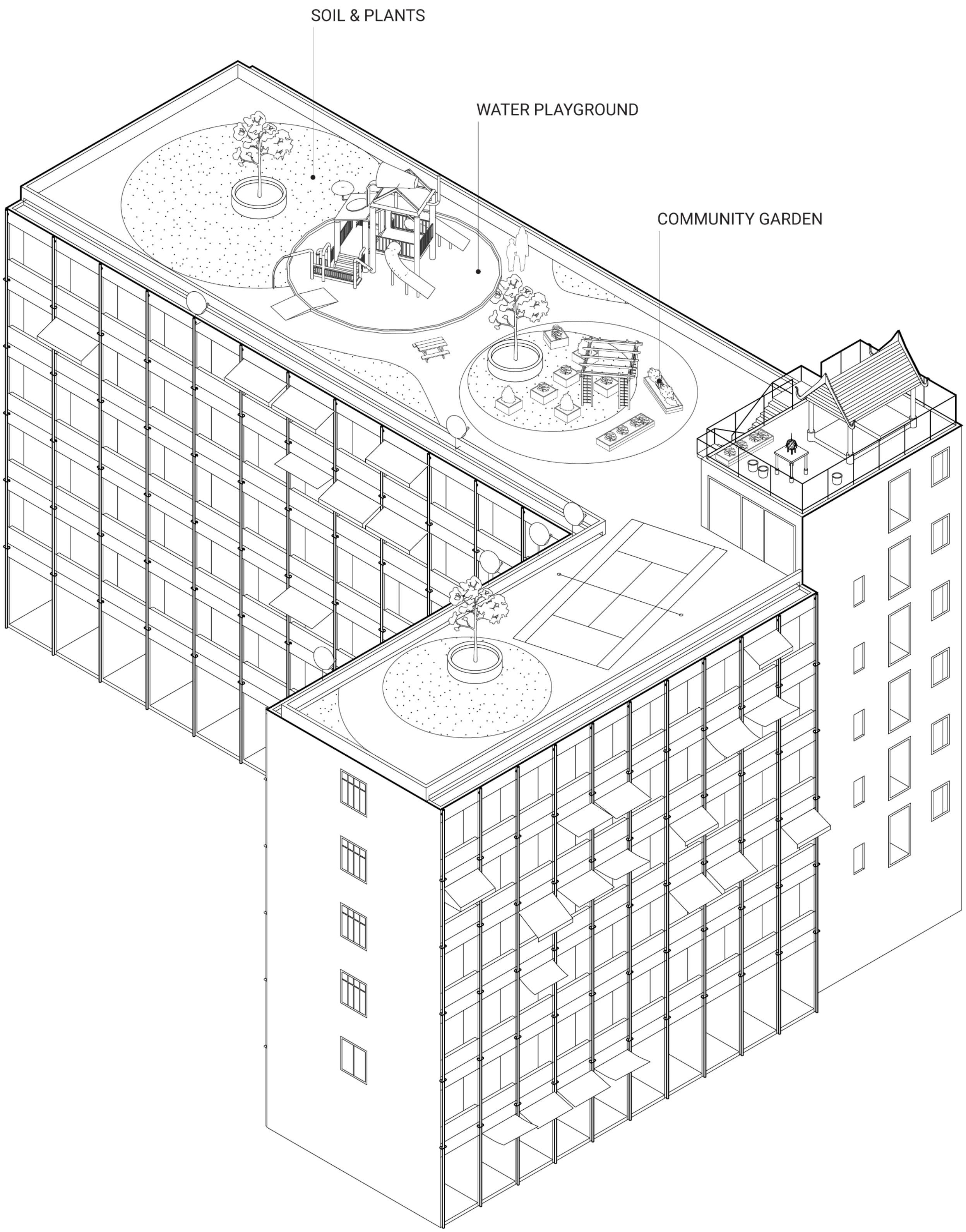
3.5 Case Study | Affordable Housing

Existing Condition



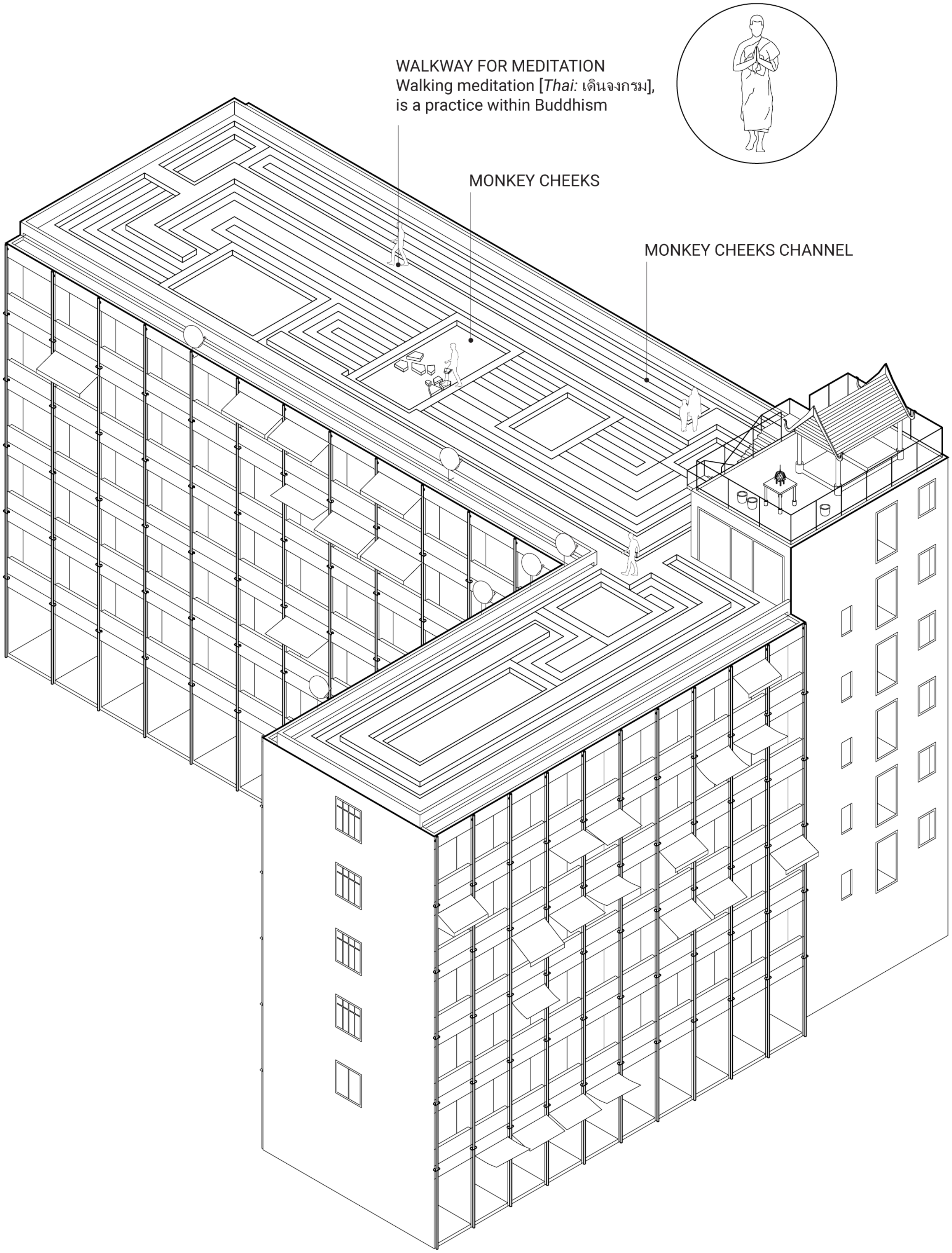
3.5 Case Study | Affordable Housing

Alternative Design I



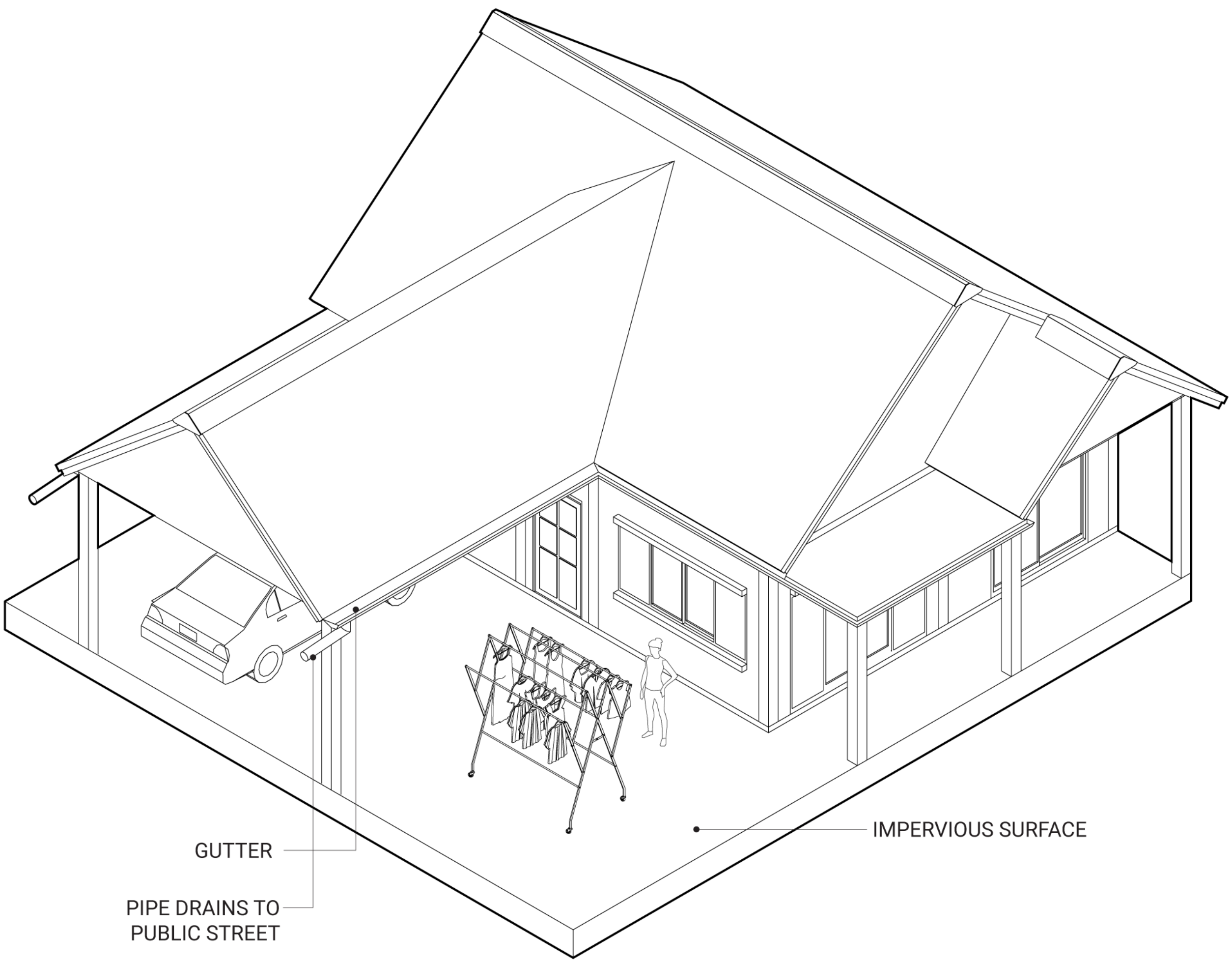
3.5 Case Study | Affordable Housing

Alternative Design II



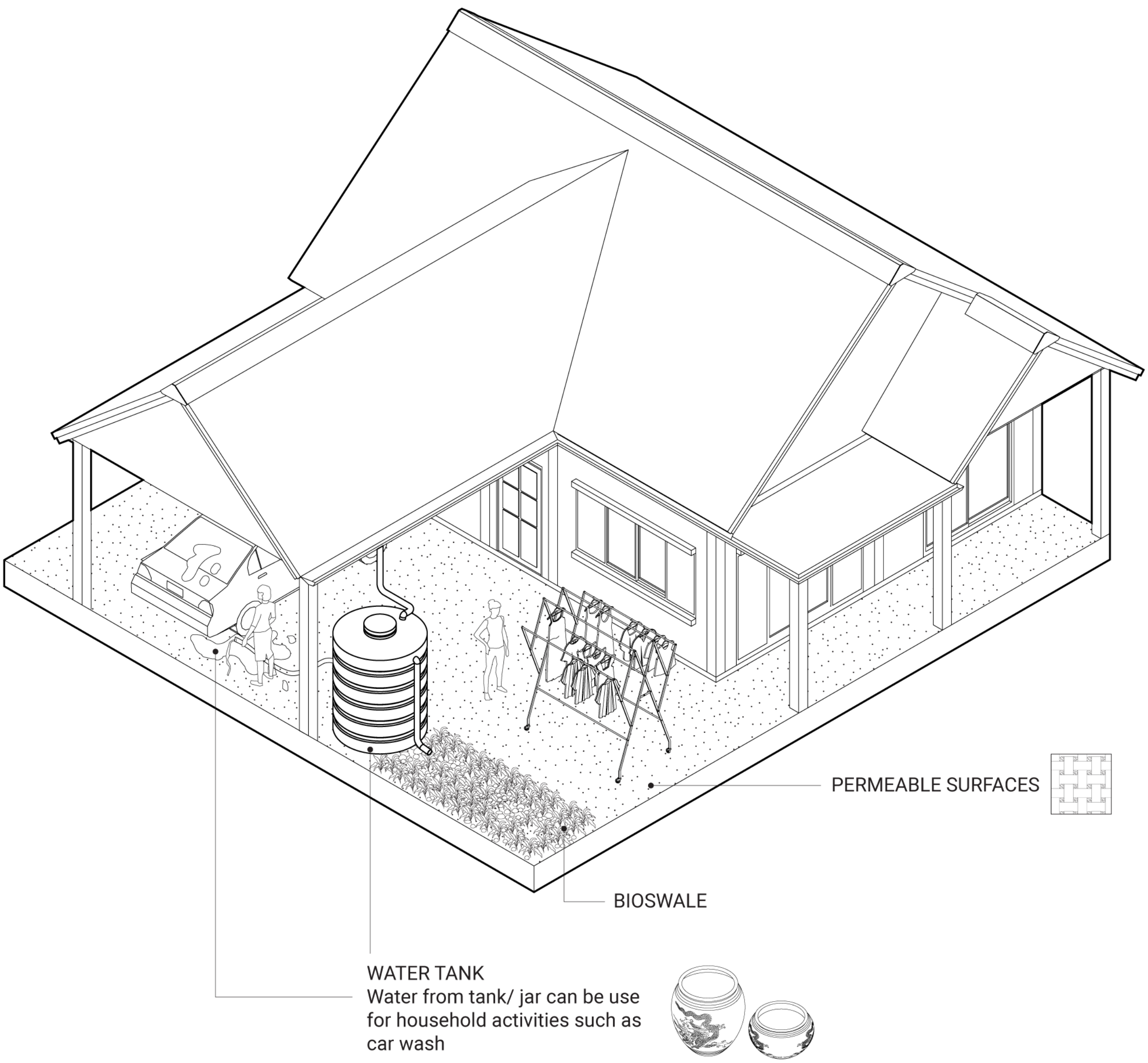
3.6 Case Study | Single Family House

Existing Condition



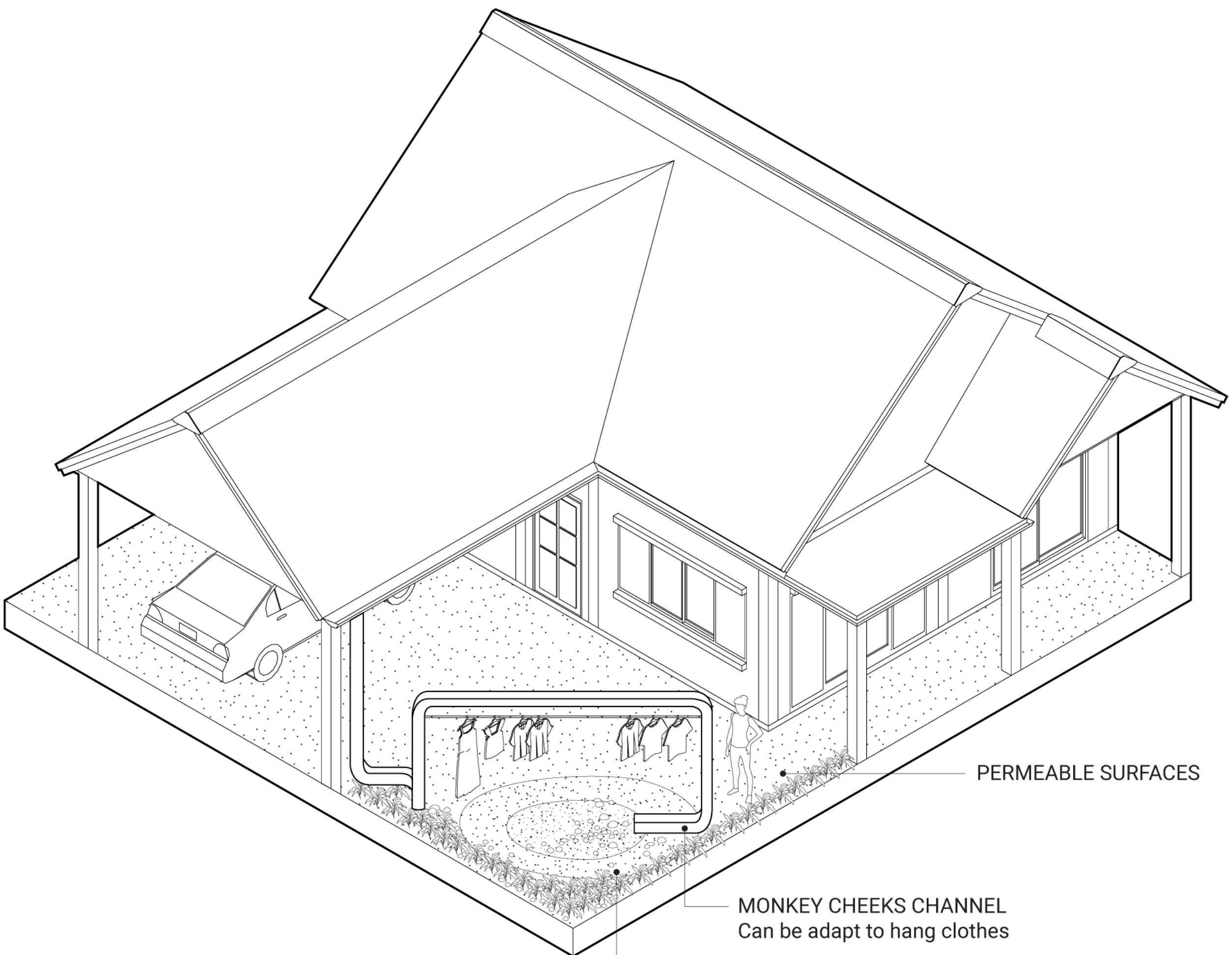
3.6 Case Study | Single Family House

Alternative Design I



3.6 Case Study | Single Family House

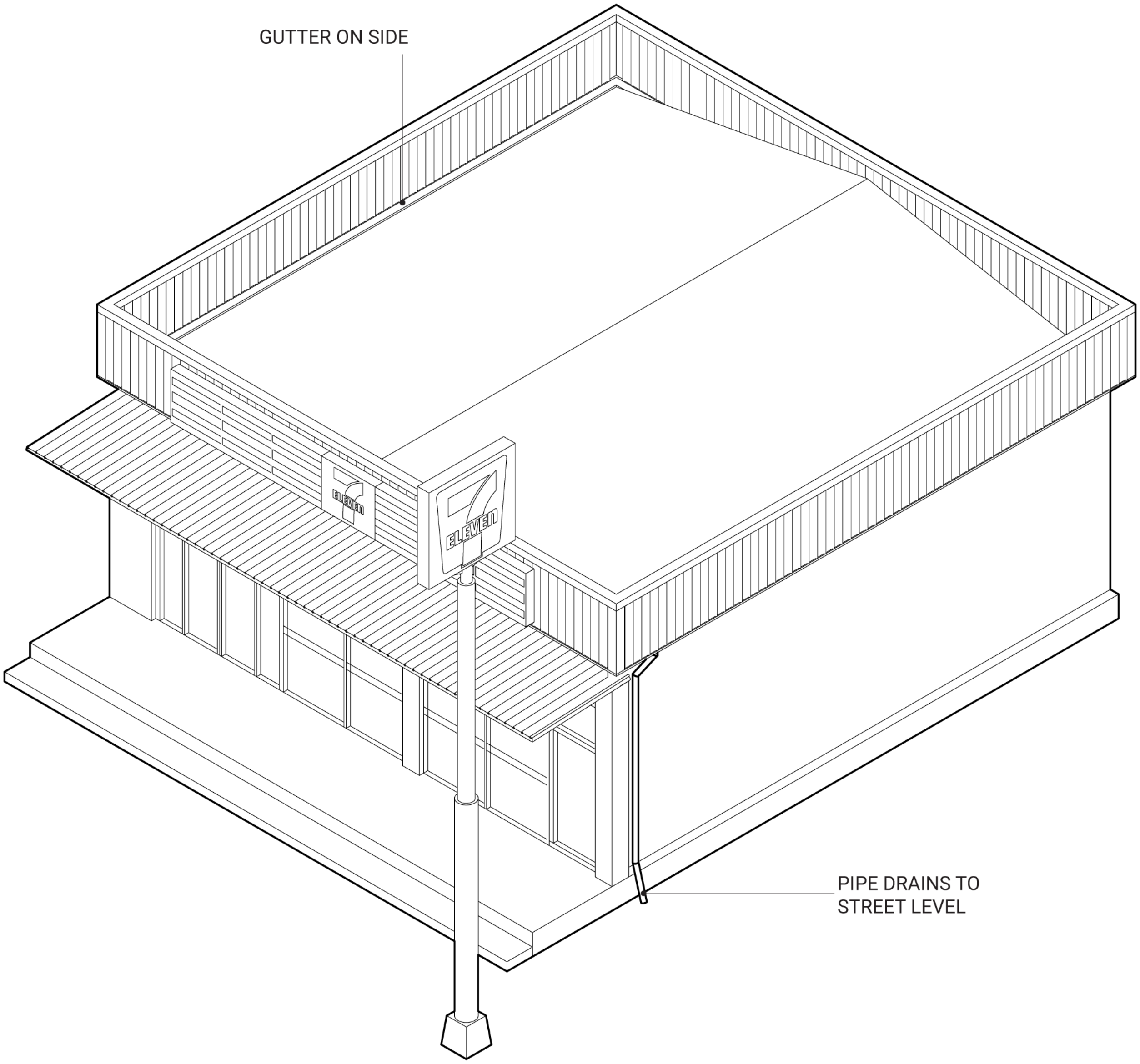
Alternative Design II




7 ELEVEn

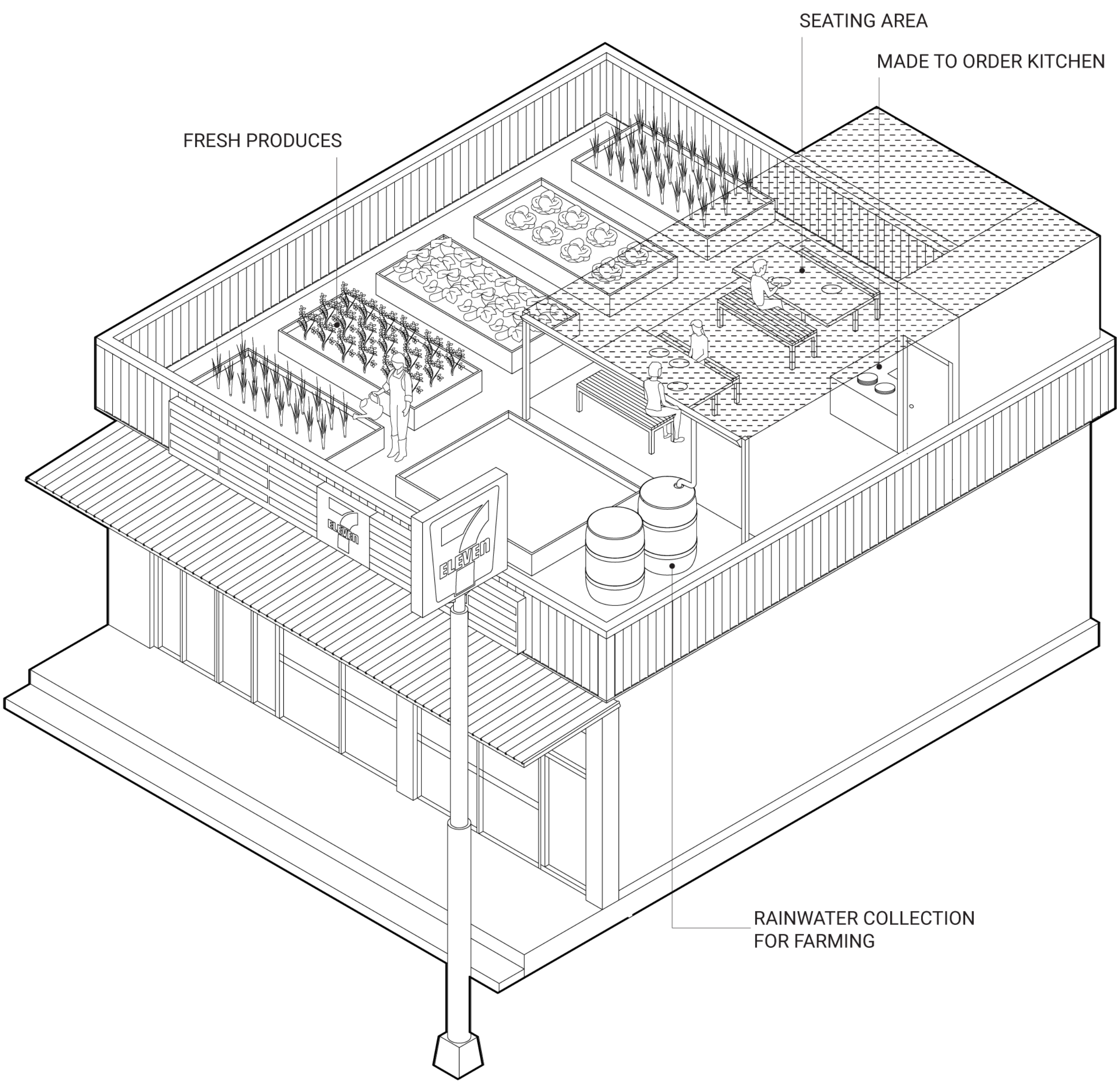
3.7 Case Study | Convenient Store

Existing Condition



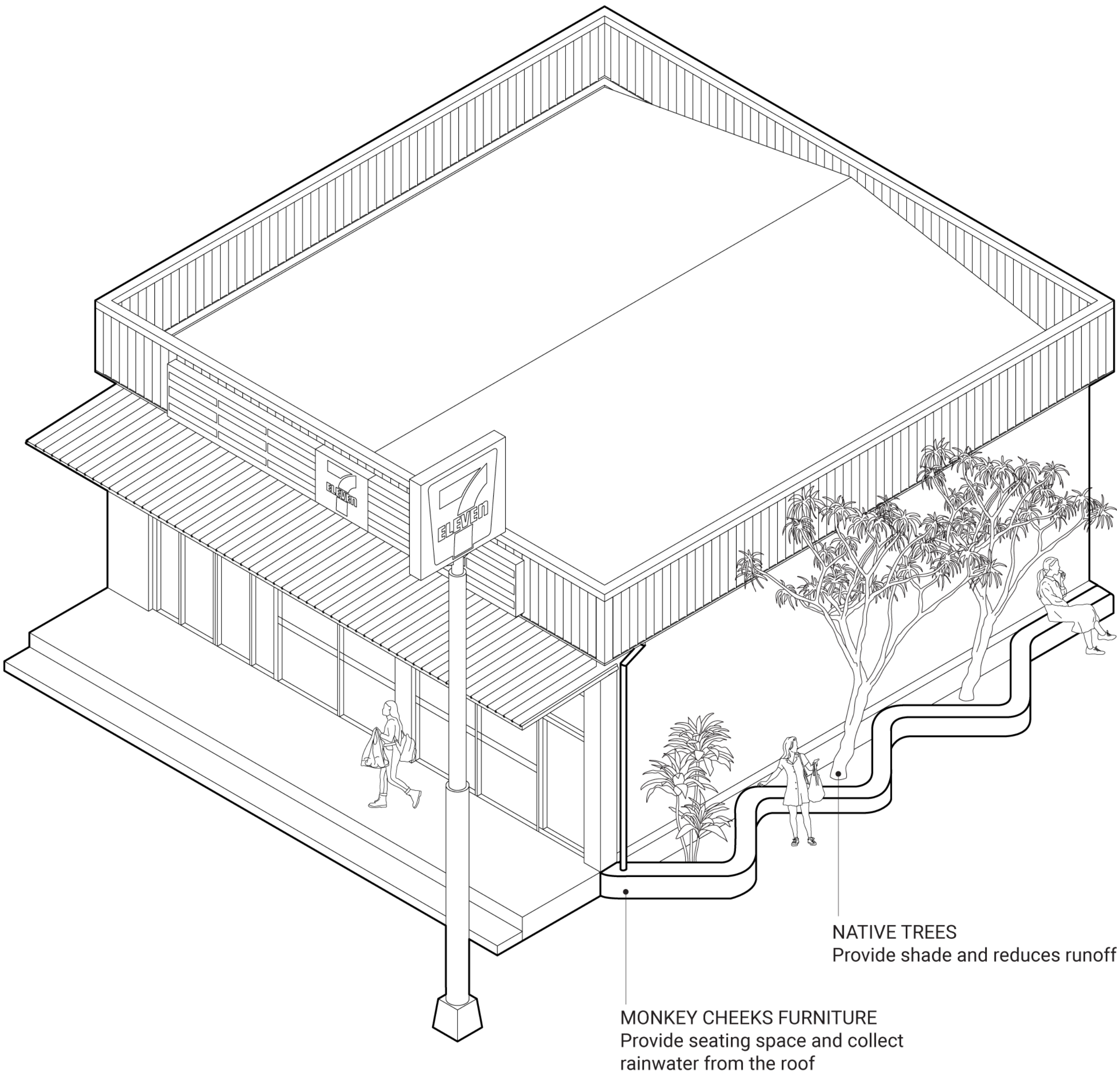
3.7 Case Study | Convenient Store

Alternative Design I



3.7 Case Study | Convenient Store

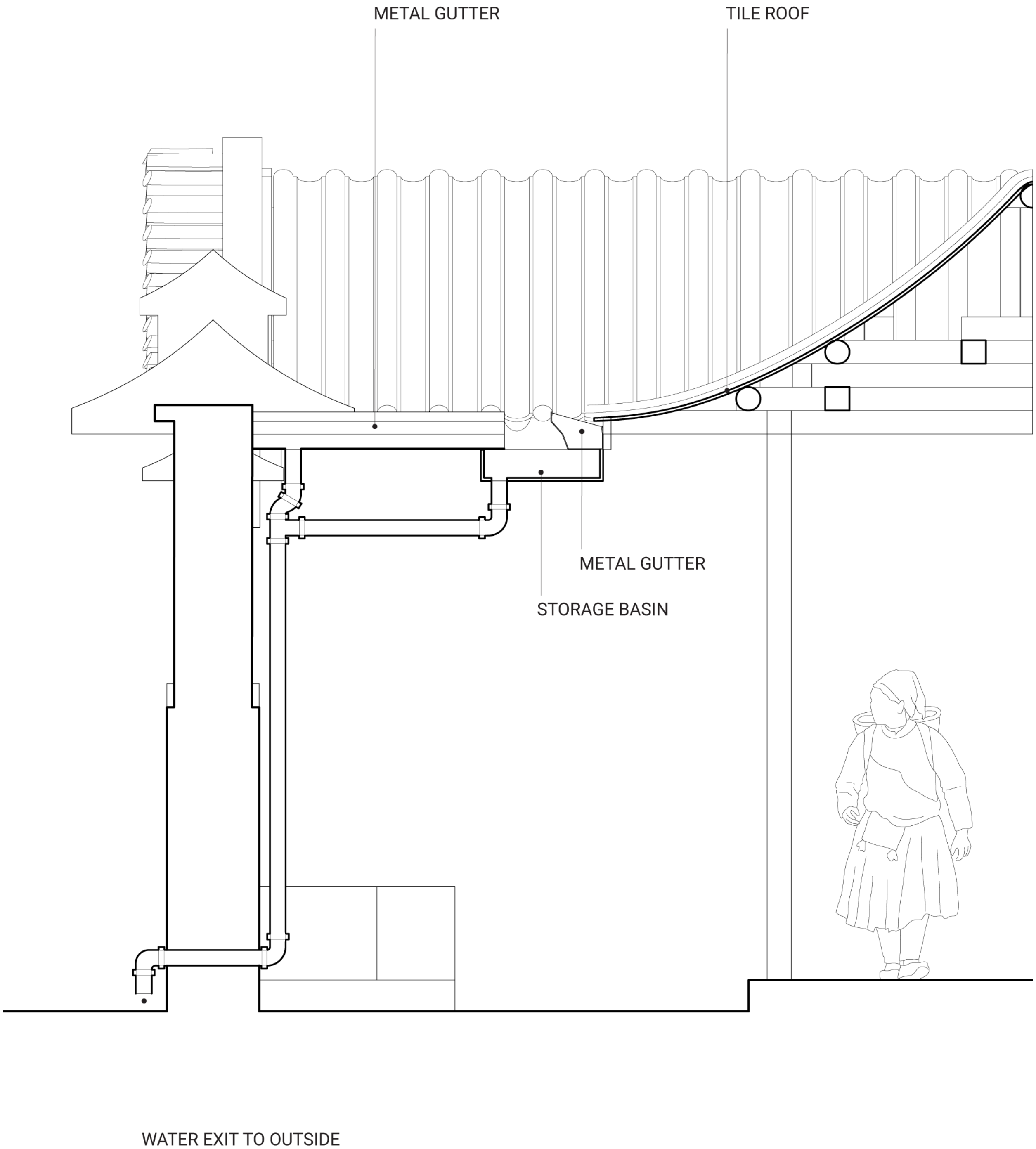
Alternative Design II




玄天上帝

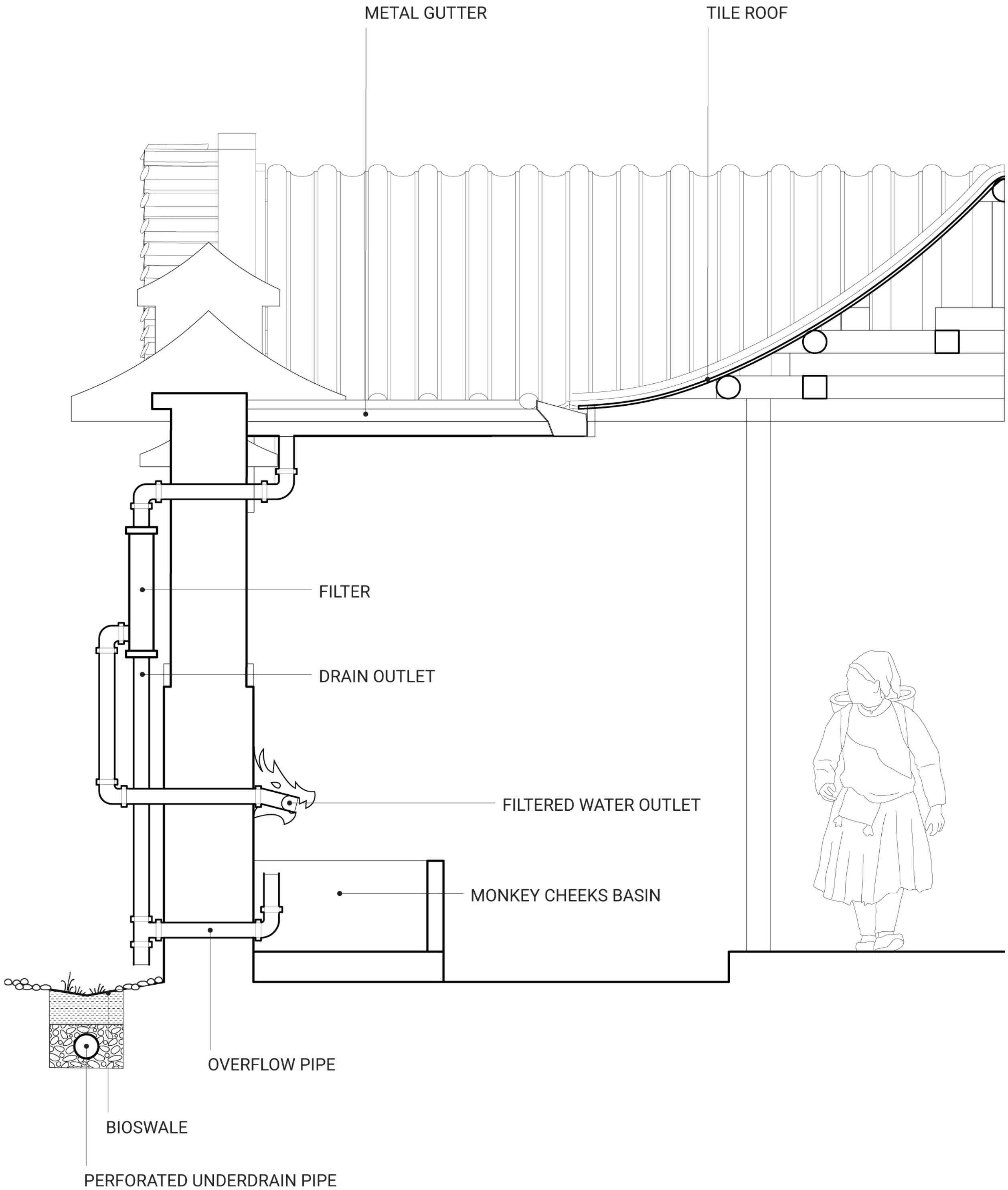
3.8 Case Study | Temple

Existing Condition



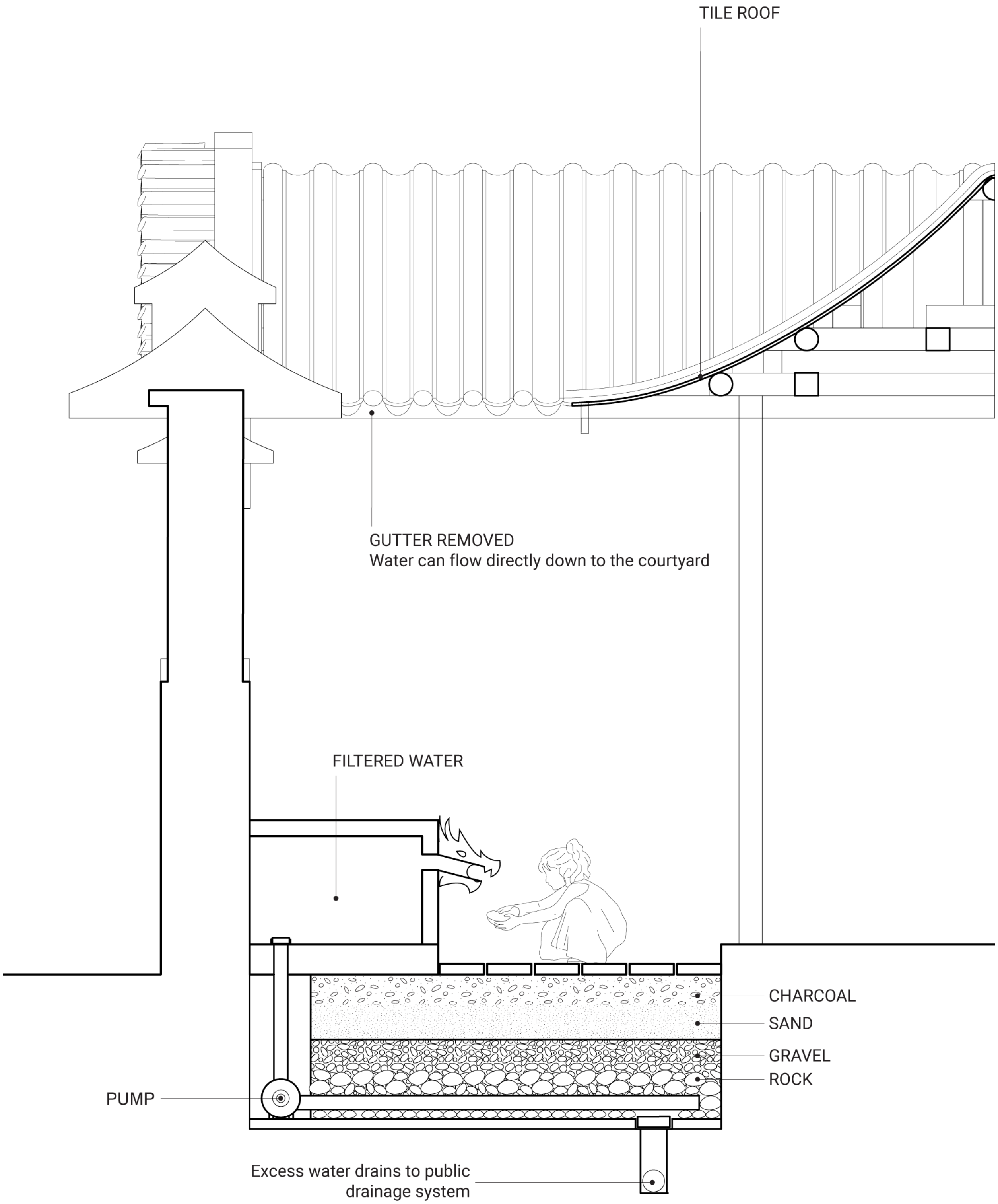
3.8 Case Study | Temple

Alternative Design I



3.8 Case Study | Temple

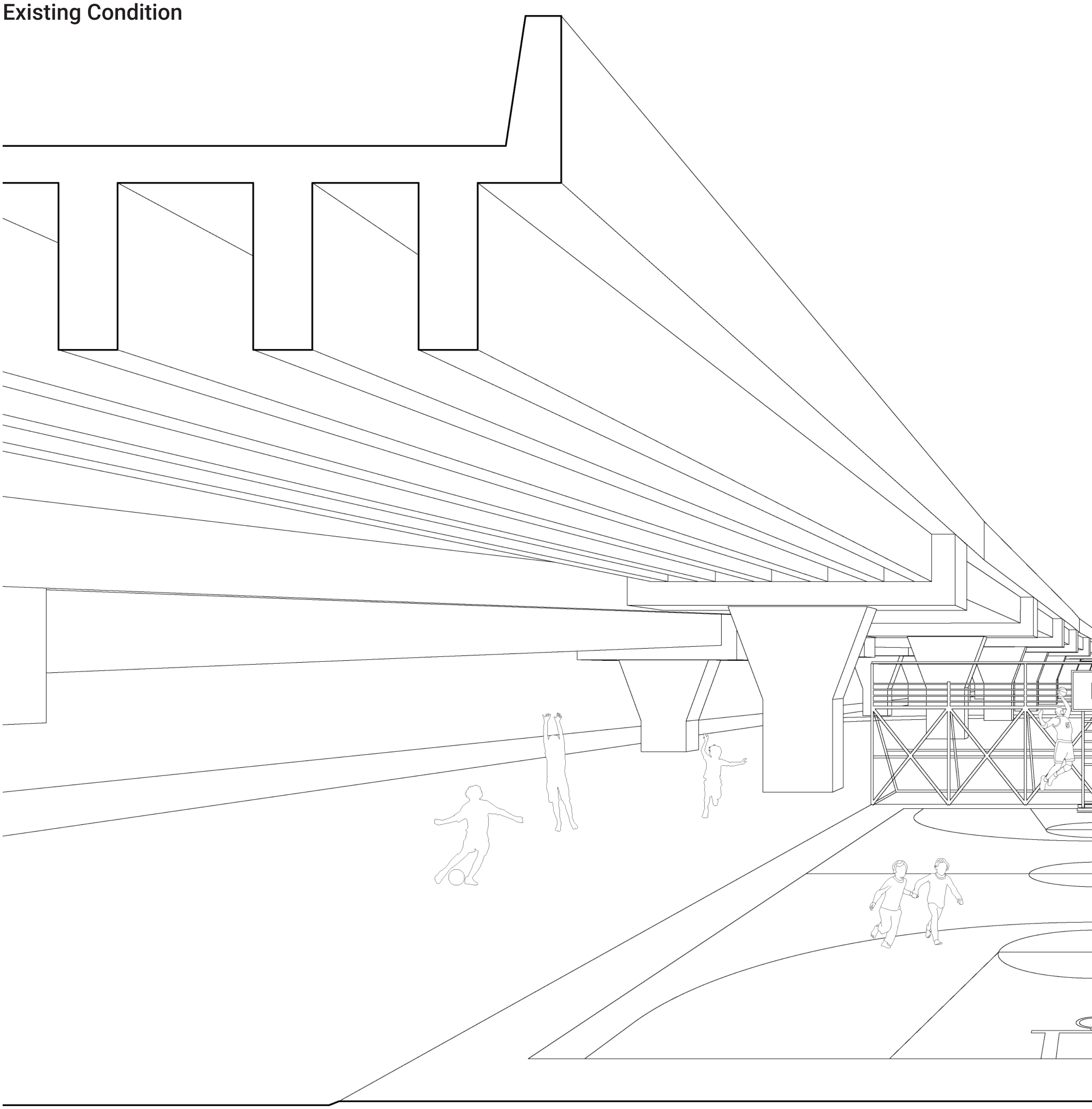
Alternative Design II

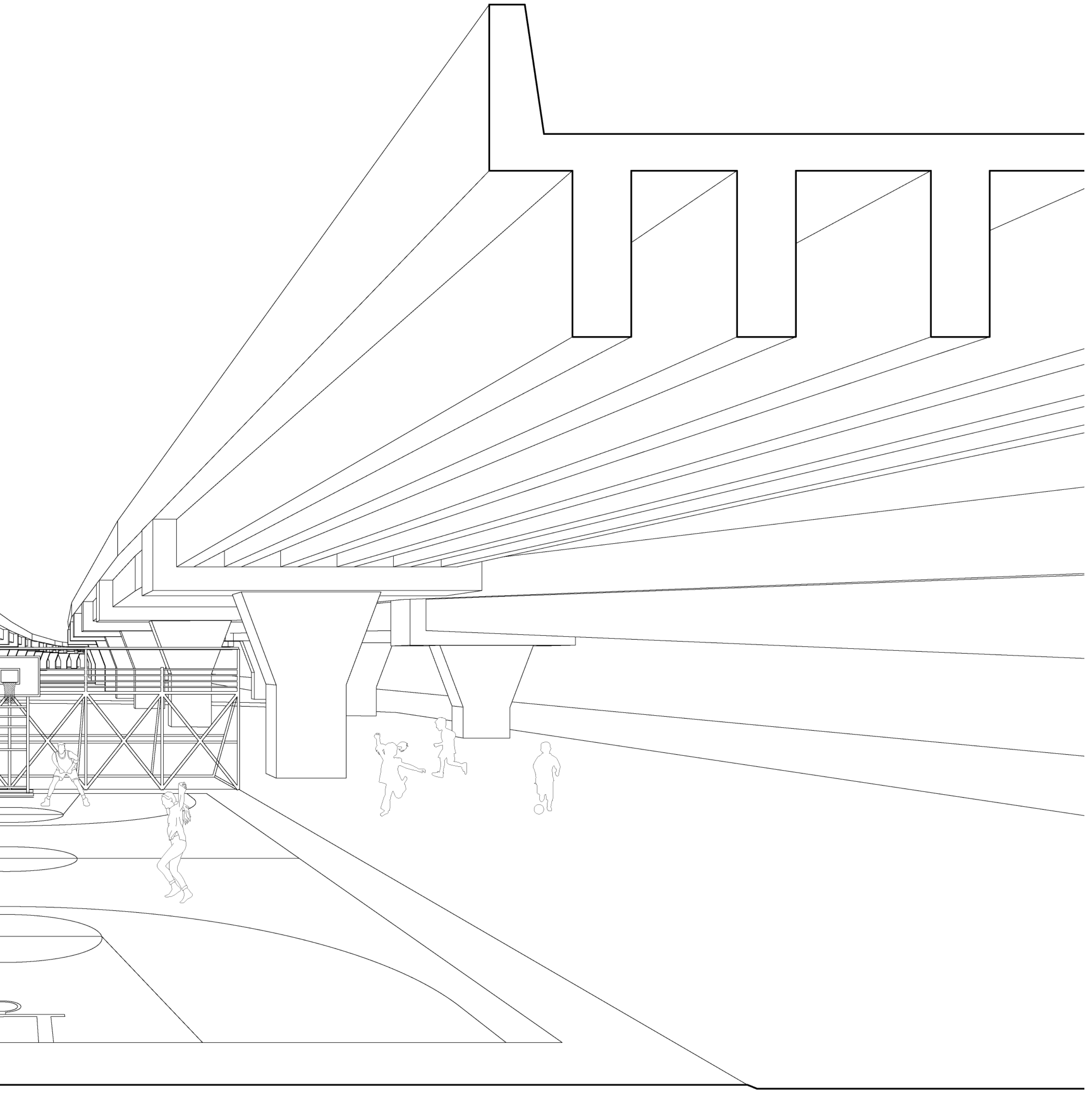



11

3.9 Case Study | Playground

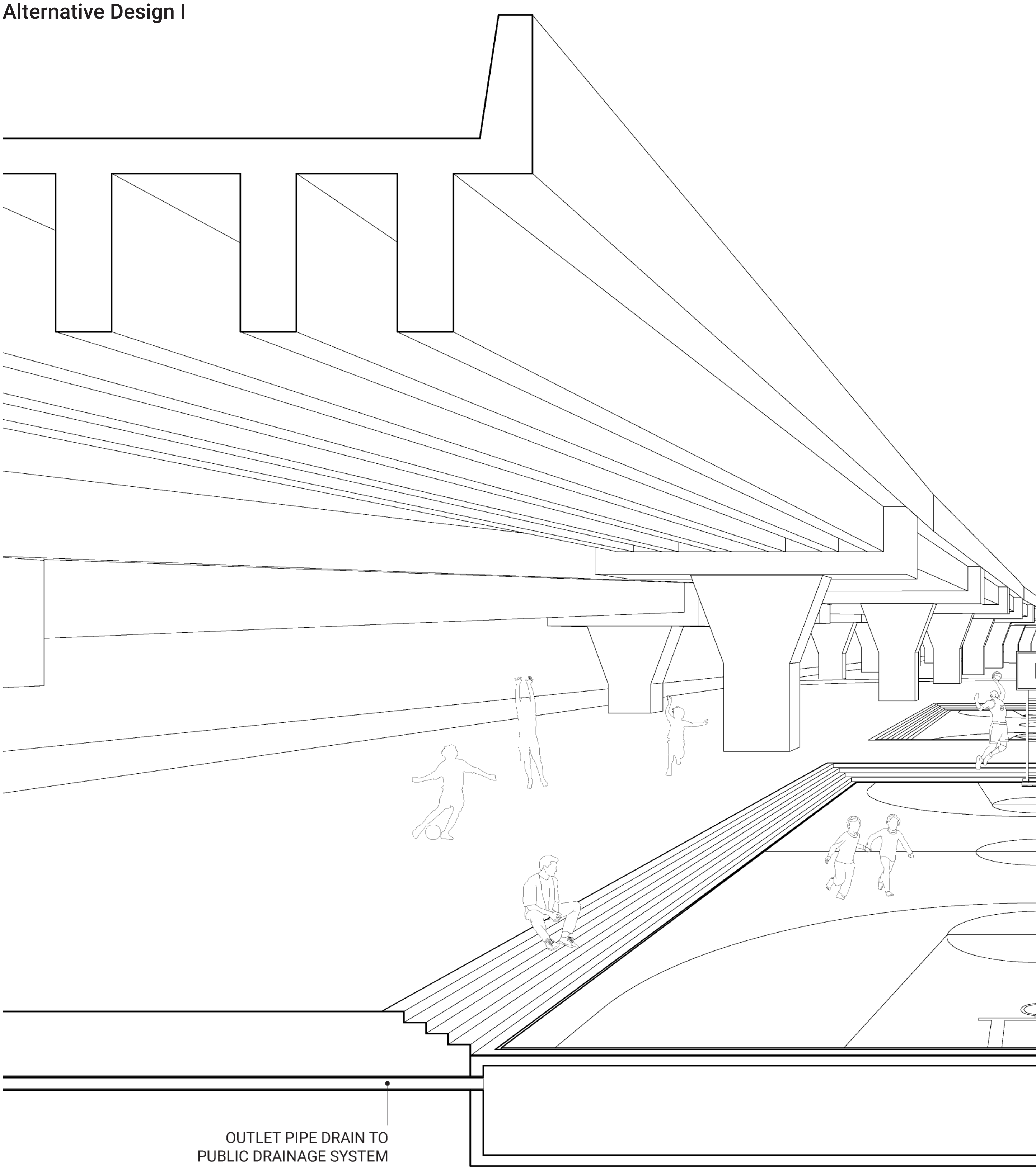
Existing Condition

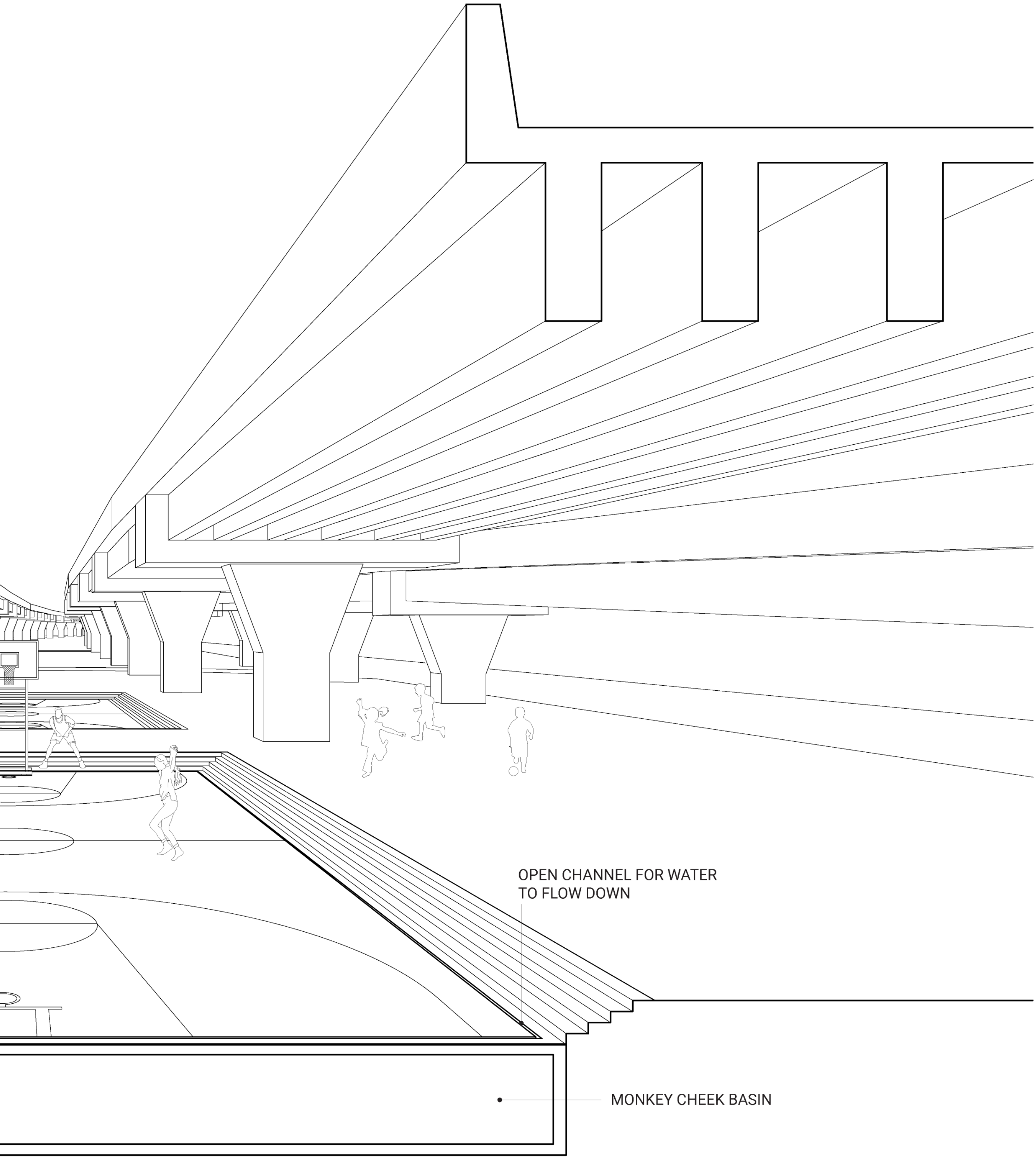




3.9 Case Study | Playground

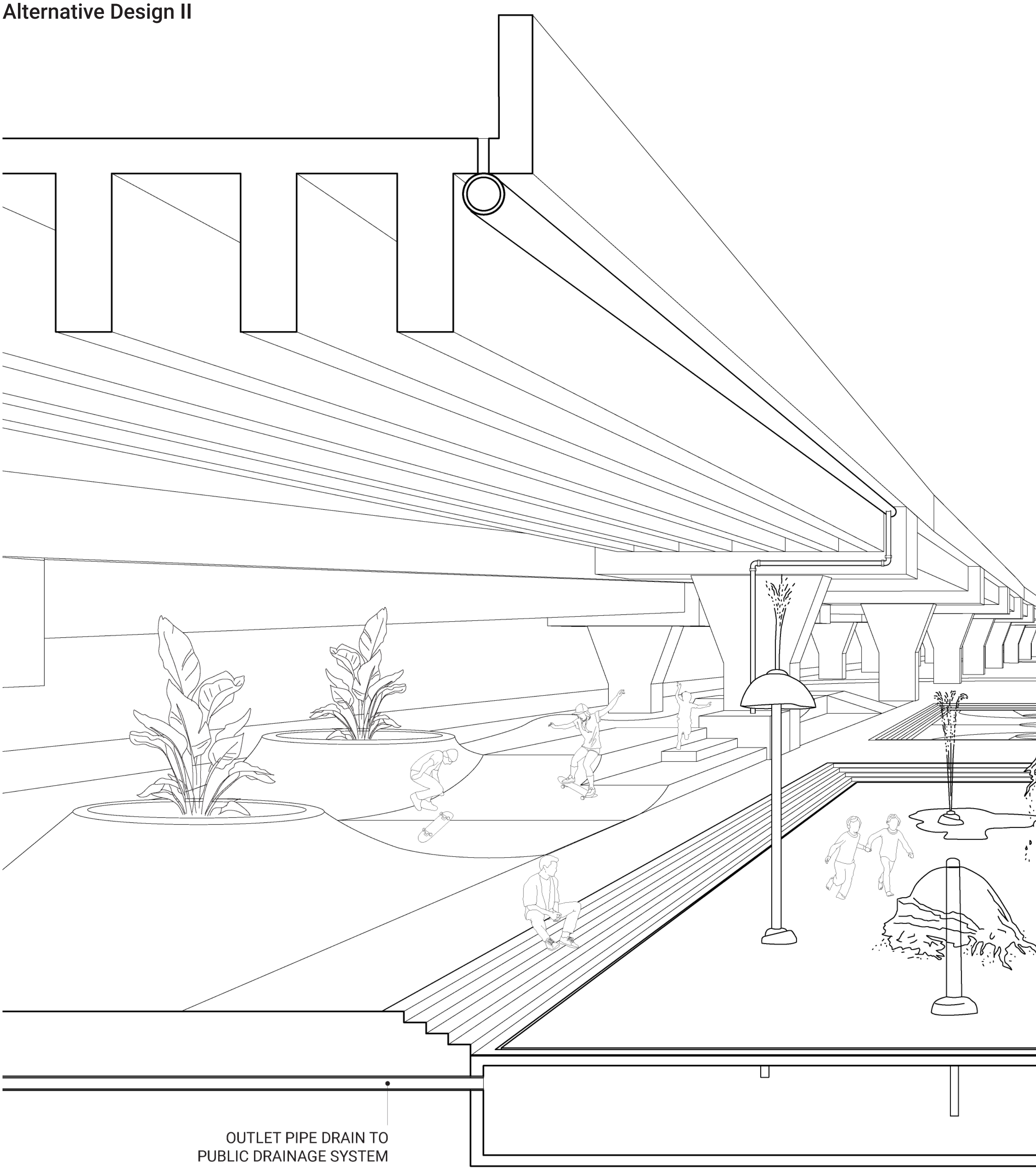
Alternative Design I

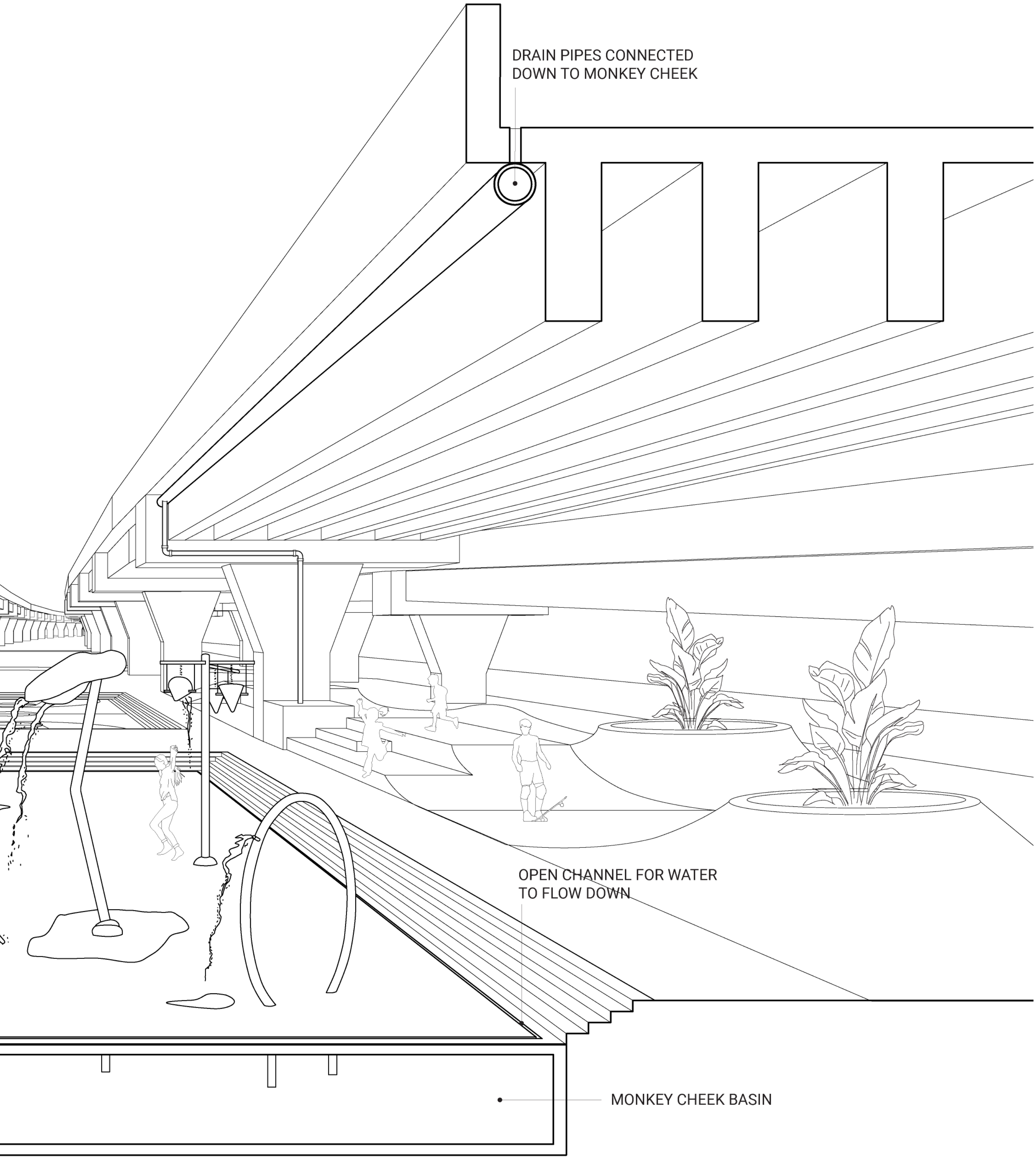



