LA 222 Hydrology for Planners

Final Paper Assignment

Holistic Approach for
Water Management Planning of
Nong Chok
District in Bangkok, Thailand

By: Wilasinee Suksawang

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Holistic Approach for Water Management Planning of Nong Chok district in Bangkok, Thailand

Abstract:

Bangkok, the capital city of Thailand, is located on a low flat plain of the lower part of the Chao Phraya River Basin, with approximately 30 kilometers from the river mouth and average elevation of 0-2 meters above the sea level. Consequently, the city has been threatened by several severe floods throughout its history. The key concept of flood management in Thailand was the 'Monkey Cheeks' project initiated by His Majesty the King Bhumibol Adulyadej in 1995. The term 'Monkey Cheeks' was initiated by the King as a metaphor to promote water detention systems for solving flood problems of Bangkok and also other areas over the country.

Regarding this project, Nong Chok is indicated as the water detention basin, or Monkey Cheeks, for mitigating the flood problem in the core area of Bangkok. Moreover, with its strategic location, Nong Chok is also projected as the expansion area of the cities in a very near future. Accordingly, the appropriate planning direction is certainly crucial for the sustainable future development of the district.

This project aims to propose the planning and design guidelines for Nong Chok district by addressing the holistic approach, or multi-objective approach, which integrates flood management and ecological restoration with the intention of reaching the sustainable future development. The guidelines consist of 2 parts. The first part is the conceptual planning of Nong Chok district. The objective of this part is to prepare the area for flood mitigation of Bangkok as well as to provide the opportunity for ecological restoration. Moreover, the proposal also proposes the opportunity for recreational and educational activities for local community as well. The second part aims to propose the re-design guideline for Nong Chok Halal Market project, as the existing proposal did not play proper attention to the water management issues. Hence, the integration of floodwater, stormwater, and wastewater management is proposed to the site design and landscape planning of this site.

Since the holistic approach is relatively new and not broadly recognized in Thailand, this study project is going to be a very beneficial and useful example or pilot study for the application and implementation in Thailand.

Introduction and Problem Statement

- **Bangkok and Annual Flood Crisis**

Bangkok is the capital city of Thailand. It is recognized as a city of merit with abundant distinctive and outstanding natural and cultural values and known as the "Venice of the East" as numerous of canals exist within the city.

Since Bangkok is located on the delta of the Lower part of the Chao Phraya River Basin[1] and stands astride the Chao Phraya River with approximately 30 kilometers from the river mouth or the Gulf of Thailand and an average elevation of 0-2 meters above the sea level, Bangkok always holds high risk on flood damage and has been threatened by several massive floods throughout its history, especially during monsoon season – when there is a heavy rainfall in the northern region, the water flows southwards and causes rising levels in the Chao Phraya River along with its branches, and then the water overflows the banks and results in floods in many areas of Bangkok.

In addition to its flood-risked location, the rapid-pace urban development in Bangkok which has certainly ignored its hydrologic processes is also the added factor which has increased the level of flood risk to the city. As a result, Bangkok nowadays is encountering many terrible environmental conditions, especially its impotent hydrologic function and ineffective flood adaptation that have caused its increasing risk of annual flood problem in its recent history.

Bangkok was threatened by a massive flood which was 1.50 meters height and stayed for 2 months in 1942. After that, it was damaged by floodwater again and again in recent years. In 1995, the highest floodwater level recorded in Chao Phraya River was 2.27 meters above mean sea level, then 2.14 meters in 1996, 2.10 meters in 2002, 2.22 meters in 2006, 2.17 meters in 2008, 2.10 meters in 2010, and 2.53 meters in 2011.

Figure 1: The location of Bangkok and the Chao Phraya River Basin

Figure 2: Topographic Map of Thailand

[1] The largest river basin in Thailand which covers an area of 159,000 square kilometers or 35 percent of the total land area of the country

Figure 3-4: Bangkok massive flood in 1942, which was 1.50 meters height and stayed for 2 months

Figure 5-7: Bangkok massive flood in 1995, which was 2.27 meters above mean sea level

In 2011, Flood Disaster in Bangkok was beyond the estimated 100-year flood recurrence in Bangkok, which was predicted at 2.50 meters above mean sea level. This flood resulted in approximately 13.6 million people affected and the World Bank has estimated 1,425 billion baht (US$ 45.7 billion) in economic damages and losses due to flooding, as of 1 December 2011. Most of this cost was to the manufacturing industry, as several major industrial estates were inundated by as high as 3 meters during this flood. The World Bank also estimated that this flood is the world's fourth costliest disaster as of 2011, only less than 2011 earthquake and tsunami in Japan, 1995 Kobe earthquake, and Hurricane Katrina in 2005. (Retrieved from http://en.wikipedia.org/wiki/2011_Thailand_floods, April 25, 2012)

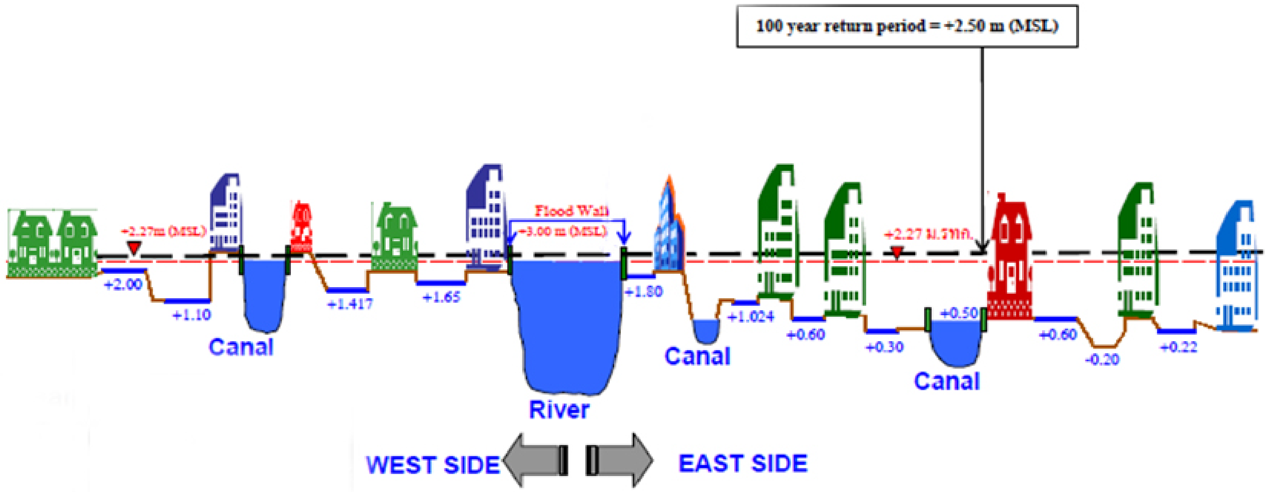

Figure 8: Cross-Section of Bangkok and the estimated level of 100-year flood return period

Figure 9: Flood damaged urban area in 2011

Figure 10: Flood damaged street in 2011

Figure 11: Flood damaged the Don Muang Airport in 2011

Figure 12: Flood damaged cars at the Honda factory in 2011

- **'Monkey Cheeks' Project for Flood Management in Bangkok**

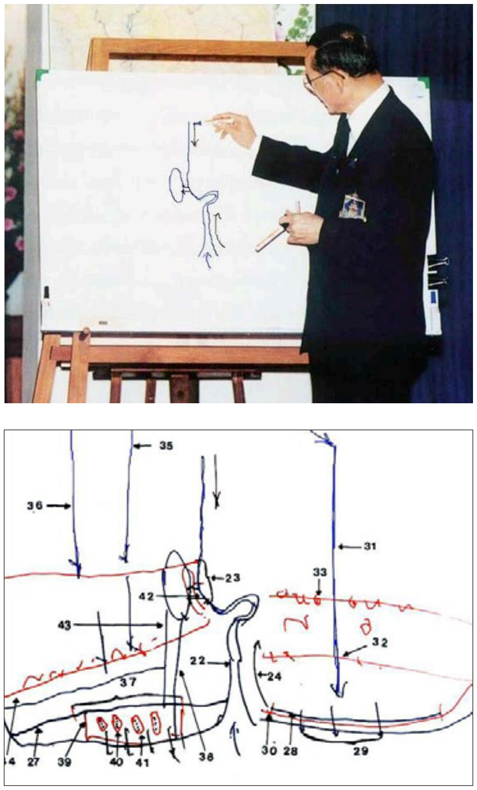

Figure 13-14: His Majesty the King and his sketch regarding his initiative of the Monkey Cheeks project

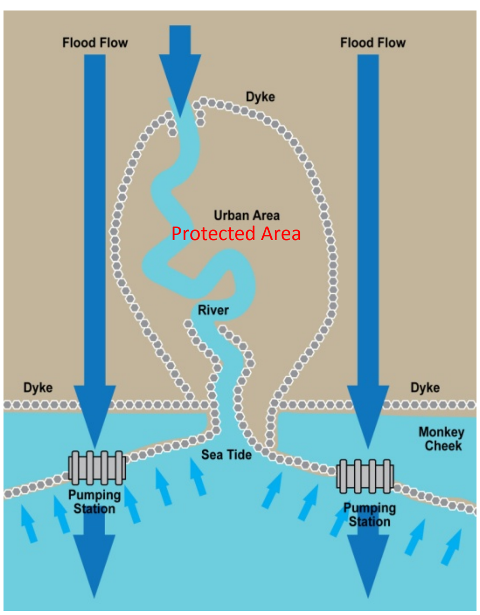

Figure 15: The conceptual diagram of the Monkey Cheeks project

The key concept of flood management in order to solve the problem in Bangkok and its vicinity was initiated by His Majesty the King of Thailand in 1995.

Due to the continuing heavy rain in the northern part of Thailand as well as in Bangkok in 1995, the huge volume of water was predicted to flood Bangkok very soon. His Majesty the king gave the advice regarding flood solving for this crisis. He did mention the flood management strategy of California as a role model for Bangkok. He said in his speech that Bangkok needs a floodway project like in California. At that time, his advice included building more dykes to prevent an overflow, and removing the flow barriers, especially the roads – all of which had to be done within 3 days. Unfortunately, these missions were not completed on time, so Bangkok was severely flooded with the highest level of 2.27 meters above mean sea level.

Afterward, His Majesty the King initiated the "Monkey Cheeks" project – or "Kaem Ling" project, in Thai. His inspiration for this project originated from his observation of monkeys, as he explained that when the monkey were given bananas, they would store all the bananas in their mouths until their cheeks filled up, and then they would start to chew and swallow the bananas. Accordingly, the term "Monkey Cheeks" was initiated by the King as a metaphor to promote water detention systems for solving the flood problems of Bangkok and also other areas over the country.

His Majesty also sketched and gave explanation regarding the guideline for implementing this concept. He suggested that the Monkey Cheeks project is a drainage system from upper areas through the canal southwards, and then to the large water storage near the coast. When the sea level is lower than the water level in the canal, the water is drained through a regulator by gravity flow and pumps. In a contrary manner, if the sea level is higher than the water level in the canal, the regulator is closed in order not to let water return. Thus, from this idea, there are three main components of the project: dykes, Monkey Cheeks or water detention basins, and regulators and pumping stations. These components work in relation with the sea tide.

Nong Chok – "Monkey Cheeks" of Bangkok

- **Location and Existing Conditions**

Bangkok, with the area of approximately 1,570 square kilometers, consists of 50 districts. Nong Chok, with the area of approximately 240 square kilometers, is the biggest district of Bangkok located at the northeastern part of the city. Nong Chok is also indicated as the rural and agricultural area in the land-use regulation.

The unique characteristic of Nong Chok is the area of agricultural lands, especially the green paddy fields and the verdant orchards. In addition, the distinctive rural riparian communities living along the canals are also the charm of this district. However, with the current demand of urban expansion, Nong Chok has urbanized rapidly in its recent history.

