TABLE OF CONTETS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ADB	Asian Development Bank
BMA	Bangkok Metropolitan Administration (Thailand)
BOD	Biochemical Oxygen Demand
CPD	City Planning Department (Thailand)
CPRB	Chao Phraya River Basin
CSOs	Combined Sewer Overflows
CWs	Constructed Wetlands
CWWM	Centralized Wastewater Management
DCP	Department of City Planning (Thailand)
DDS	Department of Drainage and Sewerage (Thailand)
DEQP	Department of Environmental Quality Promotion (Thailand)
DO	Dissolved Oxygen
DOE	Department of Environment (Thailand)
DPC	Department of Pollution Control (Thailand)
DWR	Department of Water Resources (Thailand)
EPA	Environmental Protection Agency (U.S.A.)
FAR	Floor Area Ratio
ICM	Integrated Catchment Management
IWRM	Integrated Water Resources Management
LAOs	Local Administrative Organisations
LID	Low Impact Development
LIUDD	Low Impact Urban Design and Development
MOI	Ministry of Industry (Thailand)
MoNRE	Ministry of Natural Resources and Environment (Thailand)
MWA	Metropolitan Waterworks Authority (Thailand)
NEQA	Enhancement and Conservation of National Environmental Quality Act
NESDB	National Economic and Social Development Board (Thailand)
NGOs	Non-Government Organizations
NHA	National Housing Authority (Thailand)
NPSs	Non-Point Sources pollution
NRDC	Natural Resource Defense Council
NWRC	National Water Resources Committee (Thailand)
ONEP	Office of Natural Resources & Environmental Policy and Planning (Thailand)
OSS	Onsite Sanitation System
PAHs	Polycyclic Aromatic Hydrocarbons
PCD	Pollution Control Department (Thailand)
RBOs	River Basin Organisations (Thailand)
RBSs	River Basin Sub-committees (Thailand)
RID	Royal Irrigation Department (Thailand)
SC	Stormwater Source Control
SD	Sustainable Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organisation
WWTPs	Wastewater Treatment Plants

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CO-AUTHORS

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Dr. Marjorie van Roon	Editorial, proof reading and correction

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The undersigned hereby certify that:
- ❖ the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
- ❖ that the candidate wrote all or the majority of the text.

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Extent of contribution by PhD candidate (%)	90

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CHAPTER 1: INTRODUCTION

1.1 Introduction and Research Background:

This introductory chapter provides an overview of insights of the water quality issues and investigates the ways in which Integrated Catchment Management (ICM) and stormwater Source Control (SC) approaches can contribute to environmental improvement. The consideration of catchment issues is intrinsic to urban and regional planning. As isolated management of water systems has caused negative impacts on the degradation of ecosystem function, catchment management requires the coordination and integration of practices. ICM seeks to maintain a balance between the roles of resource utilisation and protection of a catchment through considering the entire hydrological cycle and integrated planning among multi-disciplinary approaches to land and water resource management.

As a result of urbanisation, anthropogenic water contamination has increased in receiving rivers around the world particularly in floodplain cities. The increased level of impervious surfaces associated with the pollution of water runoff from hot spots in a catchment such as residential, agricultural and industrial areas, roads, and parking lots significantly degrades downstream water quality and has adverse effects upon the aesthetics of natural areas. Traditional approaches to catchment management are likely to be ineffective from both an ecological and social perspective. This approach has recognised the spatial domain of engineering as a high priority in catchment management, while considering ecological values as a low priority for preservation.

In Thailand, due to urbanisation along the Chao Phraya River and the intensification of industrial and agricultural development, the country currently faces the problem of river water quality degradation especially in the lower river where Bangkok is located (Greenpeace International, 2011). The rapid urbanisation during recent decades has led to the conversion of various canals and ponds to streets and roadways (BMA, 2009a). The agricultural areas have been changed into housing and industrial estates (Prajamwong & Suppataratarn, 2009). The increased imperviousness and the degree of catchment development resulted in a high degree of contamination and stormwater discharge to receiving waters (Marome & Asan, 2011). Recent studies reported that the level of the surface water quality standard in the lower Chao Phraya River passing through Bangkok is unsatisfactory, with low Dissolved Oxygen (DO) and high Biochemical Oxygen Demand (BOD) and nutrient levels (Leerasiri, 2010; BMA, 2011). This condition indicates that the water quality in the river needs to be improved. Without appropriate stormwater and wastewater management strategies, the impacts on the health and aquatic ecosystems of receiving waters can be devastating.

The on-going urbanisation has caused water pollution throughout the lower river and Bangkok area. As described by Greenpeace International, (2011) the Chao Phraya River passing through Bangkok has been classified as 'deteriorated' based on the index of the Thai water quality. The deterioration of the water quality in the lower catchment had become a major concern to the public and government. There is a wide range of pollutants being washed off from the catchment by stormwater runoff. The pollutants typically found in urban stormwater runoff are generated from largely non-point sources and overflows, including from urban runoff, agricultural runoff, onsite sanitation systems seepage, and combined sewer overflows containing stormwater and domestic wastewater.

High-nutrient loads, mainly phosphorus and nitrogen, are one of the most prevalent water quality pollution problems in the Chao Phraya River Basin (CPRB). Organic pollutants from household wastewater have also become a major source of water deterioration in the river. It was found that combined sewerage systems and onsite sanitation systems (OSS) in Bangkok City were the main sources of nitrogen flow from grey water and black water respectively (Buathong et al., 2013). High proportions of pollutant loads in receiving rivers around Bangkok were caused by seepage and septage from on-site treatment methods including septic tanks and leachate from composting (SSL) (Tsuzuki et al., 2009). The estimation data of Pollutant Discharges per Capita (PDCs) indicated that pollutant discharges to receiving rivers are still high even in the Wastewater Treatment Plants (WWTPs) serviced areas.

Centralised wastewater management is an approach that has been implemented extensively as a method to treat large volumes of wastewater and stormwater in high density or urbanised areas (Suriyachan et al., 2012). However, central wastewater treatment plants are still inadequate in Bangkok. Although seven central wastewater treatment facilities have been constructed, they do not cover the whole area and still have limitations. ADB (2012) reported that wastewater treatment plants in Bangkok cover only one-fourth of the Bangkok area, serving about half of the residents or slightly more than three million people. Insufficient water treatment facilities for domestic wastewater has resulted in high organic pollutant loads and lower DO than the water quality standards set for the lower Chao Phraya River.

A combined sewer system for stormwater runoff and wastewater has been applied in Bangkok (PCD, 2004; MPH & MNRE, 2012). The existing water drainage system in Bangkok collects both sanitary sewage and stormwater runoff in a single pipe system and requires a large pipe size adding to the cost of construction (ADB, 2012). As at 2012, the effluent discharge in Bangkok was generated from domestic uses up to 75 % and from industrial and commercial premises around 25% (Leerasiri, 2010; BMA, 2011; ADB, 2012; Suriyachan et al., 2012). The capacity of interceptor system in Bangkok was set at 5 times of the average Dry Weather Flow (DWF) to remove discharges. However, the flow in the channel system during the rainy season can exceed 25 times of the average dry weather flow (DWF) (Leerasiri, 2010). Although the excess combined flows will be screened before discharge to the canals, the flows may exceed the capacity of the interceptors during a heavy rainfall event. The findings were significant and clear, that is, it is mainly human activity that is altering the environment and leading to river water pollution on a large scale.

As the decreases in environmental integrity have already been manifest and ecological and environmental issues have become more complex, the sustainable solutions through various disciplines need to be incorporated transcending the effort of science and engineering alone. The reductionism paradigm is considered to be inadequate to deal with the inherent complexity of catchment management issues, resulting in ineffective decisions and negative impacts of those policies and plans on the erosion of ecosystem services.

Water quality issues have been the focus of the failure of water governance over the terms of the resource base itself. Urbanisation may lead to negative environmental impacts if effective water governance is not yet well managed in parallel to economic growth. The weaknesses of the existing catchment management systems have been revealed in several studies (Pahl-Wostl et al., 2012; Borowski et al., 2008; Kidd & Shaw, 2007; Ostrom et al., 1961). Awareness of the weaknesses on institutional framework and management capacity is significant to embrace the concepts of ICM in efforts to maintain the environment in a sustainable manner.

Fragmented administrative structures have become apparent in which policy and operating responsibilities are separated between different organisations. The absence of cooperation and transfer of knowledge between national, catchment and local authorities, and issues of government fragmentation of catchment management are typical problems of water governance in countries all over the world (Kidd & Shaw, 2007). This situation increases difficulties in catchment management and sustainable management practices.

The failure of governance affects both developing and developed nations in different forms. The ineffectiveness of governance structures in developing countries often cause difficulties in water resource management. On the other hand, industrialized countries also undergo over-regulation, rigid government bureaucracies, government fragmentation, and the current economic domination over environmental considerations (Pahl-Wostl et al., 2012). Thus, there is the urgent need to improve the effectiveness of water governance structure coupled with environmental conservation in countries with poor governance performance.

Over a decade ago, the notion of ICM was shaped to resolve the stormwater quality issue and government fragmentation. In Thailand, the concept of ICM has been introduced in national policies and plans for a decade. Although catchment plans have been developed since 2003, it is evident that most of the catchment plans have not been implemented to overcome stormwater quality issue (World Bank, 2011). Institutional fragmentation is the main barrier to the achievement of ICM and plan implementation. A lack of co-operation among responsible agencies for catchment management has resulted in the fragmented operations. The accountabilities of government agencies under the laws often overlap, with more than 30 government agencies in all administrative levels involved in catchment management (World Bank, 2011). This has contributed to the difficulty and confusion of catchment management.

With regard to water resource management, due to ineffective cooperation of water sectors and a lack of recognition of holistic management of the water resource, the existence of numerous subsector government institutions has expanded their activities to support the intentions of their sector. This has reflected the implementation of ICM planning in the country. Moreover, although several legal frameworks for environmental protection have been enacted for many decades, most environmental regulations have focused on regulating each resource individually (WEPA, 2013). The insufficiency of planning processes, institutional arrangements, legal frameworks, and catchment plans means that the implementationn of ICM remains unsatisfactory.

This thesis addresses a crucial issue of stormwater quality and environmental protection in Bangkok and its catchment including parts of the catchment beyond the city political boundary. The issues of the traditional water management system under the anthropocentric paradigm, and the concerns of unsustainable practices were taken into account.

To overcome river water quality issue, ICM and stormwater SC approaches were addressed to understand complex processes of land and water resources management. The potential of SC approaches from other countries was examined to draw parallels to Bangkok in order to promote environmental quality improvement.

To achieve ICM planning and urban sustainability, planning factors require coordination and integration of practices through institutional arrangements, legal frameworks, and catchment plans. Green practices particularly SC approaches promote integrating water cycle management within urban development. Stormwater SC approaches adopt the principle of restore, reduce, reuse, and recycle of water and emphasise the use of holistic and long-term methods to provide sustainable urban stormwater management (EPA, 2013). The approaches enhance the potential for runoff reduction and pollutant removal through retrofitting the hydrological regime in association with various green facilities. ICM planning and stormwater SC approaches may guide the planner to create comprehensive and sustainable land use practices for managing stormwater quantity and quality in the floodplain city.

1.2 Research Objectives:

This research aims to develop a planning policy framework and appropriate guidelines to mitigate stormwater contamination in floodplain cities, using Bangkok as a case study. The study investigated the water related issues, barriers to ICM planning, and potential for applying stormwater SC approaches to improve river water quality and promote environmental improvement in the country.

The objectives of this study are as follows:

1) Identify the potential for applying stormwater SC approaches in the CPRB;
2) Investigate and document the barriers to ICM planning in the catchment area;
3) Identify the planning policy frameworks needed to promote environmental quality improvement

1.3 Research Questions:

In seeking a better understanding of research objectives, the research questions derived from these objectives are as follows:

Objective 1. The key research question was

- What are the main sources of stormwater contamination in the catchment area?
- What strategies and measures have been applied to minimise stormwater contamination in the study area?
- What are the potential for implementing SC approaches in the catchment?
- How do SC approaches translate into practice in the area?

Objective 2. The key research question was

- What are the barriers to ICM planning in the CPRB?
- How does effective ICM planning promote environmental quality improvement in the CPRB?

Objective 3. The key research question was

- What are the planning policy frameworks and future guidelines that need to be provided to reduce stormwater contaminants and to promote environmental quality improvement in the catchment and similar floodplain cities?

1.4. Overview of Research Design and Methodology:

1.4.1 Research Method

Qualitative constructivism or subjectivist approaches were applied in this research. The subjectivist research paradigm relying on the qualitative method and documentary research was to explore the contamination issues in Bangkok, identify the barriers of catchment management planning within an ICM framework, and the potential for applying SC approaches to promote environmental quality improvement.

In this research, qualitative methods of information gathering involved ***documentary analysis*** and ***semi-structured interviews***. These methods shape the understanding of issues and the perspectives for the different planning solutions. The sources of information for document analysis were compiled from various written sources using archival research. As noted by Flick (2009), documents can be described as *"standardized artifacts, in so far as they typically occur in particular formats, as notes, case reports, contracts, drafts, death certificates, remarks, diaries, statistics, annual reports, certificates, judgements, letters or expert opinions"* and documents are useful for research as they provide *"a complementary strategy to other methods"* (p.255).

Interview techniques are pragmatic and adopt the basis of lived experience of people (Marshall & Rossman, 1999). There are various types of interview methods. The most documented types of interviews include structured interviews, semi-structured interviews, and unstructured interviews (Wengraf, 2001). These approaches allow the researcher to maintain control over the order or sequence of questioning (Oppenheim, 1992). Moreover, participants can be a valuable source of information to obtain rich descriptive data of social reality and may propose solutions or provide insight into events or phenomenon (Creswell et al, 2007).

The semi-structured interview approach was adopted since it helps to focus on personal experiences and perspectives of participants. This naturally makes semi-structure interviews the ideal choice as they allow the researcher to gather in-depth information of the barrier in implementing ICM planning from a different perspectives of experts. The experience, knowledge and perception of authorities on the implementation of ICM planning and the failure of catchment management in Thailand is the main focus of this interview process. This consequently enables the researcher to investigate catchment management planning issues in the different organisational cultures.

The structured and unstructured interviews are not appropriate for this research as the structured interview does not allow the interviewer to probe deeply to uncover new clues (Easterby-Smith et al., 2002) while the unstructured interview is very difficult to control and provides applicants the chance to talk freely about the issues and phenomenon (Johnson, 2001; Strauss & Corbin, 1998).

Semi-structured interviews were used to gain an idea and knowledge from experts about the barriers of ICM planning and the potential of SC approaches. The semi-structured interviews provide flexibility whereby detailed questions and an allowance for relevant topics to be raised by respondents, leads to more specific questions (Eyles & Smith 1988). Semi-structured interviews in comparison to quantitative methods tend to provide access to perceptions and valuable information. The design of semi-structured interviews may be one of the good strategies for gathering information to provide more complete, in-depth information.

In quantitative survey research, researchers may often be limited by selected factors which easily lead to unreliable or inconsistent conclusions and difficulties in gaining deeper insight into catchment management issues. Moreover, the characteristics of the people surveyed in the sample is hard to control (Creswell et al, 2007). Acquiring a high response rate to a survey is also among the most difficult of problems, particularly when the survey is carried out by post. Interview techniques increase the opportunity to motivate the respondent and provide a much higher response rate than with a questionnaire (Schumacher & MaMillan, 1993). Significantly, the questionnaire survey method may not provide a depth and richness of understanding of catchment issues and the potential in implementing SC approach in the catchment.

Considering all factors, a quantitative method based upon a positivist approach is incompatible with this study as the exposure of catchment management issues and gathering the perceptions on the potential of implementing SC approaches experts necessitates an in-depth exploration by experts and this is not easy to achieve through survey data. This study is exploratory in nature, given the purpose of the social constructionism. Therefore, a qualitative method is suitable to answer the research questions of this research.

1.4.2 Methods of Data Collection and Analysis

Data collection methods generally associated with qualitative methods of information gathering, involve **documentary analysis** and **semi-structured interviews**.

In **document analysis**, an overview of the identification of contaminants and sources of pollution in Bangkok was initially gained to understand flows from their origin into the river system and to conceive existing problems of the Chao Phraya River Basin (CPRB). Non-Point Sources (NPS) pollution or diffuse sources was addressed as the pollutants typically found in urban stormwater runoff are generated from mostly non-point sources, which are difficult to identify and measure. Pollutant discharges from these sources may include nutrients, sediment, oil and grease, metals, debris, toxic pollutants, animal wastes, bacteria and organic matter (Gan, 2004). Although there have been steady advances in minimising water quality problems from point source pollution, particularly industrial effluents and sewage treatment plants during the last decades, the water quality problems worldwide now are also associated with Non-Point Sources (NPS) pollution, known as polluted runoff from the land (Donlon & McMillan, 2004). In developing nations, point source pollution may still contribute significantly to receiving water quality degradation either by direct discharge or by seepage into overland flows.

Next, the implementation of sustainable stormwater SC approaches from other countries was reviewed to draw on experience from parallel cities to reduce runoff volumes and contaminants in the catchment. Sustainable stormwater solutions work with nature to minimise stormwater contaminant loads by establishing treatment trains of devises ranging from green roofs to detention ponds as innovative ways for creating a community environment to maintain sustainability. The practices promote alternative urban development by sustaining natural processes to provide flood protection and enhance resilience of a city (WWF, 2012). These approaches also regcognise the holistic and long-term methods to provide sustainable urban stormwater management and to protect water quality and maintain the integrity of ecosystems.

In this study, SC approaches were justified to manage the stormwater from the individual level through the neighbourhood level and expanding to the whole catchment level. The approaches take into account functions of natural features to avoid or minimise impervious surfaces, minimise waste, resource and energy uses. As the climate changes, extreme weather events with more heat waves, droughts, heavy rain and floods are expected more frequent and intense in the catchment, developing of SC approaches important to minimise these impacts and leads to the achievement of ecosystem and human well-being.

Semi-structured interviews were applied to explore the perception on the barriers of catchment management planning and the implementation of SC approaches to stormwater management among experts.

According to Cloke (2004), semi-structured interviews provide an open format to encourage involvement through a conversational focus in two-way communication. As supported by Crang (2002), the semi-formal structure contributes to an aspect of stakeholder participation, as respondents not only provide knowledge, but also exchange ideas with the researcher.

A cross-sectional survey was used to involve participants to provide perspectives about the barriers of ICM planning and the potential for applying SC approaches in order to compare a range of social and environmental factors in catchment areas. As noted by Eyles and Smith (1988), the cross-sectional survey approach is used to gather information at one point in time. It is a descriptive tool in which a snapshot of the frequency of attitudes and perspectives of respondents could be measured (Carter et al., 1997). Furthermore, it is useful for the research as it provides an opportunity to incorporate the knowledge of participants (Bollens et al., 1988).

A non-probability purposive sampling technique was used to identify the targeted participants for the semi-structured interview. The experts are composed of institutional representatives, decision makers, and academic researchers of government agencies responsible for the environmental planning, water resource management, or catchment management planning in the study area. The institutional representatives consist of (1) City Planning Department of Bangkok Metropolitan Administration (BMA); (2) Department of Drainage and Sewerage of BMA; (3) Department of Environment of BMA; (4) Royal Irrigation Department; (5) Department of Public Works and Town & Country Planning; (6) Department of Environmental Quality Promotion; (7) Department of Water Resources; (8) Pollution Control Department; (9) National Housing Authority; (10) Thailand Environment Institute (NGO); (11) The Association of Siamese Architects (NGO); (12) Chulalongkorn University; (13) Kasetsart University; (14) Ang Thong Municipality; (15) Phra Nakhon Si Ayutthaya City Municipal; and (16) Pathum Thani Municipality. This research also attempts to involve local government agencies in the lower Chao Phraya River Basin, and to seek their opinions using semi-structure interviews as those agencies can be representatives of local residents as well as being responsible for managing environmental quality improvement in local communities.

The head of each representative institution would be functioning as moderator to approach the participants responsible for urban landscape, community development, environmental or urban planning, based on their recommendations. Participation in this interview required approximately one-hour for interview completion. The research involved a personal (face-to-face) interview. To ensure accurate representation of responses, a tape recording device was utilised during the interview and the recording was transcribed. Then some excerpts of the transcripts were translated into English for this thesis.

Qualitative data from the semi-structured interviews were analysed and interpreted using NVIVO technical supports. Results of the survey were used to suggest planning policy recommendations and lead to appropriate guidelines and measures to mitigate stormwater contaminants in order to improve environmental quality in floodplain cities.

Table 1-1: Research methods applied in each research question

Research question	Chapter	Site Selection	Research Methodology
1. What are the main sources of stormwater contamination in the CPRB?	4	The catchment area where contamination issues potentially affect pollutant transport in Bangkok	Documentary Analysis
2. What strategies and measures have been applied to minimise stormwater contamination in the study area?	4	The catchment area	Documentary Analysis
3. What are the potentials for implement stormwater SC approaches in the catchment?	2	The catchment area	Documentary Analysis
4. How do SC approaches translate into practice in the area?	5-6	The catchment area	Documentary Analysis & Semi-Structured Interview
5. What are the barriers to ICM planning in the CPRB?	5-6	The catchment area	Documentary Analysis & Semi-Structured Interview
6. How does effective ICM planning promote environmental quality improvement in the CPRB?	5-6	The catchment area	Documentary Analysis & Semi-Structured Interview
7. What are the planning policy frameworks and future guidelines that need to be provided to reduce stormwater contaminants and to promote environmental quality improvement in the catchment and other floodplain cities?	6-7	The catchment area and other floodplain cities	Content Analysis

In conclusion, the integration approaches of ICM and SC approaches were examined to address the issues and outcomes of this research using constructivist approaches. The issues of contamination, the barriers of ICM planning, the potential for applying SC approaches, and other relevant social-ecological contexts were explored to provide empirically based conclusions for improving the environmental quality of the catchment area. The methodology of each research question is described in the following paragraphs.

***Research question 1*:** What are the main sources of stormwater contamination in the catchment area?

***Research question 2*:** What strategies and measures have been applied to minimise stormwater contamination in the study area?

In these research questions, relevant literature focusing on contaminant issues and sources of contamination was reviewed using **documentary analysis.** Initially, background information on contaminant issues was compiled to better understand those problems of Bangkok. Next, sources of contamination were identified by reviewing the relevant literature including government reports, academic journal articles, relevant research and any public records.

The identification of stormwater pollutants allows the selection of appropriate measures for managing the pollutants generated from stormwater runoff in order to reduce stormwater contribution and pollutant loads to the downstream catchment. Next, strategies and measures that have been applied to minimise stormwater contamination in the study area were revised. The review of contaminant issues and strategies to minimise stormwater contamination helps to form the empirical research for this study, consisting of a semi-structure interview approach.

***Research question 3*:** What are the potentials for implementing SC approaches in the catchment?
***Research question 4*:** How do SC approaches translate into practice in the area?

The potentials for SC approaches that have been applied in other countries were addressed using **documentary analysis** and draw on parallel cities for the study area. These practices involve the principle of restore, reduce, reuse, recycle of water and the use of holistic and long-term methods to provide sustainable urban stormwater management through various green facilities.

Moreover, **semi-structured interviews** were used to determine the potential for applying SC approaches and whether the approaches are appropriate to apply in the areas. The perspectives of experts on the potential for applying SC approaches were examined in order to explore various forms of knowledge and perspectives. Then, the perspectives were compared to gain an understanding of the application of SC approaches in the catchment. The participants interviewed include experts with knowledge and experience in environmental planning in both government and academic sectors. Content analysis of institutional literature and semi-structured interviews with open-ended and predefined questions were used for data collection. A database was organised including documentation, the transcription from recorded interviews, notes and observations made during survey processes. Findings from the interviews helped to clarify the research questions as several new topics and issues were raised to gain the perception of participants.

***Research question 5*:** What are the barriers to ICM planning in the CPRB?
***Research question 6*:** How does effective ICM planning promote environmental quality improvement in the CPRB?