OPEN CHANNEL FOR WATER
TO FLOW DOWN
MONKEY CHEEK BASIN

3.9 Case Study | Playground

Alternative Design II




DRAIN PIPES CONNECTED
DOWN TO MONKEY CHEEK
OPEN CHANNEL FOR WATER
TO FLOW DOWN
MONKEY CHEEK BASIN

CHAPTER 4: The Monkey Cheeks Toolkit

This Chapter presents the Monkey Cheeks Toolkit components that were designed based on the previous case studies in Chapter 3. The toolkit catalogs these components by type, describes them through drawings, and explains their performance factors and the key stakeholders that need to be involved to be implemented.

These versions of Monkey Cheeks are designed to protect, restore, or mimic the natural water cycle within built environments by retaining, detaining, and/or treating stormwater runoff. Allowing stormwater to be managed where it falls and reducing, filtering and/or slowing the amount of stormwater entering the City's sewer system.

These designs also may be considered a first step in developing a Monkey Cheeks urban typology focusing on the function of sustainable urban water management with symbolic dimensions of scale, connectivity, and familiarity. The next step of this visioning effort should be engagement with the local community and private sector partners to review and receive feedback on the alternative design visions. Ultimately, the author hoped that these designs could serve as a basis for further study and apply to future city regulation and design guidelines, which could comprise with some form of tax incentives and funding to help implement the vision.