Figure 16: Map showing the location of Nong Chok district in Bangkok

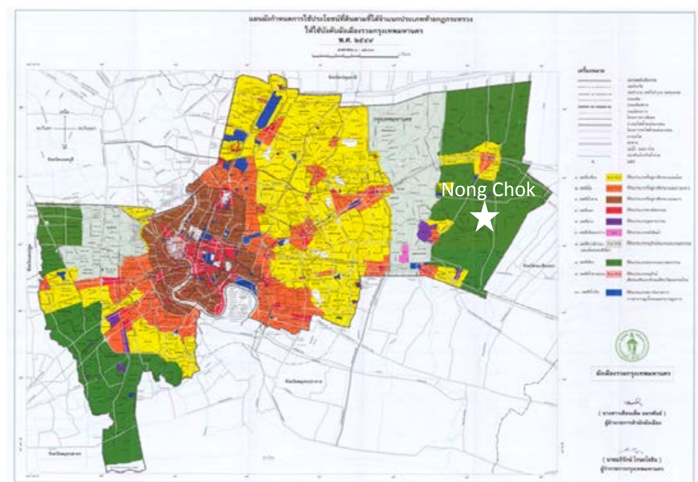

Figure 17: Map showing the land-use regulation of Bangkok

Figure 18: Green paddy field in Nong Chok district

Figure 19: Canal in Nong Chok district

- **Current and Future Challenging Roles**

  Nong Chok holds 2 important, and also challenging, roles in current and future time.

  - **Floodway and Detention Basin**

    Regarding the "Monkey Cheeks" project, Nong Chok is indicated as the water detention basin, or Monkey Cheeks, for flood mitigation and prevention of the core area of Bangkok.

  - **Urban Expansion Area**

    With its strategic location, Nong Chok is also projected as the expansion area of the cities in a very near future.

Figure 20: Local riparian community in Nong Chok district

Figure 21: Urbanization along the canal in Nong Chok district

Objectives of the Study

According to the current and future challenging roles of Nong Chok, the appropriate planning direction is certainly crucial for the sustainable future development of the district. The aim of this project is to propose the planning and design guidelines for Nong Chok district in order to deal with 2 key issues – flood mitigation and ecological restoration – in a balance manner. Hence, there are 2 main objectives of this study.

- **Propose Holistic Approach for Water Management**

  Holistic approach, or multi-objective approach, is the concept which integrates flood management and ecological restoration in order to reach the sustainable future development. This study aims to address this concept to the planning and design guidelines for Nong Chok district.

- **Propose Conceptual Planning and Site (Re)Design Recommendation**

  The proposed guidelines in this study consist of 2 parts. The first part is the conceptual planning of Nong Chok which aims to prepare the area for flood mitigation of Bangkok as well as to provide the opportunity for ecological restoration along with recreational and educational activities for local community. The second part is the re-design guidelines for Nong Chok Halal Market project which proposes the integration of floodwater, stormwater, and wastewater management into the site design and landscape planning of this site.

Result: Proposal of Planning and Design Guidelines

- **Conceptual Planning of Nong Chok District**

  - **Objective of the Planning:**

The main objective of this part is to propose the conceptual planning of Nong Chok district in order to prepare it for flood mitigation of Bangkok. Moreover, this proposal also aims to address the ecological restoration, which can also provide the opportunity for recreational and educational activities for local community, to the development plan of the district.

  - **Conceptual Proposal:**

The main idea of the planning proposal is to divert floodwater from the northern region to the proposed "Monkey Cheeks" or detention basins, and then gradually drain to the Gulf of Thailand through Bang Prakong River which located on the eastern side of Nong Chok district. For the flood water from Bangkok which flow through Saen Saeb Canal, it will be diverted to the proposed "Monkey Cheeks" – in order not to let the water flow through the community area, or protected area, of Nong Chok – and then gradually drain to the Gulf of Thailand. There are 5 main components proposed in this proposal, as shown in figure 22.

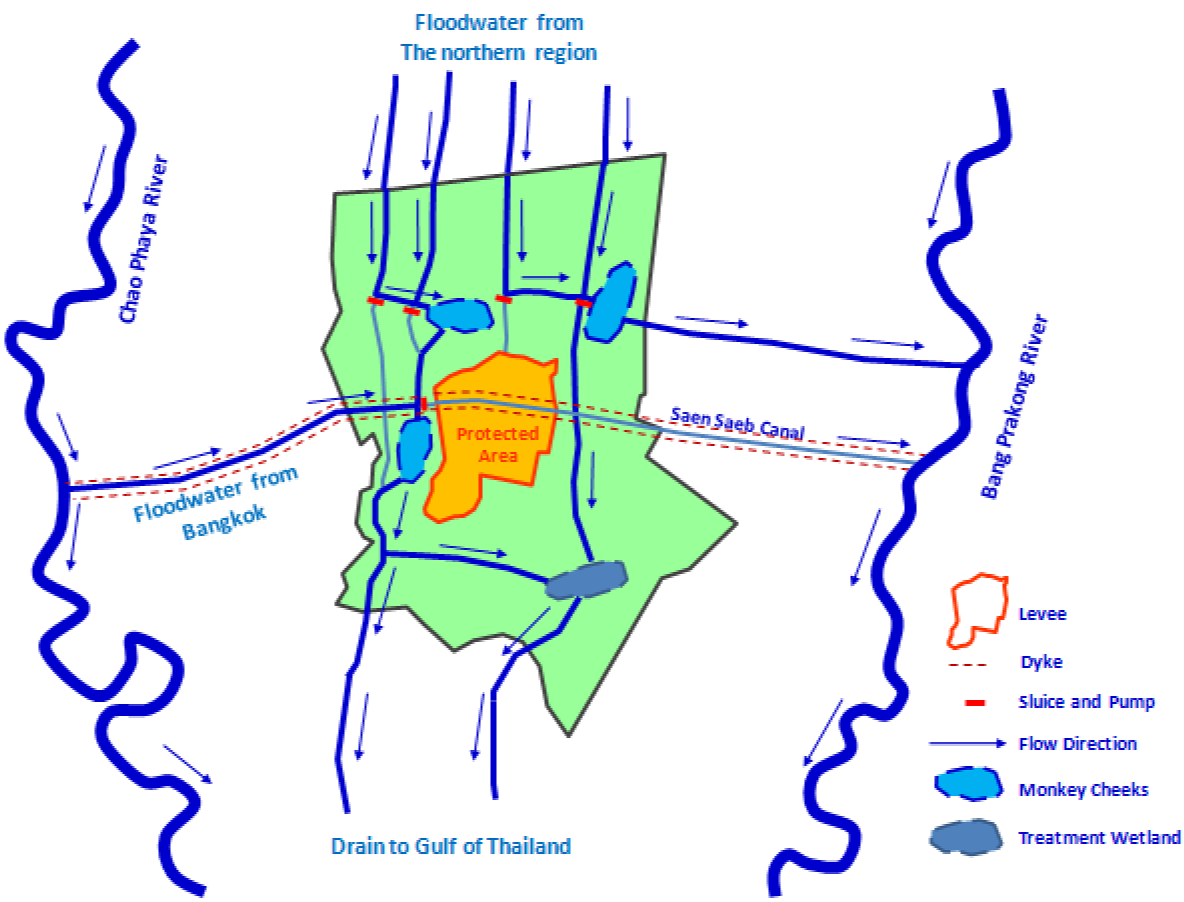

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Figure 22: Conceptual diagram for flood management and ecological restoration of Nong Chok district

- **Levee**

Levee is proposed to protect the core area of Nong Chok district. Moreover, it also can provide some recreational spaces such as scenic driveway, bikeway, and walkway, for example. Since the 100-year flood recurrence is estimated at 2.50 meters above mean sea level, the levee is proposed at this height.

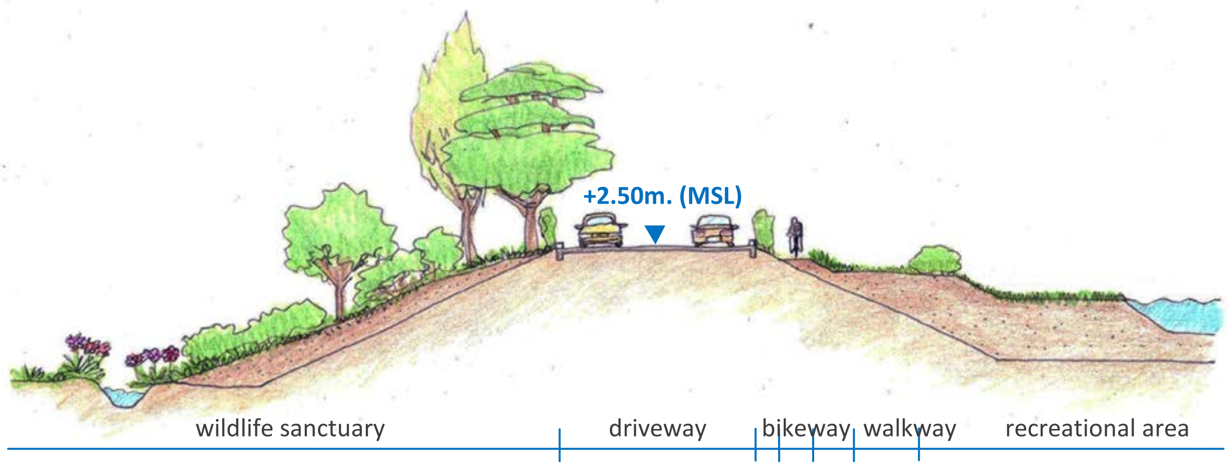


Figure 23: Cross-section of the proposed levee for protecting the core area of Nong Chok district

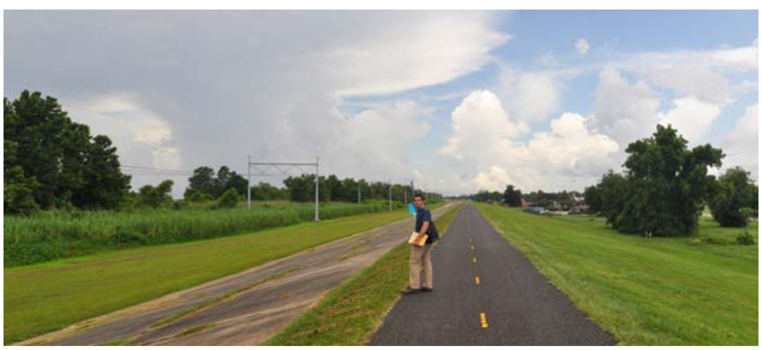


Figure 24: The image of levee and green spaces at both sides

Figure 25: The image of levee

- **Dyke**

Dyke is proposed for flood control along Saen Saeb Canal. On the top of the dyke, it is also proposed to be the promenade in order to provide recreational space for local residents. As same as the proposed levee, the height of the dyke is recommended at 2.50 meters above mean sea level. There are 3 main sections suggested. The concrete wall is recommended at the area with narrow bank. The ribrab is suggested at the area with wider bank, while the seating-stepped type is proposed to provide opportunity for people to be close to the water.