In **documentary analysis**, data were gathered from a review of government reports, policies and plans across the catchment, and peer-reviewed journals. **Semi-structured interviews** were used to gain information from the experiences and knowledge of participants. The questions targeting the perception of experts relate to the barriers in planning processes, environmental awareness, institutional and legal frameworks, collaboration of stakeholders, environmental policies and plans, water resource management, ICM implementation, and effective catchment management planning.

The barriers of catchment management planning that were investigated focused on whether or not planning efforts contribute to environmental quality improvement. Findings that show more or less effective planning provide valuable information to improve efforts in catchment management planning which may eventually lead to reducing stormwater pollutant loads and supporting natural area protection in catchments.

***Research question 7*:** What are the planning policy frameworks and future guidelines that need to be provided to reduce stormwater contaminants and to promote environmental quality improvement in the catchment and other floodplain cities?

Findings from contamination issues and the potential for and barriers to applying SC approaches were synthesised to recommend appropriate guidelines and strategies to minimise stormwater contamination. The analysis of barriers to implementing ICM including land and water resource management, planning processes, institutional arrangements, legal frameworks, and related policies and plans was analysed to understand the role of planning and to support natural area protection in the catchment and floodplain cities.

The findings from this thesis will eventually allow planning efforts to gain higher levels of implementation and will possibly be useful to other floodplain countries to draw parallels in applying ICM and SC approaches in order to manage sustainable urban stormwater and create sustainable urban areas. This will lead to minimising stormwater contamination and improving the quality of environmental conditions in those floodplain cities.

Overall, the results were compared and combined to form a more complete understanding about the sources of contamination, the barriers of catchment management planning, and the potential for applying stormwater SC approaches. An understanding of these findings will allow planning efforts to be more informed and gain higher levels of achievement through effective implementation.

As there is the significant potential in managing urban stormwater to the creation of sustainable urban areas, the optimum of urban sustainable stormwater management towards ICM and SC approaches was attempted to explore in this research. This may lead to minimising stormwater contamination, and improving quality of environmental conditions in catchments.

1.5 Site Selection

This research focuses on Bangkok area as an example of a case study, which has intense development of urbanisation and has potential effects resulting from stormwater contaminants. However, the analysis on ICM covers the areas of the CPRB due to its influence on the water systems in these urban areas and the majority of inundation inflow from the catchment into Bangkok areas. In applying stormwater SC approaches, case studies in the Chao Phraya River Basin were also selected for the interview sampling. These areas include the city, town, and municipalities where contamination issues potentially affected pollutant loads in Bangkok and the Chao Phraya River.

The criteria used to select these sites were guided by awareness of: (1) urbanisation: particularly high density of residential area where there are high pollutant loads from non-point sources; and (2) ecological drivers especially water degradation from domestic water use, agricultural activities and transportation, with pressing and serious water quality problems around contamination of land and water resources. Within those sampling sites the perceptions of government authorities and experts were compared in an effort to capture the problems of catchments and to explore the potentials for and barriers to implement stormwater SC approaches in order to develop policy recommendations and guidelines to mitigate stormwater contamination in the catchment area.

Assessing catchment management planning has been helpful in drawing attention to the issues on the governance of water resources across physical, technological, and institutional barriers within geographic scales, and provides a diverse set of examples drawn from the CPRB to integrate new approaches into catchment management from the catchment level downwards. Due to environmental crises, policy failure, and fragmented institutional structures, the Bangkok case study and its catchment provide a rich set of examples to learn from and to provide an opportunity to overcome stormwater related issues.

1.6 Ethics Approval:

Ethics approval was required for this research as human participants were involved. An application for ethics approval to the University of Auckland Human Participants Ethics Committee (UAHPEC) was approved on the 26th March 2015.

As ethics were crucial when carrying out this research, the implications of identification of interviewees were recognised to protect the rights of participants in this study. According to Yin (2009), in any research study where people are involved, there are ethical issues that need to be taken into account to protect participants from being exposed to experiences.

In this research, informed consent was obtained from each participant in the data collection process to ensure that they would voluntarily proceed with the study. Participants were identified using the city or agency they represent. In interviews, information of the purpose and scope of the study was provided to participants in order to avoid ethical threats posed to any participants in terms of well-being or professional position.

1.7 Thesis Structure:

The final section outlines the structure of the thesis and includes overviews of each Chapter. The thesis has been structured in 7 chapters, each of which has its own introduction and summary to show how the chapter relates to the key themes of the thesis.

Chapter 1 - Introduction

This chapter describes the thesis as proposed and its aims, provides general background, issues of stormwater quality in the study areas, research objectives, a summary of research design and methodology, and the structure of the thesis.

Chapter 2 - Theoretical Framework

This chapter discusses the relevant theoretical framework. The two paradigms, anthropocentric and ecocentric, have been discussed in order to help with an understanding of the concept of the current environmental regime. Holism, reductionism, systems and complexity theories were described in terms of their relationships to catchment management planning. An effect of the concept of sustainable development on environmental management and river quality improvement is one of the main debates in this chapter. These approaches are interpreted into specific aspects relevant to ICM planning. The concept of stormwater SC approaches and the potentiality of the strategies and measures that have been applied in other countries were described to provide understanding of the alternative methods for minimising the impacts of anthropogenic activities on the natural environment and ecosystems and to seek proper solutions for catchment management.

Chapter 3 – Research Methodology

This chapter describes boundaries identified, research methods and research design, instruments in data collection for documentary analysis and interviews, pilot studies, research procedure, interview's participant characteristics, interview process, transcription, data analysis, and code of ethics.

Chapter 4 - Stormwater Related Issues and Environmental Efforts in the Chao Phraya River Basin and Bangkok city

The key point of this chapter is a discussion of the causes of weak sustainable water management and the stormwater related issues over the recent decade without specific responsibility for high priority ecological concerns. This chapter also covers general overviews of multiple water issues, land use issues, contaminant issues and sources of river water pollution in Bangkok and its catchment. Lastly, policy, plans, legislation, and current practices regarding environmental efforts and sustainable stormwater solutions in Bangkok were examined and discussed.

Chapter 5 - Challenges in Implementing Sustainable Stormwater Source Control (SC) Solutions and Integrated Catchment Management (ICM) Planning

This chapter investigates the current barriers of ICM planning and stormwater management in Bangkok and its catchment. This planning analysis includes nine main groups of challenges: institutional arrangements fragmented roles and responsibilities; technocratic path dependencies; challenges of centralised systems and hierarchical administration; limits of regulatory framework; financial barriers, constraint of land use and available spaces; conceptual and performance barriers; challenges of integrated knowledge; uncoordinated institutional framework; and limited community and stakeholder involvement. Interview resulted were used to analyse the barriers to implementing ICM and sustainable stormwater solutions in the catchment area. Findings from qualitative studies allow planning efforts to be more informed perspectives and improve achievement levels for minimising stormwater contamination.

Chapter 6 - Discussion

This chapter provides planning policy recommendations and appropriate guidelines to mitigate stormwater contamination based on findings of the research. Analysis of effective catchment management planning and the potentiality of SC approaches was identified and recommended to promote environmental integrity in floodplain cities.

Chapter 7 – Conclusion

This chapter provides answers to the research questions, the summary of the main findings and insights, and the recommendation for further research.

CHAPTER 2: THEORETICAL FRAMEWORK

2.1 Introduction

The exploratory research is interdisciplinary and therefore integrates different areas of knowledge. The author initially examined the broad areas of planning philosophies in relation to Eco-centrism, Holism, Systems and Complexity Theory, and Sustainable Development. These paradigms are interpreted and narrowed down into specific aspects relevant to Integrated Catchment Management (ICM) and sustainable stormwater Source Control (SC) practices. Dixon and Sharp (2007) pointed out that environmental planning studies are currently widely addressing the interdisciplinary approach to nature. Consideration of interdisciplinary knowledge, ecological interconnectedness and system scientific methods is necessary to explain the complex phenomenon of the whole system to minimise the impacts of stormwater contamination on the receiving waters and environmental health.

2.2 Paradigms

2.2.1 Anthropocentrism and Ecocentrism Paradigms

Paradigms related to catchment management and sustainable water management will firstly be addressed in terms of the philosophies of anthropocentrism and eco-centrism. These approaches provide a different perception to manage the natural environment and all living organisms in order to seek proper solutions for human and natural relationships. Both Anthropocentricism and Eco-centrism raise complicated questions with respect to environmental protection. However, the fundamental principle of anthropocentrism perspectives is that the natural world is made vulnerable as a result of values held by humanity and humans have the ability to have a dominion over all creatures and to exploit the natural world for the purpose of serving human interests.

Under the anthropocentric perspective and worldviews humans value things as resources. This paradigm believes that humans are the centre of the earth and separated from nature, so the nature can be a source for human exploitation and all creatures exist to serve human needs based on utilitarian value (Haddad, 2003).Thus, nature will have value when it can be used. Likewise, Takace (1996) maintained that anthropocentrism also takes into account the idea of economic profits and productions. This approach considers the natural resources as utilizing interests or economic value or “instrumental or utilitarian value” as it provides goods and services as well as information to human society.

It is crucial to recognise that the primary cause of ecological degradation has developed from the influences of anthropocentric views. Under the anthropocentric paradigm, the earth's biodiversity is viewed as a resource for humankind to exploit. From an anthropocentric perspective, biological resources include *"genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity"* (CBD, 2013). Therefore, it can be assumed that nature will be a source to serve human demand. The consequences of the anthropocentric views lead to the failed sustainable management of land and water resources.

Anthropocentric debates are generally associated with Human Egoism and Social Darwinism which place human species at finality of natural evolution (Van De Veer & Pierce, 2003). According to the theory of Selfish Gene, Dawkins (2006) asserted that human's gene is naturally selfish. Therefore, the most consideration of human thought is our interest. Thus, the anthropocentric or human-centred paradigm allows us to control and subdue nature for a number of decades, resulting in devastating impacts on earth's climate and ecosystems as well as reflecting humankind as a whole.

Nevertheless, the impacts from this human-centred paradigm have been challenged by the Eco-centrism paradigm. Burdon (2011) maintains that humans and biological species are dependent and profoundly connected upon one another in the natural world. According to Bosselmann, (1995) eco-centrism resists the dominance of humans through all life forms on the Earth and also takes into account an awareness of ecological relationships and the need to balance human recognition with nature

Unlike the anthropocentric paradigm, the ecocentric regime applies ecological wisdoms to achieve environmental sustainability based on scientific knowledge and research. The primary view point of eco-centrism takes into account holism and considers the earth ecosystem and community protection as a whole rather than the protection of individual species. Regarding the basic concept of Gaia Ethics, the Earth is made up of the interaction of highly complex ecosystems among living inhabitants (Lovelock, 2010) and can adjust for changing conditions through the effort of self-renewal to continue stability between atmosphere and temperature (Capra, 1996). Thus, nature is self-sustaining and has restorative and resilient capacity to continue the functions of ecosystems.

The concept of eco-centrism is based on mutual restraint that avoids harming all life forms and Earth. Eco-centrism recognises that humans are deeply interconnected and dependent on nature. The regime argues that humans are part of the natural world on Earth system and recognises ecological values as a first priority and does not allow human needs to take control over natural resources. This approach states that as human knowledge about the natural environment is limited, the way to decrease ecological destruction and maintain ecological function is not by relying on human intervention or modern techno-science, but rather by developing and improving on principles and policies (Capra, 1996). Additionally, the ecocentric paradigm also recognises indigenous and local environmental knowledge as well as religious belief systems, which can encourage participation of all stakeholders in environmental protection.

As it relates to the ecocentric paradigm, humans should not try to control, manipulate, modify or even manage nature. To challenge the conventional concept of human dominance over nature, Meyer and Bergel (2002) developed the Bio-centric philosophy of “Reverence of life” or "the will-to-live" in 1923. They argued that all individual organisms in nature have their own values or intrinsic values and should be respected, so it is wrong to abuse their will-to-live. This Life-centreed-approach has been applied to nature as a whole and has gained the frequent attention of Eco-centrism philosophers for several decades. Similarly, Arne Naess (1986) proposed a strong idea of deep ecology to criticise the exploitation of the natural environment to support human needs. He stated that human intervention in nature should be primarily directed by the need to maintain ecological integrity rather than the needs of utilisation by humans.

In this study, the concept of sustainable stormwater practices and ICM planning opens an opportunity to consider an ecocentric, holistic and integrated approach as a core theme. The recognition of an ecocentric paradigm needs to be taken into account to avoid human activities that damage the ecological functions. As an ecocentric philosophy offers us a solution to overcome environmental constraints, the ecocentric approach will be addressed in this thesis in relation to the management of the natural environment to minimise the impacts of anthropogenic activities on natural ecosystems.

2.2.2 Holism and Reductionism

Holism can be the idea that explains a complex phenomenon by emphasising the whole system. Looijen (2000) pointed out that the scientific disciplines have been shifting from the influence of the reductionism paradigm to holism paradigm which is prevalent in most aspects of modern research. Within the paradigm of holism there is consideration of the entire system rather than separated parts. It also emphasises the interaction between biotic and abiotic components from a small scale to the large system. Indeed, there are two philosophical worldviews, environmental holists and reductionists, embedded in the environmental management regime. In several studies such as Lamarck (1802), Suess (1875), Vernadsky (1926), and Lovelock (2010) the authors have gone beyond conservative reductionism, and instead focused on the idea of the Earth as a living organism.

Holism paradigm can be demonstrated by the idea of the living Earth which takes into account the whole more than the sum of its part. The consideration of the earth as a living system has appeared in several historical scientific literary pieces including the study of *"the living matter of the Earth's crust"* by Jean-Baptise Lamarck in 1802, the concept of *"An Envelope of the Earth"* by E. Suess in 1875. These ideas were futher developed by Ivanovich Vernadsky in 1926 in *"The Biosphere"* (Vernadsky, 1998), which proposed *"everywhereness of life"* and believed that living matter resulted from all geological forces and involved life moving and transforming across oceans and continents.

The comprehensive scientific expression of the Earth as a living organism has also been seen in the "The Gaia Hypothesis" by James Lovelock and Lynn Magulis in the 1970s - which refers to the interaction of life, soil, atmosphere, and ocean. Lovelock (2010) maintains that the earth is not only an object, but a living organism which has the diversity of all life forms, and the operation of a complex ecosystem within the biosphere including the stability, resilience, interdependence, and changes. He also proposed that the plants, creatures, and microorganisms have an influence on the earth's climate and surface environment. This theory has gained public attention and become a controversial debate through decades (Kirchner, 1989).

A holistic approach also takes into account ecological functions and argues that ecology is worth considering. Savory (1988) described how ecosystem management focuses on the ecological principles of "the whole system" including succession, water cycle, mineral cycle and energy flow rather than individual organism.

An ecologically holistic concept applies ecology to preserve biodiversity and natural resources, and has explained that humans are not above nature, but also rely on other life forms. Knight-Lenihan (2007) maintained that holism recognises the intrinsic value of nature and the interconnection between living life and ecosystems. Therefore, the instrumental values of ecosystems which are based on human interests resulted in the reduction of connected life and the fragmentation of ecological function. Similarly, Bosselmann (1995) argued that reductionism focuses on the small scale in each isolated part; therefore, the reductive management is not proper for the environmental conservation in a whole system.

With regard to Reductionism, the approach includes a belief that an individual organism is essential and the whole system will not be understood by considering isolated parts. Scientific reductionists maintain that whole systems can be understood by dividing them into small parts and functions. As described by Crick (1967, p.2), the characteristic of reductionism refers to an organism as *"essentially nothing but a collection of atoms and molecules".* Likewise, Aldo Leopold (cited in Bosselmann, 1995) refused holism ideas and believed that effective understanding of the complex system can be accomplished by inquiring about the features of its individual parts. In addition, reductionism also takes into account the instrumental value of individual living organisms and maintains that the management and extraction of valuable natural resources relies on human interests. Indeed, as discussed throughout the thesis, the environmental reductionists do not seem to focus on ecological sustainability, and they have been very silent in regard to the concept of sustainable development. As a result, ecological destruction may lead to substantial harm to human wellbeing and ecosystems.

Nevertheless, both scientific paradigms have brought different solutions and policies in political ecological discourse. Many researchers believe that holism and reductionism are mutually dependent and cooperating concepts (Zandvoort, 1986; Looijen, 2000; van Roon, 2010). As described in Zandvoort's model (1986), it became apparent that holistic and reductionistic programmes rely on one another. On the one hand, the holistic programmes are considered to be a guiding programme which provide theories and generate problems at the level of wholes for reductionistic programmes to reduce and solve the problems. On the other hand, holistic programmes also depend on the theories of reductionistic programmes in order to carry out and analyse these deeper explanations (Looijen, 2000; van Roon, 2010).

The structure of ecosystems described by Looijen (2000) also indicated the interdependence relationships between the parts and whole of a natural system within various levels of organisation. In the highest level of the structure of nature, the ecosystems are composed of parts of hierarchical relationship between communities (groups of different species of organisms including plants, animals or microorganisms), populations and individual organisms of diverse species, respectively. The lines indicate these hierarchical relationships, from organisms to organs, organs to tissues, and tissues to cells. In the subsequent place, the links will be lined from three main components of cells comprised of complex chains of cell plasm, organelles, and cell walls to cells. Finally, the hierarchy of biotic components ends at the levels of these cells to the direct line of macromolecules, molecules, atoms, respectively. Apart from their biotic components, the abiotic components of nature and human artifacts also have complex chains with entire biotic components under the ecosystems.

The cooperation and mutual dependence of holistic and reductionist approaches discussed above provide the context to this thesis. The implementation of Integrated Catchment Management (ICM) and stormwater Source Control (SC) strategies will be addressed in relation to holistic philosophies to study the context of ecological functions of the whole catchment. Complementary reductionist approaches will be considered in the component parts at the level of individuals and organisms to indicate the environment health and sustainability.

The application of ICM and SC approaches is properly associated with the context of holism and eco-centrism philosophies. These paradigms also provide the understanding of the ecological processes in order to maintain sustainability and achieve the ecological integrity and functionality of the whole catchment.

2.2.3 Holism associated with Systems Thinking

In reductionist philosophy, the approach concentrates on an understanding of the parts, and origins start from understanding the parts in order to understand the whole system. In contrast, holism recognises the systems as more than the sum of their parts, and also addresses the complex relationships between the parts and the function of each part to maintain the existence of the whole system (Jackson, 2003). As the contexts of catchment ecosystems are complex and dynamic, it is necessary to address holistic and systems approaches in the implementation of catchment management.

Moreover, it is acknowledged that many scientific disciplines are undergoing significant paradigm shifts from reductionism to holism. Traditionally, scientific method has studied complex functional systems as reductionism. In recent decades, the transition of studying systems shifted from reductionism to holism, known as an alternative paradigm (Jackson, 2003).

Systems are generally classified as open systems and closed systems. Open systems need the environment for their existence. They take inputs from the environment, transform them and release them as output into the environment (Jackson, 2003). Within the open system, there is an energy flow and chemical compounds in the process of a metabolism. Similarly, Von Bertalanffy (cited in Jackson, 2003) states that the structure of open systems in biology contains arranged systems in a hierarchy of complexity. Boundaries between these subsystems and their environment are distinct. Therefore, in open systems, living organisms interact with one another and their environment to sustain themselves, while the interaction of living organisms and their environment does not take place in closed systems (Jackson, 2003). It was noted that in the human system, the basic principles of the effectiveness of the open system include public participation, clarity and transparency, correct and clear information, public consultation, opportunity for stakeholders, authorities and public to be informed of the implementation, accuracy and neutrality in assessment of performance, equality and fairness (Burapha University, 2013).

In the 1920s and 1930s, holistic biologists started to believe that the organisms are one of each hierarchy level that exist in nature at stable points and constant levels, having a clear boundary which isolates from its environment. Each organism can maintain itself at a stable level by the processes of interaction with its environment, and it is competent to sustain its own stable state through internal reformation processes such as homeostasis (Jackson, 2003).

In a catchment scale, this homeostasis concept can be referred to the system of a catchment boundary with impervious soils. In this system, the several inputs including anthropogenic and natural activities still take place via various resources such as streams, soils, land and water systems, through the atmosphere. The effects of evapotranspiration and emission of volatile particulate matters throughout streams and soils will finally become outputs of this catchment system. As a result, this system will be able to maintain itself at a steady level by the interaction of the ecosystems.

System concepts believe that ecological degradation may possibly be restored within a holistic approach, or by preventing further harm and leaving it undisturbed as the resilient approach. According to Fritjof Capra (1996), the degradation of ecosystems can be restored by itself as a feedback loop. He stated that “the living system” which includes organisms, parts of organisms, and community of organisms maintain the nest of life. The “Web of Life” theory describes interacting system processes of ecosystems that there is a system nesting within other systems throughout the living world, which has interactions and interdependence of each other through networks of individual organisms (Capra, 1996). Therefore, problems of complexity are interconnected and interdependent, which cannot be understood in isolation.

The understanding of these interconnected systems will help to address the dynamic and systematic nature of stormwater and catchment management. The application of systems theory in this thesis is necessary to provide a better understanding of the whole systems of stormwater management processes in relation to ICM. Functional elements of environment system interdependence will be further clarified.

2.2.4 Systems and Complexity Theory associated with Catchment Management

Ideas of system and complexity theory greatly influenced a revolution in thinking of all scientific disciplines. This paradigm takes into account the concept of holism in character. According to Jackson (2003), the idea of complexity theory focuses primarily on relationships between individuals or subsystems as steadily conducting exchanges with their environments. In addition, the author noted that these interactions between systems and environments always leads to co-evolution as well as system and environment change. This can be explained by the Gaia hypothesis within which the mutual interaction between living beings and the environment has created life and the conditions that support life on Earth. Speaking of complexity in terms of a network of interconnectedness, the relationship between the natural and human world exists at many different levels including chemical, biological, physical, and social dimensions.

The complexity concept was developed to aid understanding of the comprehensive issues and aims to avoid formulating simple solutions to complex environmental problems. As the operation of catchment processes is complex, the recognition of complexity will be applied within this thesis as one of the aspects of the holistic paradigm at the catchment system or ecosystem scale. Additionally, the reductionism paradigm will be applied to analyse constituent parts of natural resources at the level of community and organism.

The recognition of systems and complexity theories can be seen in a government article of the Thai Royal Irrigation Department (RID) related to water resource management, which considers the context of catchment management in two main systems consisting of natural system and human system. Natural system reflects quantity and quality of natural resources, while human system takes into account human need, the use of natural resources, the effect of human activities on environment, and environmental improvement.

In terms of the natural system, the Royal Irrigation Department (RID, 2010) claims that the integrated management of natural systems should take into account all systems of the complex catchment processes that interact with each other. This includes considering the integration of fresh water and coastal management, soil and water management, surface water and groundwater management, quantity and quality of water resources, the water and land use management in upstream and downstream areas.

In the deeper details, fresh water management should be integrated with coastal management because fresh water affects the condition of the coastal water and seawater. Therefore, the fresh water management must take into account the effects of the upstream, downstream, and coastal areas. With regard to the integration of soil and water management, hydrological cycle evidences the process of water system from evaporation into the air, condensing as rain, raining into plants and into the ground as surface water, and seeping into the soil as groundwater. Thus, land use types and green space in catchment areas also affect water quantity and quality and they must be taken into account in water management.

It is important to recognise that a catchment ecosystem is complex. Considering the integration of surface water and groundwater management is also crucial as rainwater falling on the catchment area may appear in the form of surface water or groundwater and usually flows from a high to a low level. The use of chemicals for agriculture broadly contaminates and causes problems on water quality. Moreover, water management includes the consideration of water supply in sufficient quantity and appropriate quality. Thus, the concept of ICM is different from the traditional concept that focuses on fragmented management. The integration of water quantity and quality management is an essential part of ICM, so the physical and functions of bio-complexity must be protected.

With regard to the human system, RID (2010) argued that ICM must consider the conflicting interests of stakeholders at upstream and downstream areas. The reduction of water quantity in upstream area may reduce amount of river water in the downstream areas. Moreover, the discharge of contaminants in upstream area can bring about poor water quality in the downstream rivers. Additionally, high water use in the upper catchment may reduce the amount of water to replenish groundwater and downstream water. Preventing flooding in upstream could also affect the way of life downstream that relies on stormwater. Moreover, as water quality degradation can harm the environment and water then becomes unsuitable for users in downstream areas, the need to develop organisations and laws with the capacity to integrate water quantity and quality in response to the effect of water issues is also crucial.