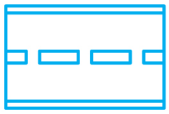
The structure of the toolkit is based on the typology as illustrated below:

MONKEY CHEEKS STREETS
PAGES: 140 -145

MONKEY CHEEKS BUILDINGS
PAGES: 146 -151

MONKEY CHEEKS OPEN SPACE
PAGES: 152 -159

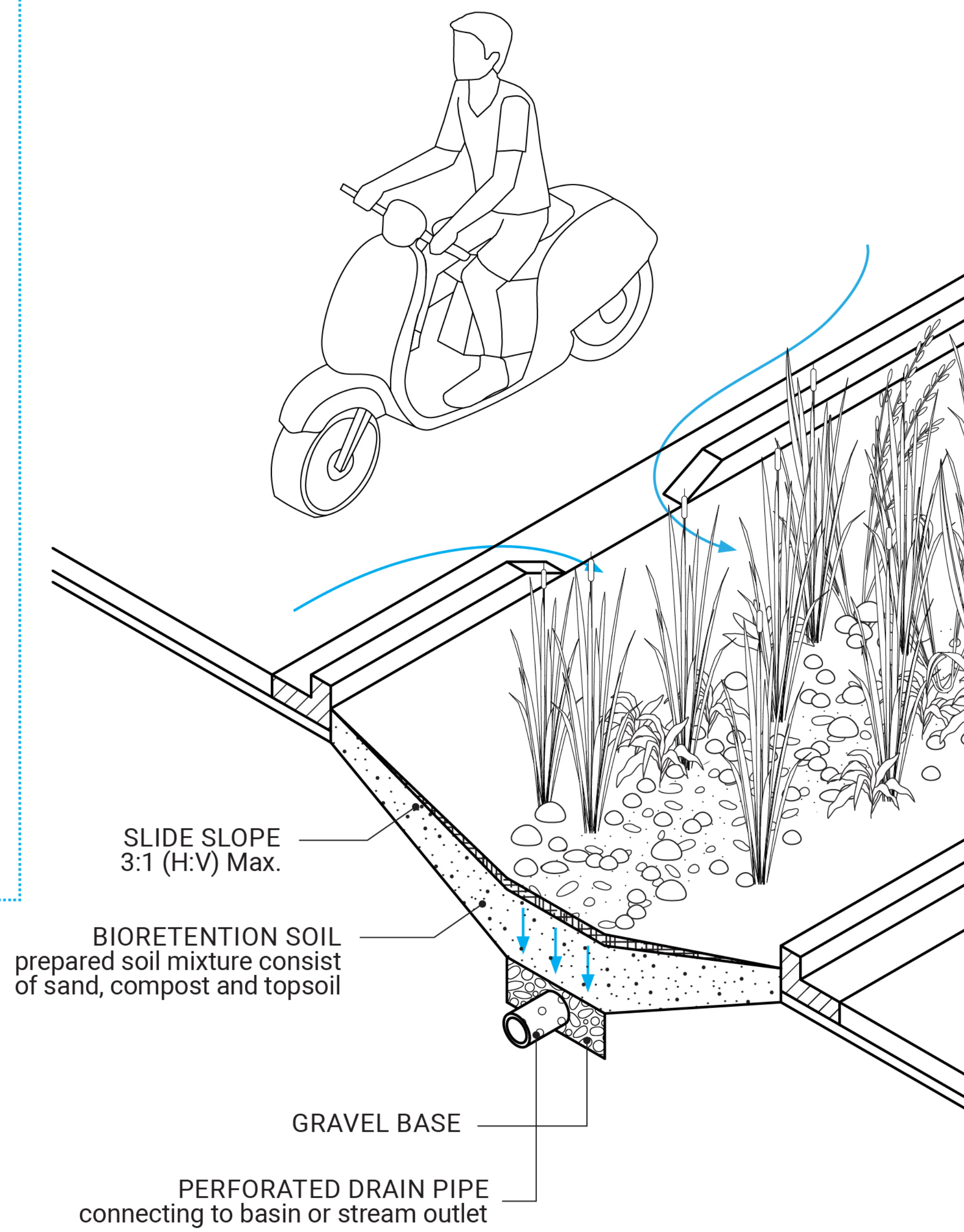
BIOSWALES



TYPOLOGY

PERFORMATIVE FACTORS

Bioretention swales, or bioswales, are vegetated open channels that capture, treat, and infiltrate stormwater runoff at a low velocity. They offer a resilient, aesthetic, and low-maintenance alternative to underground storm sewers or concrete gutters. By incorporating native plants, they can be tailored to any location and used in both residential and non-residential areas to treat and convey runoff from roadways and impervious surfaces. Bioswales work best when installed in parking lots, along roadways and sidewalks, or as an enhancement to natural or existing drainage swales. They can be constructed in any location with a mild slope of no greater than four percent.



$ - $$

COST FACTOR

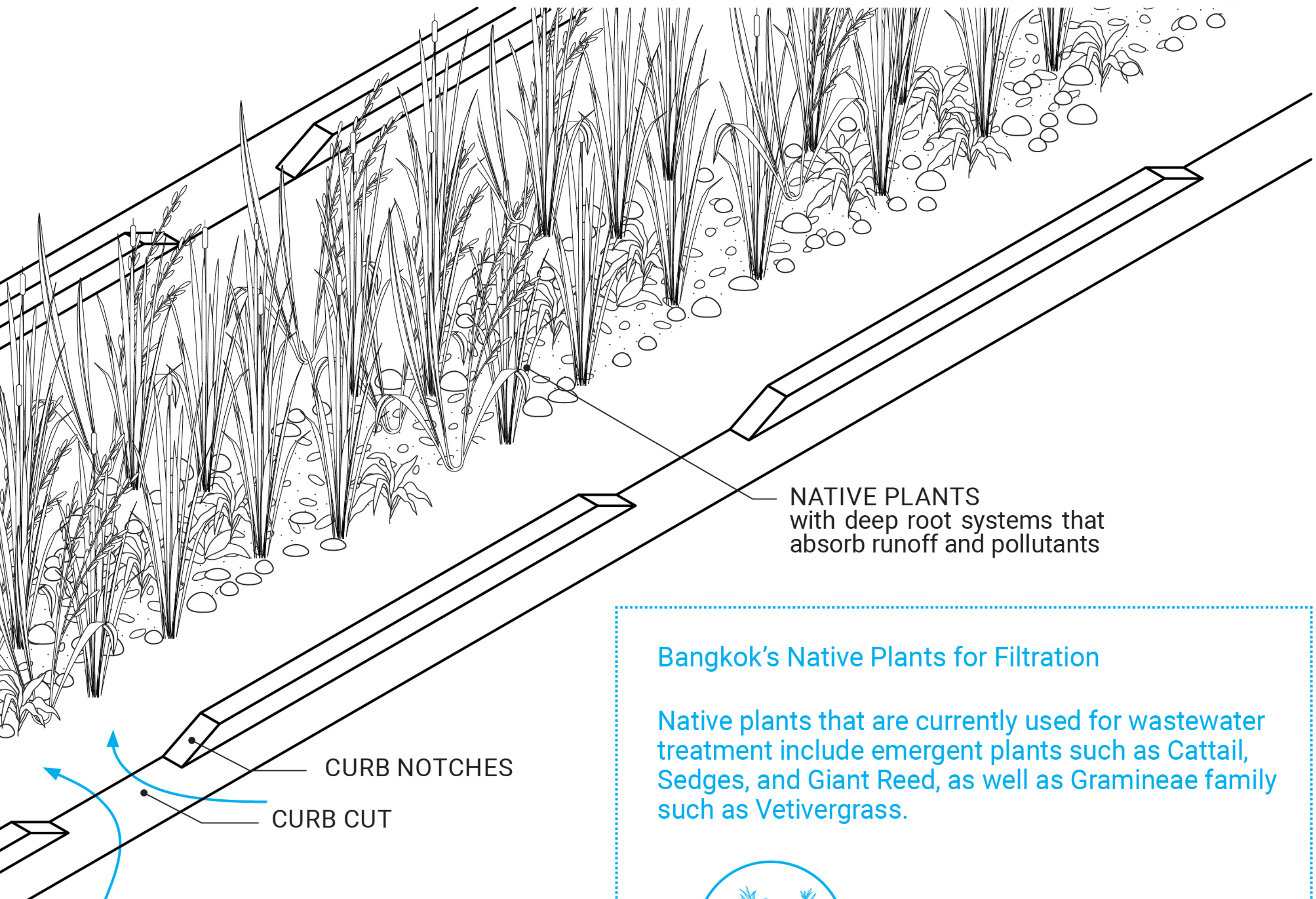
10-20%

RUNOFF REDUCTION

Public / Private Developer for Private Roads

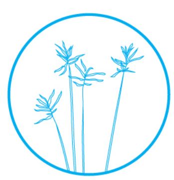
BMA for Public Road

KEY STAKEHOLDERS

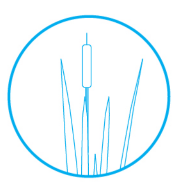


Bangkok's Native Plants for Filtration

Native plants that are currently used for wastewater treatment include emergent plants such as Cattail, Sedges, and Giant Reed, as well as Gramineae family such as Vetivergrass.