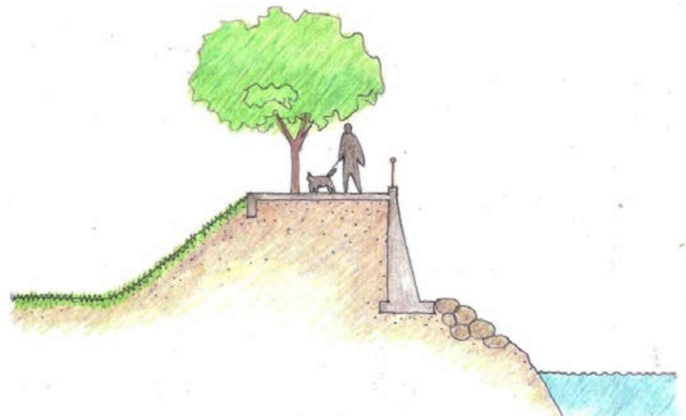


Figure 26: Cross-section of concrete-wall dyke

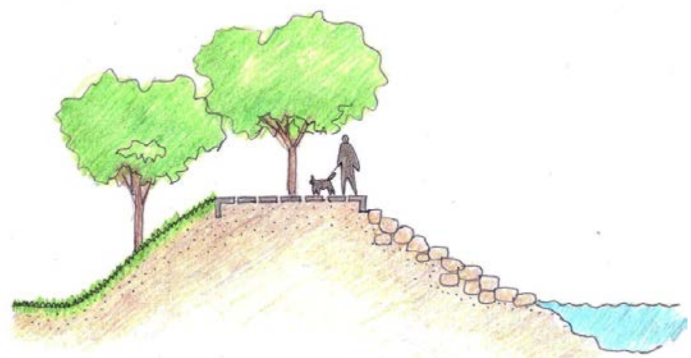


Figure 27: Cross-section of ribrab dyke

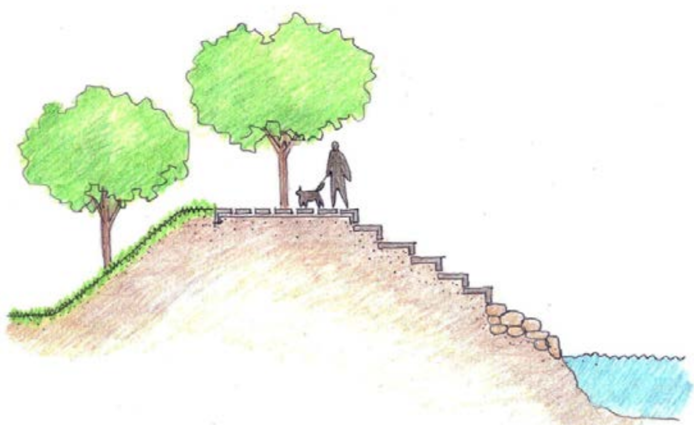


Figure 28: Cross-section of seating-step dyke

Figure 29: The image of the dyke

- **Sluices and Pumps**

Sluices and pumps are used to block the floodwater and divert it to the proposed directions or detention areas.

Figure 30: The image of sluices and pumping station

- **"Monkey Cheeks" or Detention Basins**

The "Monkey Cheeks" is the term meaning as flood detention basins. In this proposal, the detention basin is recommended to provide the opportunity for recreational spaces for local communities as well. In addition, the "Monkey Cheeks" can also be the retention basin which maintains necessary level of water to provide the opportunity for wildlife habitat, especially for birds and fishes.

Figure 31: The image of "Monkey Cheeks" which provide the opportunity for recreational spaces and activities

Figure 32: The image of "Monkey Cheeks" which provide the opportunity for wildlife habitat

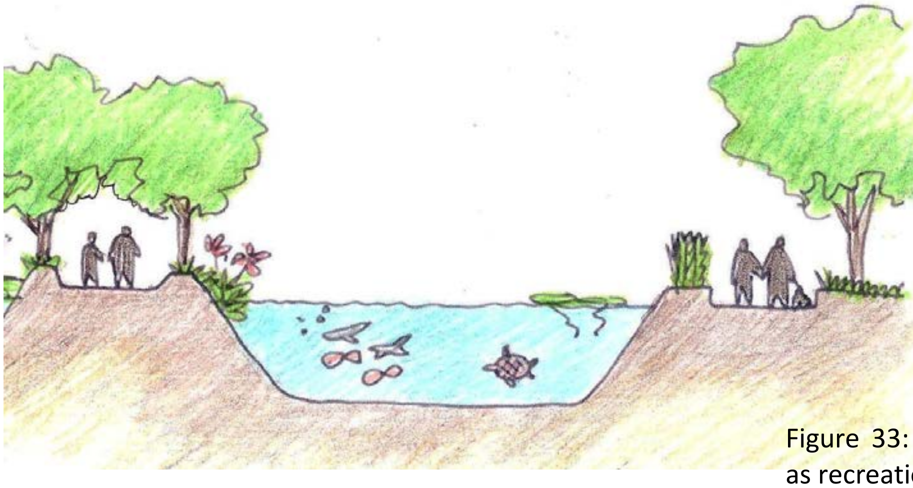


Figure 33: Cross-section of "Monkey Cheeks" as recreational space

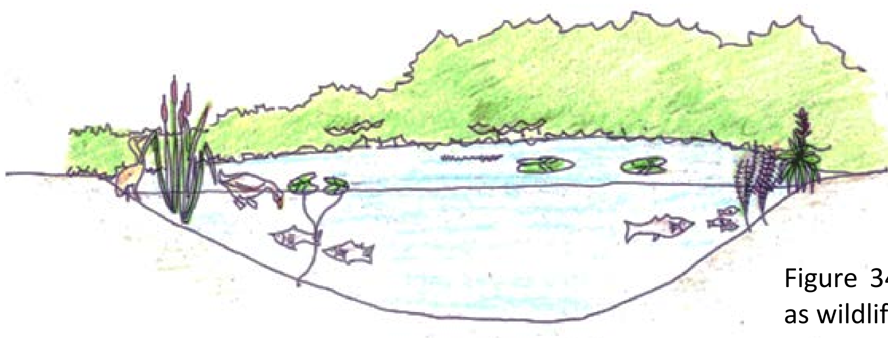


Figure 34: Cross-section of "Monkey Cheeks" as wildlife habitat

- **Treatment Wetland**

The treatment wetland is used to manage stormwater runoff with the purpose of filtering contamination and improving water quality before it is drained to the ocean. Moreover, it also provides an opportunity for water to infiltrate to the ground and plays a role in detaining floodwater during the peak time. This area is also proposed for recreational and educational activities as well as wildlife habitat.

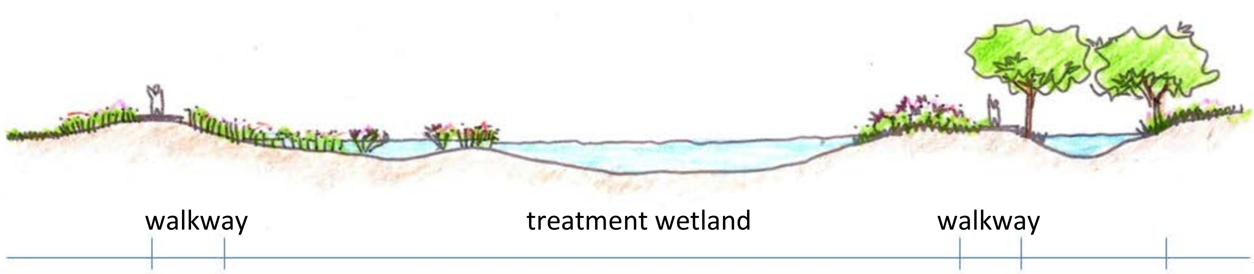


Figure 35: Cross-section of treatment wetland
which can also be the recreation space and wildlife habitat

Figure 36-37: The images of treatment wetland
which can also be the recreation space and wildlife habitat

- **Site (Re)Design of Nong Chok Halal Market**
  - **Objective of the (Re)Design**

This part aims to propose the re-design guideline for Nong Chok Halal Market project. This is because the existing proposal did not play proper attention to the water management issues. In view of that, the objective of this part is to address and integrate the management of floodwater, stormwater, and wastewater concerns to the site design and landscape planning.

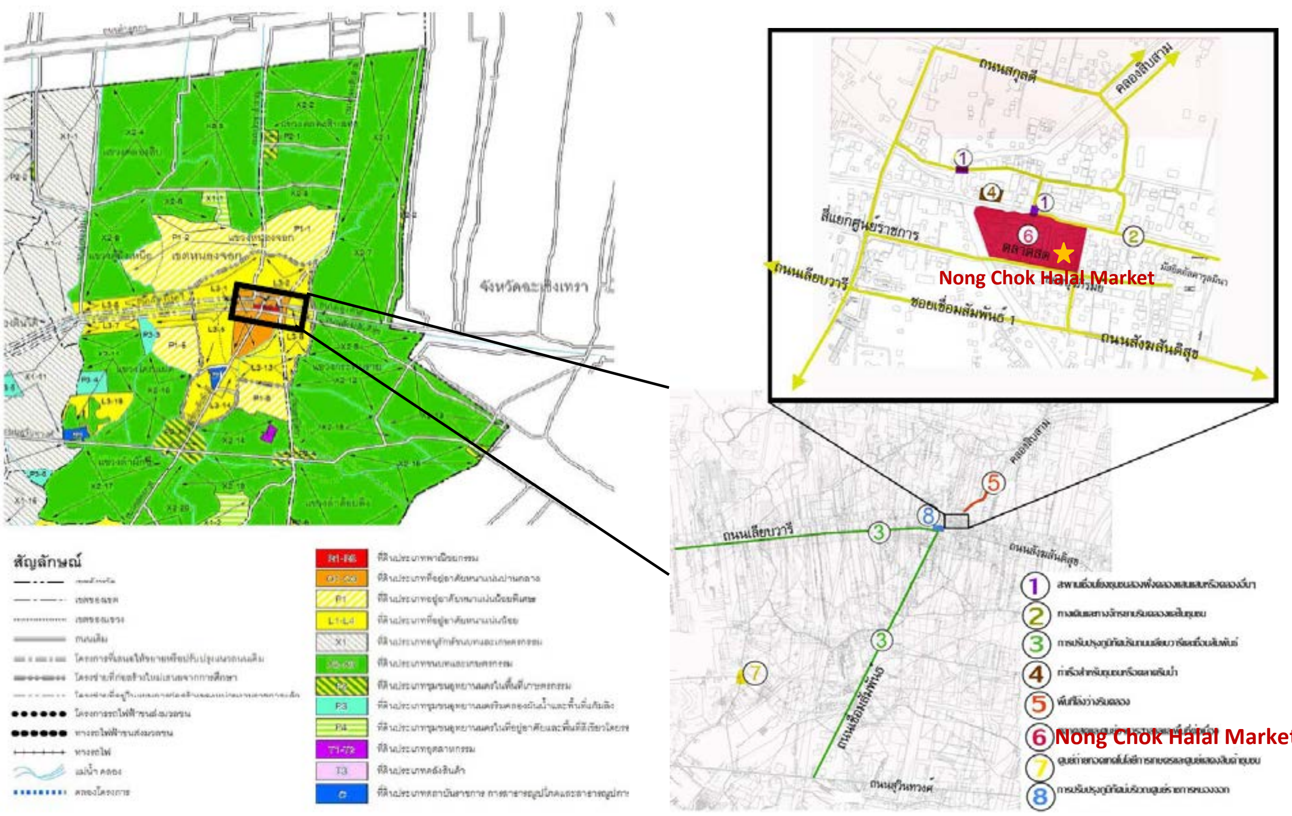


Figure 38: The location of Nong Chok Halal Market project

- **Backgroud of Nong Chok Halal Market Project**

In 2009, the Department of City Planning, Bangkok Metropolitan Administrator (BMA) – who is responsible for the city planning of Bangkok – proposed the design proposal of Nong Chok Halal Market, which is one of the eight subprojects of the 'Survey and Design of the Urban Elements in Nong Chok Community Project'.

This project, actually, was initiated with the recognition of the importance and vulnerability of Nong Chok district as the detention basin and urban expansion area of Bangkok. Accordingly, the main proposes of the project included reserving area to be the water retention land for flood protection and mitigation of Bangkok, preparing area for the inevitable expansion of the urban area, initiating sustainable development for future sustainability of the area, and planning to develop Nong Chok district to be healthy and livable city. Moreover, the Department of City Planning, BMA also recommended the idea of 'Garden and Eco City' for developing the master plan of Nong Chok district with the balance of urban and agricultural land in order to create a good social and economic community, as well as people's well-being.