The narrow point of view ignores the complex roles of urban ecosystems and biodiversity. The latter provide the life-supporting systems to enhance environmental sustainability. Thus, the need for considering the complexity of physical and social aspects in both natural and human systems is important, especially taking into account the conflict of interests between upstream and downstream activities. The scholar of RID has not ignored the importance of the human system, rather suggests that in response to environmental harm the integration of the human system should be taken into account to ensure that the safety of ecological integrity will be protected.

2.2.5 Sustainable Development

A considerable amount of literature provides definitions of sustainable development, also the term "sustainability". The origins of the sustainable development concept emerged from a series of world conferences and summits aimed at finding an agreement on the development paradigm in response to social and environmental concerns; particularly poverty, inequity and environmental degradation.

The underlying theme of this trend towards the sustainable development concept shifted from the forum of political debate, with a primary concern on environmental issues at the Stockholm Conference in 1972, to an emphasis on the balance of economic, social and environmental development at the 1992 Rio de Janeiro Earth Summit. The 1992 Rio Summit defined sustainability as an integration of economic prosperity, social well-being and environmental protection, often referred to as the triple bottom line. In 2000, Millennium Development Goals (MDGs) were developed by the UN in order to achieve triple bottom line sustainability by focusing on accomplishing national and international development in eight goals: eradicating poverty, achieving primary education, encouraging gender equality, decreasing child mortality, enhancing maternal health, combating diseases, assuring environmental sustainability, and developing global partnership for development (UN 2009). The 2002 Johannesburg World Summit focused on social development in balance with economic and environmental aspects, and the recent 2012 Rio+20 Earth Summit emphasised the green economy and the socio-economic context of development.

There are varieties of definition of sustainable development. To maintain equilibrium in environmental development, the World Commission on Environment and Development has published ‘Our Common Future’ to require people to change their extravagant lifestyle and preserve the environment. In the Brundtland Report which is the most frequently cited definition of the concept, G.H. Brundland, the Chairman of World Commission on Environment and Development, WCED, 1987 defined sustainable development as *“development that meets the needs of the present without compromising the ability of future generations to meet their own needs”* (Brundtland & WCED, 1987, p. 43). This definition conceptualises sustainable development as balancing the development of environmental, economic, and social dimensions, and includes the primary notions of equity, needs, and limitations. However, sustainability in the Brundtland report still lacks a universal definition and is far from unambiguous, as it can be interpreted in several ways particularly on philosophical and political levels, with a lack of consistency in its interpretation (Seijdel & Dullemond, 2006).

From the above concept of sustainable development, it can be concluded that the meaning of sustainable development as the development that fulfills the need of the present without compromising the ability of future generations to meet their own needs, and causes no harm to natural systems. Moreover, the exploitation of resources, direction of investment, orientation of technological development, and institutional changes must not be harmful to natural system and should comply with the future needs.

In terms of the environment aspect, Edward B. Barbier noted that sustainable economic development is the development that could meet the goals of three systems which are; biological system, economic system, and social system. The goals of the biological system are the capability to achieve genetic diversity, to reach resilience or to get back to equilibrium when disturbed or used, and the capability to achieve biological productivity. The goals of the economic system are to meet basic demand, economic equity, high quantity of products and services. In addition, the goals of the social system are to become cultural diverse, to establish sustainable institutes, to acquire justice in the society and participation of people in the society (Jarusombat & Senasu, 2014).

Viewing this definition from both perspectives, sustainable development consists of balance among three systems. The World Commission on Environment and Development (Brundtland, 1987) suggested that sustainable development should consist of social, economic, and environmental goals, while Edward B. Barbier (Barbire, 1987) suggested different goals in sustainable development, which are biology, economic, and social goals. However, G. H. Brundland (1987) had viewed sustainable development as a dynamic process that should comply with the future needs. Although sustainable development still holds its objective in economic growth, preservation of the environment should be the main goal of sustainable development.

There has been much uncertainty and disparity in terms of the composition of sustainability and the best way in which to attain it. Additionally, the distinction of the sustainable development concept has been widely discussed in terms of strong versus weak sustainability (Figure 2.1).

Hediger (1999) claimed that the strong sustainability approach is based on the idea of constant environmental quality; which implies that natural resources are limited and consumed at a rate greater than any natural rate of replenishment. On the other hand, weak sustainability is defined in terms of the non-decreasing value of environmental quality; which comes about by balancing three pillars:

economic growth, social development and environmental security, based on an anthropocentric perspective.

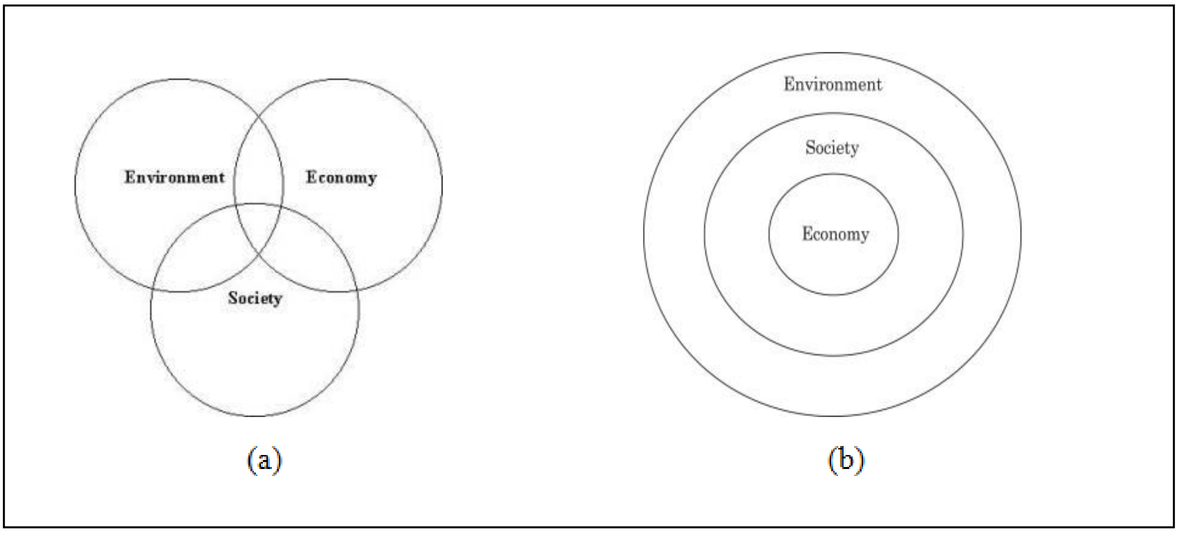

Figure 2-1: A model depicting weak sustainability (a), versus strong sustainability (b) (Van Roon & Knight, 2004, p.27).

The weak sustainability model displays that basically the three dimensions are equally balanced. It aims to maintain the three circles in an equivalent quantity and quality so that one particular sector does not take priority over the other. It represents the interlocking circles and assumes that the standpoint of the three pillars is balanced, whereas the strong model referred to as the nested egg demonstrates the hierarchal form of environmental, social, and economical elements. As we can see, the three sectors are integrated in different anthropocentric and ecocentric regimes.

It is clear that over the last decades, the sustainable development practice has gone from the strong sustainability to the weak sustainable development based on economic development. The aim of strong sustainable development is hardly achieved since the growth of the human population and our consumption is limitless. As economic growth and human consumption factors are unstoppable, both factors need to be limited to accomplish sustainable development. Hence, at the present, the pattern of sustainable development addresses the sustainable economy or the Green Economy.

2.2.5.1 The Concept of Green Economy

'Green Economy' is an important concept in sustainable development in the modern era. As a result of the Earth Summit in Rio de Janeiro in 1992 (RIO), several countries have set a target for sustainable development by following the policies set forth in the Rio Declaration and Agenda 21.

On the occasion of the 20th anniversary of the Rio Earth Summit in the United Nations Conference on Sustainable Development (RIO+20), held in June 2012, 'Green Economy in the Context of Sustainable Development and Poverty Eradication' was set as the main agenda of the meeting. As a result, the green economy concept has been discussed and applied in several contexts. Many countries and organisations have taken actions on the green economy at both local and regional levels (UNEP, 2011b).

Two main topics: the Green Economy in the Context of Sustainable Development and Poverty Eradication, and the Institutional Framework for Sustainable Development were raised at the United Nations Conference on Sustainable Development in 2012 (RIO+20). As the results of the meeting, the green economy was set as a tool to achieve sustainable development, and each country is allowed to set their own policy and targets to carry out the green economy in line with the Rio Declaration and Agenda 21 (UNEP, 2011b). The concept of a green economy is expected to be a key theme in current and future development, and becomes the proposition that countries including Thailand must continue to set its own policy to implement the green economy concept.

The concept of a green economy defined by the United Nations Environment Programme (UNEP) refers to the economic development that leads to improved human well-being, equality and reduction of risks in natural resource scarcity. Moreover, the green economy concept was also promoted as low-carbon, resource-efficient and socially inclusive. In other words, green economy means promoting employment and income from both the public and private sector that results in the reduction of carbon emissions and pollution, enhancing efficient use of energy and natural resources, and reducing loss of biodiversity (UNEP, 2011b).

In this regards, the approaches to develop the green economy include: (1) enhancing eco-efficiency in terms of the use of natural resources and reduction of emissions on the environment; (2) the use of government budgets on environmental projects (Green-Stimulus Package), such as renewable energy or rail transport; (3) Supporting marketing and public procurement of green products; (4) investment in green infrastructure; (5) restoration and enhancement of natural capital; (6) getting prices right for natural resources; and (7) eco-tax reform (UNEP, 2011b).

ONEP (2013) reported that the concept of green economy has recently been implemented by various developing countries. For example, China has set a 5-year plan so called China's 12th Five-Year Plan for National Economic and Social Development, which will invest up to 468 billion US dollars to develop a green economy, including waste recycling, clean technology and renewable energy. Indonesia has introduced a green economy programme by developing sustainable agricultural development, forest management, the efficient use of renewable energy, clean technologies, waste management, low-carbon transportation development, and eco-friendly infrastructure development to reform the subsidy system of electricity and fuel industry in order to reduce emissions of greenhouse gases by 26 percent by 2020.

In Korea, the Korean government invested 38.1 million dollars and allocated 80 % of the budget for environmental projects in 2009 in order to improve efficient use of natural resources such as water, waste, energy-efficient buildings, renewable energy, low-carbon emissions vehicles and rail transit. The government also adopted a five-year plan for green growth, intending to spend 2% of gross domestic product (GDP) for green projects (ONEP, 2013).

In Thailand, the Office of the National Economic and Social Development has introduced the concept of green economy in the National Economic and Social Development Plan No.11 (2012-2016). The plan focuses on sustainable development of the country, promoting the stability and sustainability of economic development based on eco-friendly production and consumption, leading to a low-carbon society. Besides, the plan also promoted a strategy on sustainable natural resource and environmental management by giving a priority to preparation for a low-carbon and eco-friendly economy and society (NESDB, 2012b).

However, the concept as appearing in the National Economic and Social Development Plan No.11 still has not been implemented effectively. Thus, it is necessary that various agencies shall set the policy and implementation for the integration of the green economy concept at various levels.

2.2.5.2 Sustainable Development Practice in Thailand

Sustainable Development concept becomes important in the Thai social context in all aspects. This concept is developed from the World Summit Conference on Human Environment at Stockholm, Sweden in 1972 by the United Nations to reduce extravagant use of natural resources beyond the limitation of natural resources. Jarusombat and Senasu (2014) noted that the outcome of this conference created broad awareness in environmental protection among the international community and led to the establishment of environmental agencies in several countries such as United Nations Environment Programme or UNEP and World Commission on Environment and Development.

In Thailand, The concept of sustainable development has been observed since 1992 after the World Summit RIO+10 in Johannesburg, South Africa. ONEP (2012) reported that Thailand has adopted the Johannesburg Declaration on sustainable development and Johannesburg's action plans, with the Office of the National Economic and Social Development and Ministry of Natural Resources and Environment being the primary responsible agencies.

Efforts towards sustainable development practice in Thailand can be seen in the appointment of a National Council for Sustainable Development in 2002, the development of national strategies for sustainable development and the indicators for sustainable development in 2003 and 2006, and the report on status of sustainable development since 2005. The four strategies for sustainable development of the country include: (1) eliminating poverty by creating sustainable and equitable economic growth; (2) promoting environmentally friendly development; (3) enhancing the knowledge-based society and ethnic-rich society; and (4) enhancing good governance (ONEP, 2012).

There was a remarkable change in the national development philosophy in Thailand since the government launched the Eighth National Economic and Social Development Plan (A.D. 1997–2001), which is the primary development framework for the nation. The Eighth Plan recognised holistic, people-centred development and environmental quality within balanced economic growth (NESDB, 1997) as it has been increasingly realised that expanding economic growth alone results in a plethora of environmental issues and insufficient social well-being.

In 2002, the concept of sustainable development was emphasised by the government in the Ninth National Economic and Social Development Plan (A.D. 2002 – 2006). In addition, the 9th National Plan has launched His Majesty King Bhumibol Adulyadej's principle, 'the philosophy of a Sufficient Economy' which was remarked in December1997 and 1998, to be Thailand's development framework (NESDB, 2002).

The Sufficiency Economy addresses the 'middle path' strategy as a primary principle for people at all levels. NESDB (2007) noted that the concept calls for sustainability and quality of life in national development in order to direct the country through the course of a crisis resulting from the emerging challenges of globalization to engender greater resilience and economic sustainability. The middle path solution is the means to conduct a way of living that fits the agreed goal of sustainability, like an arrow that is shot to the inner rather than left or right. As discussed with regard to sustainability, ecological value must be considered as a first priority to be protected in order to sustain other values.

There was an attempt to promote concrete actions of sustainable development. It has been pointed out that the SD philosophy has been defined in several national and local policies, plans and strategies including "the National Policy and Plan to Promote and Conserve Environment B.E. 2540-2559, the National Land Policy, the National Forest Policy and the National Policy on Municipal Waste". With regard to local policies and plans, it has been observed that there are various plans, including "the conservation and improvement plan of old town environment; and the manipulation of fiscal and financial measures" in order to maintain ecosystems and natural resources (NESDB, 2012a).

In addition, environmental issues have been included in a number of significant statutes. It is apparent that there are still many acts to be announced regarding sustainability, including: the Act on the Promotion and Protection of National Environment B.E. 2535, the Constitute of the Kingdom of Thailand B.E. 2540, and the Act Promulgating Local Administration Plan and Decentralisation Process B.E. 2542 (NESDB, 2012a).

It is significant to note that although the concept of sustainable development has been adopted in a number of policies and plans for over a decade, the economic aspect has long been considered all that is necessary for successful development. The sustainable development of the environment would be determined at a vulnerable level. According to NESDB (2012a), the assessment results of the seven major goals of the United Nation's Millennium Development Goal revealed that the country has achieved six goals, excluding the sustainable management of the environment.

Natural resources have been depleted from geographical alteration and overutilisation along with the inefficient use of natural resources contributed to the impact of overall balance of the ecosystem. Therefore, sustainable concepts in those policies and acts emphasised socio-economic development and have been implemented in such a manner that the nation's environment does not obstruct the country's development. Degradation of natural resources and the environment indicates that the growth of the country has been unsustainable and unbalanced, which likely focused on economic growth individually.

Clearly, the efforts towards environmental improvement over the last few decades in relation to sustainable development have not succeeded. As argued above, the consequences of urbanisations and population growth have resulted in a lack of balance between the three aspects of sustainable development that is the economy, society and the environment. Therefore, sustainable development might be a misguided approach, which is different from the framework of strong sustainability. By considering the principle of sustainable development, it should be understood as development that is sufficient without threatening the future generations and ecosystems/other life forms.

The term sustainability in this study is primarily targeted towards minimising unsustainable practices, particularly the reduction of human footprints on water, land and energy resources in order to maintain the quality of water and other natural resources as well as increasing a sustainable urban environment. This thesis disambiguates the definition of sustainable development and its roles in order to improve water resources, urban and natural landscapes. The term sustainability used in this research refers to the strong definition of sustainability and will imply that environmental quality including water quality will generally improve and may not deteriorate over time.

2.2.6 Integrated Catchment Management (ICM) Concept

A catchment is a hydrologic unit which contains all the surface water from rain runoff, snowmelt, streams, reservoirs and all the underlying ground water (Perlman, 2016; DCR, 2017). Other terms used to explain catchment area are catchment basin, drainage basins, drainage area, river basin and watershed area. The term watershed is frequently used in North America to represent a catchment area (Perlman, 2016; King County, 2017).

A catchment is an area of land where precipitation and all the water that falls within the area collects and drains into a common outlet such as surface water, including rivers, lakes, streams, and out to estuaries or to the ocean (NCstormwater, 2017; King County, 2017). The factors that determine how much water flows in a stream or river include precipitation, infiltration, soil characteristics, soil saturation, land cover, slope of the land, evaporation, transpiration, storage, and amounts of water use (Perlman, 2016).

The catchment area can be made up of many sub-catchments connected to each other, or areas of land around a stream, lake, or river (NCstormwater, 2017). The boundaries of catchment areas are usually created and modified by local governments using geographic information systems (GIS) (McLafferty, 2003). Each catchment is separated topographically from adjacent catchments by the drainage divide, particularly the edge of high land surrounding a drainage basin such as a ridge, hill, or mountains (Perlman, 2016; DCR, 2017; BBC, 2017).

Within each catchment, as water runs downstream, it may carry and leave behind gravel, sand, silt, bacteria or chemicals. Therefore, any activity that occurs within a catchment will impact the whole catchment. Likewise, contaminants in the surface water and groundwater upstream will eventually affect a downstream river, lake, and ocean unavoidably (Hurstville City Council, 2017, NCstormwater, 2017). Thus, a catchment should be able to absorb and filter runoff which flows overland and seeps into the ground (Hurstville City Council, 2017).

It is undeniable to say that there is an increasing number of countries facing problems in water resource management. Water scarcity, water quality degradation and the impact of the floods are the main problems that require attention and solution. ICM may help those countries to deal with water problems in a sustainable way.

It was noted that traditional approaches to urban planning and water management are likely to weaken from both a physical and social perspective. This approach has always recognised the catchment as the spatial domain of engineering in terms of infrastructure operations, constructions, and maintenance (van Roon, 2010) which is no longer concerned with the managing on a sustainable basis of ecological and social dimension. Moreover, traditional water resources management has not been broadly accepted by the general public, but was rather demanded solely by governments (Tippett, 2001). As described in Tippett and Griffiths (2007), there is also minimal integration between government departments, as they have always been responsible for single sector solutions of water management.

The concept of Integrated Water Resource Management (IWRM) has been of particular interest after the international conferences on water and environmental issues, held in Dublin and Rio de Janeiro in 1992. At the Dublin conference in January 1992, representatives from governments, social development organisations, private sector, and public sector who were in attendance, concluded by announcing a Dublin principle on ‘Water and Sustainable Development’. As the result of this announcement, international organisations pushed the Dublin principle into an agenda of the World Summit on ‘Environment and Development’ of the United Nations or generally known as the Earth Summit held in Rio de Janeiro in June 1992. The Earth Summit made a proposal to each country around the world to readjust the approach of water management focusing on water management for sustainable development. Thus, water resources management should take into account the social, economic and environmental contexts simultaneously. Thereafter, the principles of the Dublin Principle were acknowledged and recognised by the international community as the Integrated Water Resource Management (IWRM) approach (RID, 2010).

Since announcement of the United Nations at the World Summit on Sustainable Development held in Johannesburg in South Africa in 2002, IWRM have been widely accepted in all regions of the world as a framework of processes and tools to manage water resources. The approach adopts various dimensions to the joint issue of water management, particularly in the social, economic and environmental dimensions. Thus, the concept of sustainable water resources management is also based on the idea of sustainable development.

Such a concept stems from an imbalance in social and economic development so that it results in a gap between the incomes of rich and poor, as well as the gap between consumption and conservation of natural resources and the environment. Therefore, there are needs to find the development way aiming at maintaining a balance between economic development and conservation of natural resources, without exploitation of opportunities of future generations in the use of resources to meet their needs in the future (RID, 2010). It was concluded that IWRM is the process to promote coordination, development and management of water, soil and other related resources in order to bring the maximum benefit to the economy and human well-being without impact on the ecosystems.

The concept of sustainable water resources management applies the idea of sustainable development to overcome the problems of water resources, such as water shortage for consumption and agriculture, flooding, severe water pollution, as well as the failure of water management. The idea of water resource management for mankind, both present and future generations, as well as ecology is proposed as an approach for sustainable water resources management, called Integrated Water Resources Management (IWRM) or Integrated Catchment Management (ICM).

In order to achieve sustainable management of land and water resources, integrated approaches to catchment management need to encourage the participation of all stakeholders. The process of ICM requires co-ordinated and integrated planning and participation among individuals, institutes and partnerships at all levels. The approach is also responsible for using and managing the resource through a significant role of government, local community and stakeholders (Auckland Regional Council [ARC], 2009) rather than relying solely on technical managements as in the past. ICM also takes into account the importance of multi-disciplinary and inter-disciplinary approaches to land and water resource management (van Roon & Knight, 2004), as well as aiming to achieve a sustainable balance between the resource use and protection of a catchment (Tippett, 2001).

Catchment management requires a best mix of conventional structural as well as non-structural approaches to land and water management. According to Ashton (2000), four interlocking frameworks - including policy, administrative, regulatory, and strategic frameworks - should be involved in a catchment management plan. Similarly, Gregersen et al. (2007) further suggests that maintained that the practice of various non-structural measures should include reforestation, soil conservation practices, land-use measures, managing waste disposal, regulating flood plain use, maintaining riparian systems; whereas structural measures involve water harvesting, grassed waterways, flood retention, increasing infiltration, enhancing land productivity and channel restoration.

There is an increasing awareness that catchments are significant units for integrating land and water management (van Roon & Knight, 2004; Tippett & Griffiths, 2007). This response has emerged from an awareness of restrictions resulting from isolated management of water systems (Tippett & Griffiths, 2007). Moreover, one of the most typical challenges is represented in the fact that catchment management is generally divided by administrative boundaries, which rarely reflect ecological boundaries (Brunckhorst & Reeve, 2006). Therefore, the efficient integration of land and water management should extend beyond political boundaries and coordinate management practices across the boundaries of administrative jurisdictions in catchments.

The catchment-based approach seeks to maintain a balance between the roles of resource utilisation, management, and protection - which will be more effective due to the consideration of the entire hydrological cycle (Ashton, 2000). According to Gregersen et al. (2007), the main objectives of ICM are associated with the practices of land and water protection, including improving water quality in streams, reducing soil erosion to prevent sediment loads downstream, and restoring degraded land, streams, and riparian systems. In addition, ICM also addresses a framework for interventions across the entire water cycle. In order to achieve sustainable management, land and water resource management need to be integrated as holistic entities, including water supply, water use, and the disposal of wastewater (Tippett & Griffiths, 2007; ARC, 2009).

Catchment management also considers the interactions between land use, soil, water and other natural resources in a catchment as land and water degradation cannot be managed independently of each other (Ashton, 2000). With regard to the links between land and water management, evidence suggests that the conversion of forest to agricultural crops has resulted in landslides, sediment flows and flooding (Gregersen et al., 2007). The catchment, therefore, should be holistically considered, recognising the interconnection of all activities within the catchment. This includes agricultural cropping, forestry activities, urban development, and the protection of water resources in a sustainable manner, as well as taking into account the structural and biotic components of the aquatic ecosystem. Consequently, management of this land use will assist in the reduction of water contaminants as well as improving water quality characteristics.

2.2.6.1 The Status of Integrated Catchment Management (ICM) in Thailand

Although it has been broadly accepted that water resources management should be practiced within catchment areas, the implementation of ICM planning in the country has not been completely developed (Global Water Partnership [GWP], 2013). Since 1996, a long-term catchment management plan (1997-2016) has existed to direct policy for all involved government agencies for enhancing and preserving the natural environment, including six principle guidelines: Natural Resources, Pollution Prevention, Natural and Cultural Environment, Community Environment, Environmental Education and Promotion and Environmental Technology (Bunnara et al., 2004).