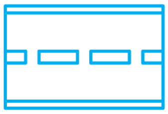


Sedges
(Cyperus corymbosus Rottb.)



Narrowleaf Cattail
(Typha angustifolia L.)

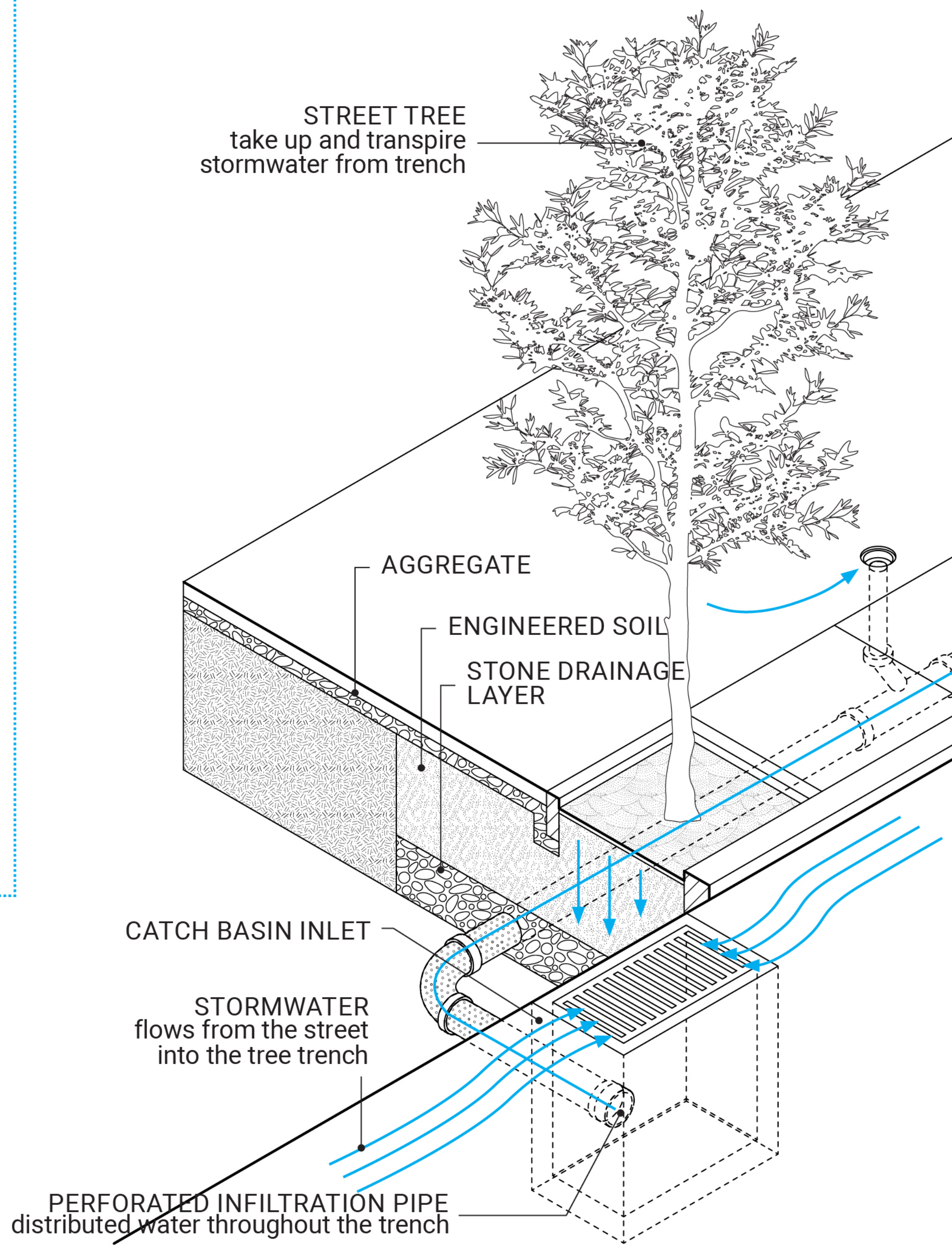
TREE TRENCHES



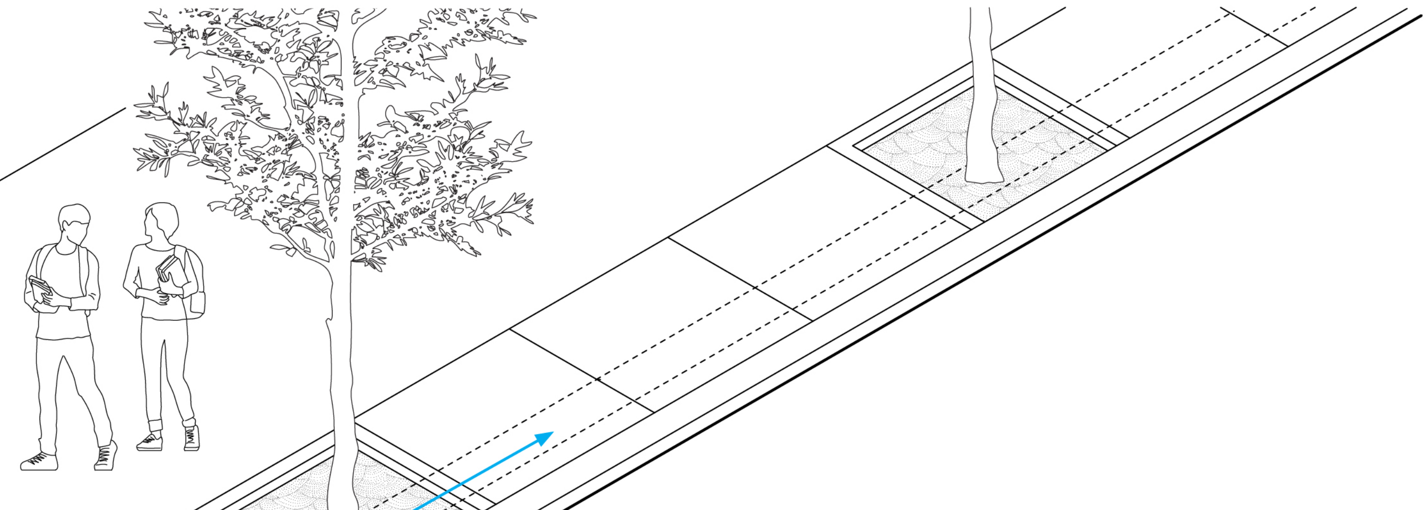
TYPOLOGY

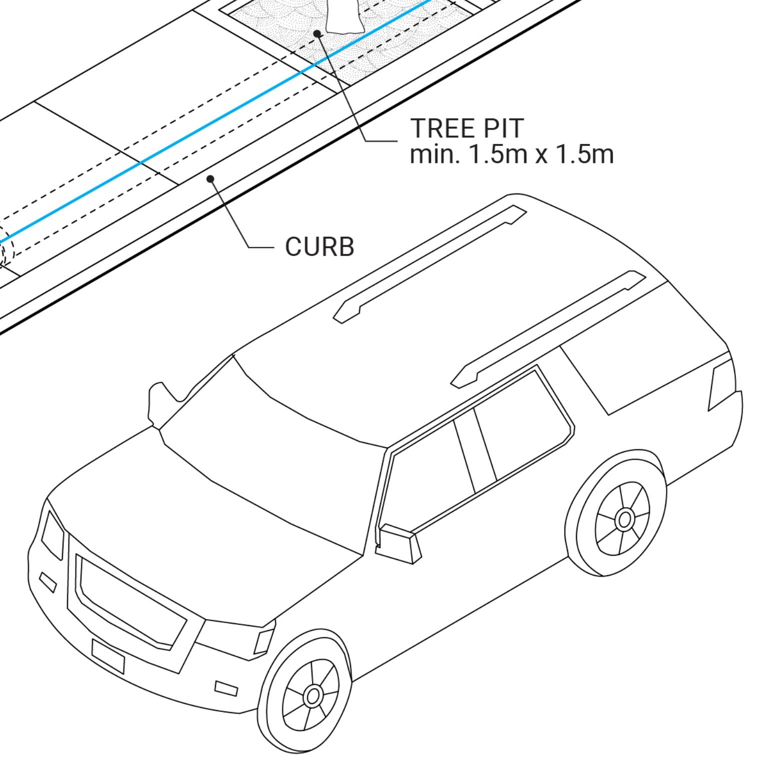
PERFORMATIVE FACTORS

A stormwater tree trench is a network of trees connected by an underground infiltration system. This system allows trees to thrive in urban areas with limited space, such as sidewalks. The surface of a stormwater tree trench looks like a row of tree pits, but underneath the sidewalk lies a sophisticated system to manage runoff. The trench is lined with permeable geotextile fabric and filled with gravel, soil, and trees. When it rains, a special inlet diverts runoff into the tree trench, where it is absorbed by the trees and slowly infiltrates through the bottom. In case of extreme flood events, a bypass system diverts excess runoff directly into the existing stormwater network.



$$ - $$$	40-100%	Public / Private Developer for Private Roads BMA for Public Road
COST FACTOR	RUNOFF REDUCTION	KEY STAKEHOLDERS



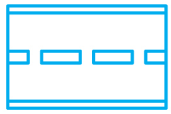


Bangkok's Native Trees for Sidewalks

Planting a sidewalk tree creates multiple benefits for urban areas. The suitable trees for planting along roadsides are those with medium height, beautiful bushy shapes, moderate growth rates, and best to avoid deciduous tree.

Spanish Cherry (Mimusops elengi)

STREET CISTERN

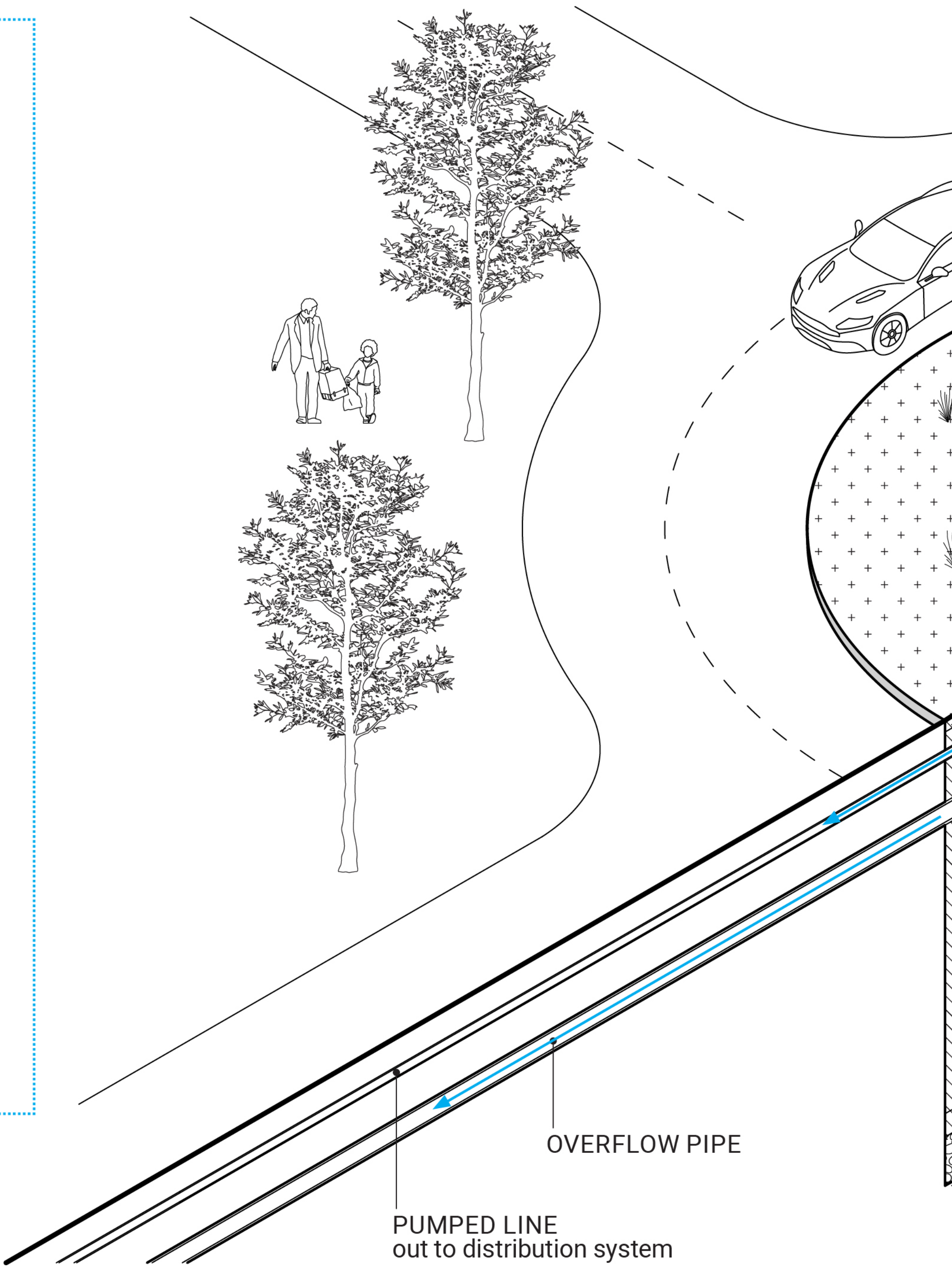


TYPOLOGY

PERFORMATIVE FACTORS

Underground street cistern, known in Thai as “Water Bank” or “Underground Monkey Cheek” is an alternative way to find a reservoir where there are no open space available. When the rain stops or the water level in the canal drops, the stored water is pumped out into the canal and eventually discharge to the Chao Phraya River.

The core of a cistern system is a water-storage tank with a water delivery point, a properly sized overflow pipe, an accessible serviceway, a working vent, an operational water-pump line, pump and tank walls. The tank can be connected to the existing drainage system, or a new drainage pipe can be installed from the storage pond directly to the canal.The advantages of storing water underground are frost protection, invisibility, landscape versatility, however, these benefits comes at a high cost.



$$$$

COST FACTOR

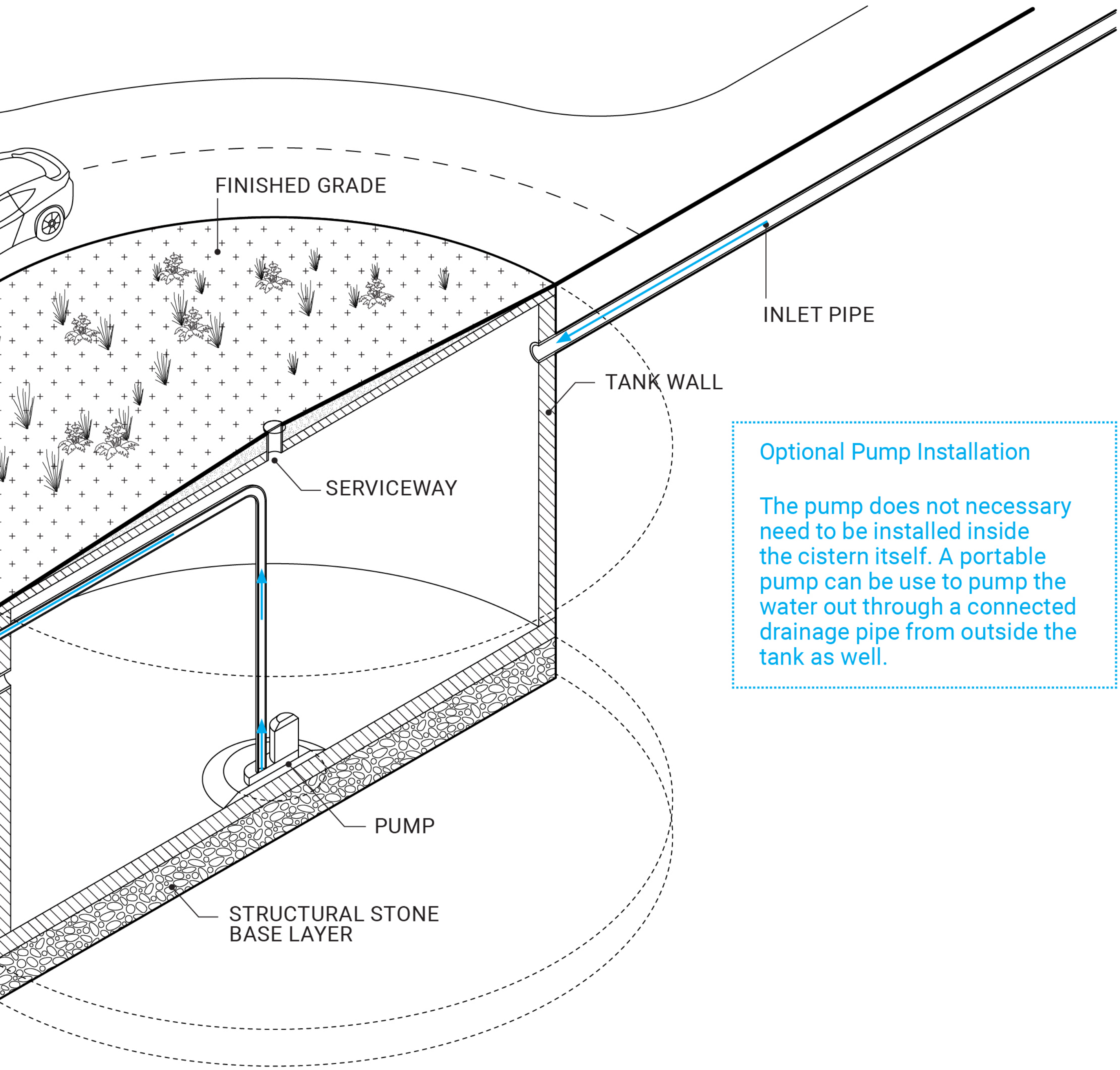
80-100%

RUNOFF REDUCTION

Public / Private Developer for Private Roads

BMA for Public Road

KEY STAKEHOLDERS



Optional Pump Installation

The pump does not necessary need to be installed inside the cistern itself. A portable pump can be use to pump the water out through a connected drainage pipe from outside the tank as well.

WATER CONTAINER

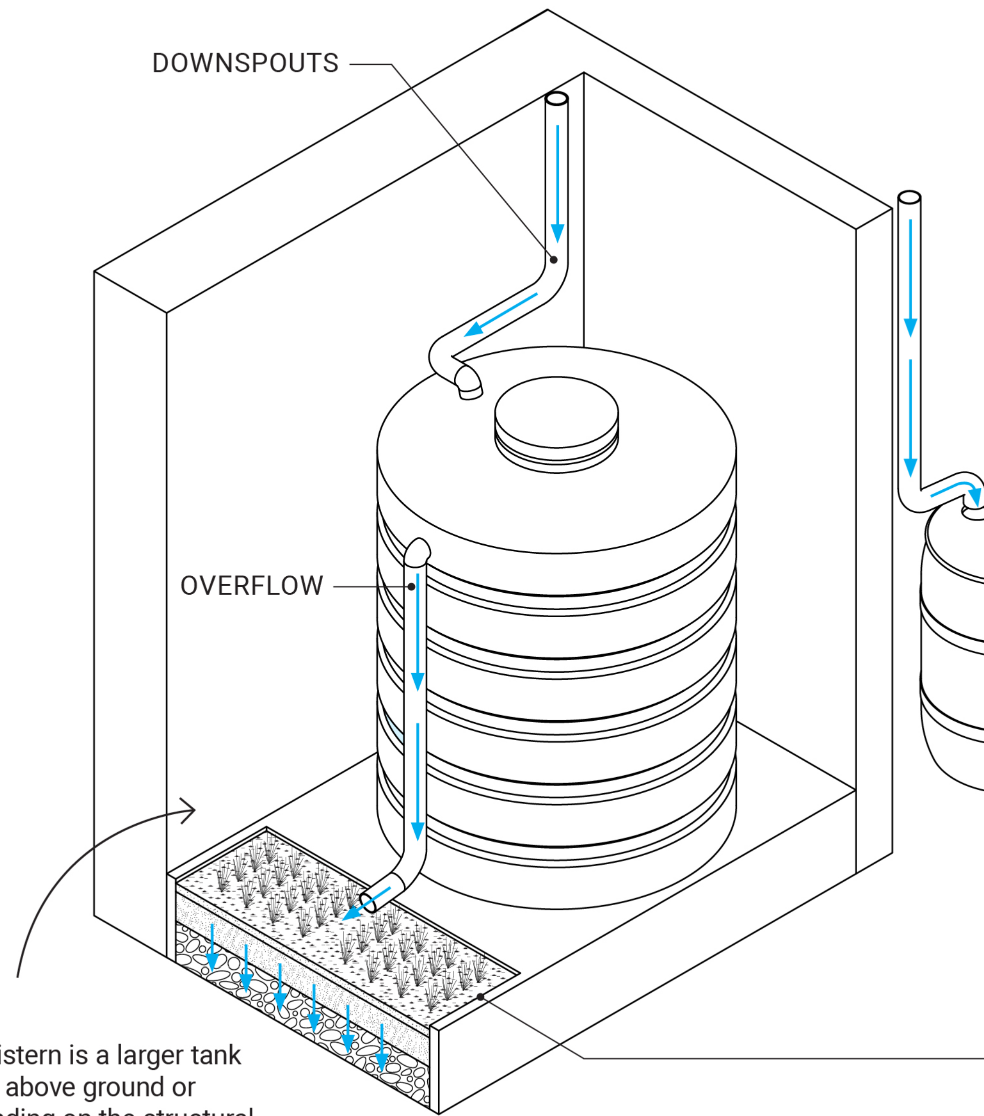
TYPOLOGY

PERFORMATIVE FACTORS

Rainwater harvesting involves collecting runoff from an impervious surface for later use. It's typically done by catching rain from a roof, which can be stored in a container. This simple and low-cost system requires little maintenance but requires household cleanliness. It can work as a standalone supply or supplement limited ground/surface water.

“Although one rain barrel is not going to capture all the water collected from the rooftop, every gallon stored helps. If every house installed a rain barrel, imagine how much water we could save.”

— Department of Drainage and Sewerage, BMA



Rainwater Tank

Rainwater Tank or Cistern is a larger tank that can be installed above ground or below ground, depending on the structural capacity of the material.