However, it is found that this design proposal did not put proper attention to the water management concerns, whether floodwater, stormwater, or wastewater issues. In this study, the Halal Market project was picked up to be the case study in order to recommend the re-design proposal regarding the importance of water and hydrologic processes.

The Halal Market project is located on the bank of Saen Saeb canal, and in the heart of Nong Chok community. Currently, this location is the central market of Muslim inhabitants, and also all local people and tourists who want to taste delicious Halal food. The site covers the area of 15,400 square meters or 3.8 acres. The market building is located right in the middle of the site, and surrounded with the 3- to 4- storey commercial buildings.

Figure 39: Satellite image showing the existing condition of Nong Chok Halal Market site

Figure 40: Site plan showing the existing condition of Nong Chok Halal Market site


Figure 41-42: Saen Seab Canal


Figure 43-44: Existing market building


Figure 45-46: Activities in the market

The site planning and design proposal of the project was focused mainly on solving traffic and parking problems, designing the new market building, and landscape planning for leisure areas. Unfortunately, the water management issues, particularly floodwater, stormwater, and wastewater, were certainly neglected.

Figure 47: Site planning and design proposal of the project

Figure 48-51: The architectural design proposal of the project

- **(Re)Design Proposal**

The re-design alternatives were proposed regarding the three main water management issues – flood protection, stormwater infiltration and treatment, and wastewater treatment.

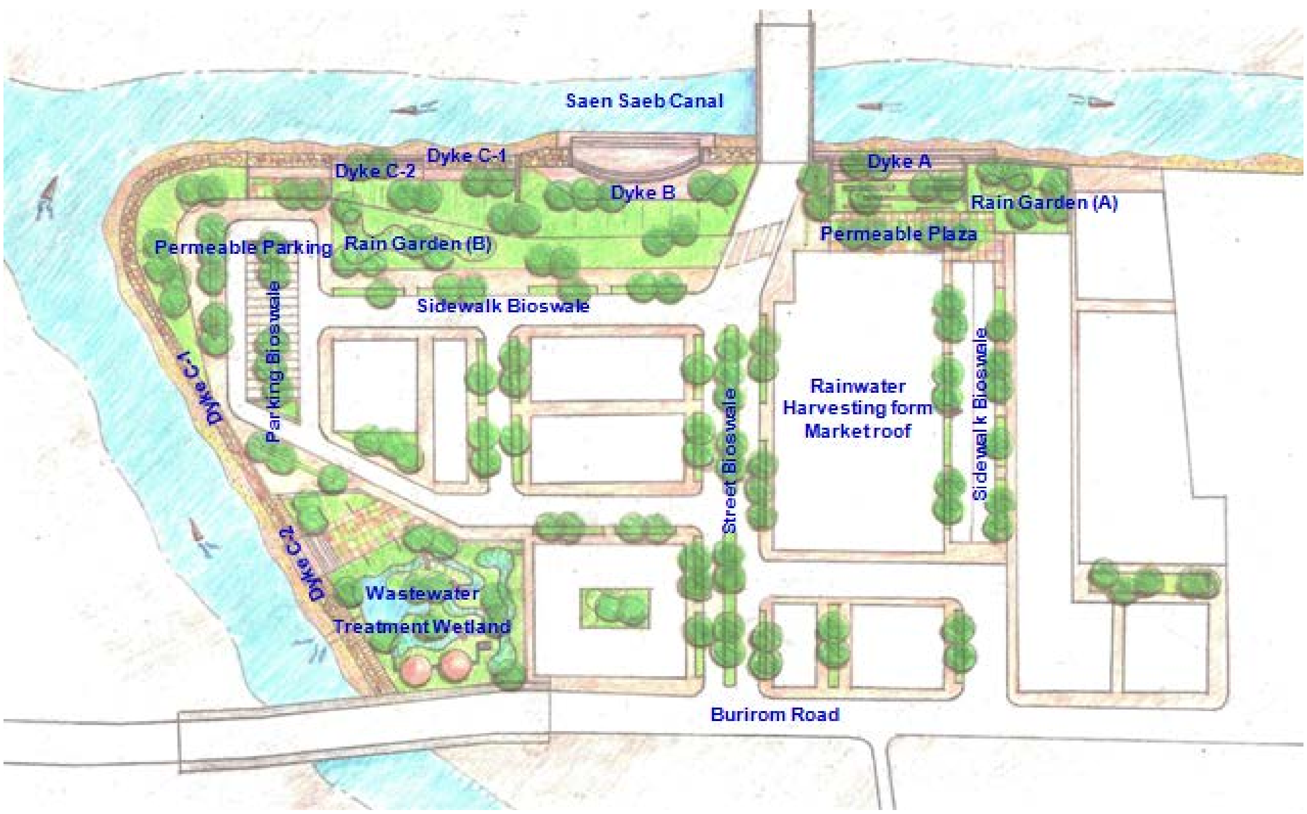


Figure 52: Master Plan of the re-design proposal in this study

- **Floodwater Protection**

Due to the estimation that the high water level in 100-year return periods is 2.50 meters above mean sea level (Retrieved from http://www.asianhumannet.org/db/datas/1102/bangkok.pdf, April 1, 2012), this design proposes floodwater protection at this level in order to prepare for 100-year flood event. Moreover, in this proposal, it is assumed to used the cross-section of Saen Saeb Canal – at the latitude 13°50’57.80856” and longitude 100°32’34.59241” surveyed by the Department of drainage and sewage, BMA (Retrieved from http://dds.bangkok.go.th/canal/, April 1, 2012) – to propose the flood control measures.

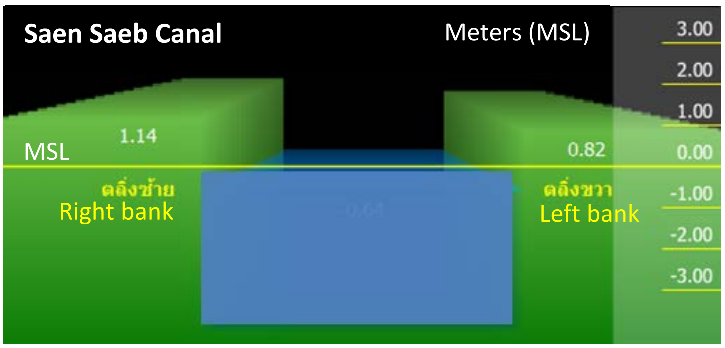


Figure 53: Cross-section of Saen Saeb Canal

The key measure proposed for flood protection in this case is the dyke along the canal. Since Nong Chok area is located on the land with approximately 1.00 meters above mean sea level, this design proposes 1.50-meter-high dyke to prepare for the 2.50-meter-high floodwater level of 100-year recurrence period. This dyke is also proposed to be the promenade along the canal as well as the amphitheater for recreational and leisure activities. There are 3 parts of dyke sections proposed in this design. The first one (section A) is the section of the dyke at the plaza in front of the market building which also proposed to be the seating steps and amphitheater at both sides of the dyke, see figure 56. The second section (section B) is proposed to be the amphitheater at the canal-faced side and the berm sloped or surf lawn connected to the stromwater infiltration and the treatment park at another side, see figure 59. The third section is the ribrab (section C-1), used for bank stabilization to prevent the erosion during high-velocity flow, and the seating steps (section C-2) at the canal-faced side and the berm sloped to the parking and wasterwater treatment area at another side, see figure 62-63.

Figure 54: The image of the seating steps at the canal-faced side of section A.

Figure 55: The image of the amphitheater of section A.

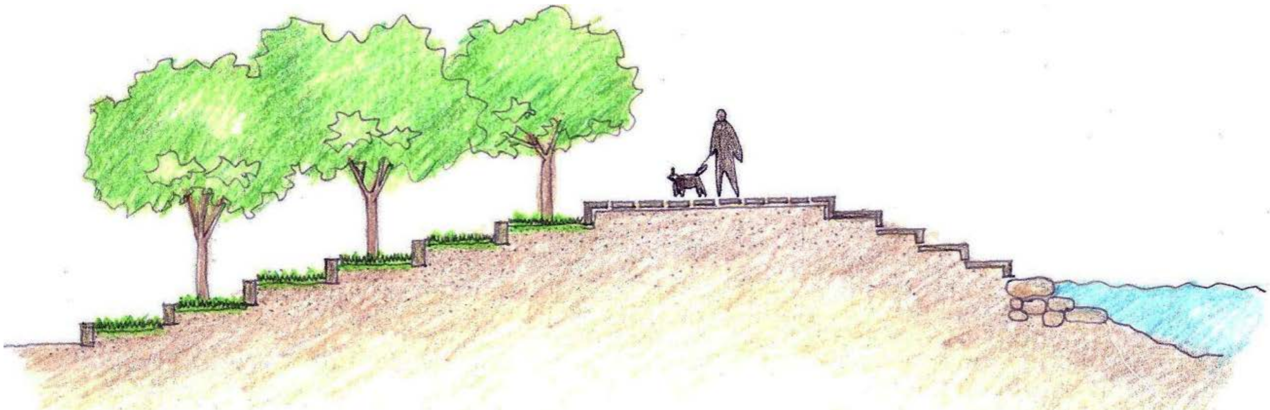


Figure 56: Section A, dyke at the plaza in front of the market building
which proposed to be the seating steps and amphitheater at both sides

Figure 57: The image of the amphitheater at the canal-faced side of section B

Figure 58: The image of the surf lawn of section B

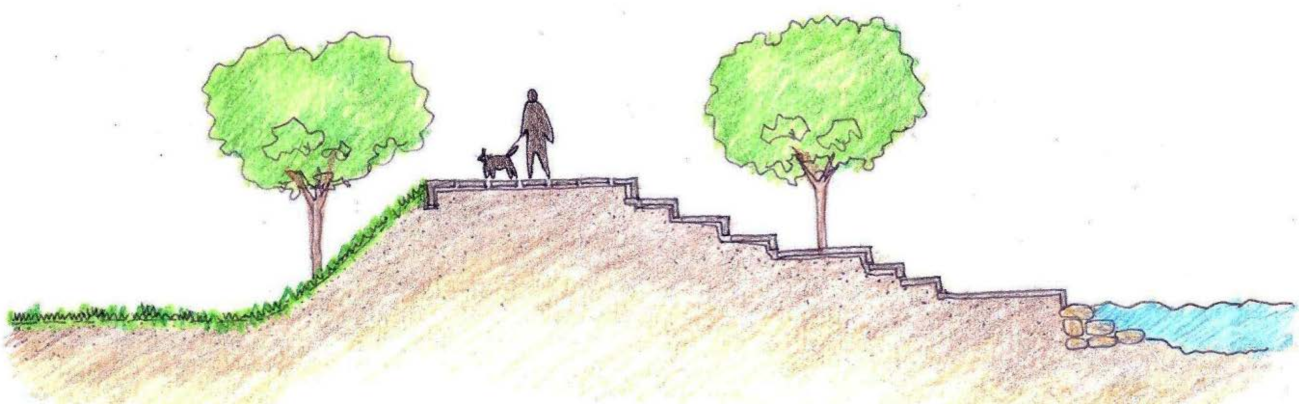


Figure 59: Section B, dyke which is proposed to be the amphitheater at the canal-faced side and
the berm sloped and connected to the stromwater infiltration and the treatment park at another side