As described by Global Water Partnership (2013), the Asian Development Bank (ADB) had set the condition for the country in 1999 under the loan project to develop a water resources management system. These conditions involve formulating water policies, legislating water-related laws, forming catchment management institutions, encouraging people's participation in the operation of irrigation systems, collecting water fee, diminishing subsidies for farm inputs, protecting upstream and recovering coastal areas. In 2000, Thailand adopted the principle of Integrated Water Resources Management (IWRM), resulting in the water resources management reform by decentralisation of the management from authorities of all government agencies to the committee system in order to enhance participation of all stakeholders.

As a result of the reform, the management structure was readjusted to the committee systems divided into 3 levels: national, catchment and local levels. The structure of water resources management based on the IWRM principle includes the National Water Resources Board, relevant agencies such as the Department of Water Resources and Department of Forestry, Catchment Committee, and Sub-catchment Committee. The composition of the water committees at each level includes representatives of water users from agriculture and industry sectors, central and local government representatives, luminaries from academia and NGOs (Jarkron, 2011). It was seen that the committee, which consists of stakeholders from all sectors, is an important mechanism for managing water resources within ICM.

The scholars stated that the Department of Water Resources (DWR) under Ministry of Natural Resources and Environment was formed to support the water management structure, serving as a secretary and coordinator at the national and the catchment levels. The main duties of the National Water Resources Board are to formulate water policy, plans, and frameworks, to prepare an annual budget proposal to the Cabinet for approval, to support the operations of the catchment committee, as well as coordinating other agencies to implement the policy on water management. The main duties of the Catchment Committee are to prepare the plans and projects for catchment management for related departments, as well as defining measures of water resources allocation and conflict mediation (Jarkron, 2011). However, in the meantime, the authorities of the committees at all levels are provided under the regulation of the Office of the Prime Minister on National Water Resources Management B.E 2550, as the National Water Resource Act was still under consideration in the House of Representatives.

In 2003, catchment plans for 25 river catchments were formulated, and sub-committees on water resources development were set up for collaborating in planning, implementation and monitoring in each main catchment (Bunnara et al., 2004). In 2005, the water resources management plans for each catchment were developed by the River Basin Committees (RBC) through local communities' involvement. These plans have addressed the integration strategies for upstream and downstream operation, while stressing land and water preservation in the upper catchment and ensuring fair water allocation for several purposes in lower catchment and floodplain areas. Additionally, these measures also take into account the maintenance of water quality, and the mitigation of water-related disaster (GWP, 2013).

In fact, the management of water resources has still not been in accordance with the IWRM principle as each related government agency still has their own procurement and projects without being approved by the catchment committee, and inconsistent with the catchment plans. Moreover, the national and catchment water resources committees are not legal entities as there is no law to support. They still do not have their own budgets and have to rely on the limited budget of the Department of Water Resources (Jarkron, 2011). Thus, the water resources management has been reformed only in terms of its structure rather than the whole system, and public participation in water management is still only a discourse without being broadly practiced.

Another issue in the sustainable management of water resources is that the consideration of information based on water resources is still scattered throughout related ministries. There are more than 30 government agencies in all administrative levels involved in catchment management. At the national level, the Ministry of Natural Resources and Environment (MoNRE) is responsible for formulation of policies and plans of catchment management, while the provincial governor plays an important role on policy implementation. The Watershed Administrative Organisation (WAO) and the Watershed Administrative Committee (WAC) has been established to take responsibility for water resource management policy, planning and implementation. The water resource management includes the issue of water use, conservation and allocation of water, floods and drought prevention, and water pollution mitigation (Bunnara et al., 2004). In response to ICM, the National Water Resources Committee (NWRC) and the River Basin Committees (RBCs) have been set up at the national and catchment levels respectively (GWP, 2013). Thus, strengthening the power and duties of the River Basin Committees to coordinate the management of water resources in the catchments is the major key in the future success of IWRM implementation.

Considering the reductionist management, water management also focuses solely on water quantity rather than the whole system of water management. Transition knowledge in water resources management still is highly influenced by the knowledge in the field of hydrography. Thus, the approach to integrated water resources management is mainly based on hydrographic methods, while institutional and political institutions, guidelines and management tools are still not developed to be consistent with social and the environmental context (Jarkron, 2011).

Water scarcity also becomes the main water issue in the country. It was found that the demand for water is at an average of 155 million cubic metres per year. The existing water limited in nature and derived from rainwater or freshwater, and is on average 197 million cubic metres per year. From such information, it shows that the demand for water is similar to the water existing naturally (Srikaew, 2012). Therefore, planning for water resources management and law enforcement of related government agencies are important to deal with future floods and drought.

A limitation of IWRM is also the expansion of water use for hydropower generation governed by centralised administration, resulting in the conflict with water quantity for domestic needs and the demand for energy production, as well as long-term effects of the dams on environmental issues and quality of life in local communities. The conflict caused by illegal use of groundwater in large quantities, and the use of water for upstream farming affect downstream people who have not enough water for consumption or agricultural use (Jarkron, 2011).

Converting the concept of IWRM into practice is the mission with a lot of challenges regarding imbalance of development, problems in the decision-making process for economic development and the need of water for industrial and agriculture uses, the imbalance of water demand and water supply, and the conflict occurring around water quantity for different purposes.

However, importance of participatory approaches and holistic or systems approaches have been increasingly emphasised in the country over the past decades. Participation in catchment management has been successfully applied in several villages in the northern sub-catchment. This coordination of community networking groups has led to an increase of upland natural resources and of forest and a reduction of environmental deterioration. Moreover, Bunnara et al. (2004) stated that decentralised management by coordination of local communities in micro-catchment areas has contributed to the reduction of forest fire, illegal logging and upland erosion, and the increase of natural regeneration of forests.

2.2.7 Stormwater Source Control (SC) Concepts

In urban areas, stormwater runoff is generally conveyed and discharged directly to receiving streams by two types of sewer systems: separate storm sewer and combined sewer systems. In separate storm sewer systems, stormwater runoff is conveyed in storm sewers without treatment prior to discharge, while sanitary wastewater is conveyed in a separate sewer system into wastewater treatment plants (EPA, 1999). On the other hand, in a combined sewer system, stormwater is combined with wastewater and treated by wastewater treatment plants before discharge into receiving waters. However, the large volumes of stormwater can exceed the capacity of the wastewater treatment system, contributing to the frequent overflow of untreated stormwater and wastewater directly into receiving streams known as combined sewer overflows (CSOs). In addition, the contamination of pollutants in stormwater runoff and CSOs can significantly pollute water in receiving streams. In addition to CSOs, stormwater can directly enter waterways from various non-point sources such as parking lots, roads, agricultural and industrial areas as diffuse flows (EPA, 1999).

Nutrients, such as nitrogen and phosphorus, are now recognised as a major pollutant in stormwater runoff and have become common pollutants in several aquatic systems all over the world. Although excess amount of nitrogen and phosphorus in water bodies can cause eutrophication issues and may result in toxic algae, nitrate can also be toxic and lead to human health risks such as methemoglobinemia, liver damage and cancers (Chang, 2010). However, as SC approaches can impact on the conveyance of nitrogen and phosphorus concentrations, these nutrients may mostly be removed through the applications of stormwater SC approaches within catchment management practices (Roy et al., 2008; Chang, 2010).

Conventional methods of stormwater management are designed to collect and rapidly remove runoff from the land as quickly as possible. To manage stormwater runoff in urban areas, conventional approach has been to construct a vast curb and gutter, and pipe network to convey runoff volume rapidly far-off from the urban area and drain into local receiving streams (EPA, 1999). Large volumes of runoff conveyed from streets, parking lots, and constructions in urban areas lead to degradation of water quality in receiving environments (Prince George's County, 1999) as well as reductions in groundwater recharge, stream erosion, increased runoff volumes and flooding (EPA, 2000), all of which have detrimental impacts on ecosystems.

Decentralised storm water management approaches that are part of stormwater source control implementation may provide more sustainable solutions to stormwater management if applied at a catchment scale. Roughly equivalent terms are used to refer stormwater source control including: Low Impact Development (LID) and Best Management Practices (BMPs) in the North America; Water Sensitive Urban Design (WSUD) in Australia; Sustainable Urban Drainage Systems (SUDS) in the United Kingdom; and Low Impact Urban Design and Development (LIUDD) in New Zealand.

In North America, the low impact development (LID) approach was launched by the Prince George's County, Maryland, USA in the early 1990s (Prince George's County, 1993). The practice aims to achieve a natural hydrology or pre-development runoff by the use of integrated control measures. The term LID has been applied to a small scale through stormwater devices such as green roofs, rain gardens, and swales as well as a large scale of catchment solutions through a treatment train (USEPA, 2000).

The term best management practices (BMPs) has also been most commonly used in North American. In the United States, the term BMPs has been addressed as part of the Clean Water Act (2011) (Fletcher et al., 2015). The approach involves practices that embrace both non-structural (operational practices, maintenance, and standard operating processes) and structural (engineered or built infrastructure) aspects, which attempt *"to maintain land and stream conditions to serve the present and future needs for usable water"* (ICE, 2004).

In Australia, the term water sensitive urban design (WSUD) has been introduced since the 1990s by Mouritz (1996), and then has been presented through a series of well-known references to it by Wong (2000, 2001, 2002) and Lloyd et al. (2002). The concepts of WSUD is frequently used as equivalent to the term water sensitive cities (Brown & Clarke, 2007), which aims to *"minimise the hydrological impacts of urban development on the surrounding environment"* (Lloyd et al., 2002, p.2).

The philosophy of sustainable urban drainage systems (SUDS) or sustainable drainage systems (SuDS) has been most frequently used in the UK. The implementation of SUDS advanced more rapidly in Scotland during the 1990s due to the enactment of strict regulation by the Scottish Environmental Protection Agency for SUDS in new developments (Butler & Parkinson, 1997; Fletcher et al., 2015). SUDS consist of a range of stormwater devices that work together to create a management train, based on the idea of mimicking the natural drainage processes from a pre-development site in order to improve water quality in receiving waters (Martin et al., 2000).

In New Zealand, the adoption of the term LID was up to 2010, largely applied by Auckland Regional Council, guided by the publication of the Low Impact Design Manual (Shaver, 2000). The primary emphasis of the practice is on site design to avoid river water pollution and to moderate changes to site hydrology (Shaver, 2003; van Roon, 2011). The concept and practice were further expanded into urban design for the minimisation of hydrological and ecological change during urbanisation. This is known as Low Impact Urban Design and Development (LIUDD) (van Roon, 2010; van Roon and van Roon. 2009).

2.2.7.1 Low Impact Development (LID)

Low impact Development (LID) is sustainable stormwater management that incorporates green infrastructure to achieve sustainable development through encouraging infiltration, evaporation, evapotranspiration, groundwater recharge, harvest water at the source, and reuse of stormwater. It is a decentralised system that incorporates on-site stormwater management practices, different from conventional stormwater management techniques that typically convey and manage runoff in large treatment facilities or direct discharge (Chang, 2010). This alternative approach should be planned and implemented at the catchment scale, as the impacts of stream ecosystem in the downstream area are connected to the proportion of impermeable surface in the upstream catchment (Roy et al., 2008).

The era of LID evolved out of prior efforts, as the growing concerns of the water quality problems associated with stormwater management. LID is a technique in sustainable stormwater management initiated by Prince George’s County, Maryland, in the early 1990's, which aims to mimic the predevelopment site in order to reduce runoff and recharge groundwater using site design methods such as storage, infiltration, evaporation, and detaining runoff (Prince George's County, 1999). LID emphasises the use of holistic and long-term methods to provide sustainable urban stormwater management and to protect water quality and maintain the integrity of ecosystems (EPA, 2013).

In predevelopment sites, natural hydrologic functions maintain the water quality of received catchments by allowing for rainwater infiltration into the soil, which detains runoff. The LID approach increases travel times by impeding flows and allowing them to permeate, and also combines natural site design with contaminant removing measures to reduce the impact of urban development on receiving water (Prince George's County, 1999). However, the use of conventional stormwater controls will not be completely replaced by the LID measures (EPA, 2000).

LID can be regarded as an integral part of green infrastructures. The practices of LID including porous pavement, infiltration trenches, detention ponds, use of vegetated swales were prevailed. These operations provide benefits to stormwater management in terms of minimising the surface runoff, reducing soil erosion, and improving water quality.

Existing studies provide evidence that LID provides a sustainable stormwater management strategy, which has been implemented extensively in the United Stated, Canada, Australia, New Zealand, and parts of Europe to maintain the natural ecosystems in those places, as well as accomplishing sustainability. Its practices through maximising opportunities for stormwater infiltration at source, storing stormwater contaminants in catchments, and vegetating catchment with indigenous vegetation counterweight receiving river degradation (van Roon, 2005).

LID approach has the potential to minimise both water quantity and water quality issues. With regard to the runoff removal capacities, LID techniques can capture and retain stormwater (e.g., rain barrels, green roofs, detention ponds, bioretention areas), infiltrate stormwater (e.g., biofiltration swales, permeable pavement), increase evapotranspiration (e.g., green roofs, rain gardens), and reduce the amount of Effective Impervious Area (EIA) in a catchment (EPA, 2000; Roy et al., 2008). The runoff generated under all rainstorm events can be trapped and prevent it from contributing to flow up to 90% for either direct use through landscape irrigation, toilet water flushing, or for indirect use through increasing groundwater recharge (Carmon & Shamir, 2010).

Vegetation aids in flood protection as it acts as a sponge that captures and absorbs rainfall in the ground, and assists in enhancing infiltration and evapotranspiration (ARC, 2003). Results from several studies indicate that bioretention areas are effective in decreasing runoff rates by reducing the first centimatre of stormwater. In a German study, it was found that the widespread use of vegetated roofs provided opportunities to reduce annual runoff by up to 50 percent (EPA, 2000). Likewise, grass swales with proper length and slope can also significantly increase infiltration (ARC, 2003). In addition, a long-term study from the University of Washington demonstrated that using permeable pavements could greatly reduce runoff volumes. However, to apply LID in selected sites, the depth of the water table, the gradient of the land slope, and soil permeability all have to be taken into account (EPA, 2000).

In terms of the contaminant removal capacities, it is apparent that LID practices play a crucial role in reducing contaminants entrained in runoff flows by seeking to remove contaminants prior to the pollutants coming into contact with, or dissolving into, stormwater runoff. Moreover, LID also enhances the expansion of flow paths or distance to increase runoff travel time in order to encourage the opportunities for infiltration and pollutant removal at the soil surface.

Detention ponds and constructed wetlands can enhance the potential for pollutant removal through retrofitting the hydrological regime even at high-urbanised areas (Chang, 2010). The detention ponds allows biological or chemical treatment to occur in retention time before the water is released into the receiving streams, which can be beneficial use for the downstream inhabitants (ARC, 2003). Grassed swales and permeable pavements also provide several benefits in reducing pollutant loadings in receiving waters (EPA, 2000). Compositions for a green sorption media such as sand, tree bark, wood chips, tire crumb, sawdust, wheat straw, sulfur, and limestone, can also be applied to enhance biological processes and allow the micro-scale distributed throughout the site to remove pollutants that cause negative impacts on ecosystems (Chang, 2010).

LID approaches have been implemented in several climates, and have demonstrated their effectiveness in reducing runoff and pollutant loads at all site scales. Although several low impact practices have been demonstrated, there are few cases of prevalent implementation at a catchment scale with the clear objective to protect and restore receiving waters.

To achieve ICM planning, LID should be practiced by managing the rainwater from the individual level through the neighbourhood level and expanding to the whole catchment level. At the individual level, LID takes into account managing household water runoffs. The application of rain garden together with grass swales, bioretention systems, green roof, and rain barrels may capture and direct rooftop runoff away from storm sewers and treat runoff onsite, which can significantly reduce the load of combined sewer overflows (CSOs) (Chang, 2010). Treated stormwater also reduces the demand for water supply as it can be used for various non-potable purposes at the household level such as gardening and car washing. At the neighbourhood level, LID primarily focuses on managing street pavements and bioretention swales in terms of stormwater quality and quantity (Marsalek & Schreier, 2010). LID also takes into account the whole water balance at the catchment level to enhance the potential for runoff reduction and pollutant removal through retrofitting the hydrological regime in association with various green facilities including bioswales, constructed wetlands, and bioretention ponds in a catchment (Chang, 2010). The example of conventional and LID approaches to stormwater management for the individual, neighbourhood and catchment levels are summarised in Table 2-1.

Conventional Approach	**Integrated Approach**
Stormwater Management at the individual level	
Roof drains rainwater to storm sewers	Green roofs detain rainwater, increase evapotranspiration, and lower water runoff; Roofs discharge rainwater into downspouts connected with a rainwater storage tank; Use collected roof water for non-potable uses such as watering lawns and gardens
Create impervious paving, driveways and walkways	Minimise impervious surfaces, use pervious pavements, and increase rainwater infiltration
Strip topsoil, allow soil compaction on construction sites and roll out a thin layer of soil over the turf surface after construction	Improve soil porosity and prevent compaction after construction, set lower limit of topsoil at least 30cm depth before planting lawn
Remove a big tree due to risk of property damage during storms	Plant and maintain trees for reducing stormwater runoff, filtering groundwater, increasing property values, increased aesthetics, improving air quality, and reducing power generation
Stormwater Management at the neighborhood level	
Create impervious pavements on roads and pavements, use curb and gutter systems to discharge runoff to storm sewers	Reduce road width and area of disturbance, in place of a system of street curbs, gutters with grassed swales, and use previous pavements to increase infiltration
Flow water runoff into streams and waterways by creating a pipe network of storm sewers	Create artificial wetlands and detention ponds to reduce non-point source pollutants and high sediment loads from urban runoff into receiving streams
Use impervious pavements in parking lots, resulting in high levels of pollutants discharged into stormwater sewer systems	Construct porous pavements in parking lots, and direct runoff into bioretention swales, detention ponds, and wetlands instead of storm sewers
Stormwater Management at the catchment level	
Pipes convey stormwater with sediments and pollutants pass through riparian zones, and release into urban streams	Restore riparian zone, riparian buffer, and wetlands as natural biofilters to retain sediments and pollutants from stormwater entering aquatic environments

Modify stream and river channels to increase flow capacity, and speedup flow regime	Maintain natural flow regime of river channels, vegetate riparian zones and allow lateral flow within the buffer zone for storage of stormwater
High flow rates of stormwater discharges from all water outlet systems become point source of pollution and impacts receiving streams	Reduce flows and pollution loads by creating detention and Infiltration systems in replacements for ponds, concrete structures, and pipe networks in order to meet stormwater quality, increase pollutant removal and groundwater recharge

Table 2-1: Conventional and Integrated Approaches to Water Management Adapted from Marsalek and Schreier (2010)

2.2.7.2 Low Impact Urban Design and Development (LIUDD)

Low Impact Urban Design and Development (LIUDD) is an urban design concept initiated in New Zealand for creating community environment to maintain sustainability. LIUDD was developed from its primary practices in stormwater management (van Roon, 2005). It emphasises sustainable urban concepts including Low Impact Development (LID) and ICM to promote alternative urban development by sustaining natural process to provide flood protection and enhance resilience of city (van Roon, M., & van Roon, H., 2009).

LIUDD philosophy works towards creating sustainable forms of development, moving away from the short-term and piecemeal planning. Its practices are based on the principles of landscape, urban design, and catchment ecology in operation. To achieve urban sustainability, LIUDD emphasises functions of natural features to avoid or minimise impervious surfaces, minimise waste, resource and energy uses (van Roon, M., & van Roon, H., 2009).

LIUDD provides a main contribution to urban sustainable aspects including enhancing recreation and amenity values of urban environment (van Roon, 2005). It also works with nature for modeling of stormwater contaminant loads on natural river systems by establishing treatment trains (from green roofs to detention ponds) in urban catchments. The processes of LIUDD to provide the greening of cities also involve using vegetation to assist in trapping sediment and contaminants by protecting and promoting existing native vegetations over planning, restoration and enhancement of local plants to create green habitats for native species and increase biodiversity (Ignatieva et al., 2008).

According to WWF, (2012) the successful practice of green corridors in New Zealand not only provides walkways and cycle routes for inhabitants, but also accelerates flood protection which contains the stormwater of even a 100-year flood as well as enhancing stream quality. Other benefits of LIUDD are also to create natural systems through water flows, minimise energy uses by reducing surface temperatures in summer, and keep buildings dry during the rainy season (Mortimer, 2010).

LIUDD techniques provide practical methods for reclamation of urban runoff through converting an urban nuisance into a valuable water resource. The reclaimed water can be used for irrigating landscapes, groundwater recharge, prevent and minimise suspended particulates and pollutants from the runoff to improve water quality before the runoff reaches downstream areas.

As untreated stormwater runoff remaining in the catchment may result in the impairment of downstream areas, the application of sustainable stormwater approaches at a catchment scale through localisation of stormwater runoff in the upstream catchment will be important to downstream improvements and lead to ecosystem sustainability. Therefore, maintaining more natural methods towards sustainable stormwater approaches may be the most effective means of resolving water quality degradation and ecosystem integrity issues.

2.2.7.3 Best Management Practices (BMPs)

Best management practices (BMPs) are defined as practical control measures, including technological, economic, and institutional considerations,that have been demonstrated extensively across the world to effectively avoid or reduce water quality impacts of stormwater discharges. The use of BMPs is broadly accepted as the most suitable technique of minimising the generation of nonpoint source pollution of urban runoff to streams (Ice, 2004). BMPs intend to promote a hydrologically functional landscape that mimics a natural hydrologic regime in a catchment (Prince Georges County 1999). The practices are also aimed at managing rainwater at its source, instead of discharge into traditional wastewater treatment systems, in order to prevent the stormwater runoff during rainfall events as well as solving sanitary problems (Martin et al, 2007).

BMPs can be divided into two groups: structural and non-structural BMPs. Structural BMPs range from green roofs, green walls, raingardens, swales to filter and transport water, and open channels to retain or detain water through to surfaces for infiltration. The systems integrate the distributed storage and infiltration storm water controls (Perez-Pedini et al, 2005). Non-structural BMPs include a range of pollution prevention, education, and management methods (Martin et al, 2007). In this paper, the focus lies in both structural BMPs such as green roofs, retention ponds, swales, porous pavements, wetlands and non-structural BMPs including economic, social, and institutional considerations of the practices.

Efforts to investigate the efficiency of BMPs have extensively been directed toward the assessment of a number of BMP facilities, particularly green roofs (Villarreal et al., 2004), bioretention systems (Garrison & Hobbs, 2011; Autixier et al., 2014), swales (Davis et al., 2012), permeable pavements (Hunt & Collins, 2008), and wetlands (Vymazal, 2011). A number of BMPs manuals have been introduced since the 1990's that promote the control of urban runoff to enhance receiving water quality (Roesner et al, 2001). Many BMPs' selection and design manuals have been published (e.g. Schueler, 1987; Claytor & Schueler, 1996; Shaver, 2000; Lucas, 2005; Rossman, 2010; Parish et al., 2012), that contributed to the actual diffusion of BMPs.

The number of BMPs policy adopted by local authorities is gradually rising in several countries due to the accelerated diffusion of policy and regulations challenging widespread implementation of BMPs. The approaches are increasingly gaining interest from policymakers and many developers in directing cities toward sustainability. It was observed that the implementation of BMPs has been increasing rapidly and is now considered as an integral component of environmental management including Water Sensitive or Low Impact Urban Design.

The implementation of appropriate BMPs was developed to deal with catchment-scale water quality issues in several states in the USA particularly Washington, Oregon, California (Ice, 2004), Seattle, Pennsylvania, and New York City (Garrison & Hobbs, 2011). In Seattle, the Seattle Department of Planning and Development, and Seattle Public Utilities (SPU) implemented a Director's Rule and that required single-family residential and parcel-based projects in 2013 to install and optimise the use of best management practices (BMPs) including bioretention systems, permeable pavements, green roofs, and rainwater harvesting. In 2014, Seattle's Office of Sustainability and Environment implemented a green stormwater infrastructure (GSI) plan to establish green stormwater infrastructure under the goal of increasing the retention capacity of 700 million gallons (3.15 million m^3) of stormwater runoff yearly by 2025 (Garrison & Hobbs, 2011).