$ - $$

COST FACTOR

40-100%

RUNOFF REDUCTION

Property Owner

Public / Private Developer

Civil Society

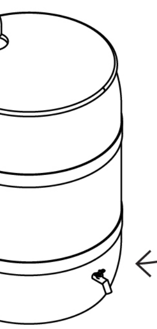
KEY STAKEHOLDERS

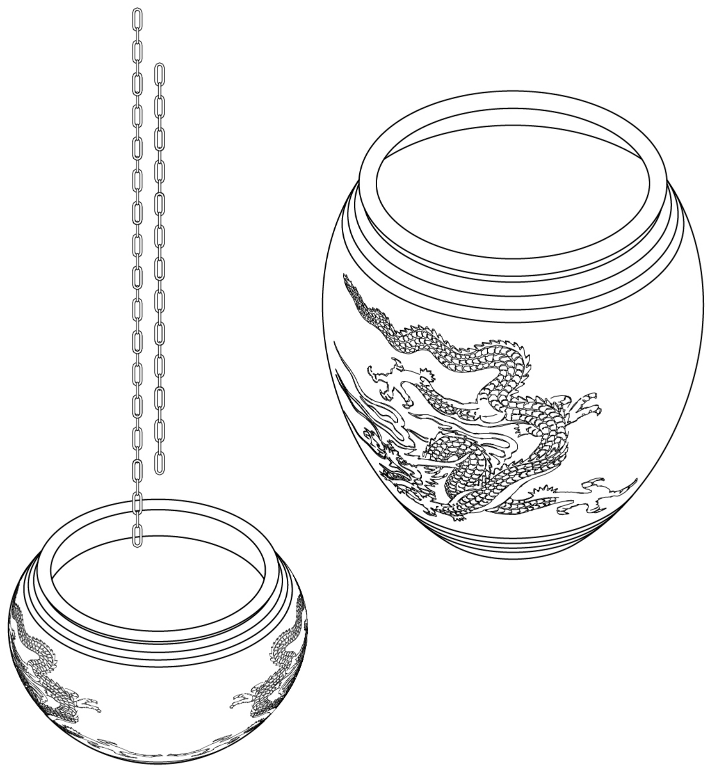
The Thailand Rainwater Jar Programme

In the 1980s, Thailand's government launched the Rainwater Jar Programme to provide an alternative water supply in rural areas. Villagers were trained in jar and tank construction and distributed them to households. The programme's "bottom-up" approach was successful, with 300 million storage jars and tanks built by 1991, providing potable water to millions of families and promoting self-management of household water security.

Rain Barrel

Common sizes for residential use are 50 gallons to 90 gallons. Rain barrels can fill up very quickly. The size and/or number of rain barrels that are needed can be determine base on the size of the roof that will drain to the barrel.





Water-harvesting Earthworks

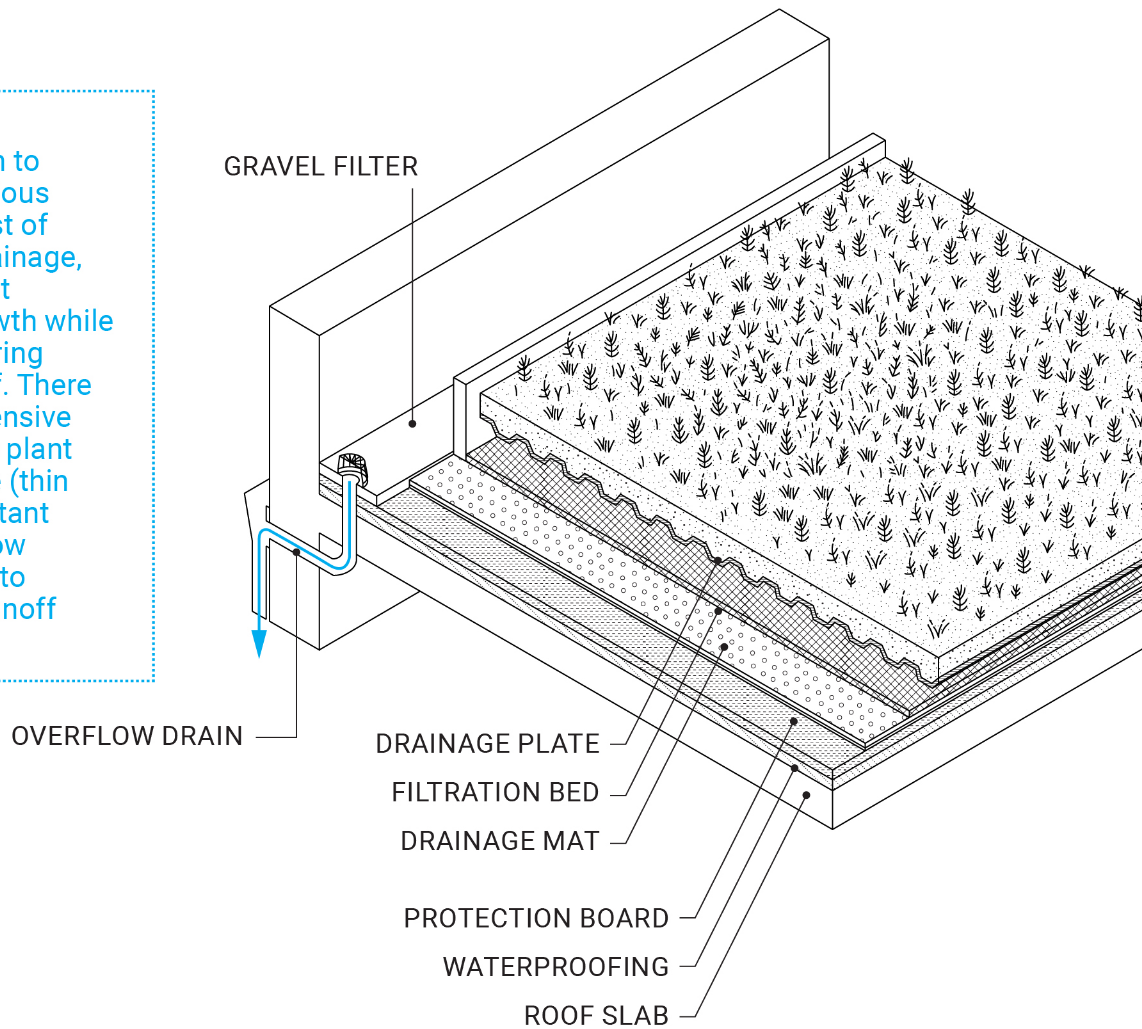
At a minimum, overflow water must be directed away from all foundations. Preferably, directed to other water-harvesting feastures such as rain gardens, swales, etc.

GREEN ROOFS

TYPOLOGY

PERFORMATIVE FACTORS

Green roofs are a sustainable option to traditional impervious roofs. They consist of waterproofing, drainage, and soil layers that support plant growth while capturing and storing stormwater runoff. There are two types: intensive (thick soil, diverse plant life) and extensive (thin soil, drought-resistant plants). An overflow system is needed to manage excess runoff during heavy rain.



$$$

COST FACTOR

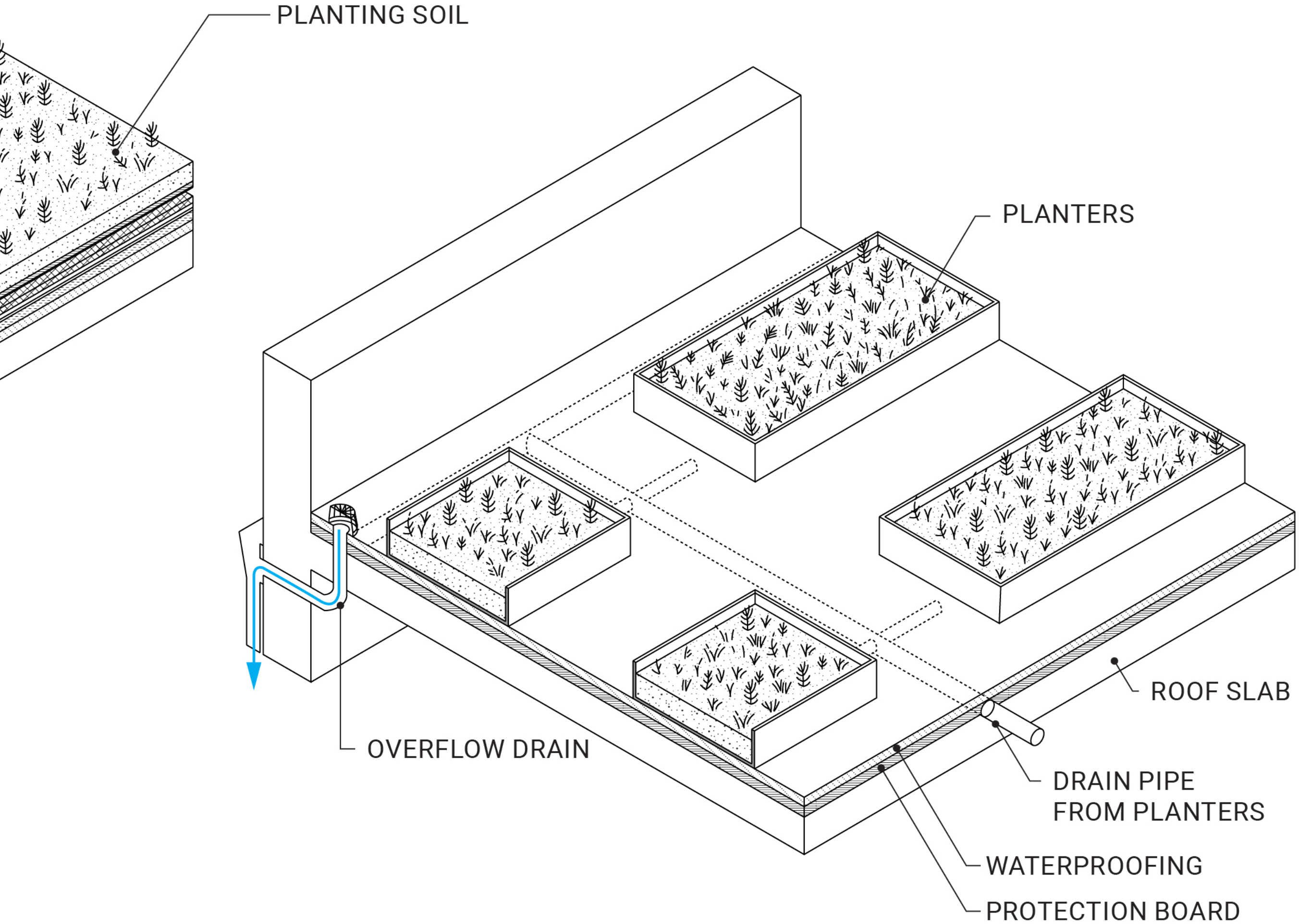
20-40%

RUNOFF REDUCTION

- Property Owner
- Public / Private Developer
- Civil Society

KEY STAKEHOLDERS

Green roofs shall only be used to replace traditional impervious roof surfaces. They shall not be used to treat any stormwater runoff generated elsewhere on the development site.



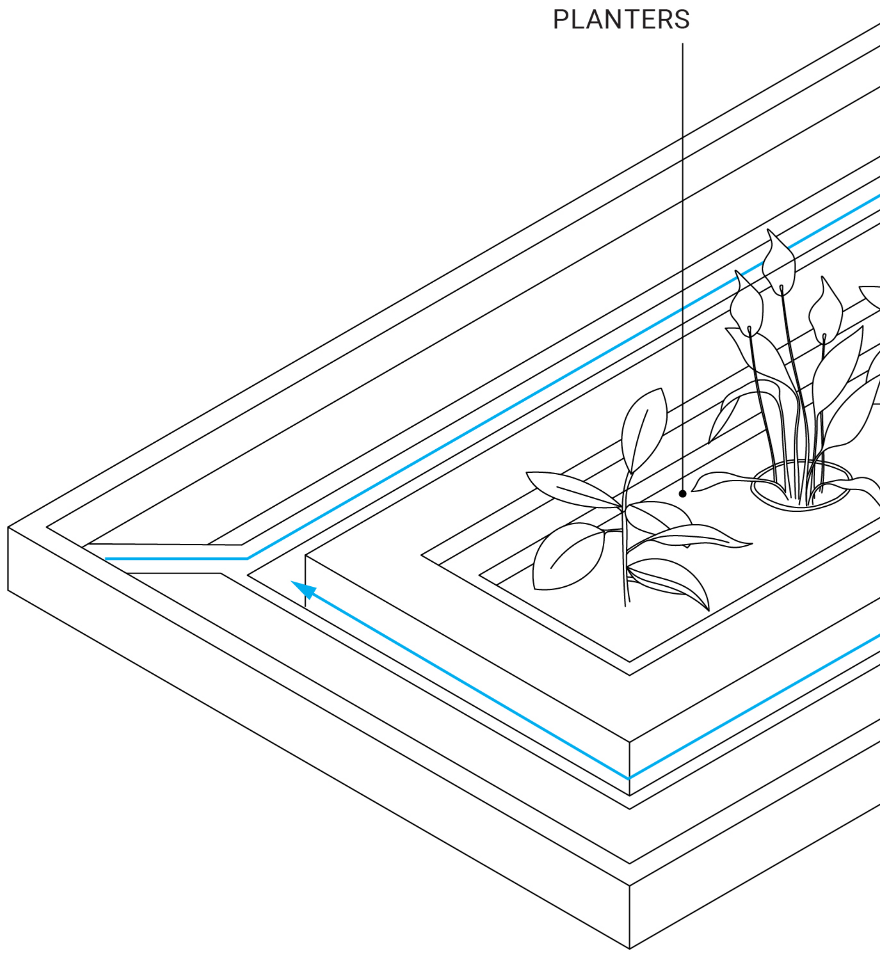
MONKEY BASINS

TYPOLOGY

PERFORMATIVE FACTORS

Monkey Basins are meticulously articulated aesthetic landscapes for holding and storing rainwater. The system comprises a sunken space that is integrated within the open areas of a building. It is an effective way to reduce runoff volumes and improve storage capacities within the building. Monkey Basins can have varying design variants. For large buildings with large rooftop spaces, Monkey Basins can become an infrastructural amenity as well as a public space.

Monkey Basins are designed to act as holding ponds that retain the water for short periods of time before discharging it into an underground storage unit.



$$ - $$$

COST FACTOR

40-100%

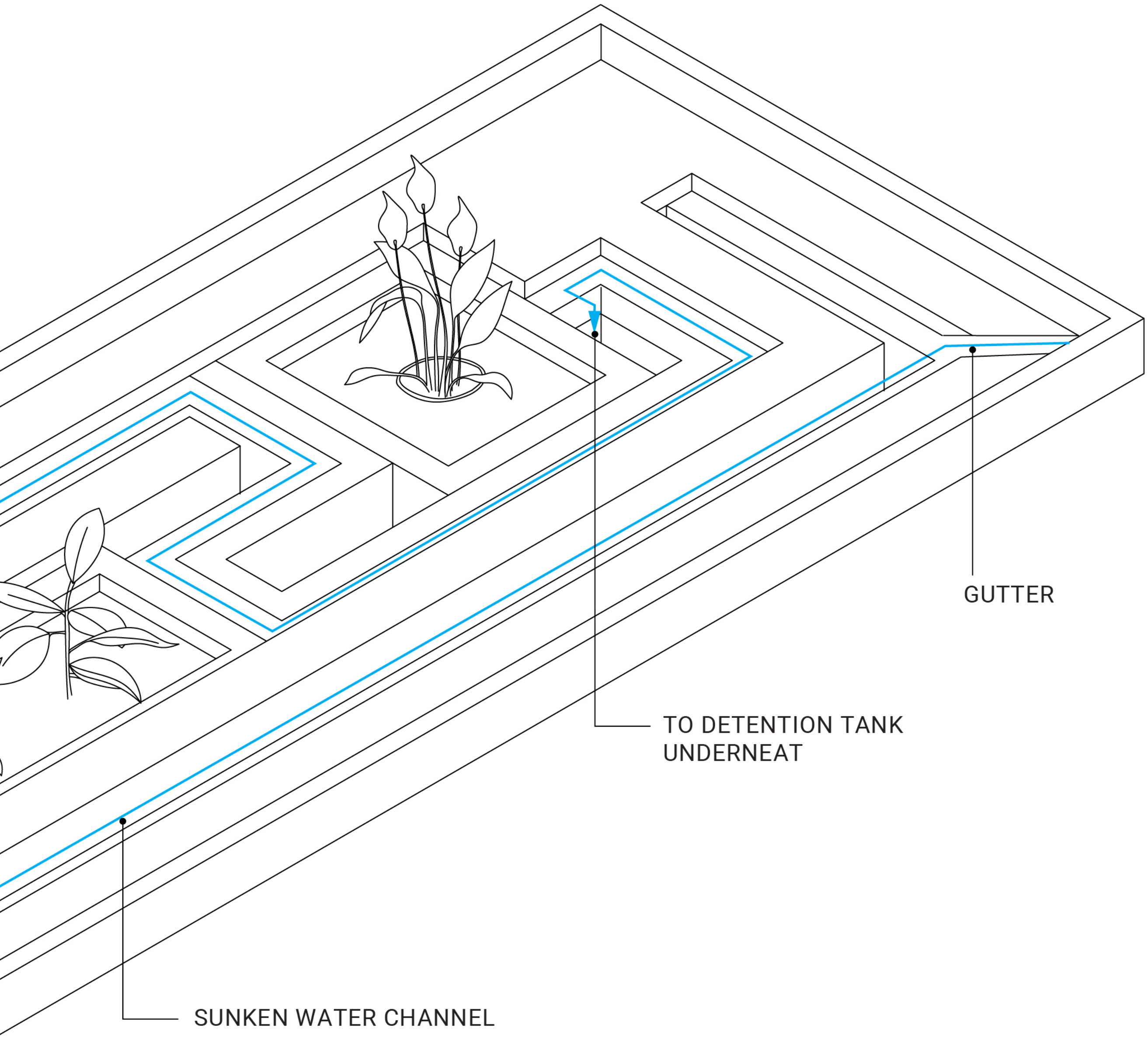
RUNOFF REDUCTION

Property Owner

Public / Private Developer

Civil Society

KEY STAKEHOLDERS

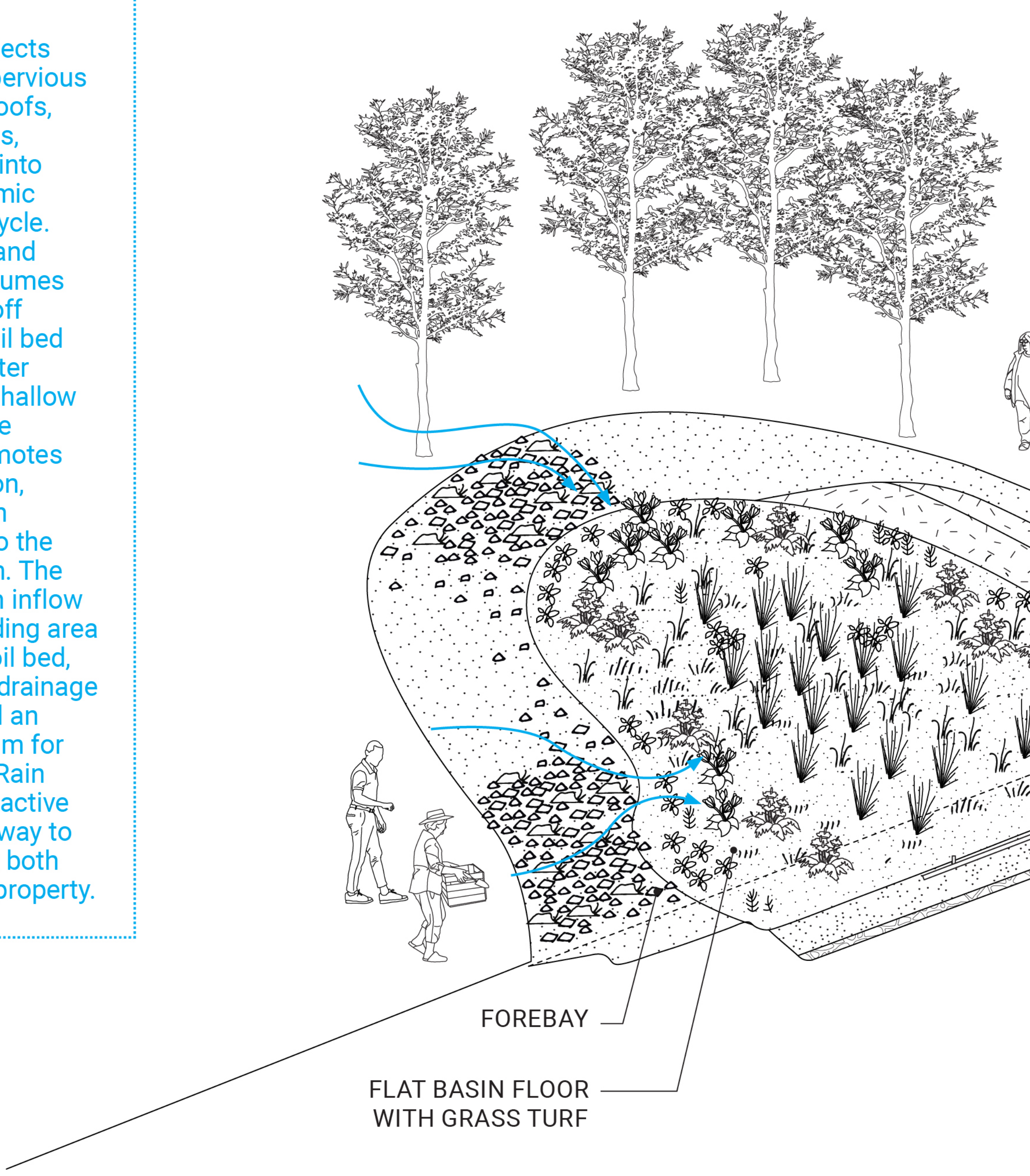


RAIN GARDENS

TYPOLOGY

PERFORMATIVE FACTORS

A rain garden is a depression in the landscape that collects rainwater from impervious surfaces such as roofs, driveways or streets, allowing it to soak into the ground and mimic the natural water cycle. The garden treats and manages small volumes of stormwater runoff using a planting soil bed and materials to filter runoff stored in a shallow depression. A stone drainage layer promotes dispersed infiltration, while an underdrain system connects to the storm drain system. The system includes an inflow component, a ponding area over the planted soil bed, mulch layer, stone drainage layer, plantings and an overflow mechanism for larger rain events. Rain gardens are an attractive and cost-effective way to reduce runoff from both public and private property.



$ - $$$

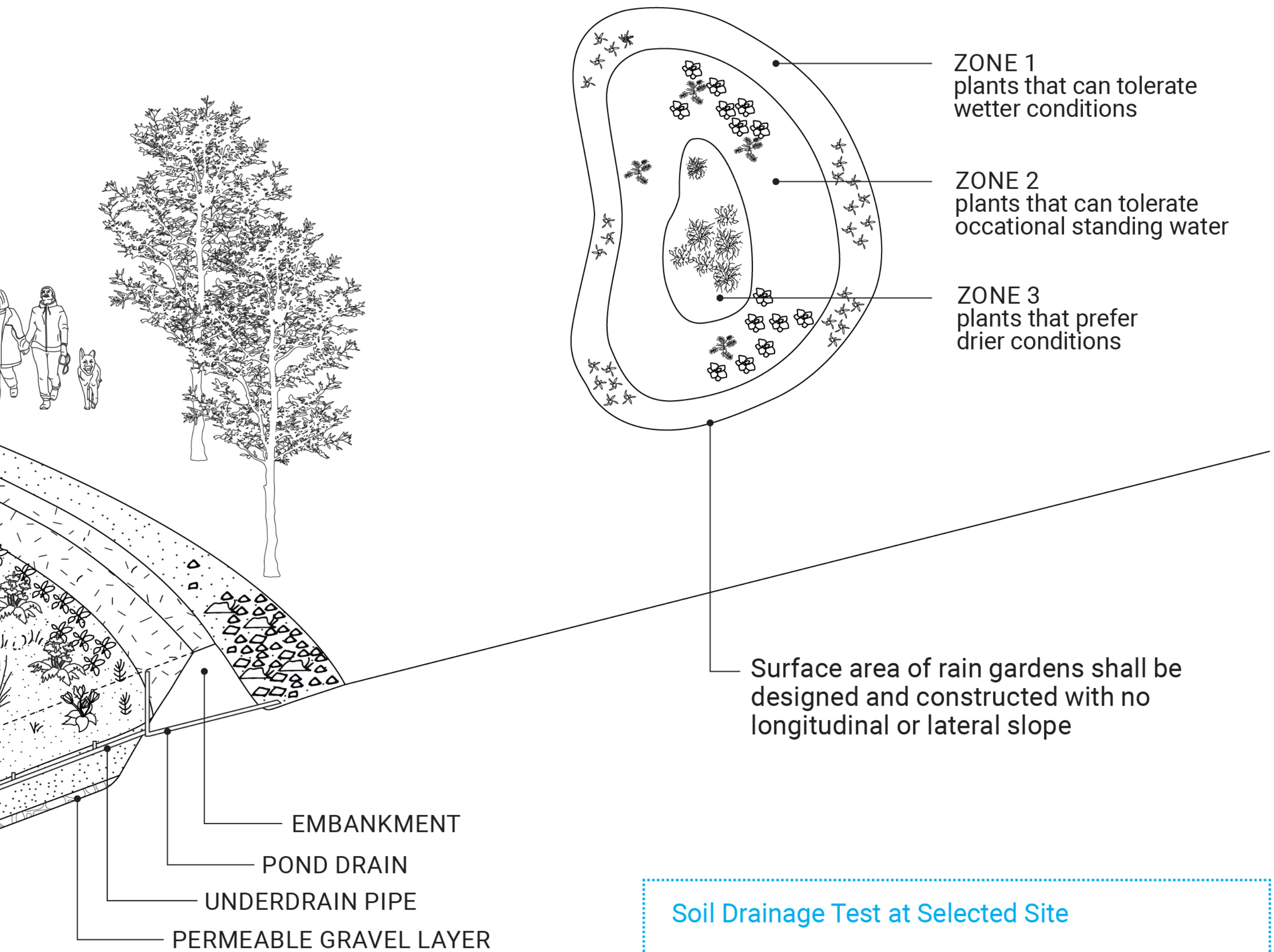
COST FACTOR

20-40%

RUNOFF REDUCTION

- Property Owner
- Public / Private Developer
- Civil Society
- BMA

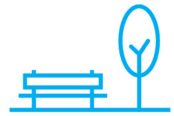
KEY STAKEHOLDERS



Soil Drainage Test at Selected Site

To avoid creating a pond, water needs to soak into the soil at a rate of at least a quarter inch of water per hour. This means a hole six inches deep would need to drain in 24 hours.