Figure 60: The image of the ribrab at the canal-faced side of section C-1

Figure 61: The image of the seating steps at the canal-faced side of section C-2

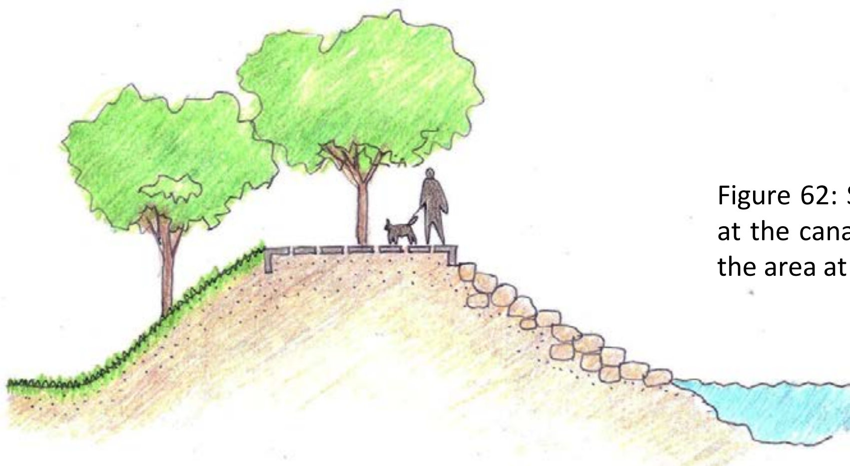


Figure 62: Section C-1, dyke which is the ribrab at the canal-faced side and the berm sloped to the area at another side

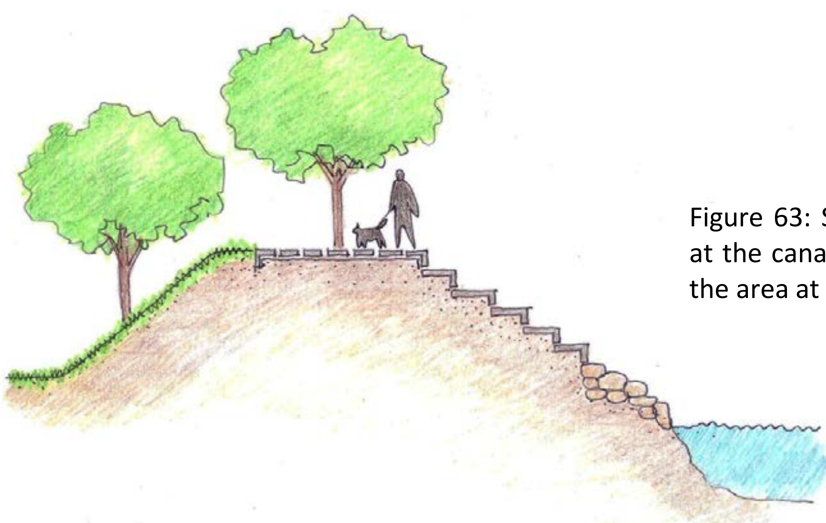


Figure 63: Section C-2, dyke which is the steps at the canal-faced side and the berm sloped to the area at another side

- **Stormwater Infiltration and Treatment**

The main goals of this part are to reduce and treat runoff from the development. The key measures are described as follows.

- **Permeable Pavement**

In order to allow stormwater to penetrate through the ground and recharge the groundwater, maximizing the permeable pavement is the crucial control, which includes planning disconnected impervious areas and using pervious pavement for plaza and parking, for example.

Figure 64: The image of disconnected impervious areas and using pervious pavement for plaza

Figure 65: The image of pervious pavement for plaza

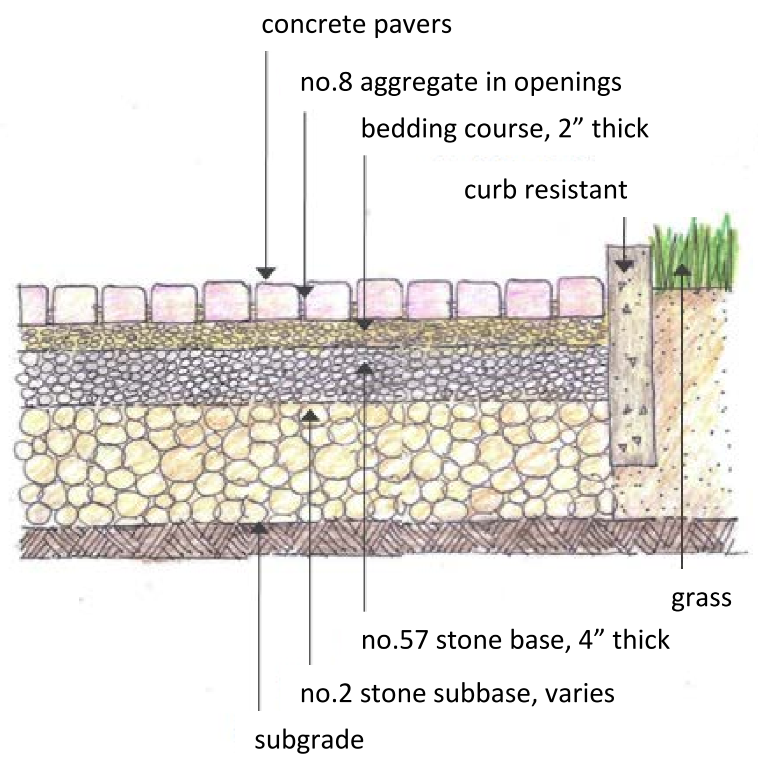


Figure 66: Cross-section illustrating the pervious plaza pavement

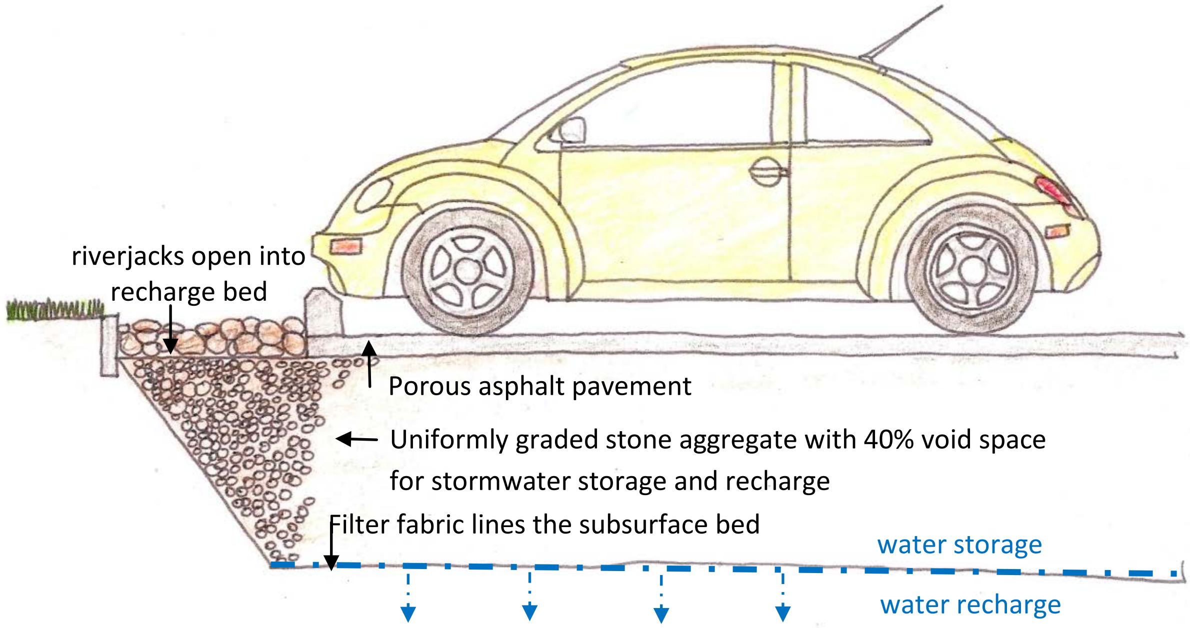


Figure 67: Cross-section illustrating the pervious parking pavement
(The design guideline for porous asphalt with subsurface infiltration)

Figure 68-69: The images of pervious parking pavement

- **Parking Bioswale**

The bioswale or vegetated swale is the constructed open-channel drainageways used to convey stormwater runoff. In addition, it is also used as pollutant filtering of the landscape element designed to remove silt and pollution from surface runoff water, particularly from parking lots. The treatment control volume can be calculated by the equation "V = CAtotRd", as shown in figure 70, and the runoff coefficient can be calculated by using the assumed runoff coefficients shown in figure 71.

Calculate treatment control volume using the formula:

$$V = CA_{tot}R_d$$

where V = design treatment volume (ft³)
R_d = design rainfall, here 1 inch
A_{tot} = total contributing drainage area, and
C is the weighted average runoff coefficient, given by

$$C = (c_i A_i) / A_{tot}$$

where c_i = runoff coefficient for ith area of contributing drainage
A_i = ith area

Figure 70: Equation for calculating treatment control volume

Assume the following runoff coefficients, c:
0.9 for impervious areas
0.6 for pervious pavement areas
0.3 for *disturbed* pervious surfaces (e.g., from truck traffic)
0.15 for *undisturbed* pervious surfaces

Figure 71: Assumed runoff coefficients for this exercise

According to the daily maximum rainfall from the statistics of rainfall at the meteorology station in Bangkok during 1999-2011 as shown in figure 72, the daily maximum rainfall in recent years was 216.8 millimeters or 8.5 inches. The treatment control volume and the minimum size of parking bioswale are calculated and shown in table 1.

สถิติปริมาณฝน ณ สถานีอุตุนิยมวิทยา กรุงเทพมหานคร พ.ศ.2542 - 2554
STATISTICS OF RAINFALL AT METEOROLOGY STATION, BANGKOK: 1999 - 2011

Item	2542 (1999)	2543 (2000)	2544 (2001)	2545 (2002)	2546 (2003)	2547 (2004)	2548 (2005)	2549 (2006)	2550 (2007)	2551 (2008)	2552 (2009)	2553 (2010)	2554 (2011)	รายการ
	สถานีอุตุนิยมวิทยากรุงเทพมหานคร (ศูนย์ประชุมแห่งชาติสิริกิติ์) Bangkok Meteorology Station (Queen Sirikit National Convention Center)													
Total rain (millimeter)	1,756.2	1,878.3	1,764.5	1,362.5	1,372.0	1,160.4	1,651.4	1,598.7	1,684.2	1,902.4	2,272.0	2,023.7	2,240.2	ฝนรวม (มิลลิเมตร)
Number of rainy days (day)	134	146	131	122	108	102	124	125	139	156	139	142	161	จำนวนวันฝนตก (วัน)
Daily maximum (millimeter)	114.5	88.1	90.4	86.6	87.6	87.9	86.9	132.9	117.9	70.1	216.8	73.5	157.4	ฝนสูงสุด (มิลลิเมตร)
	สถานีอุตุนิยมวิทยาท่าเรือคลองเตย Port Khlong Toei Meteorology Station													
Total rain (millimeter)	1,641.9	1,920.5	1,763.3	1,548.1	1,596.6	1,192.7	1,623.8	1,582.0	1,419.0	1,795.4	2,002.4	1,865.0	2,191.7	ฝนรวม (มิลลิเมตร)
Number of rainy days (day)	127	134	131	125	123	113	129	123	143	142	129	126	153	จำนวนวันฝนตก (วัน)
Daily maximum (millimeter)	118.2	88.5	91.3	105.0	88.2	73.8	90.1	95.2	125.1	80.2	140.3	80.7	152.2	ฝนสูงสุด (มิลลิเมตร)
	สถานีอุตุนิยมวิทยาสนามบินดอนเมือง Don Muang Airport Meteorology Station													
Total rain (millimeter)	1,831.6	1,390.9	1,295.2	1,257.8	1,484.5	1,100.1	1,609.5	1,433.0	1,543.0	1,553.8	2,014.2	1,902.8	1,958.0	ฝนรวม (มิลลิเมตร)
Number of rainy days (day)	133	132	124	119	106	95	124	120	128	130	138	129	124	จำนวนวันฝนตก (วัน)
Daily maximum (millimeter)	210.7	121.1	58.4	65.3	82.0	101.5	102.9	95.0	89.8	118.0	123.3	94.9	106.9	ฝนสูงสุด (มิลลิเมตร)