To increase the implementation of BMP retrofits in Philadelphia, Pennsylvania, the Philadelphia Water Department (PWD) and the Philadelphia Industrial Development Corporation provided grants to private land owners in the combined sewer overflow (CSO) drainage area under the Stormwater Management Incentive Program (SMIP) in 2012 to increase the implementation of BMP retrofits. Garrison and Hobbs (2011) noted that during 2012-2013, this programme granted approximately $9.6 million, projected to create green areas accounting for 154 acres in the CSO drainage area and adjacent part by 2013.

To reduce discharges of untreated sewage including from CSOs in New York City, a Sustainable Stormwater Management Plan was adopted in 2008, aiming to increase the implementation of BMPs, for both public and private projects (Greenroofs.com, 2014). In 2012, the New York City Department of Environmental Protection (DEP) and New York State also launched an administrative consent order to achieve CSO volume reductions in New York City. According to the order, some planned grey infrastructure projects such as two costly CSO detention tunnels were eliminated or deferred, and new BMP projects were substituted and developed. These practices include reducing CSOs through capturing or detaining the first inch (2.5 cm) of rainfall on 10% of the impervious surfaces area over the next 15 years (Garrison & Hobbs, 2011).

In Malmo, in southern Sweden, an array of BMPs in series has been implemented to solve inner-city drainage problems in an aging inner-city suburb, Augustenborg— a high density housing area in a suburb of Malmo. BMP technologies have been applied since 1997 to reduce the problems of CSOs and flooding during heavy rainstorms, causing housing damage and nuisance in an impoverished area of the city. An open stormwater system has been installed in an existing area that has been renovated in the inner city suburb of Augustenborg. These areas include commercial offices, apartment buildings, roads, footpaths, and car-parking areas (Villarreal et al., 2004).

The disconnection of stormwater from the existing combined sewer and drainage by means of an open system aimed to reduce CSOs completely and flooding by up to 70%. The results show a substantial decrease in the total runoff volume and the amount of stormwater reaching the piped systems. The Augustenborg stormwater system has become well known for the successful implementation and operation of a complex arrangement of BMP systems retrofitted to an existing residential area. This open stormwater system now drains rainwater almost completely and enhances the performance of the combined sewer system (Villarreal et al., 2004).

In the U.K., the use of BMPs for the management of stormwater runoff has been promoted by the Environment Agency and the Scottish Environment Protection Agency under the label Sustainable Urban Drainage. These BMPs typically consist of green roofs, rain gardens, infiltration basins, soakaways, swales, and ponds (Stovin et al., 2013).

The awareness of BMPs or so called Water Sensitive Urban Design (WSUD) methodologies in Australia has taken place as a result of drought, water restriction legislation, urban population growth and environmental concerns (Segaran et al., 2014). Due to climate change and uncertainties, Australia experienced a severe drought, followed by severe floods resulting from extreme 'La Nina' situation during 1997 and 2009 (Floyd et al., 2014). WSUD addresses the restoration of stormwater for local use, which then prevents the deterioration of receiving waters resulting from the contamination by sediment and pollutants from roads and urbanised areas (Wong & Brown, 2011; Floyd et al., 2014).

In Singapore, as a result of environmental concerns and the need to buy drinking water from Malaysia, there has recently been an increase of awareness on BMPs. This has arisen from the need to improve the water quality of stormwater runoff for environmental protection, particularly using rainwater harvesting techniques to treat stormwater and re-use for drinking water (Lim et al., 2015). The government of Singapore also promotes sustainable design, construction and operation practices in green and sustainable buildings through energy savings, water savings, and greenery within indoor environments (Yuen, 2013).

In Taiwan, the National Sustainable Campus Program for encouraging sustainable development through implementing BMPs was launched in 2002. This national policy aims to improve environments surrounding the campus through source control stormwater management systems including pervious pavements, constructed wetlands, green roofs, stormwater ponds, and other source control devices. The strategies for promoting sustainable campuses also include the use of green roofs under standardised regulations following the German guidelines to reduce urban runoff in cities. In 2008, a BMP approach following the USEPA' guidelines was also launched in Taiwan to mitigate flooding problems. Additionally, the Taiwanese Building Act also requires building owners to construct onsite water management, permeable pavements, green roofs, and detention ponds (Chen, 2013).

China is embarking on a project of BMP facilities in several cities. Such a project is proposed not just for the mega cities like Beijing, Shanghai and Tianjin but also for the small town of Jiangsu. It was noted that the most advanced developments in source control measures in China are in Tianjin, where the project was initiated in 2007 covering the city of 30 sq km with 350,000 residents (Li, 2012).

To cope with the urban stormwater issues in Beijing, Good Urban Design (GUD) policy has been proposed for water purification and retention in the city. The policy issued in 2012 required BMP facilities for stormwater control and reuse during the construction of new development or expanded facilities of all buildings and neighbourhood developments. Existing BMP facilities implemented in the City of Beijing consist of infiltration trenches and wells, pervious pipes, road water inlets, roof water containers, rain tanks, underground tanks, wetland detention, green roofs, and rainwater treatment techniques. However, green roof technology has recently been applied to less than 1% of the roof areas in Beijing (Li, 2012).

To deal with water scarcity problem in Beijing, the reuse of stormwater has been introduced under Rainwater Harvesting (RWH) SWITCH project in peri-urban areas of Beijing, providing the effectiveness of up to 45-80% for agricultural water use. It was suggested that these facilities are applicable in the plain area where there are well-developed facilities for agriculture, the mean annual precipitation is more than 400 mm, and the water table surface is located generally more than 5 m below ground level (Li, 2012).

BMPs also offer cost-effective stormwater facilities. Montalto et al. (2007) assessed the potential cost-effectiveness of public investments on BMP facilities in urban areas of, Brooklyn, NY, through the Low Impact Development Rapid (LIDRA) program. Results suggest that BMP are the best implemented and most effective approach that can be a potential component of conventional stormwater management and achieve cost effective reductions in CSOs, while being cost competitive or better than CSO tanks.

Best management practices are an appropriate technique for dealing with water quality issues, which provide both ecological and environmental benefits. The incremental installation of BMP measures in combination with conventional CSO technologies can minimise the amount of runoff entering the sewer system and reduce CSOs if applied across urban catchments. The examples from diverse countries clearly illustrate remarkable advantages achieved by BMP technologies.

Several studies have demonstrated the effectiveness of the BMPs in controlling the pollution of urban runoff, reducing flood risk and improving stormwater quality at the same time. Mimicking and restoring the natural hydrologic system is a vital element of urban sustainable development. Thus, incorporation of BMP strategies with urban water systems can improve water quality, enhance amenity, supplement water supplies, and mitigate the stress on urban water resources.

2.3 Planning Barriers to Integrated Catchment Management and Stormwater Source Control Management

A shift towards more sustainable stormwater practice has been broadly recognised in recent decades due to the multiple advantages of the practices demonstrated. However, the degree of implementation for the SC approaches is still low. Generally, barriers to implementing sustainable stormwater solutions may include institutional constraint, high initial costs related to the construction and operation of the systems and the constraint of land use and available spaces. A review of documents provided evidence of several barriers and underlined that challenges were largely institutional rather than technical (Earles et al., 2009; Hammitt, 2010; Jacobs et al., 2010; Tian, 2011; Eisenack et al., 2014; Ferguson et al., 2014). Based on the review of several barriers, the commonly identified barriers are categorised into four groups including institutional, technical, physical, and economic factors.

Institutional Barriers

The impediments that inhibit local governments from advancing stormwater SC measures are mainly due to institutional barriers, including institutional fragmentation (Eisenack et al, 2014), fragmented regulatory framework (Hammitt, 2010; Tian, 2011), limitations on the mandate and authority of each entity (Huron River Watershed Council, 2014), lack of multi-sectoral champions and political leadership (Ferguson et al, 2014), SC management not integrated early in the planning process (Earles et al., 2009), lack of effective incentive policies and programs, unclear and decentralised responsibilities of operation and maintenance (Tian, 2011), lack of local decision-making authority, inadequate interagency coordination, and lack of cross-jurisdictional communication and planning (Tian, 2011; Huron River Watershed Council, 2014).

It is evident that various studies have identified institutional factors as restraining the implementation of environmentally friendly stormwater practices. Eisenack et al. (2014) claimed that institutional fragmentation is the most persistent and complex problem, which is embedded and difficult to overcome. Fragmentation has hindered the mainstream of adaptation measures to sustainable stormwater management due to various stakeholders and civil societies involved in the process of decision-making advocating for the sustainable stormwater management movement. Jacobs et al. (2010) asserted that although significant public and political support has arisen for SC implementation in several countries, institutional constraints may occur due to a limited culture of collaboration in different fields. Moreover, a lack of cooperation between local practices and central agency officials can also be a barrier to learning processes in SC implementation.

To overcome the fragmentation barriers, a shift towards interdisciplinary integration of personnel in management authorities and effective water institutional arrangement in engineering, planning, operations, and maintenance is necessary. Jacobs et al. (2010) maintained that the implementation of SC measures should begin with the fundamental principles between multi-participants in different practices from local to catchment levels. Additionally, in order to seek stronger responsibility, government agencies should attempt to link state responsibility with environmental sustainability.

Overall, cooperation and coordination among separated institutions and regimes are significant for dealing with the consequences of fragmentation, as sustainable stormwater management relies greatly on cooperation and integration across various disciplines. The improvement of coordinated policies to overcome the complexity of the interactions of multi-level institutions at different scales is necessary to enable multi-partnerships to work together under the ecologically sound principles.

Technical Barriers

The barriers to stormwater SC infrastructure are also largely caused by technical factors including lack of knowledge and trust in water sensitive technologies (Ferguson et al, 2014), lack of education and training, limited good technical documentation, standing water 'nuisance' problems (Earles et al., 2009), lack of knowledge of ecology, stormwater runoff problems, gardening, site suitability, and maintenance needs (Hammitt, 2010), challenges with operations and maintenance (Tian, 2011; Podolsky, 2012), lack of performance and cost data, (Tian, 2011), and lack of design standards and maintenance guidance (Earles et al., 2009; Tian, 2011).

The barriers to integrated planning through stormwater SC management are largely caused by lack of integrated knowledge. As new approaches to challenge conventional stormwater solutions, have emerged only in the last few decades, SC features are not well integrated into the practices of engineers and planners within the urban stormwater system (Huron River Watershed Council, 2014). The lack of comprehensive knowledge was often perceived as an important barrier, arising when information does not exist or is not accessible. According to Hammitt (2010), as SC infrastructure in urban stormwater management is still relatively new and an innovative paradigm, barriers to stormwater SC management have not been very broadly researched in the academic realm. The absence of design techniques and standards for SC practices can cause negative responses by engineers and planners at all levels.

So far water management seems to be dominated by the technical authorities, while the planning and the ecological experts have not been involved. Additionally, Eisenack et al. (2014) claimed that lack of public involvement at the local level can impede SC adaptation and slow down the process of implementation for municipalities. Thus, effective governance arrangements require constructive involvement between related government agencies and civil society groups. The participation of all citizens in decision-making, monitoring and evaluating processes is important in adaptive governance regimes. The involvement of all stakeholders including government agencies, professionals, and local communities is crucial to achieve ICM planning.

The trend toward more open and decentralised decision-making may create opportunities for water resource management that reflects the local context. Moreover, bottom-up solutions may also increase SC demand and therefore increase the willingness of local residents to implement SC solutions. Bos & Brown (2012) explored a governance structure in transforming process of existing conventional socio-technical settings, on both local and regional water governance processes within the Cooks River catchment in Sydney, Australia. The authors highlighted the importance of champions and learning processes, which potentially influence socio-technical systems change in transforming governance systems. The authors also concluded that local governance arrangements have the capacity to transform traditional socio-technical regimes.

The coordination learning mechanisms on urban stormwater management provided sharing of insights and information among a number of stakeholders at different levels within each of the sub-catchments. Learning process on water planning at a local level was important as information and experiences were shared on a regular basis between municipal stakeholders. In the case of the Cooks River, the collaborative social learning on urban stormwater management has led to technical learning, resulted in development and implementation of alternative techniques of WSUD such as vegetated swales, rain gardens, permeable pavements, and sand filter projects through the interactions of social, administrative, scientific, technical actors, and other catchment stakeholders (Bos & Brown, 2012). Pahl-Wostl (2009) also noted that learning potentially results in changes in social norms, values and beliefs, goals, operational policies, and actors that will direct decision-making processes and actions in a sustainable manner to support transitions, which will finally lead to change in successful governance in the socio-technical regime of the water sector.

Physical Barriers

Physical constraints are identified as challenges with consequence for physical characteristics in a catchment that cannot simply be overcome, particularly: high urbanisation, land availability, and geographical characteristics that prevent implementation of SC approaches. Physical factors were also defined as potential barriers to application of SC practices by Earles et al. (2009), including poorly drained soils, high groundwater table, expansive soils, construction defect lawsuits, and semi-arid area hydrology.

A study on impacts of land developments and housing density in three different locations with similar geological, topographical and climate variables conducted by Goonetilleke et al. (2005) indicated that urbanisation had a substantial influence on the quality of water bodies due to the increase of overflow with impervious surfaces. The drainage area is also a crucial geophysical constraint for both water quantity and quality. The land topography and hydraulic factors are important for stormwater SC practices that include pipe or open channel.

Considering land available issue, Barbosa et al. (2012) noted that the available space for stormwater management and disposal is a significant constraint in high-density areas. Raja Segaran et al. (2014) also noted that the implementation of SC is favorable for new urban developments. However, spatial and economic constraints are the barriers to implementation in urban areas. The data on land use requirement for SC practices conducted by Barbosa et al. (2012) shows that ponds and detention basins require substantial land. The findings from surveys in Augustenborg, Sweden, by Villarreal et al. (2004) also revealed that changes in land use to the courtyard pond or open water areas became the highest concern for residents. As those devices require large land areas, to overcome physical constraint, Barbosa et al., (2012) suggested that implementing practices that do not detain runoff such as green roofs and raingardens is suitable for installing in high density areas as they do not require large areas compared to detention ponds and wetlands for infiltration or evapotranspiration.

Economic Barriers

Stormwater SC infrastructure is also being implemented in a piecemeal way largely because of economic factors, particularly inadequate budgets (Eisenack et al, 2014), lack of sufficient funding and revenue stream (Tian, 2011; Huron River Watershed Council, 2014), no clear economic incentives for municipalities and building owners to invest in stormwater infrastructure (Earles et al., 2009; Huron River Watershed Council, 2014)

A financial restriction is considered as an impediment preventing wide implementation of SC features and may enlarge other barriers. Several levels of government jurisdictions are facing inadequate budgets when trying to implement stormwater SC management (Tian, 2011). Moreover, the high initial cost of SC devices is also perceived as a main barrier for their implementation. It was suggested that the cost of stormwater management facilities needs to be taken into account in the first stage of the decision process. These costs may involve the construction, operation, maintenance, monitoring, and depreciation costs, land acquirement, and the cost of training technical employees (FHWA, 2000; Barbosa et al., 2012). Well-designed SC controls might increase property values and provide an economic benefit in the long run.

The maintenance of SC systems was identified as a major barrier to SC implementation due to doubts about future maintenance needs, costs, and unclear responsibility to sustain their performance (Hammitt, 2010). According to Tian (2011), operation and maintenance of stormwater SC systems creates larger challenges than conventional stormwater practices. It was noted that some maintenance activities are required for SC practices. In general, grass swales require mowing and permeable pavements also require sediment removal, as well as bioretention facilities requiring the replacement of deceased vegetation. However, EPA (2000) maintained that although SC practices require these forms of long-term maintenance, such measures offer greater cost effectiveness and are less maintenance intensive than conventional stormwater management. Furthermore, although the construction of permeable pavements is more costly than conventional asphalt pavements, the costs of these alternative pavement types will be offset by a reduction in curb and gutter conveyance systems. Additionally, according to a study conducted in Florida by EPA (2000), retrofitting impervious pavements into parking lots has no impact in terms of a loss of parking spaces.

It is apparent that SC maintains healthy streams, provides both ecological and environmental benefits at various scales while allowing urbanisation at all densities. Substantial cost savings of SC are feasible in terms of long-term operation and maintenance cost consideration. Therefore, new enabling legislation, efficient administrative structures, major funding arrangements, and economic incentives should be taken into account in order to allow cities to carry out the implementation of large-scale SC facilities and to ensure the sustainable management of urban ecosystem.

2.4 The Potential and Implementation of Stormwater Source Control Approaches

Stormwater source control systems are regarded as the approaches of retention, treatment and infiltration of stormwater that are implemented at the source, primarily applicable for land uses such as individual building lots, parks, and highways (Li, 2012). The methods adopted by countries vary in a number of design procedures. In recent years, these systems have received a high level of interest in several countries. The literature on these practices consists of many reports on the hydrological and contaminant removal performance of both experimental and field-site scale installations.

The systems may consist of an array of devices constructed to treat stormwater at the source or close to the discharge into the sewer system, or into the receiving rivers (Barbosa et al., 2012). Common practices within these systems include green roofs, bioretention devices, permeable pavements, swales, detention ponds, and constructed wetlands.

2.4.1 Green Roofs

Stormwater runoff from traditional roofs has potentially contributed to urban runoff and water quality problems. Conventional roofs in most developed cities may cover up to 40 - 50% of the impervious urban surface area (Stovin et al., 2013). Green roofs are one of several techniques of SC approaches. The techniques aim to reduce runoff volumes and the risk of urban flooding and minimise water and contaminant loads to sewer systems and receiving rivers.

Two different types of green roofs include intensive green roofs and extensive green roofs. Intensive green roofs typically have moderate slopes and soil covers with a thickness of more than 15 cm. These roofs require regular watering for large plants. In contrast, extensive green roofs require little soil cover of a few centimetres and can be placed on slopes up to 40–45%. For existing buildings where the weight of the green roof is limited as the soil layer is thin, extensive green roofs can usually be placed without structural reinforcement (Locatelli et al., 2014).

Since the 1990s, green roofs have become increasingly popular in several countries such as in the United States and European countries particularly Germany. Moreover, several countries such as the U.K., the U.S.A., Germany, Australia, and New Zealand have also been publishing guidelines for the implementation of green roofs for a few decades (Locatelli et al., 2014).

The hydrological performance of green roofs may vary among geographic regions due to different climates, a wide range of precipitation patterns, building practices and plant materials. Locatelli et al. (2014) stated that the most influential hydrological performance functions of green roofs during rainfall events are the interception capacity of the vegetation layer, infiltration in the soil substrate, and retention/detention in the soil substrate and drainage layer.

Green roofs minimise stormwater runoff compared to traditional roofs due to the capacity of water infiltration, retention, and evapotranspiration. The amount of water stored on a green roof is lost through evapotranspiration. Rainwater in excess of the storage capacity will be carried into an outlet by main drains, which receive water from the laterals. Volume retention mainly depends on hydrologic characteristics of the rainfall events such as the rainfall intensity, rainfall duration, the initial moisture conditions; and green roof characteristics such as layer thickness, slope, and materials of the green roof (Locatelli et al., 2014). Complementary SC devices, particularly swales, ponds, and infiltration trenches are crucial to be connected with green roofs to minimise flooding and ensure river water quality during storm events (Stovin et al., 2013).

The Potential of Green Roofs

The effect of green roofs on runoff reduction for various conditions has been described in literature (Locatelli et al., 2014; Villarreal et al., 2004). A study on the potential of extensive sedum roofs in Denmark by Locatelli et al., (2014) showed that green roofs even with a few millimetres of water storage were estimated to reduce the mean annual runoff volumes up to 20% when compared to a typical roof.

The finding of surveys in Augustenborg, Sweden, revealed that green roofs offered benefits over stormwater ponds as they make use of previously vacant space and do not reduce the access of the people to open space. Moreover, it has been suggested that green roofs can be successfully used to reduce the total stormwater runoff as they provide high evapotranspiration rates particularly at the time of convectional rainstorms in summer, while ponds are effective at attenuating peak runoff rates from developed areas. However, as the typical storage capacity of the roofs is only 10mm, they still have limitations in reducing storm flow peaks (Villarreal et al., 2004).

In terms of the performance of green roofs in contaminant removal, Skinner (2006) reported the water quality of outflows from the four full-scale intensive and extensive green roofs located on the roof top of a building in the Adelaide central business district (CBD) during a 9-month period. Results indicated that the contaminant concentrations in outflows from green roofs typically reduced during the period of study. Significantly, the performance of intensive (deep bed) green roofs was shown to be greater than the extensive (shallow bed) green roofs in terms of nitrate, phosphate and potassium removal. However, the study found that outflow water from green roofs is suitable to be reused only for non-potable applications, such as toilet flushing and landscape irrigation.

Vegetated roofs provide benefits not only for reducing urban stormwater but also for promoting urban cooling. Sandifer (2009) reported a substantial reduction of temperature with a green roof compared to a concrete roof. The substitution of dark-coloured roofs with green roofs also provides substantial effects in reducing urban temperature (Thani et al., 2012). Moreover, green roofs also reduce high summer temperatures during prolonged periods of no rainfall (Locatelli et al., 2014).

Stovin et al. (2013) suggested that high moisture-holding capacity of green roofs and low evapotranspiration rates provide significant levels of retention and drought resistance. The retention capacity of a green roof not only significantly depends upon rainfall characteristics, but is also influenced by evapotranspiration in the period prior to a storm event. In dry seasons, the minor evapotranspiration rates are usually found due to the depletion of the moisture available within the substrate.

A study on green roof performance in Taiwan by Chen (2013) showed that green roofs have high energy-saving functionality and significant thermal reduction. However, as Taiwan is located in a tropical and subtropical region and has a high annual average rainfall, without proper maintenance, the runoff from green roofs generated more nutrients and sediments compared to the runoff from bare roofs.

The author concluded that green roofs mainly contributed to decreasing energy consumption, carbon emissions and thermal reduction, and moderate temperature around buildings, which are greater benefits than the reduction in stormwater runoff. This is due to the fact that retention and detention capacities were affected by high rainfall intensity in the country. Thus, additional irrigation is required to maintain water level for green roofs in hot climatic regions.

The Implementation of Green Roofs in Other Countries

The implementation of green roofs is increasingly popular in several countries. To promote the implementation of the device, governments have enacted green roof regulations particularly London, Munich, Seoul (Greenroofs, 2014), Copenhagen (Nusca, 2010), Taipei, and Singapore (Chen, 2013).

In the UK, the development of green roofs has been included in the London Plan since 2004. The green roofs agenda has been fully supported through the incorporation of the city and the role of local authorities, and the Homes and Communities Agency (HCA). In 2012, the city facilitated the installation of 100,000m^2 green roofs. Currently, London City has also required all main new developments located within London’s Central Activities Zone policy area to green their rooftops in order to meet London's Climate Change Adaptation Strategy (Greenroofs, 2014).

Since the 1990s, green roofs have become increasingly popular in a number of European Countries particularly Germany. In 2001, it was evident that 13.5 million square metres of green roofs had been installed in Germany, of which 80% of the green roofs in the country are extensive green roofs. In 2003, green roofs equated to 13% of all flat roofs (Locatelli et al., 2014). It was evident that incentives and subsidies have been provided to building owners for the installation of green roofs over 80 cities in the country. In Munich, the requirement of green roofs in building ordinance has been introduced since 1984. By 2000, around 4.2 million square feet (390,600m^2) of rooftops have been installed in the city (Greenroofs, 2014).

The use of green roofs has been increasing in Denmark in recent years. The City of Copenhagen has set up requirements for green roofs for new private and public buildings which contain flat roofs at less than a 30 degree-pitch. Additionally, it also applies to old roofs, and public financial support will be provided to the building owner if aged roofs have to be retrofitted. Recently, green roofs for new buildings in the city are expected to increase around 5,000 m^2 per year. This target has been set in order to meet the goal of becoming the world’s first carbon neutral capital by 2025 (Nusca, 2010).