MONKEY CHANNELS

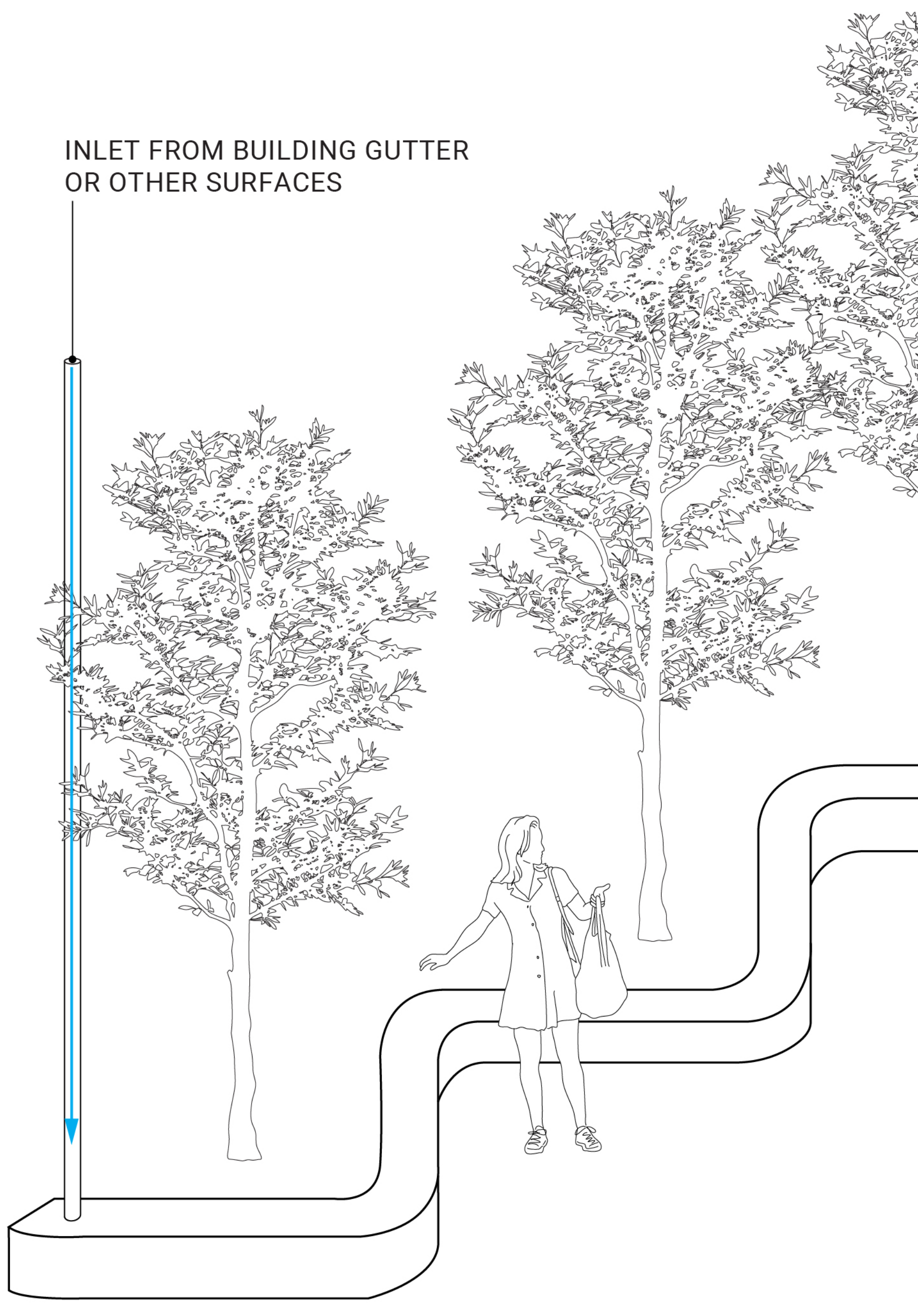


TYPOLOGY

PERFORMATIVE FACTORS

Monkey Channel is a type of urban furniture. The design stems from how the drainage systems works, by incorporating elements that help delay the flow of water during storm events. The piece is constructed with a series of ridges and curves, designed to slow down and redirect the flow of water. These ridges and curves create a channel that collects and delays the flow of water until it reaches the public drainage system, helping to prevent flooding and damage to urban infrastructure.

The channels are also flexible in its placement, meaning that it can be installed in a variety of locations throughout the city. It can be an be attached to the side of a building or placed in areas prone to flooding, helping to alleviate the risk of damage and costly repairs. It can also be placed in public spaces, serving as both functional and visually interesting additions to the urban landscape.



$ - $$

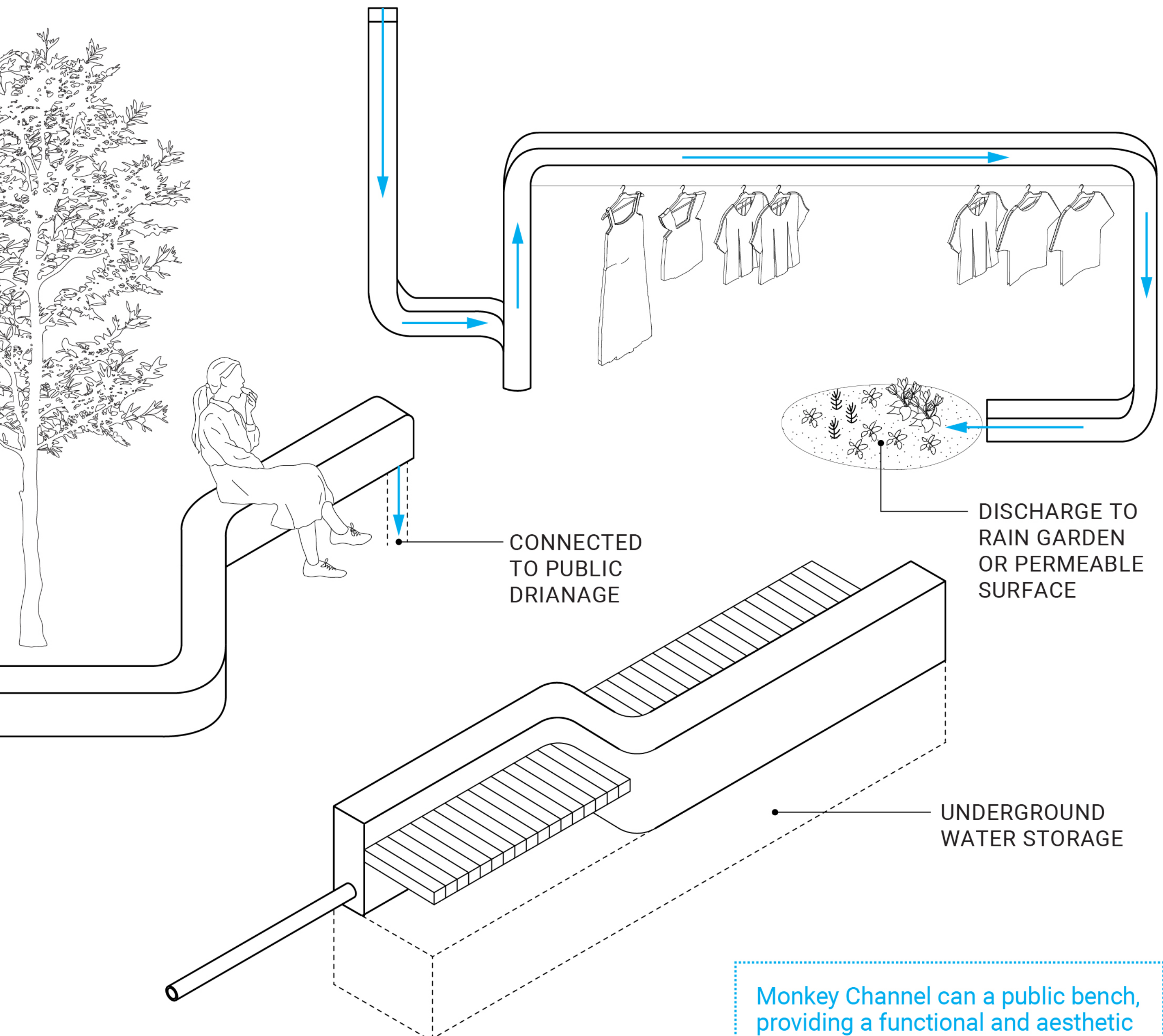
COST FACTOR

20-100%

RUNOFF REDUCTION

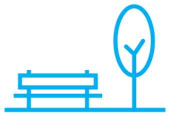
- Property Owner
- Public / Private Developer
- Civil Society
- BMA

KEY STAKEHOLDERS



Monkey Channel can a public bench, providing a functional and aesthetic addition to the cityscape.

MONKEY CANOPY

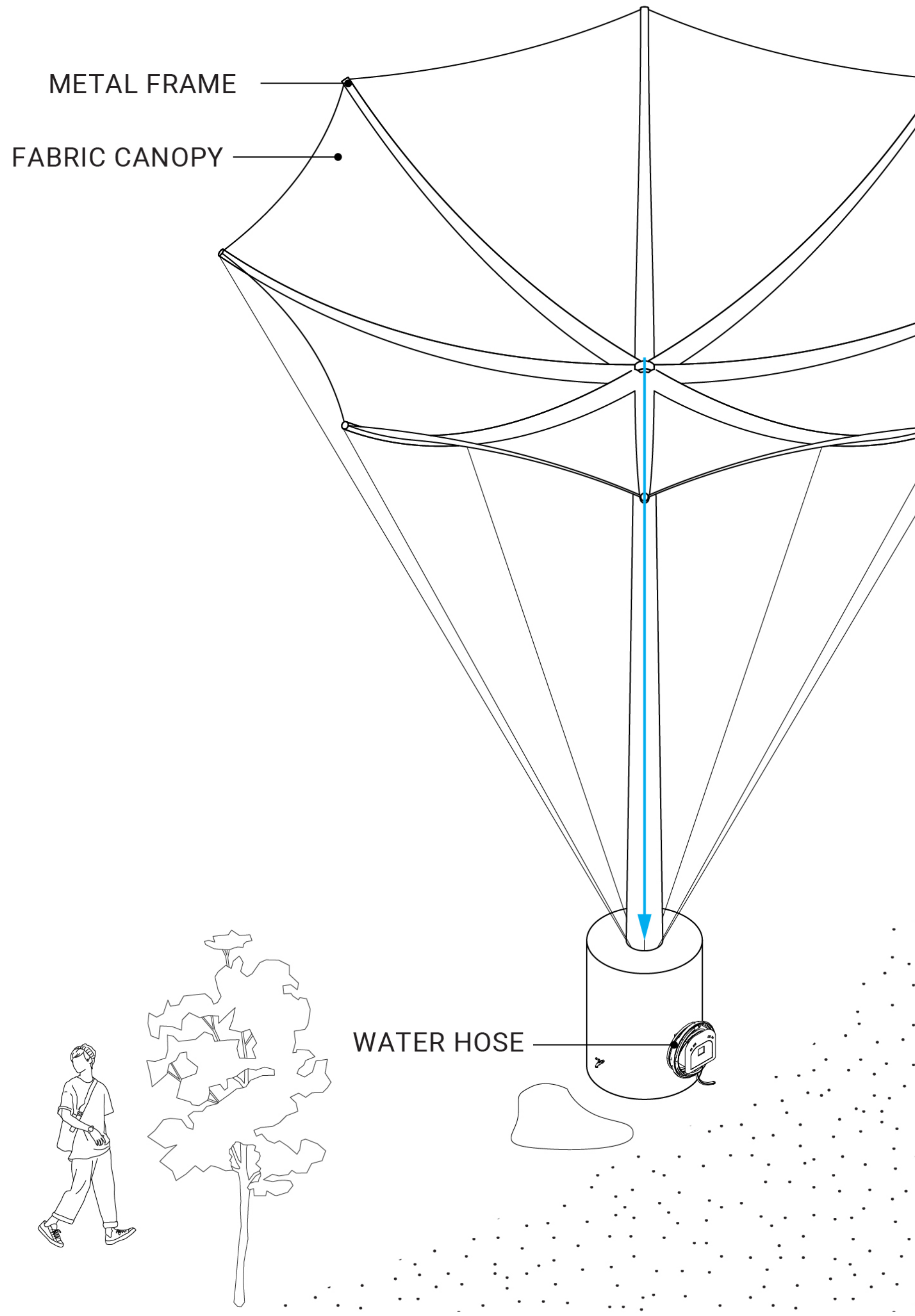


TYPOLOGY

PERFORMATIVE FACTORS

Monkey Channel is a multipurpose urban infrastructure that aims to mitigate the effects of urban heat and provide a comfortable public space for the community. The canopy is designed to capture and store rainwater at its base, which can then be used for various purposes. This innovative infrastructure can be installed in different locations throughout Bangkok to help cool down the surrounding areas and provide seating space for the public.

The canopy's structure is designed to provide ample shade, as well as capture and store rainwater, which can be reused for various purposes. The water can be used to irrigate the vegetation around the area, which helps to improve the local microclimate, or it can be used as a cistern during fire events, helping to support firefighting efforts.



$ - $$

COST FACTOR

20-40%

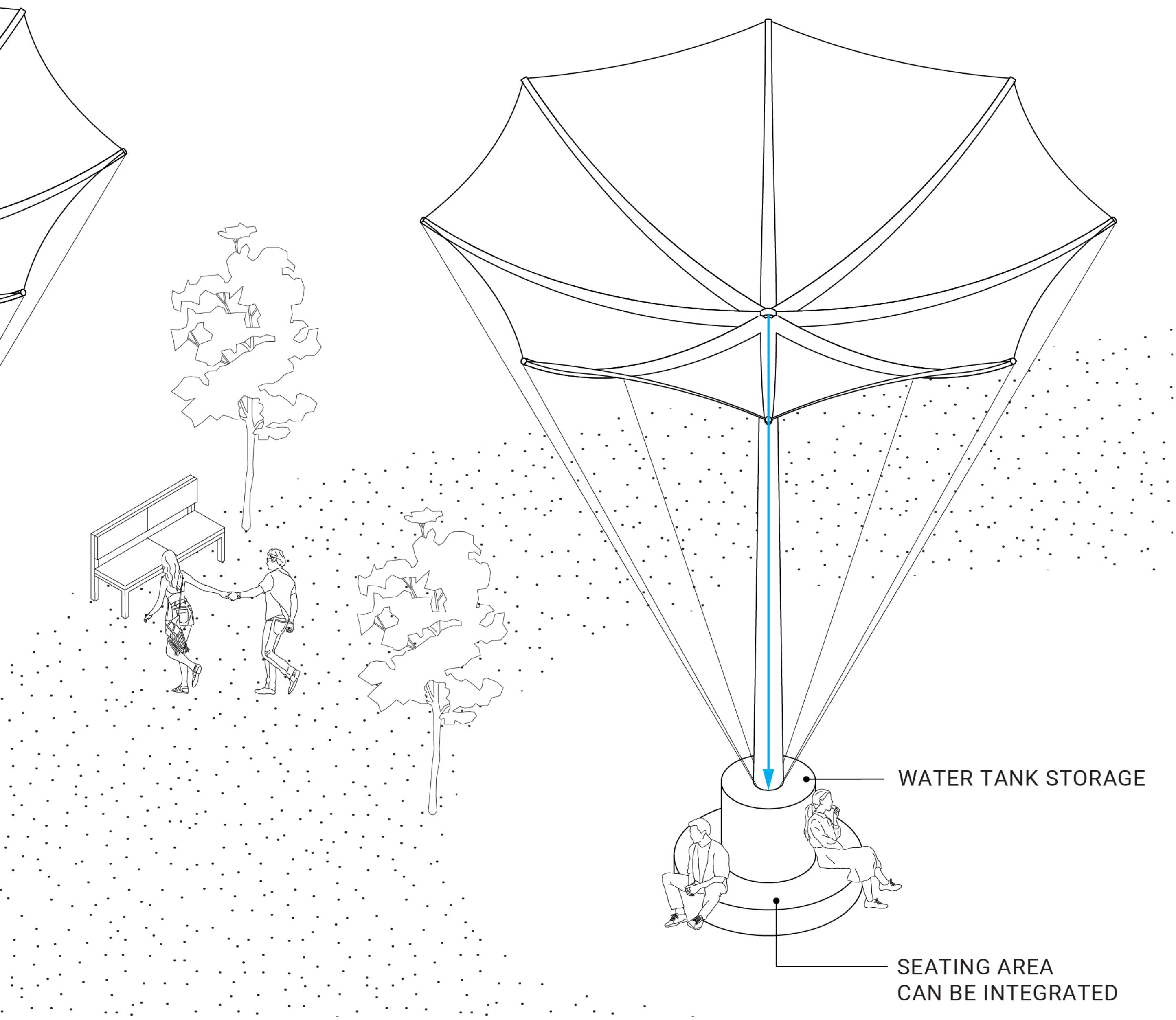
RUNOFF REDUCTION

Public / Private Developer

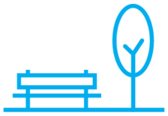
Civil Society

BMA

KEY STAKEHOLDERS



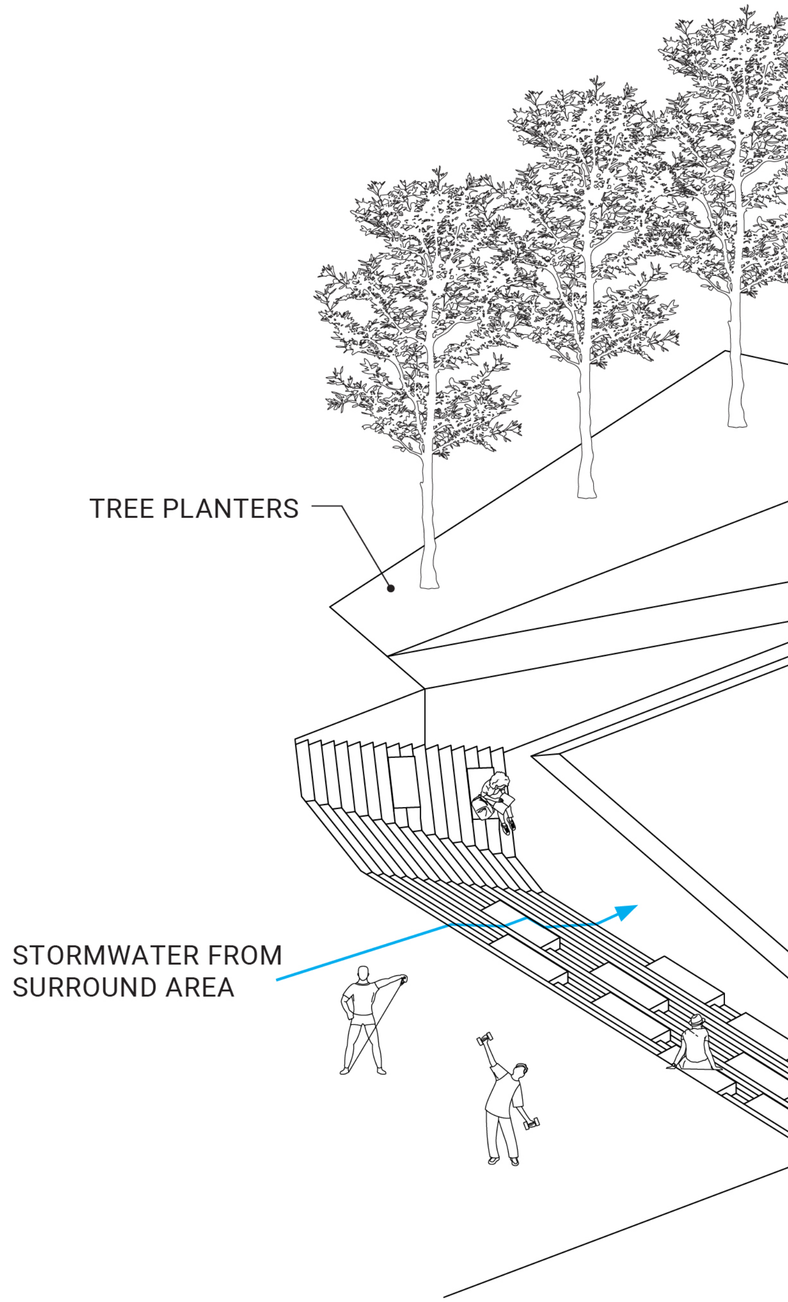
SUNKEN PLAZA



TYPOLOGY

PERFORMATIVE FACTORS

Sunken plazas offer an opportunity to create detention ponds in public areas. These architectural/landscape features have a drainage system and both hardscape and softscape elements. They form a depression in the urban fabric that detains stormwater runoff and also serve as a public space during dry periods. Sunken plazas creatively celebrate rain by showcasing water circulation in playful ways, making water a prominent part of the public realm. During heavy rainfall, they hold stormwater, preventing it from overloading the public sewer, and slowly release it back into the system through gutter and underground pipes or into the aquifer if possible.



$$ - $$$

COST FACTOR

40-100%

RUNOFF REDUCTION

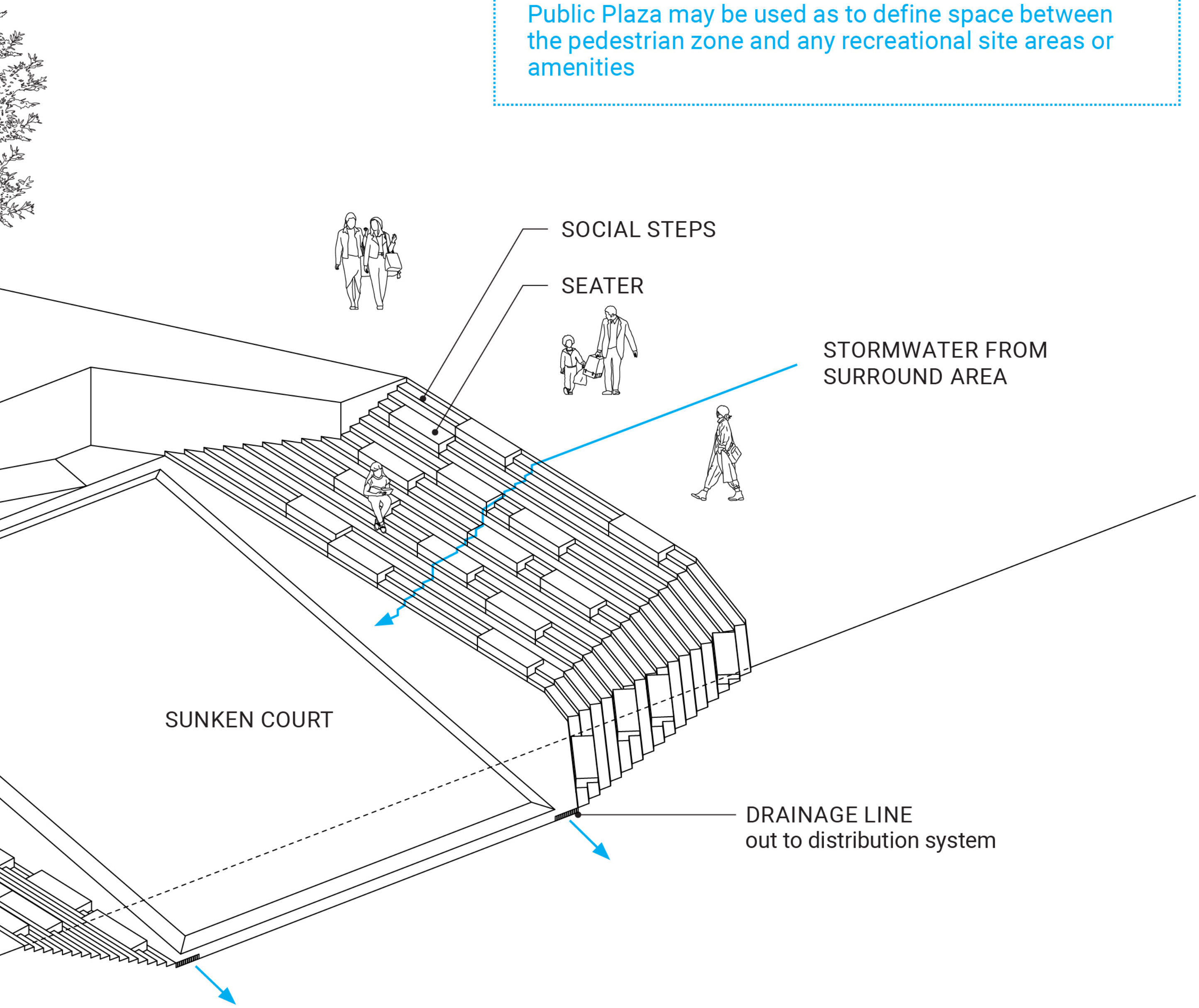
Property Owner

Public / Private Developer

Civil Society

KEY STAKEHOLDERS

Public Plaza may be used as to define space between the pedestrian zone and any recreational site areas or amenities



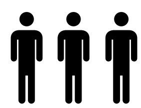
CHAPTER 5: Toolkit Demonstration Project

The main objective of this demonstration project is to showcase the practical implementation of 'Monkey Cheeks' infrastructure at a site scale, with the aim of setting a precedent for other districts in Bangkok. A suitable location has been identified for this project, with the district of 'Pom Prap Sattru Phai' selected as the proposed site. Located in the heart of Bangkok, 'Pom Prap Sattru Phai' is one of the 50 districts bordered by the districts of Samphanthawong, Bang Rak, Pathum Wan, Ratchathewi, and Dusit. The district's diverse mix of building typologies and urban landscape make it an ideal location to demonstrate various Monkey Cheeks typologies. This project will serve as a model for sustainable development in Bangkok and will provide valuable insights into the feasibility and benefits of implementing such infrastructure citywide.