Figure 72: Statistics of Rainfall at Meteorology Station, Bangkok (1999-2011)

***Table 1:** Treatment Control Volume and Minimum Size of Parking Bioswale*

Surface Type	Runoff coefficient	Treatment control area (acres)	Rainfall (inches)	Treatment control volume (cubic feet)	Minimum Treatment control size (WxLxD)
Pervious Pavement	0.6	0.17(100%)	8.5	0.867	2’x2.2’x0.2’

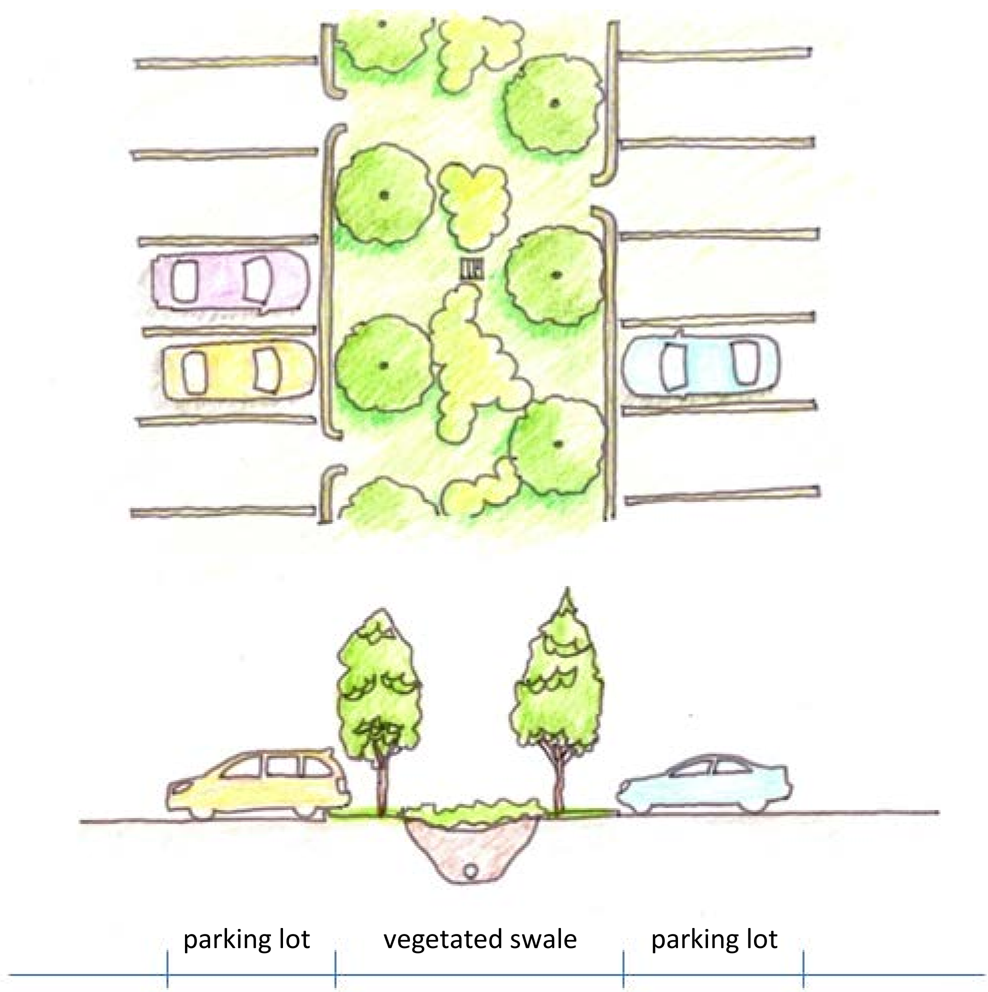


Figure 73: Plan and cross-section illustrating the parking vegetated swale

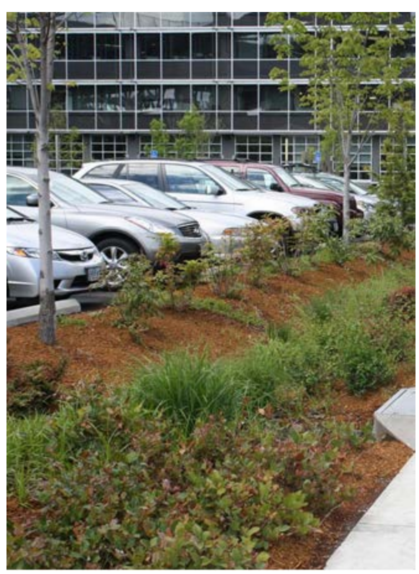


Figure74-75: The images of parking vegetated swales

- **Street Bioretention Basins**

In order to remove pollutants from street runoff, the street bioretention planter is one of the key measures. Curb extension can be used for filtering stormwater, whether at the street medians or sidewalks. The calculation of treatment control volume and minimum size of basin are shown in table 2 and 3.

Table 2: ***Treatment Control Volume and Minimum Size of Street Median***

Surface Type	Runoff coefficient	Treatment control area (acres)	Rainfall (inches)	Treatment control volume (cubic feet)	Minimum Treatment control size (WxLxD)
Impervious Pavement	0.9	0.20(100%)	8.5	1.530	2’x4.0’x0.2’

Table 3: ***Treatment Control Volume and Minimum Size of Street Sidewalk***

Surface Type	Runoff coefficient	Treatment control area (acres)	Rainfall (inches)	Treatment control volume (cubic feet)	Minimum Treatment control size (WxLxD)
Impervious	0.9	0.84(44.21%)	8.5	-	-
Pervious	0.6	1.06(55.79%)			
Total	0.73	1.90(100%)	8.5	11.80	2’x30’x0.2’


Figure 76-77: The images of street bioretention planters at the street median

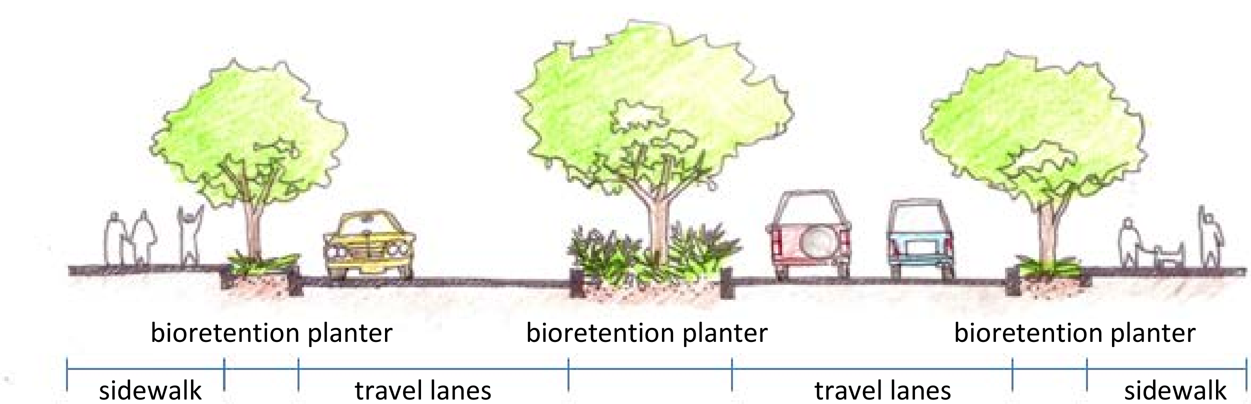


Figure 78: Cross-section illustrating the street bioretention planter at the street median and sidewalk

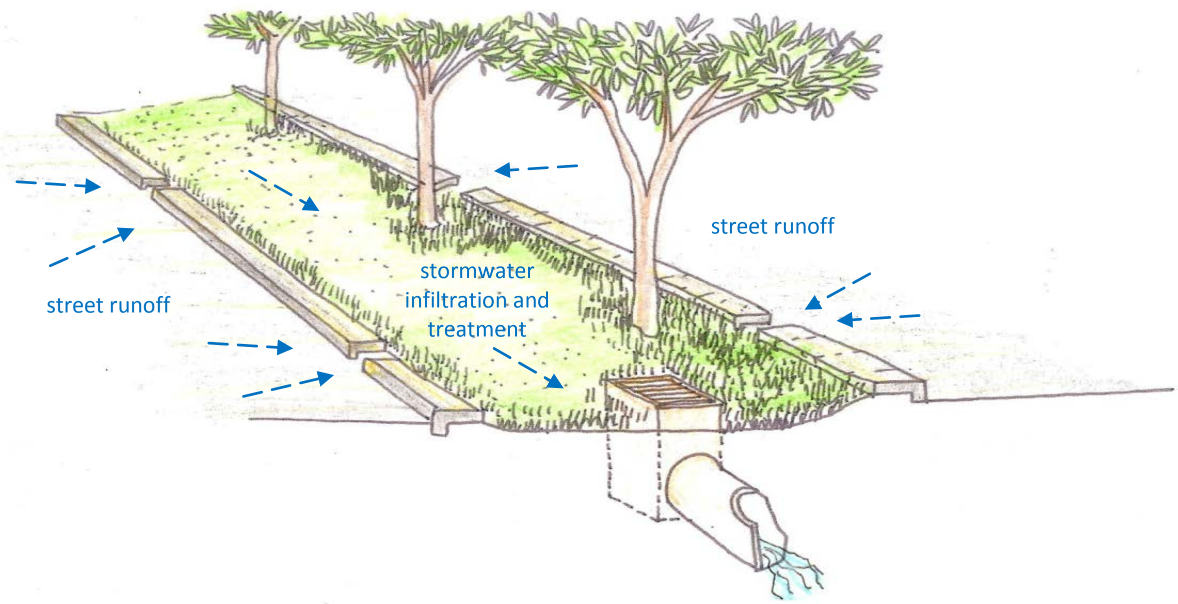


Figure 79: Perspective illustrating the street bioretention planter at the street median

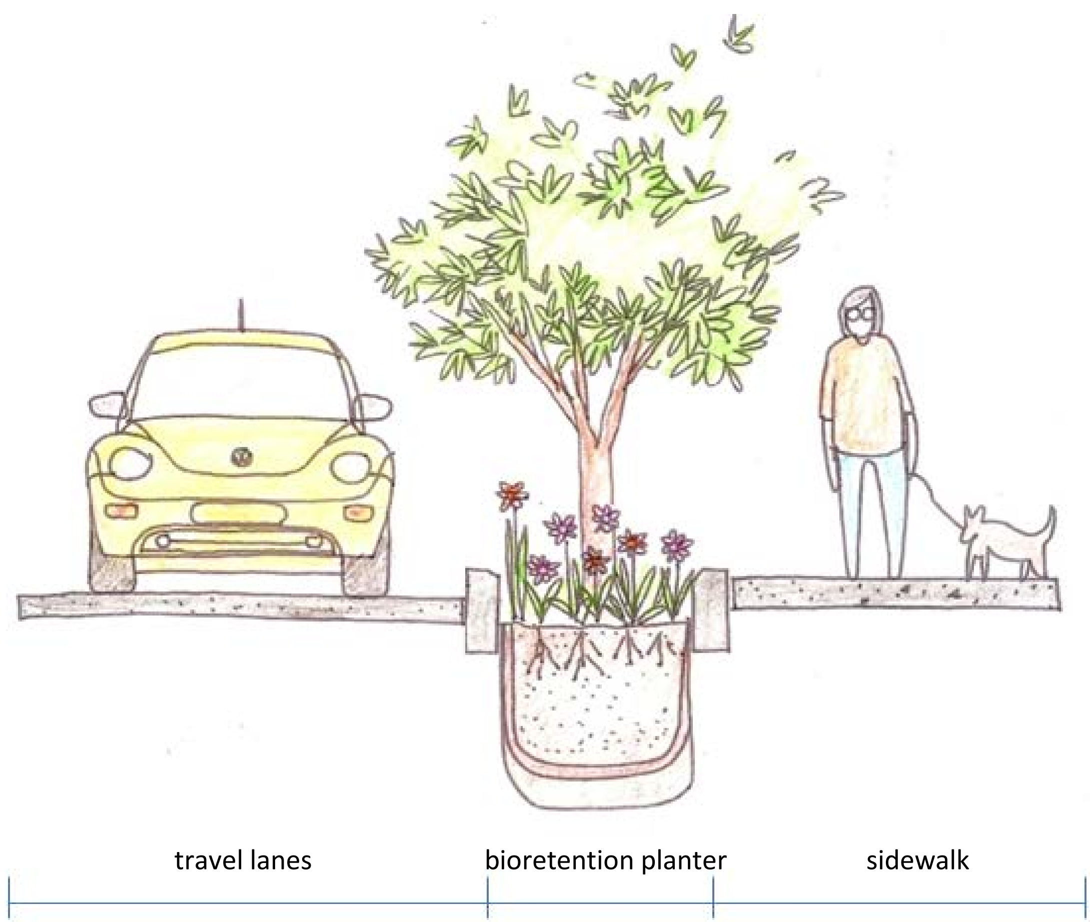


Figure 80: Cross-section illustrating the street bioretention planter at the sidewalk