In Philadelphia, one of the large green roof projects has been installed at the Fencing Academy, which a 3,000-square-foot extensive green roof was installed on top of an existing building to detain and treat a 2-year 24-hour storm event. The system includes an underdrain layer, a lightweight growth media, perennial Sedum varieties, with the average 2.75 inches thick of the roof cover. The light weight of these materials allowed installation on existing roofs without structural adjustments. The roof system can reduce runoff for rainfall events up to 3.5 inches and detain runoff with little or no direct runoff occuring for rainfall events up to 0.50 inches, which was projected to reduce annual runoff volume by 54 percent (NRDC, 2014).

The implementation of green roofs in South Korea has become increasingly popular during the last decade. Korea Green Roof and Infrastructure Association (KOGRIA) was established in 2003 and has played an important role in promoting the Urban Green Space Project. The association also cooperates with governments, research and educational institutions, and private organisations to create urban green spaces for the country. Recently, green roofs programme has also been promoted under the Green School Project in South Korea to restore existing roofs in elementary and middle schools (Greenroofs, 2014).

The use of green roofs has been introduced in Taiwan since 2000 and became popular since 2006 due to the Taiwan Sustainable Campus Project launched in 2002 to encourage the use of green roofs to build sustainable campuses throughout Taiwan. As located in a tropical and subtropical region, Taiwan has an annual average rainfall of 2500 mm, with a large amount of rainfall during the rainy season representing an average rainfall of 230 and 300 mm in May and June, respectively (Chen, 2013).

To minimise a large amount of stormwater runoff, extensive green roofs are generally used in Taiwan due to limitations on weight loading of roofs (Chen, 2013). In New Taipei City, the implementation of green roofs on buildings and campuses has recently increased as the city government has made an effort to direct the city towards a low-carbon city and a more sustainable city. In 2011, Taipei City released a regulation to increase stormwater retention capacity through the use of retaining and detaining stormwater facilities to increase green space surrounding building areas (Chen, 2013).

2.4.2 Bioretention Systems

Bioretention systems, also referred to as biofilters or rain gardens, are the most commonly used SC approach. The systems use physical and biological processes to remove pollutants, slow down stormwater flows, absorb and filter contaminants before stormwater flows to streams and rivers (Auckland Council, 2014). Bioretention uses the processes of infiltration, evapotranspiration, filtration in the treatment of stormwater runoff. The device has been widely implemented across the United States and several counties in Europe and Asia due to its capacity to reduce runoff and to maintain predevelopment hydrology in urban catchments (Hathaway et al., 2014).

According to Auckland Council (2014), the main elements of a rain garden typically include: soil mix; ponding area; plants; overflow system; mulch, pebble and rock layer; sand layer; underdrain system and; grass buffer strip. Soil mix, typically sandy loam is used to filter pollutants. Rain garden soil mix should be more than 700mm thick layer for the plants and for providing the significant performance of water quality treatment. Ponding area works by holding stormwater runoff until it infiltrates through soil mix planting bed, and into the underdrain system. The ponding area should be a maximum of 200mm - 300mm deep for security reasons.

Plants help filter and absorb pollutants. Native plants are widely used as they provide better tolerance of extreme wet and dry conditions. Fertilizers, herbicides or pesticides are restricted to avoid polluting downstream water quality. Overflow system is designed to convey runoff flows in excess of designed filtration capacity. Mulch, pebble and rock layer serve as a protecting layer for maintaining soil moisture and preventing weeds. Sand layer may be included in order to help maintain soils within the rain garden and to remove pollutants passing through the sand bed. The sand layer is normally installed at a depth of approximately 300mm, to prevent the clogging of soil mix, debris, fine sediments and clay moving into the underdrain.

The underdrain system usually needs to drain remaining runoff filtering through the soil mix, then returned to the drainage system or rivers. Some free draining soils can be designed without an underdrain to enable full infiltration of runoff draining to groundwater aquifers. The full depth of underdrain gravel should be about 400 mm from the surface of the ground to the top of the underdrain areas. Grassed buffer strip may not be included in a rain garden due to a site constraint. However, it can be designed to filtrate large particles and to maintain runoff sheet flow and avoid erosion (Auckland Council, 2014).

The Potential of Bioretention Systems

Some studies have reported on factors influencing treatment performance of biofilter devices. For instance, Hathaway et al. (2014) reported that a wide variation of bioretention performance to reduce runoff volumes depends on system size, underdrain systems, and soil type. Henderson et al. (2007) found that a fine sand or sandy loam filter media for biofiltration provides a substantial nutrient removal as they support plant growth as well as show little leaching. Davis et al. (2001) demonstrated that increased depth in biofilters also provides support for total phosphorus removal.

In Melbourne, Australia, Bratieres et al. (2008) reported the effectiveness of stormwater biofilters for sediment, nitrogen and phosphorus removal, using 125 large-scale biofilter columns. Different factors were compared to offer guidance on the optimal design elements for an effective biofilter in terms of treatment performance. The results indicated that the optimally designed biofilter should be sized to at least 2% of its catchment area. Additionally, biofilters planted with *Carex appressa* and *Melaleuca ericifolia* using a sandy loam filter media provided a significant nutrient removal when compared with those using other plant species. Biofilters constructed according to these optimal factors offer consistently very high removal in both nutrients and suspended solids, which accounted for around 70% for nitrogen, 85% for phosphorus, and up to 95% for suspended solids removal. However, the addition of organic matter to the biofilter soil media can reduce the phosphorus treatment efficiency.

In the US, Yang et al., (2013) evaluated hydraulic performance and agricultural pollutant removal efficiencies of two field-scale rain gardens at The Ohio State University's Wooster campus in 2008. In this study, three agricultural runoff conditions with high concentrations of nutrients and herbicides were investigated during a 2-yr period. Results indicated that under a high degree of pollution loading, the rain gardens provided a great performance in removing 91% nitrate, 99% phosphate and 90-99% herbicide. The main factors influencing overall nutrient and herbicide removal are the increase of runoff retention time and water-saturated conditions in the rain gardens. In terms of runoff reduction, it was evident that the water saturation zone of rain gardens played a significant role in reducing both peak flow and runoff volume through a retaining process.

In Auckland, New Zealand, a field-scale bioretention system with the surface area of $200m^2$ was installed in North Shore City in 2006 to receive contaminated sediment and heavy metals, in particular zinc from runoff flowing through a light industrial catchment and a heavily trafficked local road, with 95,900 vehicles travelling weekly. The soils in the bioretention system were chosen to have high metal removal efficiency and high permeability (>50 mm/h).

This study indicated that the bioretention system reduced peak flow and volume for all 12 rainfall events with little or no baseflow from impermeable surfaces. In terms of contaminant removal, it is clear that the majority of the zinc, lead and Total Suspended Sediments were consistently reduced from the stormwater flowing through the bioretention system. However, the overall capacity of the system to reduce the concentrations of copper entering the bioretention system was still relatively ineffective, and median concentrations of dissolved zinc in the systems still exceeded ecological guidelines (Trowsdale & Simcock, 2011).

The Implementation of Bioretention Systems in Other Countries

Bioretention systems are becoming increasingly in widespread use in several countries. In Montreal, Canada, it was observed that an increase in the annual rainfall had lead to a high volume of CSO for a catchment. Moreover, continued urbanisation has also contributed to the increase of the impervious surfaces, accelerating the volume of stormwater in urban catchments (Autixier et al., 2014). To deal with these issues, rain gardens have been installed to reduce the impact of sewer overflows in a residential and commercial area of Montreal, with a drainage area of 345 ha. Results showed that rain gardens provide a good performance in reducing volumes of stormwater entering a drainage system for the total catchment ranging from 12.7% to 19.4%. In terms of the CSOs reduction, it was found that the decrease of discharged volume ranged from 13% to 62% and the decrease of peak flow rate ranged from 7% to 56% during 2009-2010 (Autixier et al., 2014).

In Chicago, Illinois, CSO discharges have become the main environmental issue, which often reduce dissolved oxygen levels in receiving rivers. To enhance river water quality and localise street flooding, the city government adopted the Green Stormwater Infrastructure Strategy and allocated $50 million in 2013 to integrate green stormwater infrastructure under a five-year plan. In response to this green infrastructure plan, several green facilities particularly community gardens and rain gardens were installed in the areas most vulnerable to flooding, areas reached by small service pipes, and vacant public land to reach the goal of managing 10 million gallons (45,000 m^3) of stormwater runoff by 2015 (Garrison & Hobbs, 2011).

In urban areas of Columbia District, Washington, DC, urban runoff contaminated by stormwater pollutants becomes a serious environmental issue. Impervious surfaces, covering around 65 percent of the District's area, have created large quantities of surface runoff and caused severe environmental and river degradation. Additionally, combined sewer overflows (CSOs) and urban runoff discharging through separate stormwater sewer systems are the main sources of pollutants in urban rivers, representing roughly 70 percent of contaminant sources in the district. It was evident that the dissolved oxygen levels in the Anacostia River were too low and the river was too polluted for swimming (NRDC, 2014).

In response to environmental concerns, a number of SC retrofits including bioretention and detention cells have been applied across the Washington Navy Yard in order to reduce peak discharge and to protect and restore the Anacostia and Potomac Rivers and Chesapeake Bay. These source control projects are in place to treat runoff at the Navy Yard from about 3 acres (1.2 ha) of the 60 acres (24.3 ha) of impervious surfaces, while conventional treatment systems are also applied to treat runoff from a further 10 acres (4.05 ha). At Willard parking areas, several bioretention and detention cells were applied to capture and treat stormwater runoff from parking lots, roadways, rooftops, and landscaped areas. To maximise parking spaces, bioretention strips were also installed throughout Willard Park. Rain barrels are also used to capture and store runoff from rooftops for landscape irrigation (NRDC, 2014).

2.4.3 Permeable Pavements

Permeable pavements have been demonstrated as effective devices in reducing surface runoff volumes and delaying peak flows due to their high surface infiltration capabilities (Hunt & Collins, 2008). Moreover, permeable pavement has been used to protect water quality by filtering out urban contaminants.

Five types of permeable pavements include Porous asphalt (PA), Pervious concrete (PC), Permeable interlocking concrete pavers (PICP), Concrete grid pavers (CGP), and Plastic grid pavers (PG). However, it is evident that different types of permeable pavement provide a minor difference in reducing runoff. A study of performance of PICP, and CGP in North Carolina showed that no substantial difference in runoff reduction could be detected among these permeable pavement types (Collins et al., 2008).

Permeable pavements have performed effectively for surfaces on pedestrian walkways, pavements, courtyards, parking lots, residential driveways, and low-traffic roads (Burkhard et al., 2000). It was suggested that sandy soils provide good infiltration. However, providing enough infiltration is the major concern for low permeability soils such as clay, therefore, the underdrain is needed in place to slowly drain the base layer of the permeable pavement (Hunt & Collins, 2008).

The Potential of Permeable Pavements

Much research has been conducted in several countries on permeable pavement, particularly focused on runoff reduction and water quality, clogging, and long-term hydrology. Recently, experience in North Carolina has clearly shown that permeable pavement is appropriate for runoff reduction. The average curve numbers ranging from 45 to 89, which lower numbers mean less runoff, more water storage, and less clay underlying soil (Hunt & Collins, 2008).

Although previous papers on permeable pavers show their effective removal of runoff and pollutants, the most commonly cited reason for maintenance problems is surface clogging decreasing the long-term function of permeable pavements. A field study conducted in North Carolina, Virginia, Maryland, and Delaware found that surface infiltration rates of pavements generally exceed 1 inch (2.5 cm) per hour when clogged (Bean et al., 2004).

Fine particles can be deposited and clog on the surface of permeable pavements. Pavements age and constant traffic will increase clogging of pavement and cause the pavement to deteriorate more quickly than traditional concrete (Kresin et al., 1997). Moreover, this can result from activities associated with roads and highways, soil particles eroded from the land, and sediment runoff from surrounding disturbed areas (Balades et al., 1995; Bean et al., 2007a).

The Implementation of Permeable Pavements in Other Countries

Permeable pavements have been extensively used in the USA. In North Carolina, more than 20% of a parking space was required by law in 2007 to be either made of permeable pavement or used to implement other environmentally friendly stormwater techniques (Hunt & Collins, 2008).

In Beijing, China, with rapid urbanisation, severe stormwater overflows have been a common problem in urban areas after every short-term intense rainstorm, mainly under overpasses or low-lying areas. Li (2012) reports that this resulted from climate change, increasing impervious surfaces, inadequate green areas and an inadequate stormwater drainage system.

To prevent overflows in the city, permeable surfaces such as pervious brick, pervious concrete and asphalt ground have been constructed for pavements, yards, parks, and low-volume roadways in residential areas in Beijing to enhance rainwater infiltration, reduce runoff, and recharge groundwater. It was noted that during a one-hour rainfall of 107.17 mm, the permeable pavements reduced runoff peak flow by up to 82.29% compared to the impermeable ground surface (Li, 2012).

2.4.4 Swales

Swales are biofiltration and bioretention practices in SC approaches designed to convey urban stormwater and capture pollutants from runoff. The devices contain a drainage course with moderate sloped sides and typically lined with grass that receive flow laterally over the vegetated surface (NRDC, 2001). In contrast to conventional green spaces, a minimal lateral slope or domed shape of bioretention swales provides benefits to capturing stormwater from adjacent areas and filtering it through a soil media before conveying into drainage systems or receiving waters (Kazemi et al., 2011). The swales provide the principal process for removing high influent concentrations in the first flush through infiltration process, following this contamination is reduced by sedimentation and filtration processes. However, it was noted that a sedimentation process along grass swales is the most significant mechanism in removing runoff pollutants (Deletic, 2005; Stagge et al., 2012).

To enhance the effectiveness of swales, Stagge et al. (2012) suggested that treatment performance of grass swales could be improved by increasing hydraulic retention time through installing vegetated check dams, increasing channel roughness, and expanding swale length with mild slope. Similarly, Deletic (2005) suggested that the performance of the systems is highly dependent on: density and thickness of grass blades, slope and length of swales, infiltration capacity and roughness of soil types, size and density of sediment particles, intensity and duration of rainfall, and type of polluted water. However, swale maintenance involving mowing or fertilizing activities may also affects nutrients removal efficiency, which dissolved phosphorus may increase up to a 3-fold from effluent leached from mowed vegetated swales (Stagge et al., 2012).

Bioretention swales are not only designed to capture and treat pollutant runoff from stormwater but also have promising potential for enhancing urban biodiversity. It is apparent that a higher number of bioretention swales projects have been installed in Melbourne than other Australian cities (Kazemi et al., 2011). Urban biodiversity enhance aesthetic, recreational values, quality of life and reduce the mental stress resulted from environmental urbanised disturbance. Appropriate planning of urban development through changing conventional green strips in streets to bioretention swales has the potential for offsetting the loss of biodiversity in urban landscapes.

The author addressed that the variety of vegetation structure, particularly the amount of mid-stratum vegetation coverage, the number of flowering plants, and other landscape characteristics including pH and lateral slope of the bioretention swales is the main favoured habitat factors influencing the richness and composition of faunas. These may increase food resources available and more habitat resources, which are less available in garden bed type and totally absent in lawn-type green spaces. Moreover, a higher number of plants in flower also have important influences on increasing abundance of the flower visitor species as well as the composition of diverse species attracted to bioretention swales (Kazemi et al., 2011).

The Potential of Grass Swales

Grass swales provide primary treatment for road runoff, and are increasingly popular for installation alongside highways in several cities (Yu et al., 2001; Deletic, 2005; Zanders, 2005; Davis et al., 2012; Stagge et al., 2012). In Taiwan, Yu et al. (2001) monitored a grass swale along a highway with the length of 30 m and slope of 1% using standardised runoff event simulation procedure. The percentage of contaminant removed ranged from 30 to 97% for TSS, 29 to 99% for total phosphorus, and 14 to 24% for total nitrogen.

In Maryland, the U.S.A., Davis et al. (2012) investigated the hydraulic performance of two grass swales with pre-treatment grass filter strips and vegetated check dams to reduce highway runoff near a Maryland highway. Results showed that during 4.5 years swales greatly reduced total runoff volume and overflows with a rainfall event less than 3 cm, while functioning as stormwater conveyance with no runoff reduction during a large storm event. Additionally, it was found that pre-treatment grass filter strips and check dams increases swale effectiveness in runoff reduction.

In Sweden, performance of nine different grass swales was investigated with simulated event water runoff. Average TSS removal efficiencies varied from 79 to 98%. It was observed that sedimentation processes were the main factor in overall particle trapping efficiency, compared to grass filtration (Deletic, 2005). Furthermore, recent studies have revealed that grass swales are an effective stormwater SC technology in reducing Total Suspended Solids (TSS) and phosphorus, with its performance ranging from 48 to 98% for TSS, and 12 to 60% for phosphorus removal. A study on the performance of grass swales for treating highway runoff also showed to be successful at removing metals with zinc concentration reductions of 75-91% and lead reductions of 17-41% (Stagge et al., 2012).

In Melbourne, Kazemi et al., (2011) determined the influence of nine bioretention swales on urban biodiversity. The study applied above-ground active invertebrate species captured by sweep-nets as biodiversity indicators. It was suggested that terrestrial invertebrates are more influential biodiversity indicators than vertebrates or vascular plants as they provide an important role as soil decomposers, pollinators, predators, and offer crucial food sources for vertebrates in ecological functioning. In terms of pH of soils, the moderately low soil pH in bioretention swales appear to be an important habitat factors for supporting the existence of invertebrates active above the ground as the soils provide the availability of nutrients or food sources. The low soil pH in bioretention swales might be the result of rainwater which is generally mixed with carbon dioxide and gases in the atmosphere was draining into bioretention swales (Kazemi et al., 2011).

The Implementation of Swales in Other Countries

Swales are commonly used for treating stormwater runoff in several countries. In Portland, Oregon, a large-scale 2,330 foot (710 metres) swale was installed in Willamette River Park in 1996 to detain and capture stormwater contaminants entering the Willamette River. These swales provided a high performance with a 50 percent reduction of all suspended solids entering the river (France, 2002). In Sonoma County, California, a large-scale two mile swale was designed in 1997 to reduce and capture pollutants in urban runoff entering Sonoma Creek (Hogan, 1998).

Replacing side nature strips or planting strips or median nature strips of streets to allow space for bioretention swales has resulted in dispute in implementation of swales. In New York, green infrastructure projects have been rapidly constructed over the last few years, including 135 right-of-way bioswales installed in 2013, increase to 2,000 bioswales in 2014, and projected to rapidly increase to 6,000 bioswales in 2015. Additionally, dozens of bioswales were also installed in three

Neighborhood Demonstration Areas to reduce runoff flowing into the combined sewer system, and they were projected to capture more than 7 million gallons (31,500 m^3) of runoff per year (Garrison & Hobbs, 2011).

In Frederick County, Maryland, the study showed that conventional stormwater management approaches that apply a peak discharge control along with detention ponds do not adequately address the range of negative impacts associated with urban runoff. To reduce stream channel degradation and downstream flooding in Frederick County, the comprehensive SC techniques particularly vegetated swales have been applied in Pembroke covering a half-acre plot residential development (NRDC, 2014).

These measures allowed developers using integrated small-scale hydrologic controls to replicate the pre-development land use patterns that capture and treat rainwater as close as possible to the spot where it hits the ground through infiltration and evapotranspiration processes. The implementation of vegetated swales instead of curbs and gutters also saved the developers up to $60,000 in construction cost as well as reducing overall imperviousness, while reducing paving width of the road from 36 to 30 feet reducing paving cost up to 17 percent in the County (NRDC, 2014).

In Singapore, Lim et al. (2015) reported the potential of biofiltration systems for water quality improvement in a highly urbanised area. The author suggested that as sand is limited in the country, alternative filter media including large variety of biological materials, particularly compost and water treatment sludge, rice husk, coconut coir, and tealeaves are suitable for using in biofiltration systems. These materials provide the high potential to remove the metals through ion-exchange reactions, adsorption on surface, and complexation.

2.4.5 Detention Ponds

Ponds have been popular and particularly well represented in sustainable drainage literature across different fields of SC approaches. As the main factor governing the efficiency for reducing peak storm flows is the storage volume of facilities, ponds can play an important role in attenuating peak flows due to the retention and detention capacity of the systems, especially for the low frequency storms or high intensity rainfall events. This system can reduce the total flow volume through maximising the storage capacity between storm events. Rapid removal of stormwater from developed areas by ponds was observed even during a once in 10-year storm event with wet conditions in upstream areas (Villarreal et al., 2004).

Previous study suggested that the combination of ponds and parks not only reduces both runoff volume and pollutant loads through retention of stormwater by ponds, and infiltration and purification runoff by plants, but also increases biodiversity and provides an aesthetic purpose (Li, 2012). There is, however, evidence that some off-line ponds produce adverse downstream aquatic ecosystem effects (van Roon, 2013).

The Potential of Detention Ponds

Stormwater ponds are an alternative approach to store water runoff frequently implemented through making use of aquifers to store and filter water runoff for domestic supplies in water-stressed basins. In Helsingborg, a coastal city in southern Sweden, new development for both residential and industrial land use has recently been planned in the municipal comprehensive plans for the catchment over the upcoming decades. Source control devices and ponds to regulate flows into streams have also been planned and installed to be a central part of each new development (Semadeni-Davies et al., 2008).

During recent decades, the city has been undergoing city growth and has increasingly heavy rainfalls. In addition, impervious surface areas are increasing and pipes have replaced streams. This has not only resulted in higher peak flow volumes and increased flood risk, but the rivers in the town also continue to be degraded. The study by Semadeni-Davies et al., (2008) indicated that the implementation of 11 new ponds in new developments of Helsingborg increased storage capacity by approximately 33,000 m^3. This will provide a positive impact on the urban environment, reduce peak flows, and minimise impacts of stormwater on the combined sewer system of the city centre of Helsingborg. Overall, the installation of ponds and other sustainable urban drainage systems (SUDs) not only improve the urban environment through blue–green space creation, but also increase the pervious areas by up to 25% of the catchment.

Stormwater ponds are becoming increasingly common in collecting rainwater for domestic supplies in populated areas. Worldwide, technologies to harvest and store water runoff at the ground surface have been largely practiced throughout water scarce cities, while stormwater harvesting practices in the subsurface have been mostly limited in arid and semi-arid regions.

In Thailand, the stormwater ponds or 'monkey cheeks' principle is one of the surface storage techniques designed to capture and store floodwater in a retention pond linked to agricultural areas. This practice has been widely applied in the CPRB. For agricultural purposes, Pavelic at el. (2012) suggested that stormwater-harvesting structures should be located off-channel to avoid causing damage to retention barriers resulting from large overflows during heavy stormwater events, and to allow low and regular flows to by-pass harvesting. Moreover, off-channel systems should contain natural components that allow stormwater to infiltrate into the soil and underlying aquifer.

During the wet season, the stormwater harvesting process will divert runoff away from waterways and spread out to irrigate adjacent fields to increase agricultural production as well as minimise flood risks in the downstream catchment. In contrast, during the dry season, stormwater harvesting for groundwater recharge would generally take place around 25% of each year to irrigate adjacent fields. The harvested rainwater from stormwater ponds can be used for irrigating decorative gardens, toilet flushing, or other purposes which are less sensitive to water quality (Pavelic at el., 2012).

The encouragement of rainwater harvesting or stormwater ponds also helps to reduce land subsidence, as well as mitigate flood problems in Bangkok. Polprasert (2007) suggested that if rainwater was harvested properly, the city would be able to use 0.7 mm^3/day of rainwater, which is equivalent to the usage of water from aquifers. Nevertheless, the rainwater should be treated before being used in order to eliminate some pollutants which contaminate the harvested water.

The Implementation of Stormwater Ponds in Other Countries

The use of detention ponds is very popular in Sweden and a typical practice in the centre of a small park. Ponds are normally incorporated into parks to provide habitats for urban wildlife, enhance leisure activities in greenspace, and cool urban environments. Recently, there were roughly 1,000 urban stormwater ponds and an additional 400 ponds for treating highway runoff in Sweden. These so-called SuDS are multi-purpose in increasing water quality, minimising stormwater runoff, and also providing urban blue–green spaces (Semadeni-Davies et al., 2008).