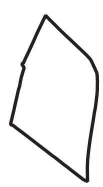
5.1 Site Context and Design Scenarios

Pom Prap Sattru Phai district is the most densely populated district in Bangkok. According to the data from The Bureau of Registration Administration and the BMA Department of City Planning, as of 2021, the district has a population density of approximately 20,746 people per square kilometers.

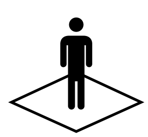
The district has a diverse mix of building typologies. Due to its central location in Bangkok and its long history, the district has a rich architectural heritage with buildings from different eras and styles. One of the most prominent building typologies in the district is shophouses, which are narrow and tall buildings with shops on the ground floor and residential units on the upper floors. These shophouses are common throughout Bangkok and are a unique feature of the city's urban landscape. The district also has several modern high-rise buildings, such as condominiums and office towers, however, none of these include older apartments and townhouses, have green roofs and other forms of rainwater harvesting capacity.



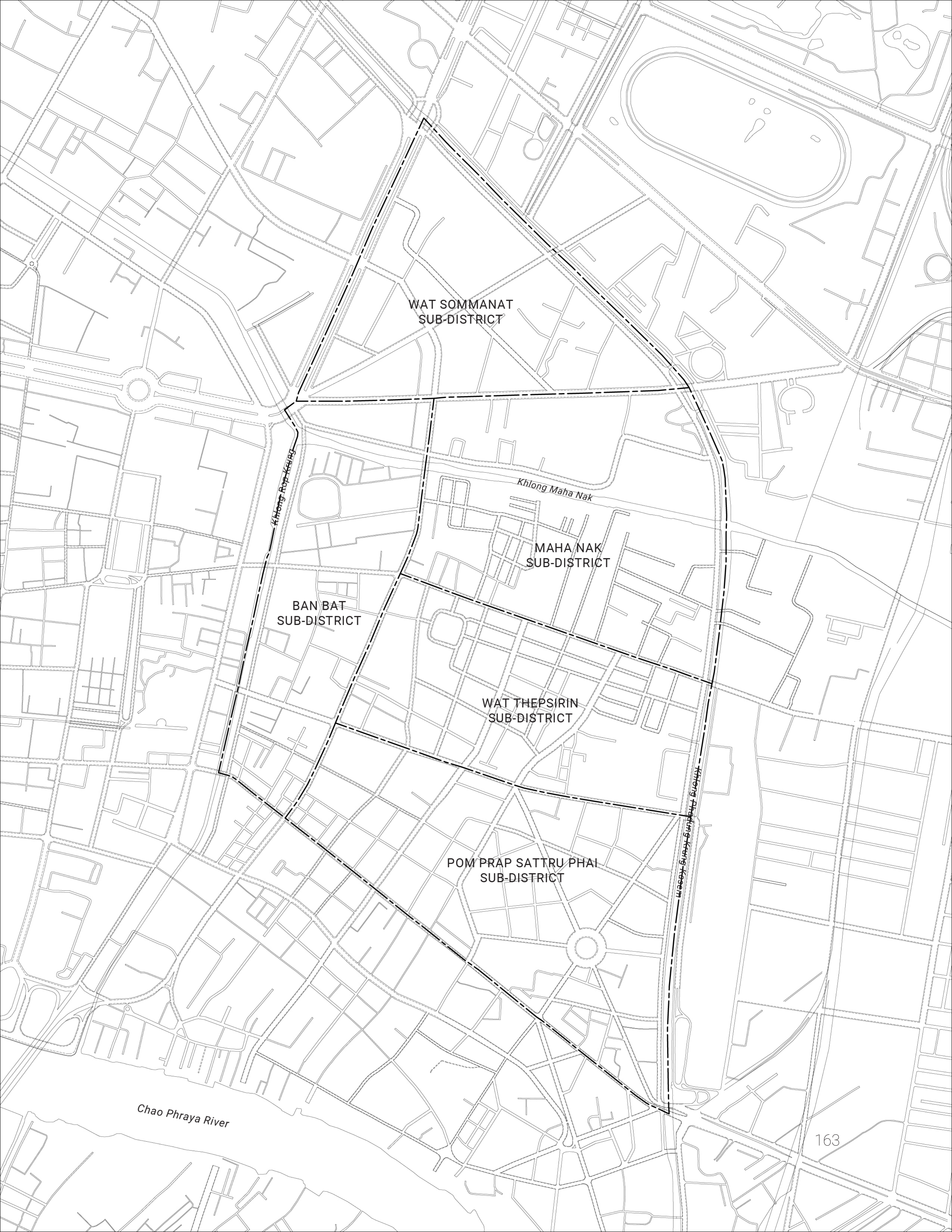
Total population of 40,418

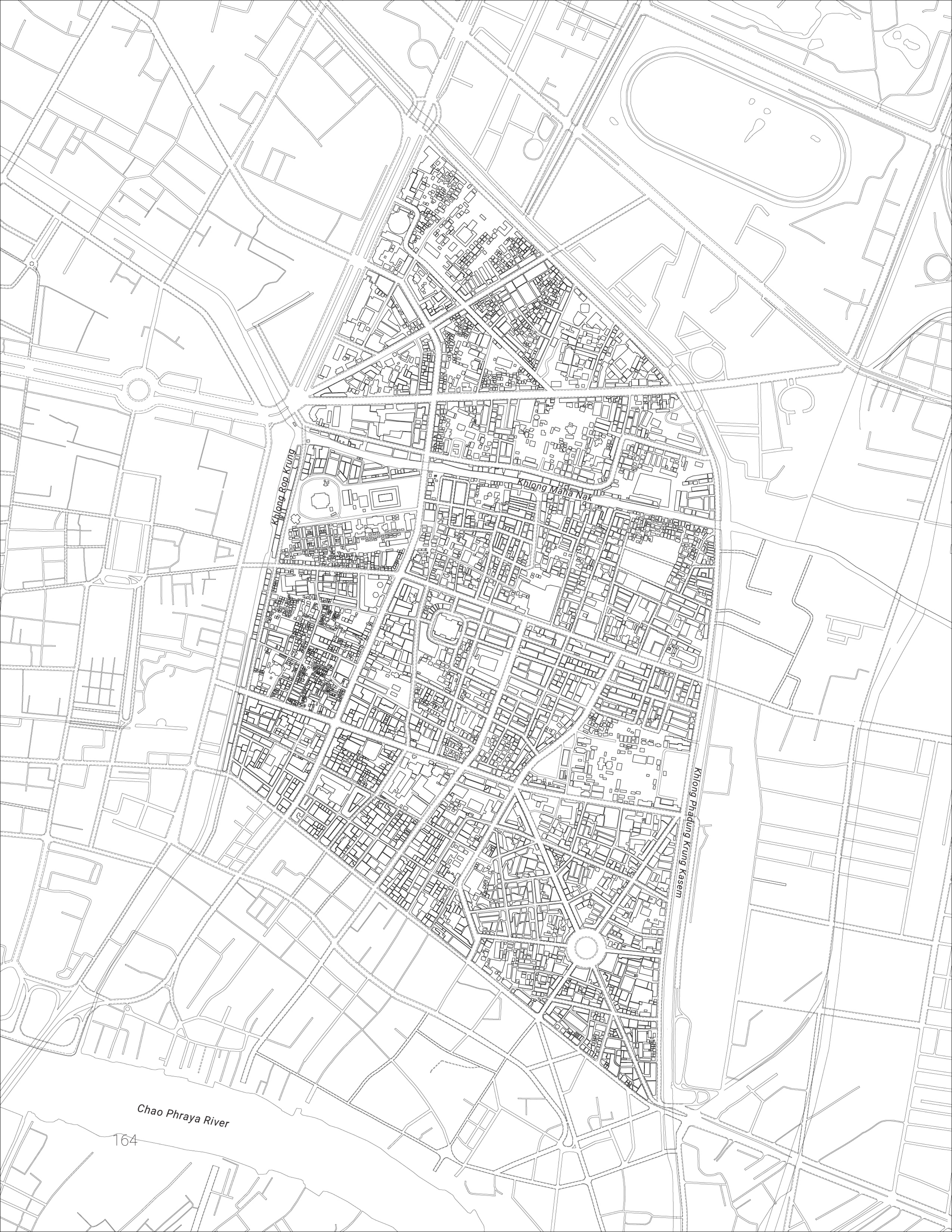


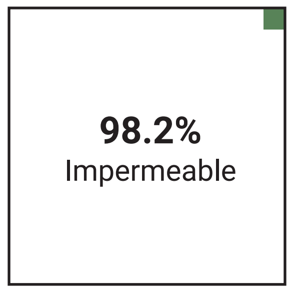
District area of 1.931 km²



Population density of 20,746 / km²

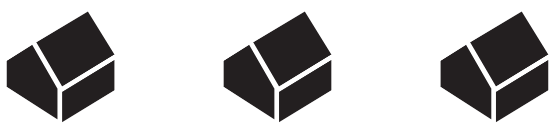

WAT SOMMANAT
SUB-DISTRICT
Khlong Maha Nak
MAHA NAK
SUB-DISTRICT
Khlong Rop Krung
BAN BAT
SUB-DISTRICT
WAT THEPSIRIN
SUB-DISTRICT
Khlong Phadung Krung Kasem
POM PRAP SATTRU PHAI
SUB-DISTRICT
Chao Phraya River


Khlong Rop Krung
Khlong Maha Nak
Khlong Phadung Krung Kasem
Chao Phraya River

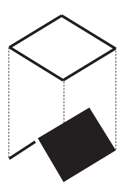


34,778 m² of Green and Open Space

1,896,222 m² of Impermeable Surfaces



5,200 Buildings



1,125,600 m² of Roof Catchment Area

0 Number of Green Roof

5.2 Monkey Cheeks Performance

The majority of Bangkok typically experiences an average rainfall amount between 1,400-1,600 millimeters, with a number of rainy days ranging from 120-130 days. The month with the most rainfall in this province is September, with an average rainfall amount of 300-340 millimeters and 20-21 rainy days.[66] The rainfall amount used in the calculation of the drainage system is based on the below table. For general area, return period of 2 years is use, and the return period of 5 years for the primary drainage area.[67]

Return Period (year)	Rainfall Period								
	5 min	10 min	15 min	30 min	1 hr	2 hr	6 hr	12 hr	24 hr
2	11.3	20.2	25.0	42.5	58.7	72.4	85.8	90.0	93.6
	(135.5)	(121.1)	(99.8)	(84.9)	(58.7)	(36.2)	(14.3)	(7.5)	(3.9)
5	14.1	24.3	31.7	54.3	76.0	95.0	114.0	120.0	122.4
	(168.9)	(152.0)	(126.7)	(108.6)	(76.0)	(47.5)	(19.0)	(10.0)	(5.1)
7	14.9	26.9	33.7	58.0	81.5	102.2	123.0	129.6	134.4
	(178.3)	(161.4)	(134.9)	(115.9)	(81.5)	(51.1)	(20.5)	(10.8)	(5.6)
10	15.7	28.4	35.7	61.5	86.8	109.2	132.0	139.2	144.0
	(188.3)	(170.2)	(142.7)	(122.9)	(86.8)	(54.6)	(22.0)	(11.6)	(6.0)
12	17.1	31.0	39.2	67.9	96.5	122.4	149.4	157.2	163.2
	(204.9)	(185.9)	(156.9)	(135.7)	(96.5)	(61.2)	(24.9)	(13.1)	(6.8)

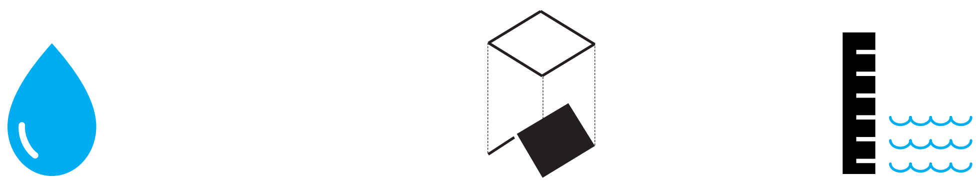
Table 5.1 Accumulated rainfall depth (mm) and rainfall intensities (mm/hr) for each return period. (Source: Department of Drainage and Sewerage BMA, 2021)

The number in parentheses () refers to the rainfall intensity value in mm/s.

[66] Thai Meteorological Department, 2023

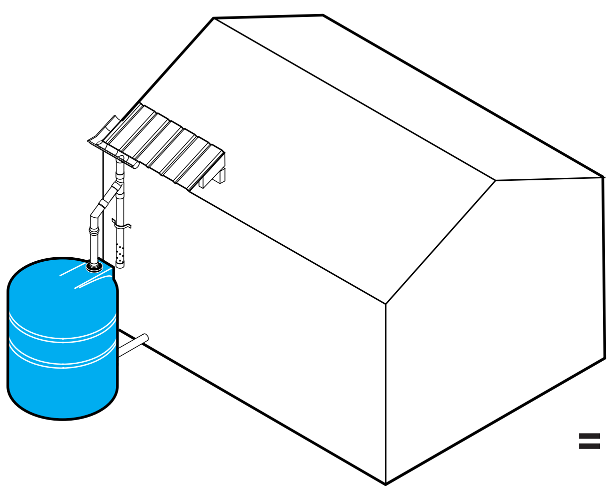
[67] Department of Drainage and Sewerage BMA, 2021

Therefore, if we would assume a 30 minutes rainfall event on a typical 2 years return period, the total amount of buildings in Pom Prap Sattru Phai district would produce a total of 47,838,000 litre of water. For a rough estimation, if each building in the district were to install one standard typically household of 2000 gallon (≈7500 litre) water tank, 39,000,000 litre of water would be saved, that's 82% of the total runoff.



Volume of Water Received = Catchment Area X Rainfall Depth

For example, 1 mm of rain on 1 square metre of roof area produces 1 litre of water

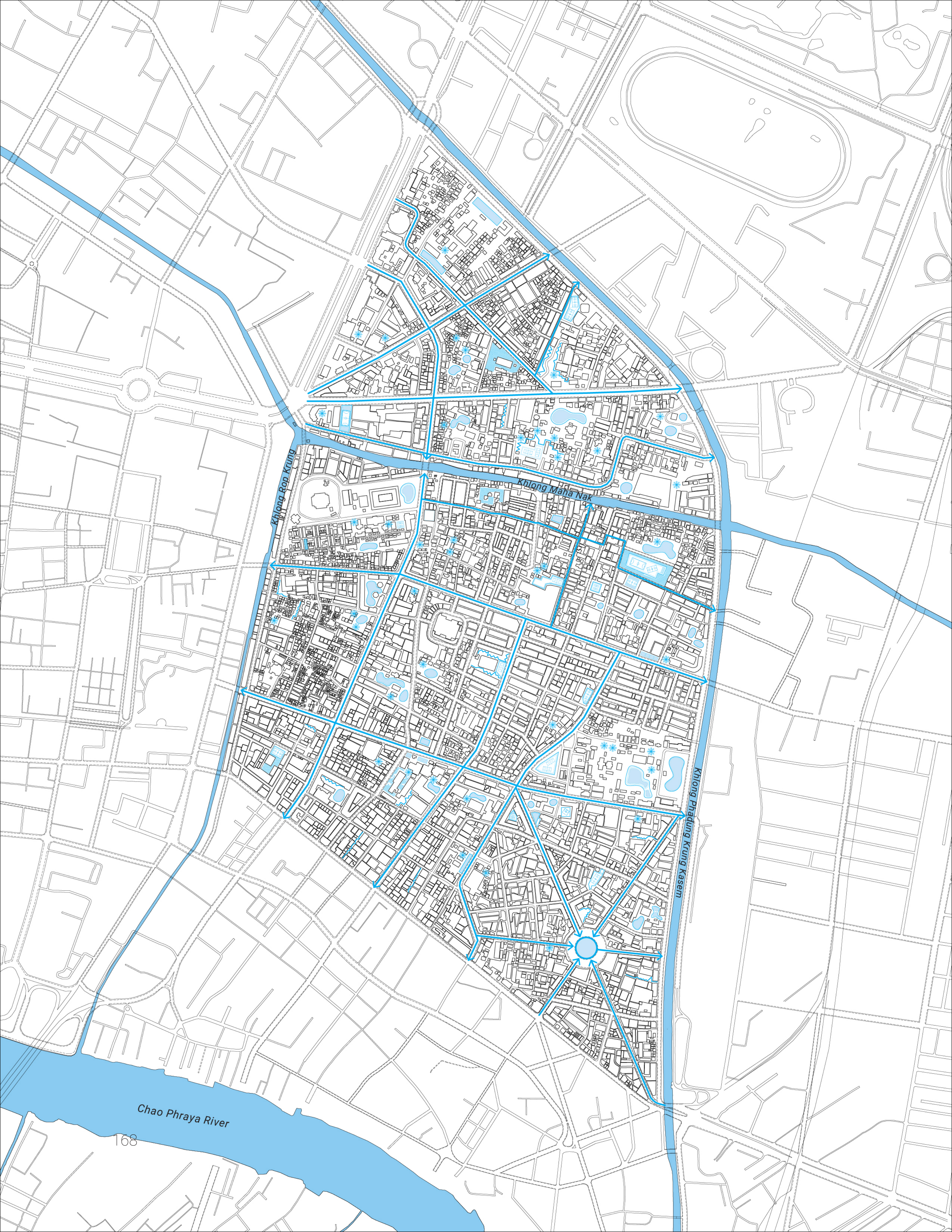


2000 Gallon Tank

X 5200 Buildings

= 82% of Runoff Saved*

*Assumption for 30 minutes rainfall event on a typical 2 years return period



Khlong Rop Krung
Khlong Maha Nak
Khlong Phadung Krung Kasem
Chao Phraya River

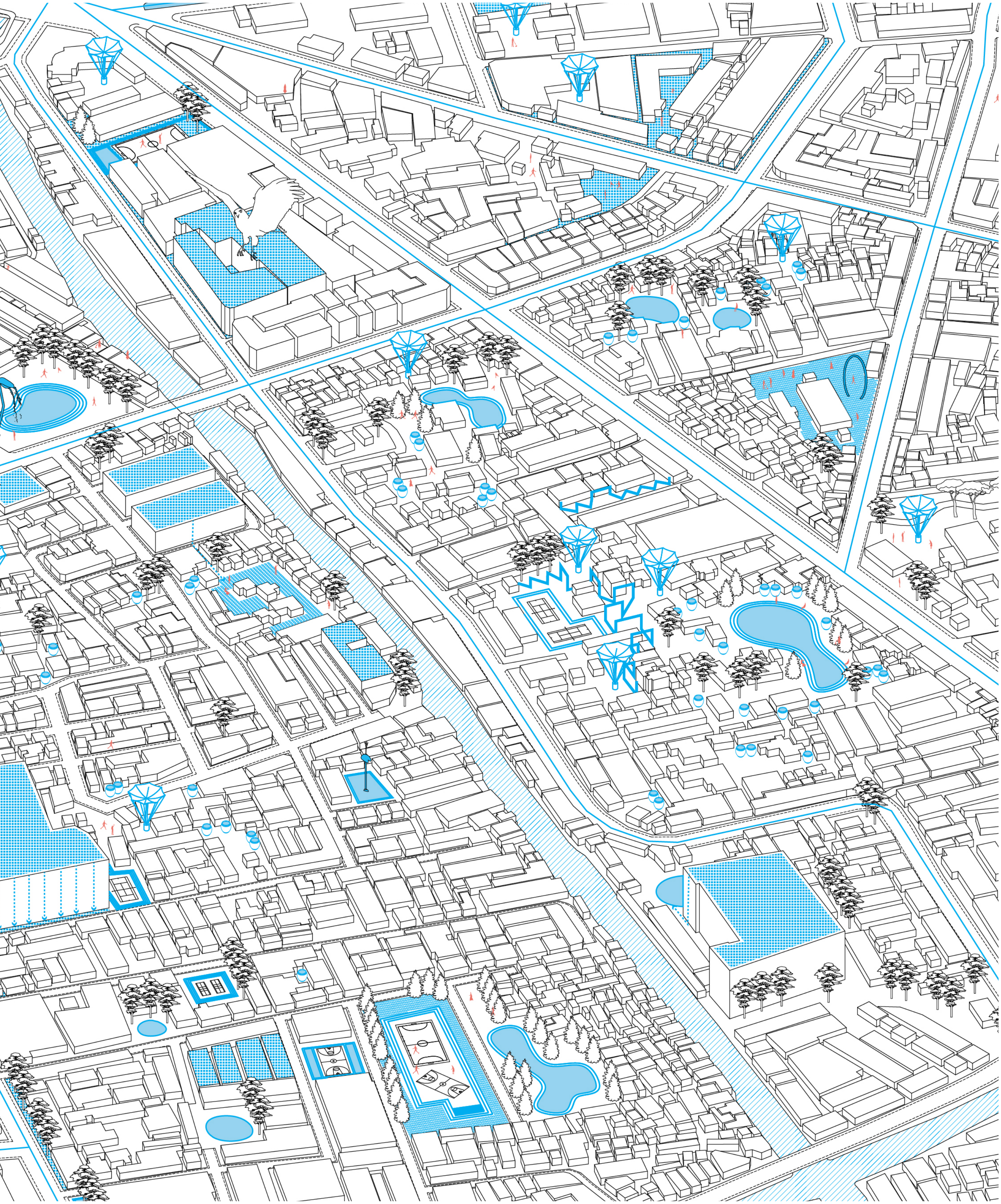

x38
x22
x10
x15
x1
x12

100% saved*

+77% additional capacity for a larger rain event

Total Capacity:
84,471,000 L

*compared to 30 minutes rainfall event on a typical 2 years return period



Conclusion and Reflection

In conclusion, the issue of flooding in Bangkok is a multifaceted and complex problem that requires a collective effort to solve. There is no one-size-fits-all solution, and addressing the issue requires a combination of strategies and approaches. While the government has a crucial role to play in improving the drainage infrastructure, it is not enough. Private sectors and individuals can contribute by implementing the Monkey Cheeks methods on their own property to reduce the amount of runoff overwhelming the system.