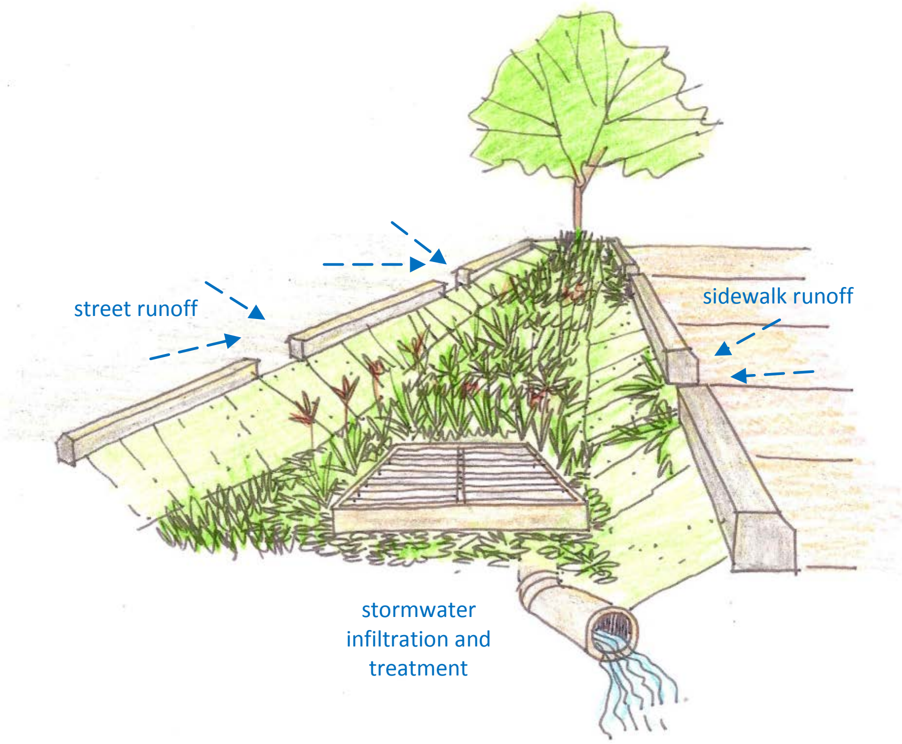


Figure 81: Perspective illustrating the street bioretention planter at the sidewalk

Figure 82-84: The images of street bioretention planters at the sidewalks

- **Rain Garden**

The rain garden is the planted depression or shallow basin that allows rainwater runoff from impervious urban areas like roofs, driveways, walkways, parking lots, and compacted lawn areas the opportunity to be absorbed and treated. In this design, the rain garden is also proposed to be used as the recreational park for the community. The calculation of treatment control volume and minimum size of the rain gardens are shown in table 4 and 5.

***Table 4:** Treatment Control Volume and Minimum Size of Rain Garden (A)*

Surface Type	Runoff coefficient	Treatment control area (acres)	Rainfall (inches)	Treatment control volume (cubic feet)	Minimum Treatment control size (WxLxD)
Lawn	0.3	0.14(60.87%)	8.5	-	-
Pervious	0.6	0.09(39.13%)			
Total	0.42	0.23(100%)	8.5	0.82	2'x2.05'x0.2'

***Table 5:** Treatment Control Volume and Minimum Size of Rain Garden (B)*

Surface Type	Runoff coefficient	Treatment control area (acres)	Rainfall (inches)	Treatment control volume (cubic feet)	Minimum Treatment control size (WxLxD)
Lawn	0.3	0.11(44.21%)	8.5	-	-
Pervious	0.6	0.07(55.79%)			
Total	0.52	0.18(100%)	8.5	0.80	2'x2'x0.2'

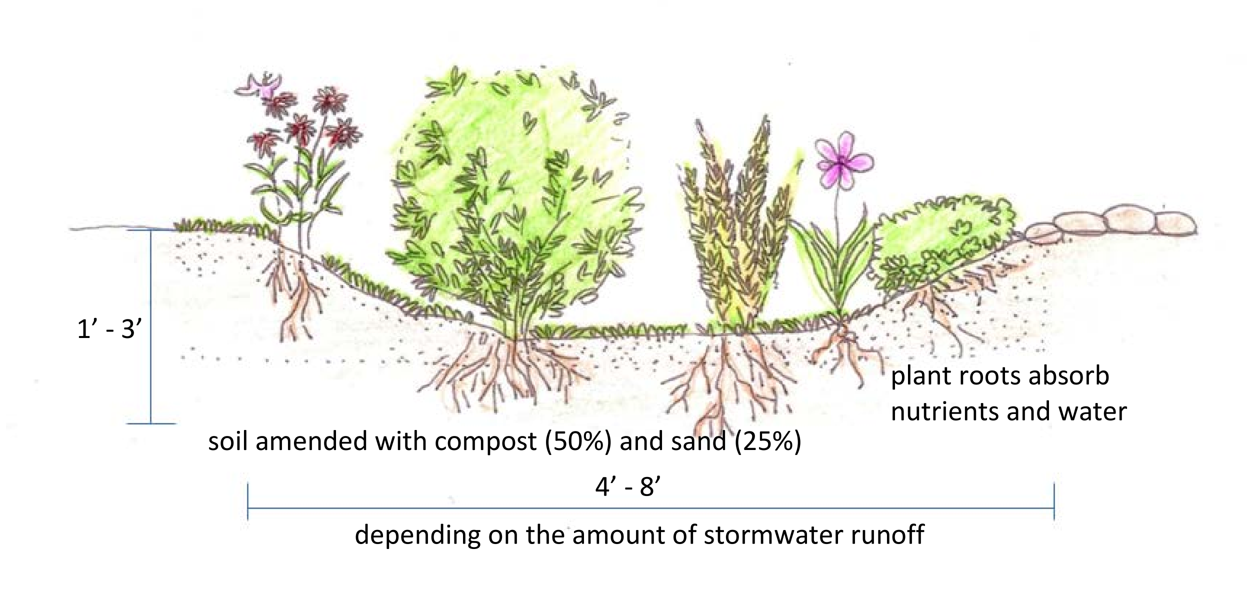


Figure 85: Cross-section illustrating the rain garden

Figure 86: The image of rain garden

Figure 87: The image of activity at rain garden

- **Rainwater harvesting**

Rainwater Harvesting refers to the collection and storage of rain; usually from rooftops, and storage in catchment tanks. This stored water can be used for non-potable purposes such as irrigating lawns, washing cars, or flushing toilets. Rainwater harvesting systems can range from a simple barrel at the bottom of a downspout to multiple tanks with pumps and controls. Rainwater harvesting is also effective in reducing stormwater runoff pollution. When rain falls, it is clean, but it immediately picks up pollutants from rooftops and pavement. This pollution is carried into storm drains and then into streams. Therefore, rainwater harvesting can later help decreasing the pollution of runoff. (Retreived from http://www.portlandonline.com/bps/index.cfm?c=ecbbd&a=bbehfa, April 1, 2012).

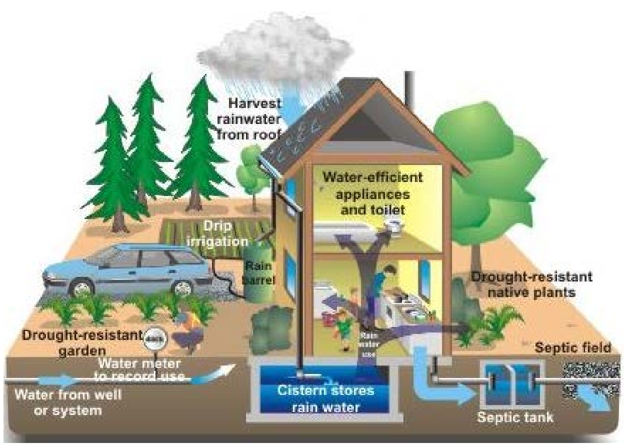


Figure 88: The diagram illustrating the rainwater harvesting concept

Figure 89: The example of rainwater harvesting

This design proposes rainwater harvesting from the roof of market building. Since the roof area of the market building is 1,350 square meters and the average rainfall is 150 centimeters per year, the volume of the tank can be calculated at 26,000 liters or 920 cubic feet. This volume is calculated by using the excel program which is available to be downloaded online at http://www.rainwaterharvesting.co.uk/calculator.php (April 1, 2012), as shown in figure 91-92. Accordingly, the size of tank for this project is estimated at ϕ10’ x 12’ (diameter x height)

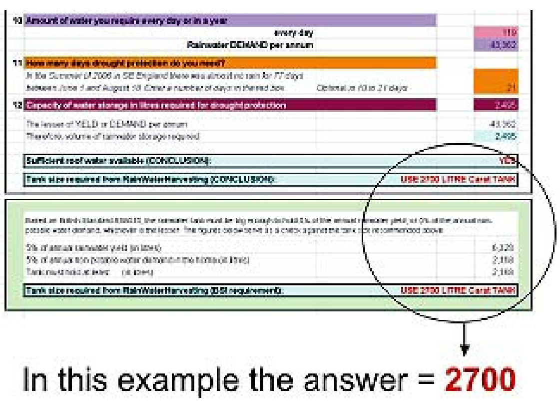
Climate data for Bangkok (1961-1990) [hide]													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	32.0 (89.6)	32.7 (90.9)	33.7 (92.7)	34.9 (94.8)	34.0 (93.2)	33.1 (91.6)	32.7 (90.9)	32.5 (90.5)	32.3 (90.1)	32.0 (89.6)	31.6 (88.9)	31.3 (88.3)	32.7 (90.9)
Daily mean °C (°F)	25.9 (78.6)	27.4 (81.3)	28.7 (83.7)	29.7 (85.5)	29.2 (84.6)	28.7 (83.7)	28.3 (82.9)	28.1 (82.6)	27.8 (82.0)	27.6 (81.7)	26.9 (80.4)	25.6 (78.1)	27.8 (82.0)
Average low °C (°F)	21.0 (69.8)	23.3 (73.9)	24.9 (76.8)	26.1 (79.0)	25.6 (78.1)	25.4 (77.7)	25.0 (77.0)	24.9 (76.8)	24.6 (76.3)	24.3 (75.7)	23.1 (73.6)	20.8 (69.4)	24.1 (75.4)
Rainfall mm (inches)	9.1 (0.358)	29.9 (1.177)	28.6 (1.126)	64.7 (2.547)	220.4 (8.677)	149.3 (5.878)	154.5 (6.083)	196.7 (7.744)	344.2 (13.551)	241.6 (9.512)	48.1 (1.894)	9.7 (0.382)	1,496.8 (58.929)
Avg. rainy days (≥ 1 mm)	1	3	3	6	16	16	18	20	21	17	6	1	128
Mean monthly sunshine hours	272.8	251.4	269.7	258.0	217.0	177.0	170.5	161.2	156.0	198.4	234.0	263.5	2,629.5
Source no. 1: Thai Meteorological Department[13]													
Source no. 2: Hong Kong Observatory [14]													

Figure 90: Average rainfall data for Bangkok[2]

Want to do the calculation yourself? It will only take a minute or two

1. **To start the calculation**, click on the **Tank Size Calculator** link **here** and

download the Excel spreadsheet.
2. Insert your home's measurements, in metres, in the yellow boxes. Try to estimate the dimensions of that part of the house from which you will be collecting rain water.
3. Refer to the table on Tab "Rainfall" and find out the average annual rainfall in centimetres in your part of the country, then type it in the 3rd yellow box; e.g., if you live in East Anglia, the driest part of the country, use 58.
4. Insert in the red box the number of days drought protection you would like from your rainwater harvesting system. You can change the number of weeks at will to see what impact it has on the tank size you need.
5. The results of the calculations are shown in the three light blue boxes:
5.1. The first blue box shows the amount of water you need to protect your home use and garden from drought.
5.2. The 2nd blue box shows YES if your roof is big enough to provide the water you need to fill the tank!
5.3. The 3rd blue box shows the tank size we would recommend.