In Beijing, it was suggested that the combined use of SC devices through the retention pond and the Living Water Park provided great potential for enhancing river water quality and reducing runoff pollutant loads or CSOs in the city. In these systems, ponds were designed to receive inflows of polluted water from the park and finally purify water for local water supply and river discharges. To enhance the potential of these facilities, Li (2012) suggested that the water in the retention pond should be emptied shortly before a coming rainstorm event to enhance the storage capacity for runoff reduction during the flood season.

Beijing City has a great potential for applying SC approaches as rainwater resource is sufficient during the wet season with an average annual rainfall of 585 mm, of which 75% occurs in summer (Li, 2012). However, water scarcity still becomes the main water issue during the dry season. It is evident that there has been a 9-year drought in Beijing in the last decade, during which time the light rainfall each year was lower than the average annual rainfall. The water scarcity issue in Beijing is intensified by decreases of rainwater volumes and surface water resources per capita are less than 300 m^3 per day (Li, 2012).

Stormwater ponds have become more popular in Singapore due to the problem of a highly urbanised city-state, where water is a limited resource in this island environment. The major heavy metals found in urban runoff in Singapore include Copper (Cu), Zinc (Zn), Cadmium (Cd) and Lead (Pb), which are generated primarily from roads, vehicles, and industrial activities. These metals are crucial pollutants in Singapore as they can lead to poisoning at low concentrations and tend to accumulate in living things (Lim et al., 2015).

As with many other coastal cities, Singapore will likely face several potential impacts including rising sea levels and storm surges, urban heat stress, extreme precipitation, inland and coastal flooding, water resource scarcity, and increased energy demand. Moreover, the loss of coastal land to flooding will be forthcoming if the sea levels rise up to 5 metres. Singapore has adopted holistic and integrated urban planning approaches to sustainable development through actions that fit into a long-term vision and sound environmental policies. The Marina Barrage is the barrier across the most well-known of catchment areas which captures and harvests stormwater across Marina Channel which then forms Marina Reservoir. It is primarily used as a source of city water supply, flood control and a lifestyle attraction in the city centre of Singapore. The Bay has a low public transport accessibility level to control the water quality and support a lifestyle attraction. As a flood protection measure, it will be activated to release excess stormwater into the sea during the low tide, and to pump the seawater out in the case of high tide (Yuen, 2013).

2.4.6 Constructed Wetlands

Constructed Wetlands (CWs) are a crucial part of urban environments and play significant ecological roles in river catchments. They are recognised as a sustainable solution practice for water treatment before discharge to receiving rivers. The artificial complexes of CWs generally include water, medium, plants and the associated microbial communities designed to mimic the ability of natural wetlands to remove contaminants from water (Brix, 1997).

Constructed wetlands (CWs) are artificial wetlands consisting of saturated or unsaturated substrates; emergent, floating or submergent plant species; and a number of microbial communities for purifying effluents such as wastewater, stormwater runoff, and other ecological disturbances. CWs can be classified into two major types: Free Water Surface (FWS) systems with shallow water depths and subsurface flow (SF) systems with water flowing down through the sand or gravel. Free water surface (FWS) wetland is comparable to natural wetlands, with shallow water flowing above saturated soil substrate. Polluted water can be treated by sedimentation, filtration, oxidation, and precipitation processes (Vymazal, 2013a). The systems generally contain a subsurface barrier of clay or impermeable material to avoid seepage, soil surface to support the emergent plants, and water at a relatively shallow depth of less than 6 cm deep (Saeed & Sun, 2012).

Subsurface Flow (SF) systems typically comprise a channel with impervious material to avoid seepage; soil to support the growth of emergent plants; and rock, gravel or crushed stone media to purify water during the contact with surfaces of the medium and the roots of the vegetation (Polprasert, 2004). Subsurface flow CWs can be further classified as vertical flow (VF), and horizontal flow (HF) systems, which are generally more effective than the free water surface (FWS) systems in regard to mass pollutant removal (Saeed & Sun, 2012). A combination of HF and VF systems, known as hybrid systems, provides advantages in complementing processes in each system for the treatment of wastewater. This system also enhances nutrient removal through aerobic and anaerobic processes.

CWs are an effective stormwater treatment measure to achieve removal of soluble contaminants such as nutrients, suspended sediment and associated contaminants. The systems apply a combination of physical, biological and chemical processes in removing stormwater contaminants. CWs have demonstrated effectiveness in reducing runoff and pollutant loads at all site scales. Existing studies provide evidence that CWs promote a sustainable stormwater management strategy with the potential to minimise both water quantity and water quality issues. However, although several CW practices have been demonstrated, there are few cases in tropical regions of prevalent implementation at a catchment scale with the clear objective to protect and restore receiving waters.

The Potential of Constructed Wetlands

The performance of CWs on contaminant removal is significant. Primary treatment mechanisms of CWs include sedimentation, chemical precipitation, adsorption, microbial interactions, and uptake by vegetation (Polprasert, 2004). CWs are efficient for nutrient removal in treating various wastewaters, particularly sewage, urban and agricultural runoff.

The role of CWs to provide for improved water quality has been demonstrated in several studies. A number of CW techniques are well described in the literature and a number of case studies have been published. In tropical countries, constructed wetlands are used for treatment of urban runoff (Wang et al., 2011; Lai & Lam, 2009; Sim et al., 2008; Sim, 2007), mine runoff (Kantawanichkul, 2010), and agricultural runoff (Sim et al., 2010). CWs have also been extensively used for treatment of sewage (Rai et al., 2013; Wang et al., 2011; Rivas, 2008; Brix et al., 2006; Lim et al., 2001; Juwarkar et al., 1994), polluted river (Jing & Lin, 2004; de Ceballos et al., 2001), agricultural wastewater (Wu et al., 2010; Kantawanichkul et al., 2003; Lin et al., 2002), industrial wastewater (Khan et al., 2009), and landfill (Akinbile et al., 2012; Sim et al., 2012). The incorporation of CWs into urban water management is desirable for urban sustainability.

Plants affect the organic removal efficiency by supporting the microbial community, and by accumulating media due to the high degree of transpiration (Brix, 1997). Plants in a CW provide the main advantages including increasing the growth of microorganism biofilm and aerobic bacteria, and up-taking pollutants (i.e. N, P, and heavy metals) from wastewater. Plants also have a great potential for runoff removal through transpiration. Water losses to the atmosphere through evapotranspiration can be high under tropical conditions. Some wetland plant species, particularly cattail and reed provide high degrees of nutrient removal, making them suitable in treatment wetlands. In Thailand, the most commonly used of emergent plants in CWs are cattail (*Typha latifilia*), bulrush (*Scirpus lacustris*) and reed (*Phragmites australis*) (Brix, 1993).

Wastewater treatment efficiency in CWs is typically measured based on the capacity of pollutant removal in inlet and outlet. The pollutants generally include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen (TN) and total phosphorous (TP). Plants commonly used in tropical CWs include *Typha, Phragmites, Cyperus, and Scirpus* (Maneewan & van Roon, 2014). Several types of CW systems have been tested for treatment of contaminated waters under various conditions in tropical countries. Several authors illustrated that there is a difference in treatment efficiency in plant species.

In the pilot scale tests carried out in Malaysia, Akinbile et al. (2012) found that *Cyperus haspan* with sand and gravel base substantially reduced concentrations of pollutants in leachate from Pulau Burung Sanitary Landfill (PBSL) compared with un-vegetated filters in the sub-surface CWs. During 3 weeks retention time, the highest removal efficiencies of *C. haspan* for TSS, COD, BOD5, NH3-N, TP, TN, Fe, Mg, Mn, and Zn were 98, 92, 79, 54, 99.7, 67, 59, 75, 71, and 89%, respectively. Moreover, the Common Reed *Phragmites* and the Tube Sedge *Lepironia* were tested in Putrajaya constructed wetland, for purification of stormwater runoff from agricultural activities from an upstream area. The performance of six wetland systems has been reported to remove 82% for total nitrogen, 71% for nitrate–nitrogen and 84% for phosphate, respectively. This wetland was designed for treating stormwater runoff before entering Putrajaya Lake, and using as flood control and for recreational activities (Sim et al., 2008).

In Vietnam, a pilot scale horizontal subsurface flow constructed wetland planted with *Phragmites* was tested on river sand based systems for purifying municipal wastewater. The overall nutrient removal efficiency of the system was 86–95% for TSS, 65–83% for BOD_5, 57–84% for COD, 16–84% for TN, and 72–99% for TP (Trang et al., 2010). Additionally, Dan et al., (2011) compared the ability of horizontal subsurface flow systems and saturated vertical downflow systems for the treatment of high-strength wastewater from a mixture of domestic and pig farm wastewater. The results revealed that vertical downflow systems (VF) with *Sesbania sesban* provided higher pollutant removal than horizontal subsurface flow systems (HF). At a hydraulic loading rate of 160 mm d^{-1}, removal efficiencies for TN, NH4-N, COD, BOD and TP in the VF system were 85, 88, 68, 72, and 92%, respectively.

In Singapore, Chua et al. (2012) compared the ability a floating wetland systems (FWS) planted with different plants: Vetiver grass, *Typha angustifolia,* and *Polygonum barbatum* to remove nutrient contaminants in the baseflow to the reservoir. The results revealed that the removal efficiencies for *Vetiver, Typha* and *Polygonum* were 40.8, 67.5, 7.8% for TN, and 19.1, 39.2 and 46.0% for TP, respectively.

In Thailand, attempts are also being made to combine subsurface horizontal flow bed with vertical flow bed with *Scirpus* to treat agricultural wastewater (Kantawanichkul et al., 2003). In general, the removal efficiencies of both subsurface horizontal flow bed and vertical flow bed were comparable. With a hydraulic loading rate of 3 cm/d, a maximum of dissolved phosphorus removal was obtained at 97–99% (1.1–1.4 g/m2.d), while mass removal rates for SS and fecal coliform bacteria achieved 98–99%. With a hydraulic loading rate of 6 cm/d, BOD, TP, SS and FC achieved 90–99% removal efficiency. Furthermore, Sohsalam et al., (2008) demonstrated the capability of a surface flow wetland planted with the six-wetland plants, *Cyperus involucratus, Canna siamensis, Heliconia spp., Hymenocallis littoralis, Typha augustifolia* and *Thalia deabata J. Fraser*, to remove pollutants from seafood processing. The authors reported that units vegetated with *C. involucratus, T. deabata and T. augustifolia* significantly outperformed units with other species at a hydraulic retention time of 3 days. The removal efficiencies of BOD5, SS, TN and TP were 91–99%, 52–90%, 72–92% and 72–77%, respectively.

In Sri Lanka, Jinadasa et al. (2008) reported higher pollutant removal BOD, nitrate, ammonium, phosphorus, total suspended solids, and fecal coliforms in a free water surface CWs planted with

Typha angustifolia and *Scirpus grossus* in treating effluent from domestic wastewater. However, the performance of pollutant removal was not significantly affected by plant species.

In Brazil, a study on a subsurface horizontal flow constructed wetland for treating effluent from a natural *Typha spp* wetland to purify polluted river water has been conducted under the tropical semi-arid region (de Ceballos et al., 2001). The authors described that CWs vegetated with *Typha spp* rhizomes with stone gravel based system provide a good reduction of organic load: 74-78% BOD5; 58-82% ammonia; 90% FC; 94–98% FS; and 92–96% coliphages and bacteriophages, at the best results on a retention time of 10 days.

In India, success of on-site sewage treatment with a sub-surface flow constructed wetland planted with six macrophytes: *Typha latifolia, Phragmites australis, Colocasia esculenta, Polygonum hydropiper, Alternanthera sessilis* and *Pistia stratoites*, has also been demonstrated. Removal efficiencies of 90, 65, 78, 84, 76 and 86% for BOD, TSS, TDS, NO_3–N, PO_4–P and NH_4–N, respectively, were achieved at a retention time of 3 days (Rai et al., 2013).

Water hyacinth has been used to purify wastewater in the several tropical regions where climatic conditions are suitable for plant growing for the whole year. Its extensive root system increases the ability for attaching microorganisms and decomposing organic matter (Kivaisi, 2001). Plant uptake is also the main process for nutrient removal from wastewater. Nitrogen and phosphorus are removed by plant uptake, while ammonia is removed by volatilisation, nitrification, and denitrification processes.

An example of a tropical treatment wetland with water hyacinth (*Eichhornia crassipes*) to serve the purpose of treating organic matter and nutrients of effluents was found in Costa Rica. Five tropical treatment wetlands have been reported to function well in terms of effluent treatment, with the removal efficiencies 92% for ammonia levels, and 92, 45, 83, and 80% for phosphate phosphorus reductions through dairy farm wetlands, landfill wetlands, banana paper wetlands, and dairy processing wetlands, respectively (Nahlik & Mitsch, 2006).

CWs enhance the potential for pollutant removal through retrofitting the hydrological regime even in highly urbanised areas. Compositions for a green sorption media such as sand, tree bark, wood chips, tire crumb, sawdust, wheat straw, sulfur, and limestone, can also be applied to enhance biological processes to remove pollutants that cause negative impacts on ecosystems (Chang, 2010).

Table 2-2 Examples of the use of constructed wetlands for various types of wastewater treatment reported in tropical countries

Study	Reference	Country	Type of CW[a]	Plant species	Type of effluent
1	Saeed et al. (2012)**	Bangladesh	VF-HF-VF	*Phragmites australis*	Tannery
2	de Ceballos et al. (2001)	Brazil	HF	*Typha spp rhizomes*	Polluted river
3	Dornelas et al. (2008)***		HF	*Typha latifolia*	Sewage

4	Philippi et al. (2010)**		VF-HF	*Typha sp. e Zizaniopsis*	Sewage
5	Mariangel and Vidal (2007)*	Chile	FWS	*Phragmites australis, Typha angustifolia*	Winery wastewater, Swine wastewater
6	Caselles-Osorio et al., (2011)	Colombia	HF	*Eriochloa aristata, Eleocharis mutate*	Septic tank effluent
7	Williams et al. (1999) ***		HF	*Typha angustifolia*	Sewage
8	Nahlik & Mitsch (2006)	Costa Rica		*Pistia stratiotes (*water lettuce) and *Eichhornia crassipes* (water hyacinth*)*	Mixture of wastewater
9	Dallas & Ho (2005)***		HF	*Coix lacryma-jobi*	Domestic grey water
10	Diement (2006)*	Honduras	FWS	*Typha domingensis*	Sewage
11	Lai and Lam (2009)*	Hong Kong	FWS	*Phragmites australis*	Stormwater runoff
12	Rai et al. (2013)	India	HF	*Typha latifolia, Phragmites australis, Colocasia esculenta, Polygonum hydropiper, Alternanthera sessilis* and *Pistia stratoites*	On-site sewage treatment
13	Diwan et al. (2008)***		HF	*Typha latifolia*	Hospital
14	Billore et al. (2001)***, Murphy et al. (2008)		HF	*Typha latifolia, Phragmites karka*	Distillery and winery
15	Juwarkar et al. (1994) ***		HF	*Typha latifolia*	Sewage
16	Abira et al. (2005)***	Kenya	HF	*Typha domingensis, Phragmites mauritianus, Cyperus immensus (Fula fulfulde)*	Pulp and paper industry
17	Bojcevska and Tonderski (2007)*		FWS	*Cyperus papyrus, Echinochloa pyramidalis*	Sugar factory
18	Kimani et al. (2012)*		FWS	*Cyperus papyrus*	Flower farm
19	Akinbile et al. (2012)	Malaysia	HF	*Cyperus haspan*	Leachate from Landfill
20	Katayon et al. (2008)		HF	*Lepironia articulata*	Mild domestic wastewater
21	Lim et al. (2001)		FWS-SF	*Typha augustifolia*	Primary-treated sewage
22	Sim et al. (2008)			*Phragmites karka, Lepironia articulata*	Stormwater runoff
23	Sim (2007)*		FWS	*Phragmites karka, Typha angustifolia, Scirpus grossus, Lepironia articulata, Eleocharis dulcis*	Polluted river+ stormwater
24	Rivera et al. (1995)***		HF	*Phragmites australis, Typha sp.*	Sewage
25	Rivas (2008)***		HF	*Typha latifolia*	Sewage

26	Belmont et al. (2004) ***		HF	*Typha latifolia*	Sewage
27	Mustafa (2012)*	Pakistan	FWS	*Phragmites karka*	Sewage
28	Khan et al. (2009)*		FWS	*Typha latifolia, Scirpus cyperinus, Carex aquatilis, Phragmites australis, Juncus articulatus, Alisma plantago-aquatica*	Industrial wastewater
29	Chua et al. (2012)	Singapore	FWS	*Chrysopogon zizanioides (Vetiver* grass), *Typha angustifolia and Polygonum barbatum*	Tributaries feeding into the Kranji reservoir
30	Sim et al. (2012)*		FWS	*Eleocharis dulcis, Lepironia articulata, Phragmites karka, Cyperus alternifolius*	Landfill leachate
31	Sim et al. (2010)*		FWS	*Phragmites karka, Lepironia articulata, Typha angustifolia, Scirpus mucronatus, Eleocharis dulcis*	Agriculture runoff
32	Jinadasa et al. (2008)	Sri Lanka	FWS	*Scirpus grossus, Typha angustifolia*	Domestic wastewater
33	Tu et al. (2014)*	Taiwan	FWS	*Phragmites australis, Phragmites communis, Typha orientalis, Typha latifolia, Ipomoea aquatica, Pistia stratiotes*	Domestic, agricultural, and industrial wastewaters
34	Yang & Hu (2005); Lee et al. (2004); Lin et al. (2002); Kao et al. (2001); Jing et al. (2001)***		HF	*Phragmites australis*	Petrochemical industry, Pig farm effluent, Fish farm effluent, Shrimp culture effluent, Stormwater runoff, Polluted river
35	Wang et al. (2011)*	Taiwan	FWS	*Phragmites australis, Typha orientalis, Cyperus malaccensis, Hygrophila progonocalyx*	Runoff + sewage
36	Lin et al. (2003)*		FWS	*Phragmites australis*	Shrimp culture
37	Wu et al. (2010)*		FWS	*Phragmites australis, Typha latifolia, Scirpus sp.*	Agricultural and industrial wastewater

38	Jing and Lin (2004)*		FWS	*Phragmites australis, Pennisetum alopecuroides, Miscanthus floridulus*	Polluted river
39	Yeah et al. (2009)*		FWS	*Typha latifolia, Phragmites australis*	Swine sewage
40	Lin et al. (2005)**		FWS-HF	*Typha angustifolia e P. australis*	Shrimp aquaculture
41	Yeh and Wu (2009)**		FWS-FWS-HF	*Typha latifolia, Phragmites australis*	Sewage
42	Yang & Hu (2005)***		HF CWs	*Typha orientalis*	Petrochemical industry
43	Kaseva (2004)	Tanzania	HF	*Phragmites mauritianus and Typha latifolia*	Sewage
44	Kantawanichkul et al. (2003)	Thailand	HF-VF	*Scirpus grossus Linn*	agricultural wastewater
45	Kantawanichkul et al., (2009)**		VF	*Cyperus involucratus, Typha angustifolia L.*	High-strength wastewater
46	Sohsalam et al. (2008)		FWS	*Cyperus involucratus, Typha augustifolia and Thalia deabata J. Fraser*	Seafood processing
47	Klomjek and Nitisoravut (2005)*		FWS	*Typha angustifolia, Digitaria bicornis*	Shrimp culture
48	Brix et al. (2006)		FWS	*Cyperus papyrus*	Sewage
49	Kantawanichkul et al. (2009)**		FWS	*Canna hybrida*	Fermented fish production wastewater
50	Kantawanichkul (2010)*		FWS	*Typha angustifolia*	Lignite mine runoff
51	Kantawanichkul et al. (2009)*		HF-FWS	*Cyperus flabelliformis, Canna hybrida*	Fish industry
52	Brix et al. (2006)**		VF-HF-FWS-Pond	*Cana sp., Heliconia sp., Canna sp. e Cyperus papyrus*	Sewage
53	Kantawanichkul et al. (2003)		HF CWs	*Cyperus flabelliformis* (Umbrella plant)	Agricultural wastewater
54	Kantawanichkul & Wara-Aswapati (2005) ***		HF CWs	*Typha angustifolia*	Laundry
55	M'hiri et al. (2005)***	Tunisia	HF	*Typha latifolia*	Sewage
56	Byekwaso et al. (2002)***	Uganda	HF	*Phragmites mauritianus*	Cobalt recovery processing
57	Dan et al. (2011)	Vietnam	VF	*Sesbania sesban*	High-strength wastewater
58	Trang et al. (2010)		HF	*Phragmites vallatoria (L.) Veldkamp*	Municipal wastewater

[a] Type of CWs: HF = horizontal subsurface flow CW, VF = vertical subsurface flow CW, FWS = free water surface CW
* as cited in Vymazal, 2013a, ** as cited in Vymazal, 2013b, *** as cited in Vymazal, 2011

In Table 2-2, examples of CWs used for treatment of various types of wastewater in 20 tropical countries are demonstrated.

The potential for application of CWs in the tropics is substantial. CWs enhance the potential for pollutant removal through retrofitting the hydrological regime even in highly urbanised areas. CWs have been widely used in many tropical countries, particularly in Malaysia, Thailand, Singapore, India, Taiwan, Mexico, and Brazil. The review of CWs identified several macrophyte species used in tropical regions. The three most frequently used are *Typha spp*., *Phragmites spp.,* and *Cyperus spp*. However, there is no clear pattern in the use of particular species for treatment of a particular type of wastewater or stormwater runoff. Most CWs are typically planted with several species.

The Implementation of Constructed Wetlands in Other Countries

In Los Angeles, stormwater runoff from urbanised areas causes significant water quality problems in the Los Angeles River. The city created an interconnected network of separate storm sewers to convey discharge runoff from urban impervious areas to local waterways. However, this untreated stormwater has resulted in contamination by metals, nutrients, and pesticides in rivers (Garrison & Hobbs, 2011).

Since 2004, many green infrastructure projects have been constructed including Wetland Park in South Los Angeles and Green Streets L.A. in the Sun Valley neighbourhood north of downtown. The Wetland Park Project in South Los Angeles was converted from a former bus yard to create green space for lower-income housing and the treatment of stormwater runoff from urban areas. Two large ponds with storage capacity of 1 million gallons were also installed inside the park to receive polluted runoff from adjacent canals, allowing infiltration into the ground and replenishment of groundwater, or even irrigating the park during dry seasons (Garrison & Hobbs, 2011).

2.5 The Combined Use of Stormwater Source Control Approaches

Many publications on stormwater Source Control (SC) approaches have primarily focused on the treatment efficiency of different facilities under a variety of conditions and climates. However, very few publications report on the combined performance of these approaches. The implementation of a combination of stormwater management measure to reduce urban runoff, contaminants and combined sewer overflows (CSOs) in some countries is presented as follows.

Sweden: Malmo

In Sweden, the popularity of Sustainable Drainage Systems (SuDS) has gradually increased in cities due to the concern of increased precipitation and climate change. SuDS for stormwater management are becoming prevalent in newer housing developments in Sweden for lowering flood risk and treating stormwater. The common practices include swales, porous pavements, rain gardens and detention ponds (Semadeni-Davies et al., 2008).

In Malmo, the southern Sweden, an array of SC practices in series has been implemented to solve inner-city drainage problems in an inner-city suburb, Augustenborg— a high density housing area in a suburb of Malmo. In the past, the stormwater management approach was to drain the old inner-city area by traditional combined systems. Wastewater and stormwater were mixed and were removed as quickly as possible from towns. As towns continued to grow and systems aged, the amount of stormwater and combined sewer overflows (CSOs) became more intense (Villarreal et al., 2004).

These SC practices aim to reduce runoff from impervious areas by disconnecting impervious areas from the combined sewer system; to create recreational green space and natural habitats in suburban developments; and to manage stormwater at source in order to reduce flood risk further downstream and improve stormwater quality. The range of multiple SC approaches includes green roofs, swales, open channels, stormwater ponds, and small constructed wetlands. These open stormwater systems provide an ability to reduce CSOs and handle runoff volumes locally (Villarreal et al., 2004).