This thesis has demonstrated that individual rainwater harvesting could be an effective means for mitigating flooding in Bangkok. It is therefore recommended that the BMA implements various policies and incentives to encourage the adoption of these Monkey Cheeks systems. Examples of such policies could include providing tax exemptions and subsidies for building owners and developers who install these systems. For existing developments, tax incentives could be applied if a certain amount of runoff is collected and stored on-site. Additional credit could be given if the collected water is treated, or a rain-tax could be imposed based on the amount of impervious surface cover on a property.

For future developments, it is important to enforce policies and urban regulations that limit the amount of impervious surface allowed on the ground level. New development projects should be required to include stormwater storage as part of the building permit application process, and ideally, this storage should be connected to a separate storm sewer system. This would facilitate the transition away from a single combined-pipe system and help the city move towards a more sustainable approach to managing stormwater and mitigating flooding.

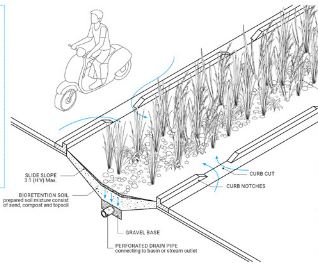
In order to realize this idea, a participatory collaboration between all stakeholders is a must as a step toward improving flood planning in Bangkok. It is essential to recognize that everyone has a role to play in tackling the issue of flooding in Bangkok, and it is only through collective action that we can make progress. As a researcher, this study has highlighted the need for a holistic approach to address environmental problems in urban areas.

The issue of flooding in Bangkok is just one example of how human activities can affect the natural environment, and it emphasizes the need for sustainable development. The thesis uses the Bangkok Metropolitan Area to demonstrate how the Monkey Cheek toolkit can lead to the re-imagination of urban neighborhoods towards flood resiliency. The author hopes this toolkit will be used as a resource by the Bangkok residents, corporate initiatives, and government bodies to adopt a fundamentally different approach to infrastructure. The Monkey Cheeks' approach to infrastructure will lead to more livable neighborhoods and more resilient regions. It is my hope that this document is a first step in mobilizing the support needed to transform these visions into reality for Bangkok and many other cities around the world.

BIOSWALES

TYPOLOGY	PERFORMATIVE FACTORS	COST FACTOR	RUNOFF REDUCTION	KEY STAKEHOLDERS
	DELAY / STORE / RELEASE	$ - $$	10-20%	Public / Private Developer for Private Roads; BMA for Public Road

Bioretention swales, or bioswales, are vegetated open channels that capture, treat, and infiltrate stormwater runoff at a low velocity. They offer a resilient, aesthetic, and low-maintenance alternative to underground storm sewers or concrete gutters. By incorporating native plants, they can be tailored to any location and used in both residential and non-residential areas to treat and convey runoff from roadways and impervious surfaces. Bioswales work best when installed in parking lots, along roadways and sidewalks, or as an enhancement to natural or existing drainage swales. They can be constructed in any location with a mild slope of no greater than four percent.



Bangkok's Native Plants for Filtration

Native plants that are currently used for wastewater treatment include emergent plants such as Cattail, Sedges, and Giant Reed, as well as Gramineae family such as Vetivergrass.

Sedges (Cyperus corymbosus Rottb.)

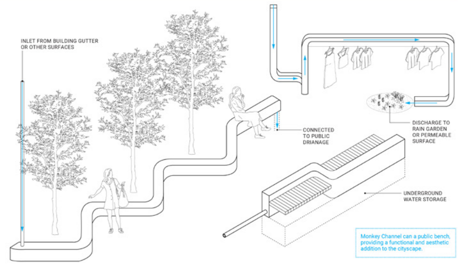
Narrowleaf Cattail (Typha angustifolia L.)

MONKEY CHANNELS

TYPOLOGY	PERFORMATIVE FACTORS	COST FACTOR	RUNOFF REDUCTION	KEY STAKEHOLDERS
	DELAY / STORE / RELEASE	$ - $$	20-100%	Property Owner; Public / Private Developer; Civil Society; BMA

Monkey Channel is a type of urban furniture. The design stems from how the drainage systems works, by incorporating elements that help delay the flow of water during storm events. The piece is constructed with a series of ridges and curves, designed to slow down and redirect the flow of water. These ridges and curves create a channel that collects and delays the flow of water until it reaches the public drainage system, helping to prevent flooding and damage to urban infrastructure.

The channels are also flexible in its placement, meaning that it can be installed in a variety of locations throughout the city. It can be an be attached to the side of a building or placed in areas prone to flooding, helping to alleviate the risk of damage and costly repairs. It can also be placed in public spaces, serving as both functional and visually interesting additions to the urban landscape.

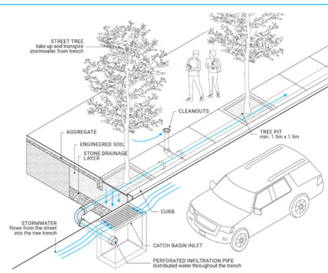


Monkey Channel can a public bench, providing a functional and aesthetic addition to the cityscape.

TREE TRENCHES

TYPOLOGY	PERFORMATIVE FACTORS	COST FACTOR	RUNOFF REDUCTION	KEY STAKEHOLDERS
	DELAY / STORE / RELEASE	$$ - $$$	40-100%	Public / Private Developer for Private Roads; BMA for Public Road

A stormwater tree trench is a network of trees connected by an underground infiltration system. This system allows trees to thrive in urban areas with limited space, such as sidewalks. The surface of a stormwater tree trench looks like a row of tree pits, but underneath the sidewalk lies a sophisticated system to manage runoff. The trench is lined with permeable geotextile fabric and filled with gravel, soil, and trees. When it rains, a special inlet diverts runoff into the tree trench, where it is absorbed by the trees and slowly infiltrates through the bottom. In case of extreme flood events, a bypass system diverts excess runoff directly into the existing stormwater network.



Bangkok's Native Trees for Sidewalks

Planting a sidewalk tree creates multiple benefits for urban areas. The suitable trees for planting along roadsides are those with medium height, beautiful bushy shapes, moderate growth rates, and best to avoid deciduous tree.

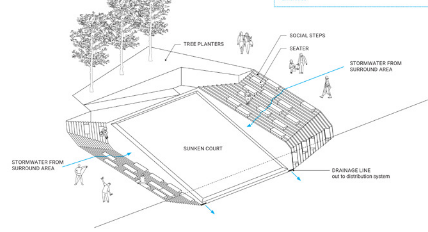
Spanish Cherry (Mimusops elengi)

SUNKEN PLAZA

TYPOLOGY	PERFORMATIVE FACTORS	COST FACTOR	RUNOFF REDUCTION	KEY STAKEHOLDERS
	DELAY / STORE / RELEASE	$$ - $$$	40-100%	Property Owner; Public / Private Developer; Civil Society

Sunken plazas offer an opportunity to create detention ponds in public areas. These architectural/landscape features have a drainage system and both hardscape and softscape elements. They form a depression in the urban fabric that detains stormwater runoff and also serve as a public space during dry periods. Sunken plazas creatively celebrate rain by showcasing water circulation in playful ways, making water a prominent part of the public realm. During heavy rainfall, they hold stormwater, preventing it from overloading the public sewer, and slowly release it back into the system through gutter and underground pipes or into the aquifer if possible.

Public Plaza may be used as to define space between the pedestrian zone and any recreational site areas or amenities

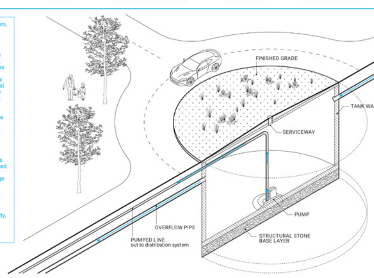


STREET CISTERN

TYPOLOGY	PERFORMATIVE FACTORS	COST FACTOR	RUNOFF REDUCTION	KEY STAKEHOLDERS
	DELAY / STORE / RELEASE	$$$$	80-100%	Public / Private Developer for Private Roads; BMA for Public Road

Underground street cistern, known in Thai as "Water Bank" or "Underground Monkey Cheek" is an alternative way to find a reservoir where there are no open space available. When the rain stops or the water level in the canal drops, the stored water is pumped out into the canal and eventually discharge to the Chao Phraya River.

The core of a cistern system is a water-storage tank with a water delivery point, a properly sized overflow pipe, an accessible serviceway, a working vent, an operational water pump line, pump and tank walls. The tank can be connected to the existing drainage system, or a new drainage pipe can be installed from the storage pond directly to the canal. The advantages of storing water underground are frost protection, invisibility, landscape versatility, however, these benefits comes at a high cost.



Optional Pump Installation

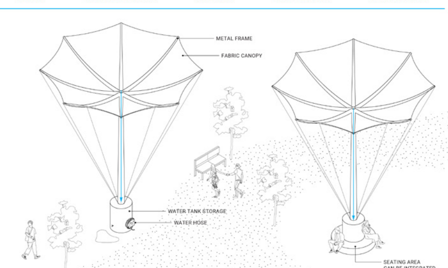
The pump does not necessary need to be installed inside the cistern itself. A portable pump can be use to pump the water out through a connected drainage pipe from outside the tank as well.

MONKEY CANOPY

TYPOLOGY	PERFORMATIVE FACTORS	COST FACTOR	RUNOFF REDUCTION	KEY STAKEHOLDERS
	DELAY / STORE / RELEASE	$ - $$	20-40%	Public / Private Developer; Civil Society; BMA

Monkey Channel is a multipurpose urban infrastructure that aims to mitigate the effects of urban heat and provide a comfortable public space for the community. The canopy is designed to capture and store rainwater at its base, which can then be used for various purposes. This innovative infrastructure can be installed in different locations throughout Bangkok to help cool down the surrounding areas and provide seating space for the public.

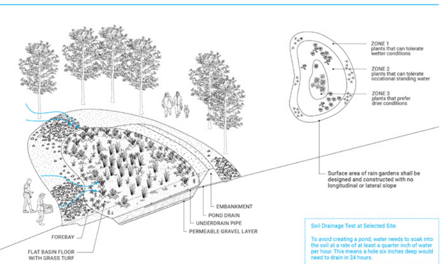
The canopy's structure is designed to provide ample shade, as well as capture and store rainwater, which can be reused for various purposes. The water can be used to irrigate the vegetation around the area, which helps to improve the local microclimate, or it can be used as a cistern during fire events, helping to support firefighting efforts.



RAIN GARDENS

TYPOLOGY	PERFORMATIVE FACTORS	COST FACTOR	RUNOFF REDUCTION	KEY STAKEHOLDERS
	DELAY / STORE / RELEASE	$ - $$$	20-40%	Property Owner; Public / Private Developer; Civil Society; BMA

A rain garden is a depression in the landscape that collects rainwater from impervious surfaces such as roofs, driveways or streets, allowing it to soak into the ground and mimic the natural water cycle. The garden treats and manages small volumes of stormwater runoff using a planting soil bed and materials to filter runoff stored in a shallow depression. A stone drainage layer promotes dispersed infiltration, while an underdrain system connects to the storm drain system. The system includes an inflow component, a ponding area over the planted soil bed, mulch layer, stone drainage layer, plantings and an overflow mechanism for larger rain events. Rain gardens are an attractive and cost-effective way to reduce runoff from both public and private property.



Soil Drainage Test at Selected Site

To avoid creating a pond, water needs to soak into the soil at a rate of at least a quarter inch of water per hour. This means a hole six inches deep would need to drain in 24 hours.

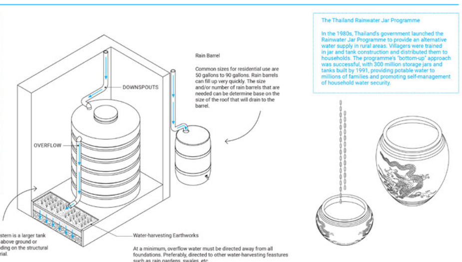
WATER CONTAINER

TYPOLOGY	PERFORMATIVE FACTORS	COST FACTOR	RUNOFF REDUCTION	KEY STAKEHOLDERS
	DELAY / STORE / RELEASE	$	40-100%	Property Owner; Public / Private Developer; Civil Society

Rainwater harvesting involves collecting runoff from an impervious surface for later use. It's typically done by catching rain from a roof, which can be stored in a container. This simple and low-cost system requires little maintenance but requires household cleanliness. It can work as a standalone supply or supplement limited ground/surface water.

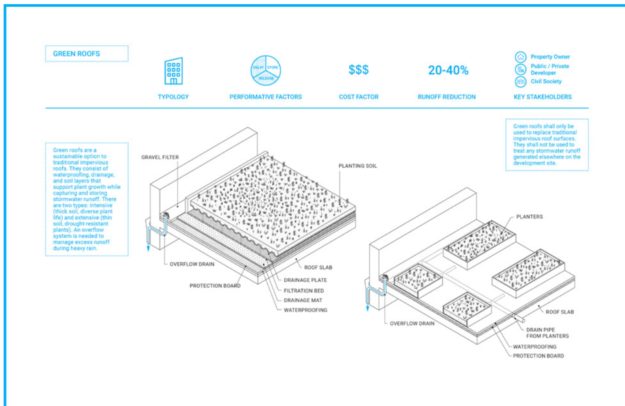
"Although one rain barrel is not going to capture all the water collected from the rooftop, every gallon stored helps. If every house installed a rain barrel, imagine how much water we could save."

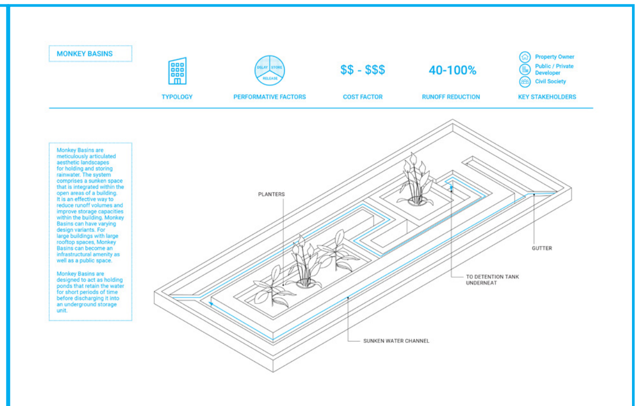
— Department of Drainage and Sewerage, BMA



The Thailand Rainwater Jar Programme

In the 1980s, Thailand's government launched the Rainwater Jar Programme to provide an alternative water supply in rural areas. Villagers were trained in jar and tank construction and distributed them to households. The programme's "bottom-up" approach was successful, with 300 million storage jars and tanks built by 1991, providing potable water to millions of families and promoting self-management of household water security.


GREEN ROOFS
TYPOLOGY
DELAY
STORE
RELEASE
PERFORMATIVE FACTORS
$$$
COST FACTOR
20-40%
RUNOFF REDUCTION
Property Owner
Public / Private Developer
Civil Society
KEY STAKEHOLDERS
Green roofs are a sustainable option to traditional impervious roofs. They consist of waterproofing, drainage, and soil layers that support plant growth while capturing and storing stormwater runoff. There are two types: intensive (thick soil, diverse plant life) and extensive (thin soil, drought-resistant plants). An overflow system is needed to manage excess runoff during heavy rain.
GRAVEL FILTER
PLANTING SOIL
OVERFLOW DRAIN
PROTECTION BOARD
ROOF SLAB
DRAINAGE PLATE
FILTRATION BED
DRAINAGE MAT
WATERPROOFING
Green roofs shall only be used to replace traditional impervious roof surfaces. They shall not be used to treat any stormwater runoff generated elsewhere on the development site.
PLANTERS
OVERFLOW DRAIN
ROOF SLAB
DRAIN PIPE FROM PLANTERS
WATERPROOFING
PROTECTION BOARD


MONKEY BASINS
TYPOLOGY
DELAY
STORE
RELEASE
PERFORMATIVE FACTORS
$$ - $$$
COST FACTOR
40-100%
RUNOFF REDUCTION
Property Owner
Public / Private Developer
Civil Society
KEY STAKEHOLDERS
Monkey Basins are meticulously articulated aesthetic landscapes for holding and storing rainwater. The system comprises a sunken space that is integrated within the open areas of a building. It is an effective way to reduce runoff volumes and improve storage capacities within the building. Monkey Basins can have varying design variants. For large buildings with large rooftop spaces, Monkey Basins can become an infrastructural amenity as well as a public space.
Monkey Basins are designed to act as holding ponds that retain the water for short periods of time before discharging it into an underground storage unit.
PLANTERS
GUTTER
TO DETENTION TANK UNDERNEAT
SUNKEN WATER CHANNEL

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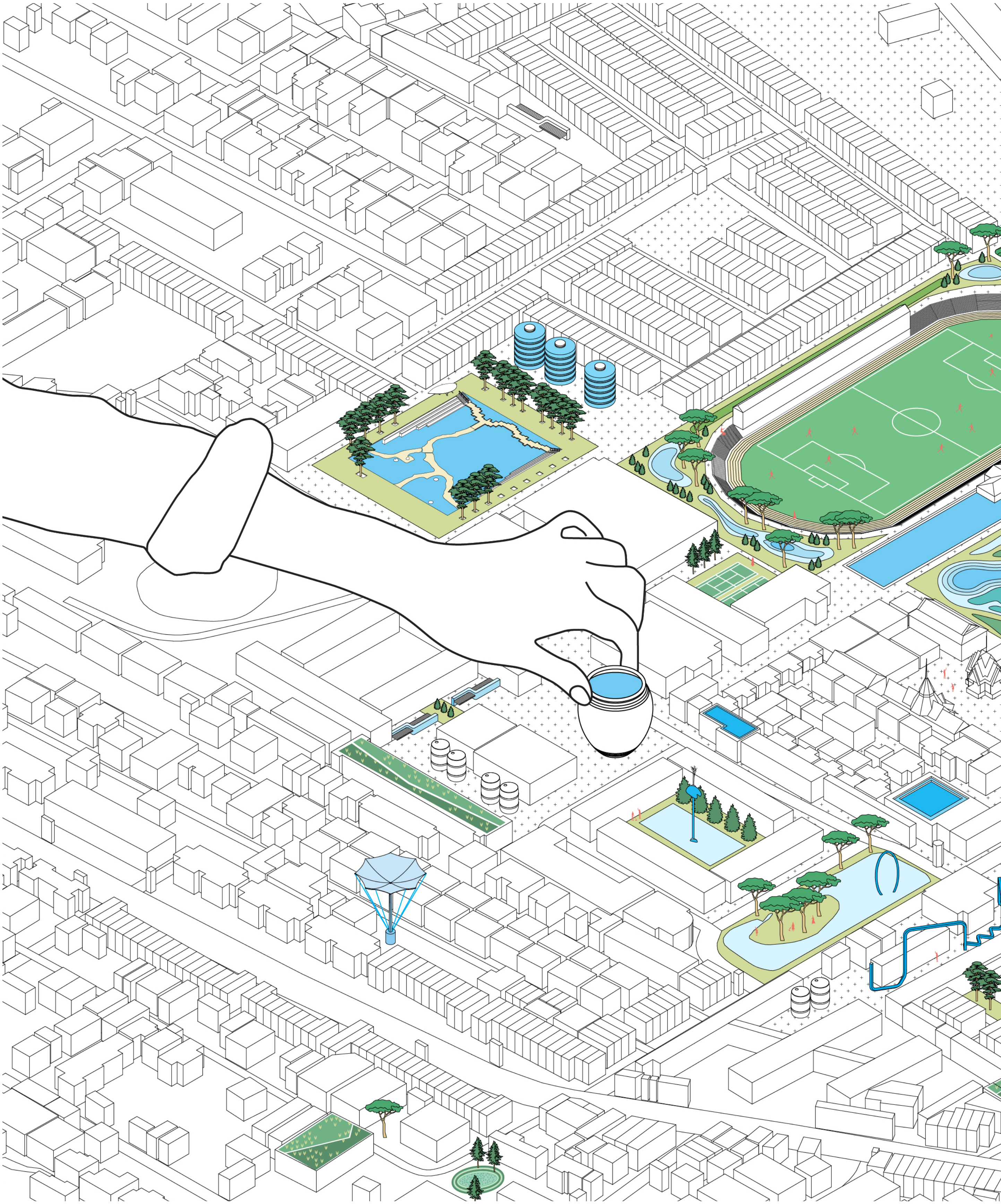

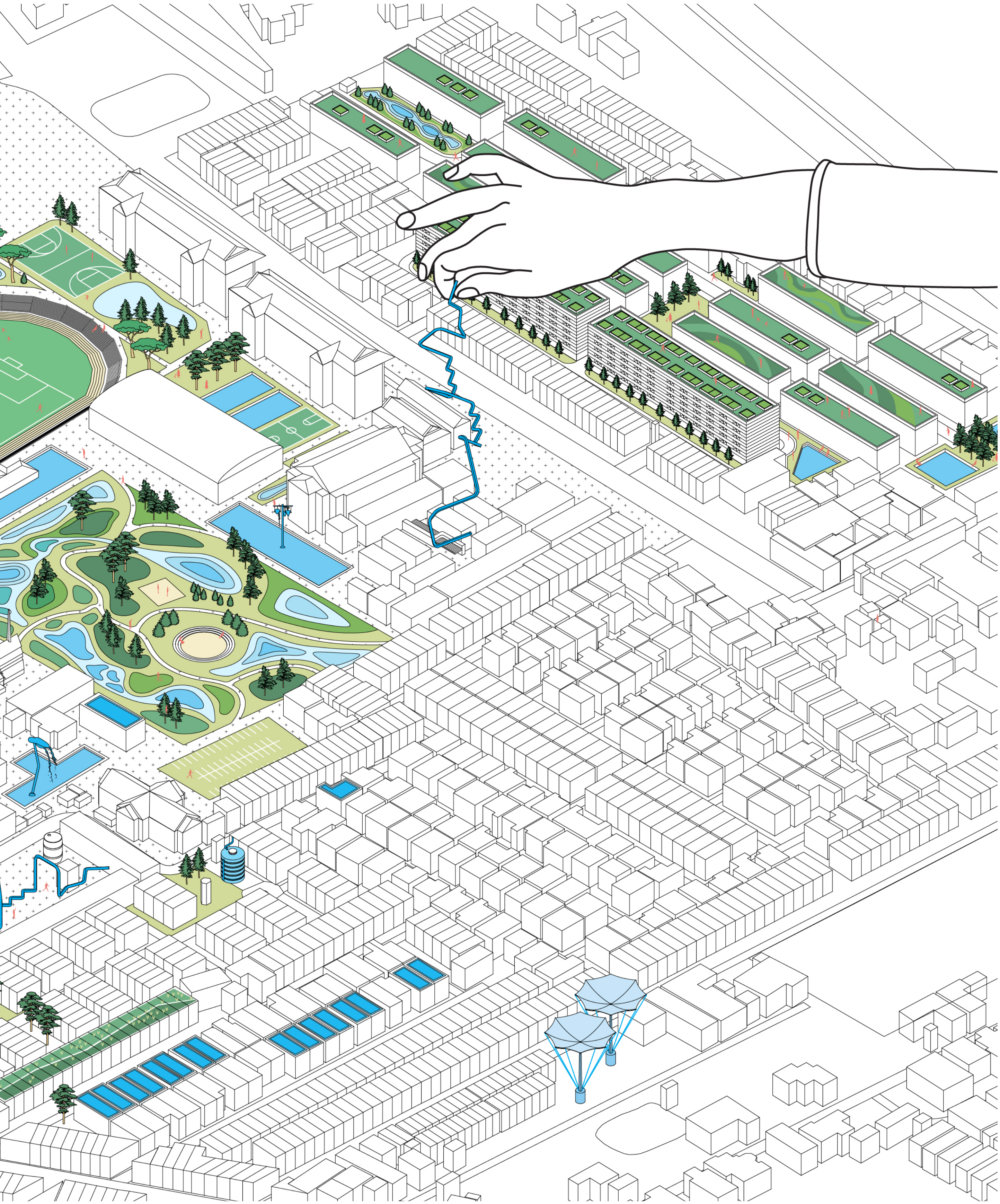

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