You're done! Congratulations. To find the tanks suitable for your application, type the size of tank into the search box below - say.. 2700 - and the search should bring up the tanks and systems of that tank size. You can place an order online (or by phone if you have queries) and even have the system installed.

Where next? Here's the search box to type in your tank size. To find the tanks and systems, just click Search

[ ] Search

Further Advisory Notes

Figure 91: The program for calculating the rainwater harvesting tank size
which is available to be downloaded online

[2] Bangkok has a tropical monsoon climate; or a tropical wet and dry climate under the Köppen climate classification system, in particular. The mean temperature ranges from 26°C to 31°C; the maximum is in April and the minimum is in December. For the annual rainfall over the basin, approximately 85 percent occurs between May and October with the average annual rainfall ranges from 1,000 to 1,500 mm. (Source: http://siteresources.worldbank.org/EASTASIAPACIFICEXT/Resources/226300-1287600424406/coastal_megacities_chapter3.pdf, http://www.citiesalliance.org/ca/sites/citiesalliance.org/files/CA_Docs/resources/cds/liveable/bangkok.pdf, http://std.cpc.ku.ac.th/delta/conf/Acrobat/Papers_Eng/Volume%201/Wirat%20RID.pdf, and http://en.wikipedia.org/wiki/Bangkok, Available online, April 1, 2012)

www.RainWaterHarvesting.co.uk — Client and details

TANK SIZE CALCULATOR ©2009 ©2011 ©2012 RainWaterHarvesting.co.uk

Insert your building's data in the yellow boxes.
From the roof area off your property, you assess the amount of water available, and equate it to the amount you will use.

1	**Main Building area**		
	Building width (metres)	30	
	Building depth(metres)	45	
	Rain Collection Area 1 (square metres)		1,350
6	**TOTAL of collectable roof areas (square metres)**		**1,350**
7	**Rainfall per year in your area (cms).** Use rainfall chart on sheet 2, a figure between 60 and 170.	150	
8	**Collectable rainwater per annum (in litres - discounted by 20% to account for water loss) (YIELD)**		**1,620,000**
9	**Use of water in the building**		
	Washing machine and toilet flushing are the main usage for rain water in domestic systems. Add an allowance for daily garden use.		
	Number of people in the house	200	*people*
	Number of clothes washing cycles per day (50 litres each)	50.00	2,500
	Number of toilet flushes per day (4.42 flushes per person, average 5 litres each)	884	4,420
	Outdoor use per day (minimum 5 litres per person per day) *or adjust till F46 = F35 more or less*		1,000
10	**Amount of water you require every day**		7,920
	Amount of water you require every year (DEMAND)		2,890,800
11	**How many days drought protection do you need?** Enter a number in the box to the right, typically 21		**30**
12	**Capacity of water storage in litres required for drought protection**		**237,600**
	The lesser of YIELD (8) or DEMAND (10) per annum		1,620,000
	Therefore, volume of rainwater storage required		**133,151**
13	**Is there sufficient roof water available (CONCLUSION):**		**NOT ENOUGH ROOF WATER**
14	Tank size required - either, in the bestselling **Carat** range,		Use a quad 6500 Carat kit [26,000 litres]
	or, in the shallow-dig tank range,		Use multiple shallow tanks
	or, in the **Rondus** range,		Use multiple Rondus tanks
	or, if your tank is going to be above ground, in the **Balmoral** range...		Use multiple Balmoral tanks

15	Cross check with the British Standard BS 8515:2009	
	Based on British Standard BS 8515, the rainwater tank must be big enough to hold 5% of the annual rainwater yield, or 5% of the annual non-potable water demand, whichever is the lesser. The figures below serve as a check against the tank size recommended above.	
	5% of annual rainwater yield (in litres)	81,000
	5% of annual non-potable water demand in the home (in litres)	144,540
	To be conform to BS8515, tank must hold at least ... (in litres)	**81,000**
	Tank size required from RainWaterHarvesting (BSI requirement):	**use a quad 6500 Carat kit i.e. 26,000 litres**

Figure 92: The result of rainwater harvesting tank size calculation from the program is available to be downloaded online

Figure 93: The roof of market building proposed for rainwater harvesting

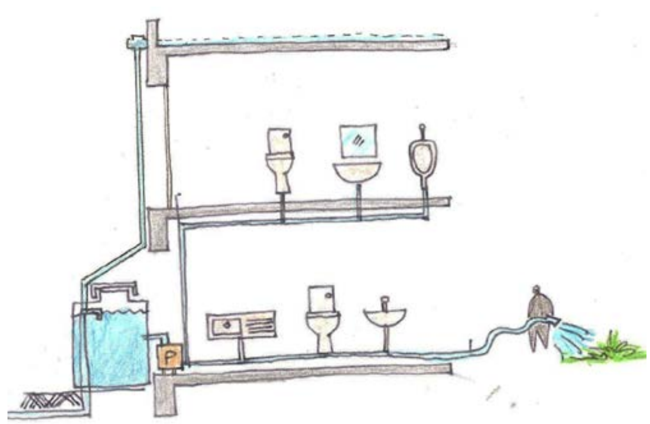


Figure 94: The diagram illustrating the concept of rainwater harvesting from the roof of market building

- **Wastewater Treatment**

The wastewater treatment proposed in this part focuses on the wastewater from the fresh market. Because the wastewater from this area is dirtier or higher contaminated than the stromwater, it should be treated separately from the stromwater treatment system. For wastewater from other sources – sinks and toilets, it will be piped to the sewage treatment system of the district. In this case, it is estimated that the fresh market generates wastewater approximately 0.25 inch per square. Since the area of the fresh market is 400 square meters or 4,300 square feet (one-third of the market area), the wastewater to be treated is 1,075 cubic feet.

Figure 95: Wastewater from cleaning the fresh market area.

The wastewater treatment system is proposed to be located at the southeastern part of the site. The system comprises of three main parts – the sedimentation pond, the sewage treatment tank and the treatment wetland. The wastewater from the fresh market is piped to the sedimentation ponds for removing big particle – such as sand, grit, stones, and broken glass – because these particles may damage pumps and other equipment. Then it flows to the sewage treatment tank to remove grease and some nutrients, especially nitrogen and phosphorus. After that the water is drained to the treatment wetland, or the vegetated swale proposed to let the plants absorb the contaminants in the water again before draining to the canal or pumping to be reused. The proposed shapes of the sedimentation pond and treatment wetland are meandering in order to increase the distance of the pond, to let the water flows through the pond as long as possible. The size of the pond and the swale along with sewage treatment tank are estimated as presented in table 6.

***Table 6*: The wastewater treatment size estimation**

Treatment Part	Wastewater Volume	Treatment Size
Sedimentation pond	1,075 ft3	4’ x 90’ x 3’ (width x length x depth)
Sewage treatment tank*	1,075 ft3 (8,050 gallons)	2 x ϕ9.5’ x 8’ (quantity x diameter x height)
Treatment wetland	1,075 ft3	6’ x 120’ x 2’(width x length x depth)

* The size of sewage treatment tank is calculated by using the guideline as shown in figure 96.

Calculating Septic Tank Capacity in Gallons	
Round Septic Tanks	3.14 x radius squared x depth (all in feet) = cubic capacity. Cubic capacity x 7.5 = gallons capacity.
Rectangular Septic Tanks	Length x Width x Depth in feet x 7.5 = gallons
Rectangular Septic Tanks (alternative method 1)	Length x width in inches / 231 = gallons per inch of septic tank depth. Multiply this number by septic tank depth in inches to get gallons
Rectangular Septic Tanks (alternative method 2)	Length x Width x Depth in feet / .1337 = gallons

Figure 96: Guideline for calculating the size of sewage treatment tank

In addition, this treatment area is also proposed to be the educational park for the children as well as every local people to learn about the water treatment processes. Moreover, it is also expected to plant the awareness toward the importance of their water resource to all inhabitants in the community.

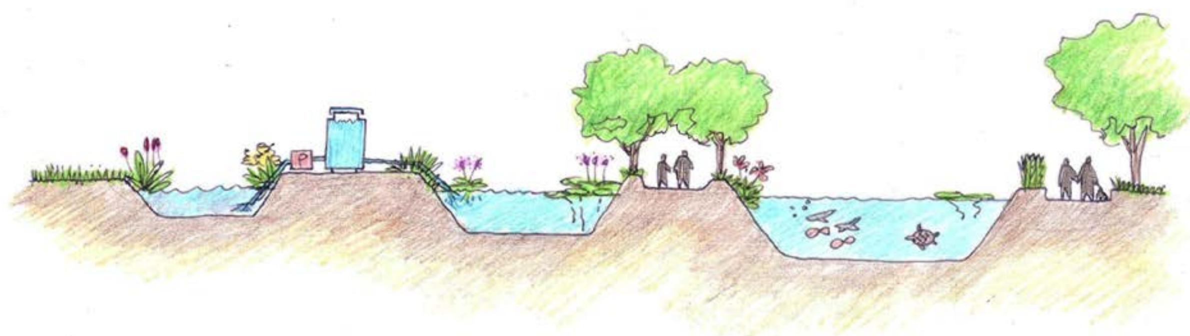


Figure 97: Cross-section of the wastewater treatment pond

Figure 98-100: The images of treatment wetland as learning park

Conclusion and Discussion

Hydrologic processes and water management is realized as the significant issues in sustainability of the cities over the world, including Bangkok, Thailand. With its location and current rapid-paced urban development situation, Bangkok holds high risk in flood damages during monsoon season as well as water quality problems. Accordingly, the appropriate planning which regarding the hydrologic processes and holistic water management is certainly crucial for the sustainable future development of Bangkok and all areas over the country.

The holistic approach, or multi-objective approach, proposed in this study is the planning strategy which integrates flood management and ecological restoration with the intention of reaching the sustainable future development. In this study, the levee, dyke, and water detentions basin are proposed for flood prevention and mitigation, while permeable pavement, bioswales, bioretaintion basins, rain gardens, rainwater harvesting, and treatment wetlands are proposed for stromwater and wastewater management. Moreover, this study also recommends the provision of these areas of opportunities for recreational and educational activities for local residents. Since the this approach is relatively new and not broadly recognized in Thailand, this study project is going to be a very beneficial and useful example or pilot study for the application and implementation in Thailand.

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