China: Beijing

In Beijing, the common practices of the combined SC facilities include roof water containers, rain tanks, infiltration trenches, wetland detention, and rainwater treatment techniques. Beijing City has an area of 16,808 km^2 with a population of 16.95 million in 2008, 12.28 million people of which lived in the metropolitan area (Li, 2012). Water scarcity and stormwater overflow problems have been a major constraint for socio-economic development and improvement of environmental quality in Beijing during the last decade.

To prevent stormwater overflows in residential land use, SC technologies have been installed in Shuiduizi housing estate in the urban area of Beijing, including 28,000 m^2 of pervious surface, three infiltration wells, and two stormwater storage tanks in residential areas. These facilities also provided water reuse for 1000 m^3 of stormwater per year, and led to annual stormwater infiltration up to 10,000 m^3. By 2010, the rainwater harvesting generated from 688 of these facilities in the urban area of Beijing offered water supply volumes up to 13.18 million m^3 per year. However, the main limitation of these technologies is the small scale of urban area coverage, which was less than 10% of the total urban area, and a lack of public awareness to expand projects to a larger scale (Li, 2012).

As rainfall intensity has a considerable effect on overflows in Beijing, it was noted that 1-2 infiltration wells (0.226 m^3) installed for every 100 m^3 is potential for preventing overflows under a rainfall intensity of more than 40 mm $hour^{-1}$ through directly infiltrating into surrounding soil or capturing rainwater for landscape irrigation and other outdoor, non-potable uses (Li, 2012). Moreover, constructed wetlands were recommended to combine with sewage treatment plants in order to enhance the potential of water purification and reduce pollutants from sewage overflows (Zalewski 2002; Li, 2012). Overall, it was suggested that the combination of source control facilities according to costs and features enhance the potential of these facilities and reduce runoff pollutant loads or CSOs in the City of Beijing.

China: Jiangsu, Suzhou

In Suzhou, Southern China, a combination of several SC approaches has been constructed to reduce runoff volume entering into rivers. Suzhou is a highly developed historical city in Jiangsu Province, which has faced serious urban water problems particularly water pollution and flooding in the wet season. The rainfall amount in Jiangsu is relatively high in the wet season during April to October, representing 75% of the annual rainfall or around 650 mm, whereas the rainfall during the dry season is normally light and therefore difficult to harvest (Jia et al., 2014).

It has been suggested that the encroachment on the river channel in the city is also manifest. Rivers have been cut-off or truncated, and, as a result of rapid urbanisation, the numbers of enclosed water systems have enlarged. Recently, the Suzhou municipal government has introduced a river revitalisation project and worked on water pollution control to restore the urban rivers and historical landscapes.

In response to river revitalisation and pollution control policies, SC practices for stormwater treatment for urban river systems in the Taohuawu Cultural District have been implemented, including 52% constructed wetlands, 10% bioretention cells, 9% permeable pavements, 13% grassed swales, 9% infiltration pits, and 7% buffer strips. However, a conventional stormwater drainage system has also been implemented to convey excess stormwater runoff (Jia et al., 2014). These planning objectives aimed to maintain the quantity and quality of the river system and to mitigate flood risks through a river revitalisation project in an old historical district in the Taihu Lake Basin, which has faced rapid urbanisation and industrialisation over the past 30 years (Jia et al., 2014).

The river revitalisation projects showed promising results for the practicability of SC devices. Stormwater runoff from most parts of the Taohuawu cultural areas (covering 3,303 m^2, which represents 4.8% of the total urbanised area) has been captured and treated by these devices for use as the main water source for the local residents. These facilities were considered as a solution to reduce runoff volume entering into the conventional stormwater drainage system by up to 39.8% and the infiltration quantity increased by 42.7% compared to a conventional drainage system without SC practices (Jia et al., 2014).

Furthermore, the results clearly showed that with the SC facilities in place, the quantity of harvested rainwater during the wet season (April to October) was up to 7,598 m^3. The benefit obtained in terms of runoff reduction was quite evident in reducing flood risks during 5-year recurrence-interval storms (Jia et al., 2014).

Philadelphia, Pennsylvania

In Philadelphia, the combined use of SC practices including rain gardens, pervious pavements, infiltration trenches, city tree planting and swales has been implemented since 2011 under the Clean Waters Programme of the 25-year Green City Project. This programme primarily aims to reduce

CSOs through creating green infrastructure of 744 acres in area within a five-year target. In response to this target, the strategies rely primarily on installing green infrastructure on both private property and public space (Garrison & Hobbs, 2011).

For private property, owners are required to install green infrastructure to capture the first inch (2.5 cm) of runoff on-site for new development and redevelopment projects. In 2011, it was evident that 146 greened acres have been created in the CSO drainage area. For public works projects, 61 greened acres on vacant lots, public squares, and along roadsides, were completed in 2011 under the corporation of the city, state, federal agencies, and nonprofit organisations (Garrison & Hobbs, 2011).

Los Angeles, California

In the past, Los Angeles has faced the urban growth alongside the Los Angeles River associated with a number of devastating flood events. The area was previously damaged by flooding when the rate of rainfall exceeded the capacity of drainage systems. In response to flood risk concerns, the river and its tributaries were mostly channelised and lined with concrete since the 1930s, contributing to the large concrete-lined rivers of more than 90 percent of the city's rivers (Garrison & Hobbs, 2011).

During the last decades, a series of green infrastructure including an infiltration device along with curb cuts, grass swales, and porous pavement was installed under the Green Streets L.A. Project for Elmer Avenue in the Sun Valley neighborhood north of downtown. By the introduction of green infrastructure, the runoff from the street has been greatly reduced and pollutants, and stormwater is retained for a 2-inch (5 cm) storm event within developed areas (Garrison & Hobbs, 2011).

Portland, Oregon

In Portland, Oregon, the implementation of green infrastructure to manage stormwater runoff and resolve combined sewer issues was launched in 2008, with a $55 million investment in green infrastructure systems. During 2008 to 2013, the city planted 32,200 native shrubs and street trees, re-vegetated 4,400 acres of natural areas, and constructed 867 green street facilities. Additionally, 398 green roofs have currently been installed in Portland (Garrison & Hobbs, 2011). With a number of green facilities implemented in the city, Portland reduced the quantity of CSOs entering the Willamette River by 94 percent and the Columbia Slough by up to 99 percent in 2011 (Environmental Services, 2014).

Waterford, Connecticut

In Waterford, Connecticut, the combined use of permeable pavements, grassed swales, and bioretention cul-de-sac systems to detain runoff from roofs and parking lots has been implemented to compare the quality and quantity of stormwater runoff between a conventional catchment and SC catchment in residential areas within the Jordan Cove Urban Watershed Project (Bedan & Clausen, 2009). The project was located in the town of Waterford, for which the average precipitation was 1,237 millimetres per year and the steady infiltration rates of soil was 33 cm hr^{-1}. Research has shown that in the LID catchment, there was a 42% reduction in urban runoff, and peak flows were comparable to that of pre-development catchments.

In the catchment with the traditional development an area of 2.0 ha containing 17 lots was constructed in 1997 using a typical curb and gutter stormwater collection system, an asphalt road, and a traditional stormwater device similar to that in other new development landscapes. Total impervious surface area was 32% after completion.

In the SC catchment, a 1.7 ha SC subdivision in 1999 included 12 lots and several SC stormwater measures. A primary feature was the replacement of conventional asphalt roads, curb and gutter stormwater systems by using an Ecostone paver road, grassed swales, and bioretention cul-de-sac systems to detain and infiltrate roof and lot runoff. Furthermore, houses in a cluster layout were constructed to reduce lawn areas. Total impervious surfaces cover an area of 21% after installation. SC practices have been implemented to reduce the impacts of urban runoff from the impervious surfaces on river degradation (Bedan & Clausen, 2009).

It was evident that nitrogen and phosphorus export were consistent with export from pre-development catchments. In contrast, pollutant export from the development of traditional subdivision was consistent with export from urbanised catchments, where nitrogen and phosphorus export represented 10 and 1 kg $ha^{-1}yr^{-1}$, respectively. This indicates that increased impervious areas resulted in an exponential increase in annual runoff volume in the development of a traditional site (Bedan & Clausen, 2009). Overall, the results showed that the implementation of SC approaches on a catchment scale can significantly reduce a large runoff volume and minimise the impacts of development on downstream catchments.

2.6 Legislation Related to Sustainable Stormwater Source Control Solutions in Other Countries

Water legislation is a crucial requirement for sustainable stormwater source control (SC) solutions. Due to the increasing awareness on the problem of non-point source water pollution, recent legislation requirements related to water quality concerns were enacted in the USA and the Europe, with strict planning and control requirements. The Clean Water Act (1987) in the United States and the Water Framework Directive (2000) in the European Union countries can be regarded as well-known legislation.

The EU's Water Framework Directive (2000) pronounces an alternative approach to stormwater management, based on the perception by society to ensure a high level of participation and to transform the paradigms of institutions and governments across the regions (Barbosa et al., 2012).

In the US, the stormwater management practices were first adopted in the State of Maryland in 1984 by the United States Environmental Protection Agency (USEPA) (Petrucci et al., 2013). The Clean Water Act requires states to reduce pollution and remediate an impaired waterbody through defining total maximum daily load (TMDL) in the water body and developing an implementation plan, also known as best management practices (BMPs) (Wang et al., 2014). It was found that Low Impact Development (LID) during the mid-70s to the 2000s in the US predominately used stormwater retention ponds as best management practices (BMPs) to store and treat urban runoff through sedimentation.

To promote the installation of SC practices more broadly, stormwater regulations have been adopt in several cities. For example, in Washington D.C., the new District-wide stormwater regulations was modified in 2013 to meet local water quality standards and to improve the retention capacity of SC practices for both existing properties and newly developed, redeveloped projects. The regulations set the standard of the 1.2-inch retention for newly developed and redeveloped properties, and require that substantial renovations and improvements of current properties must include SC practices to meet a 0.8-inch retention standard through infiltrating, evapotranspiration, or reusing stormwater processes (District Department of the Environment, 2014).

In Los Angeles, the L.A. County revised a Clean Water Act stormwater permit and required new development, redevelopment, and some existing development to apply SC practices to capture and retain stormwater runoff from the 85th percentile storm event on-site. In addition, large new development projects with the area of more than 500 square feet are also required by law to install stormwater SC devices into their design (Garrison & Hobbs, 2011).

In France, the first legal's enactment for stormwater regulations for all new developments to prevent sewer overflows was introduced in 1982 in the city of Bordeaux. It was suggested that by 2010 the operation of SC policies has prescribed 470,000 m^3 in the Seine-Saint-Denis county, France, covering a 20% of impervious areas and creating around 10 mm of water storage on the total impervious surfaces of the county. Currently, the proposed SuDs in France are primarily designed to prevent flooding and peak flow discharge in developed areas (Petrucci et al., 2013).

In Canada, the Toronto City Council released a mandatory green roof requirement in 2009 to install green roofs for all new buildings made after January 2010, including commercial and industrial buildings, schools, and residential housing over six stories. This green roof by-law required for green roofs on all new buildings over 2,000 m^2 of Gross Floor Area with a coverage requirement ranging from 20-60% of the roof area. Toronto became the first City in North America to have a greroof bylaw provided on new development. Eco roof incentive programme was also introduced in 2009 to encourage the creation of green roofs on new and existing buildings. Under the incentive programme, owners of industrial and commercial buildings who install green roofs may receive incentives up to $50 per square metre or up to $100,000 on a one-year basis (Greenroofs.com, 2014).

In New Zealand, there has been a growing interest in implementing SC approaches since 1991 to reduce the quantity of runoff and mitigate environmental effects and protect its natural resources under the Resource Management Act 1991 (Zanders, 2005). Low Impact Urban Design and Development (LIUDD) is an urban design concept initiated in New Zealand primarily aimed at reducing the generation of stormwater, through sensitive urban layout treating residual stormwater at source and protecting aquatic ecosystems from the effect of stormwater. It emphasises sustainable urban practices including Low Impact Development (LID) and Integrated Catchment Management

(ICM) to promote alternative urban development by sustaining natural processes to provide flood protection and enhance resilience of the city (van Roon& van Roon, 2009).

In Australia, water legislation has been introduced by state governments in support of WSUD principles in several states such as Queensland and Victoria. The Victorian government proposed the pollutant removal targets to improve stormwater quality for new developments, which required 85, 45, and 45% removal of Total Suspended Solids (TSS), Total Phosphorus (TP), and Total Nitrogen (TN) annual loads in urban runoff, respectively, based on historic rainfall data of 1959 (Segaran et al., 2014). However, existing stormwater management policies and legislation in Australia are likely to focus on the mitigation of stormwater quality for new developments rather than on an established urban catchment and the awareness of the impervious surface areas impacts on urban catchments. This is attributed by Segaran et al. (2014) to legislation that generally requires municipalities to formalise plans for stormwater quantity and quality management to ensure water savings targets for new urban developments.

2.7 Conclusion

This study focuses on the existing environmental regimes related to ICM planning. It investigates how the impact of ecocentric and anthropocentric regimes have been influential in the environmental management system. The broad philosophies in relation to ecocentrism, holism, systems and complexity theories, and sustainable development were interpreted to explain the complex phenomenon of the catchment and stormwater systems, which aim to promote environmental improvement and support sustainable stormwater management practices in floodplain cities.

Anthropocentrism and eco-centrism are very significant to the discussion in relation to ICM planning as they approach the natural environment through different values and perceptions. Anthropocentrism considers humans to be separate from nature, and perceives nature as a resource for human exploitation. Anthropocentric paradigms that influence political boundaries, technocratic bureaucracy and unsustainable human activities have driven the environment into danger beyond the point where damage to ecological integrity is reversible.

Recognition of sustainable approaches to urban stormwater management has grown globally over the last few decades. The shift in recognition of stormwater as a nuisance to being a resource resulted from rising environmental awareness. Stormwater Source Control (SC) approaches are being implemented in different parts of the world, from North America and Europe to Australia, New Zealand and Asia. This approach has potential for improving stormwater quality through the integrated performance of stormwater treatment devices. These practices are considered as an alternative and/or supplement to conventional piped stormwater systems to minimise the negative impacts of urbanisation on water systems.

As greening urban development has become ever more prominent and urgent in recent decades, managing water pollution through source control to reduce the amount of stormwater discharged into rivers has become more prevalent. These common practices are a part of concepts such as Low Impact Development (LID) and Best Management Practices (BMPs) in the United States; Low Impact Urban Design and Development (LIUDD) in New Zealand; Water Sensitive Urban Design (WSUD) in Australia; and Sustainable Urban Drainage Systems (SUDS) in the United Kingdom. This chapter explored the potential and implementation of stormwater source control approaches including green roofs, bioretention systems, permeable pavements, swales, detention ponds, and constructed wetlands.

As climate changes, extreme weather events with more heat waves, droughts, heavy rain and floods are expected more frequently and intensively in many parts of Thailand. This Chapter argues that the development of stormwater SC approaches is important to minimise these impacts and leads to the achievement of ecosystem and human wellbeing. In this thesis, the concept of SC practices was used to emphasise sustainable landscaping practices to integrate sustainable stormwater management in CPRB to create efficient management of stormwater and ecosystem services.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The thesis is a cross-disciplinary research to present a critical analysis to challenge stormwater management practice in the river-mouth city context. This chapter presents the methodology applied to accomplish the research objective as outlined in Chapter One.

This study applies qualitative methods to integrate and interpret the broad philosophy regarding environmental improvement and stormwater practices in both anthropocentric and ecocentric points of views. Stormwater is a crucial part of the urban water cycle, which creates problems of flooding and water quality deterioration. Stormwater management is not solely a technical issue but greatly influenced by the social aspect. The thesis synthesises information from reviews of scientific literature and also couples them with the experts' viewpoints.

Thus, the methodology used in this research includes documentary analysis and semi-structure interview, based on ecocentric paradigm and ecological holistic approach rather than a reductionistic approach, in order to explore the viewpoints of individual stakeholders on ICM and stormwater management, how stakeholders perceive the problems, and available solutions of stormwater management.

3.2 Justification for the Case Study Approach

The awareness of water quality problems in the Chao Phraya River has become a growing concern due to the increasing degradation of water quality. In response to this concern, the research will investigate the mitigation measures to stormwater quality issue in floodplain areas, using Bangkok as a case study. A case study approach was adopted, initially utilising documentary research. Subsequentally, an inductive process of in-depth, semi-structured interviews was developed aligning the issues identified from the documentary findings.

According to Erickson (1986) and Stake (2005) as a case study approach focuses on a particular unit or issue compared to other types of qualitative research, much can be learned from a specific case that may be transferable to similar situations. The case study also provides a means of examining holistic and complex social units in understanding the phenomenon that in turn can affect and even improve practices. Similarly, as noted by Yin (2009), a case study approach is appropriate due to its ability to capture the richness of complex conditions through empirical strategies and surveys. The Bangkok case study and its catchment provide a rich set of examples to learn from and to provide an opportunity to transition to a new system.

Yin (2009) maintained that the case study approach is ideal to use for investigating contemporary events and generally is advantagious when a 'how' or 'why' question is being asked in the research questions. This is due to the fact that such questions deal with research requiring to be traced over time, rather than dealing with regular incidences. The method helps to understand a contemporary phenomenon in depth that is too complex for the survey or experimental approaches (Yin & Davis, 2007). Thus, the case study research provides the rationale for its selection in this study as it provides promise to deepen the physical, social and environmental contexts of this investigation.

In this research, the case study provides the context of ‘how’ this phenomenon is examined through documentary research and interviews with participants involved in the water resource management and land use planning practices. To ensure that the case study area is appropriate with the broad dimensions of systems thinking, socio-environmental systems on ICM planning of the Chao Phraya River Basin were investigated.

However, the case study research also presented some limitations in its practice. As noted by Stake (2005), qualitative case studies may require a long time commitment by the researcher to conduct a worthy case study. Additionally, qualitative case studies are also restricted by the bias and integrity of the researcher and others involved in the case in particular for data collection and case analysis, which can result in the lack of rigor of the research (Guba & Lincoln, 1981).

Likewise, Yin (2009) claimed that the lack of rigor of the case study may occur when a researcher has not followed processes systematically, or has allowed ambiguous evidence or biased notions to influence research findings. According to Hamel (1993), the limitations of the case study research also include the issues of reliability, validity, and generalisability. The case studies, like experiments, are generalisable to theoretical propositions to guide data collection as populations are not to be studied or measured. Thus, it is important for the researchers to be aware of unethical methods and biases that can influence thesis results.

Nevertheless, a case study has proven particularly useful for several fields of study due to its strengths, and it involves acknowledgements that require comprehensive answers. In this research, a case study design was selected as its strengths outweigh its limitations. It is also the best method for answering the research questions being asked in this study. The case study applications in this thesis start from the investigation of the stormwater related issues, barriers to ICM planning, and potential for applying stormwater SC approaches to improve river water quality and promote environmental improvement in the country. The empirical instrument integrated with a case study method helped to explicate more explanation of qualitative findings for the research. The following section provides the rationale for selecting the case study and the definition of the case study boundary. Subsequent sections outline the overall research design, methods and instrumentation applied in this study.

3.3 Justification for the Selection of Case Study and the Boundaries Identified

In conventional planning, the administrative boundaries have been perceived as units of analysis for policy formulation for land and water resources management. However, this has created the fragmented geographical boundaries as stormwater runoff travels across political boundaries and connects to the larger environment, catchment, and the oceans, which cannot be certainly captured under the administrative boundaries. It was argued that the boundaries of integrated catchment management are characterised by bio-cultural indications, regardless of man-made boundaries. Thus, in this research, the proposed case study area was selected to represent the ecological, social and administrative features under the spatial frameworks of the catchment boundary in the Thai ecological planning context.

3.3.1 The Chao Phraya River Basin

This catchment was selected because it provided diverse perspectives on similar water resource issues in river-mouth cities and in arid and humid regions. Moreover, the researcher already had developed some relationships with authorities and stakeholders in the catchment. The selected catchment area represents important topographies of sub-bioregions in nested hierarchies of ecological systems. The Chao Phraya River is considered to be the most important river of Thailand as it supplies significant water for irrigating rice field areas from the northern to central region, in addition to providing raw water for Bangkok residents (Anukularmphai, 2010). However, the lower Chao Phraya River is also one of the most deteriorated water sources in the country (TEI, 2015). Analysing specific case study of the Chao Phraya River Basin (CPRB) offers insight into IWRM or ICM practices in Thailand. The appropriate scales for water resource management require detailed integration of social and physical processes.

In terms of the management of land and water resources in Bangkok, most studies have typically focused on each resource category such as forest, land, water and coastal fishery resources separately. Moreover, they are limited to only certain types of areas; especially rural area, forest area, highland and coastal area, but catchment areas still do not have much attention. Additionally, there are also few studies focusing on the management of land and water resources in catchment areas, which combine diverse dimensions. To ensure the broad dimensions of systems thinking, the physical and socio-environmental systems on ICM planning are explored.

3.3.1.1 Overview of the Chao Phraya River Basin

The Chao Phraya River Basin (CPRB), also called the lifeline of Thailand (Divakar et al., 2011), is the country's largest internal drainage catchment located in northern and central Thailand. This catchment also has been justified as being the most suitable for cultivation of crops and the heart of economic activities in the country (Pavelic et al., 2012) as well as holding a crucial place in socio-economic and cultural Thailand (Emde, 2012).

The CPRB covers an area of approximately 160,000 square kilometres (km^2), representing a catchment area of about 30% of the total area of Thailand (Divakar et al., 2011; Komori et al., 2012; Pavelic et al., 2012; Tingting & Chuang, 2010; Vongvisessomjai, 2007). In 2009, the population of the CPRB represented almost 25 million people, being home to about 40% of the country's population and creating roughly 70% of the GDP annually (Divakar et al., 2011).

Climate

The catchment is influenced by a monsoon tropical climate weather, which has an obvious distinction between the rainy season and the dry season (Kotsuki & Tanaka, 2013). There are three main seasons: the summer, the rainy season, and the winter. The dry season during November to April is a yearly period of minimal rainfall in the area (ADB, 2012). The rainy season extends from May to October and occasionally has more rainfall from westward storm depressions starting in the Pacific Ocean (UNESCO, 2003; Vagneron, 2007) resulting in the high proportion of precipitation at about 90% during this season, (Kotsuki & Tanaka, 2013) while a relatively dry season lasting from November to April. The average monthly and daily temperatures represent at 25–33 °C, while the average annual rainfall accounts for 900 to 1400 millimetres (Vagneron, 2007).

The heavy rainfall combined with tropical cyclones and monsoon winds are likely to increase and become more extreme in this region. It has been found that increased precipitation in the regions caused by both higher temperatures and changes in El Niño Southern Oscillation (ENSO). Increasing temperatures will boost convergence of moisture in the monsoons. Moreover, changes in El Niño will result in the power of the summer monsoons currents, contributing to extreme rainfalls and winds in the areas (BMA, 2009a).

Geography

Based on geographic location, flowing condition and topographical criteria, the CPRB has been divided into two regions: the upper catchment and the lower catchment (delta) by a narrow area at the Nakhon Sawan section (Komori et al., 2012, Kotsuki & Tanaka, 2013). The area of the upper catchment represents large drainage areas of around 110,000 km^2, being 68 percent of the total catchment area (Kotsuki & Tanaka, 2013). The catchment consists of four large rivers: the Ping, Wang, Yom and Nan tributaries, flowing down from the northern mountainous area to the confluences on the Chao Phraya River at the central plains, Nakhon Sawan (Komori et al., 2012; Vongvisessomjai, 2007). Nevertheless, the encroachment on a forest reserve and its transformation into economic plantations in the upper catchment has become problematic (UNESCO, 2003).

The lower CPRB, covering an area of about 37,300 km^2 (Vongvisessomjai, 2007), is generally a low-lying geographical region adjacent to the sea, with ground altitude ranging from 0 to 20 metres above mean sea level (Prajamwong & Suppataratarn, 2009).

Generally, the Chao Phraya delta is crossed by four main tributaries – Ping, Wang, Yom, and Nan – connected together including an intense network of canals (Vagneron, 2007; Divakar et al., 2011). The Chao Phraya River runs about 365 km in length and flows southwardly from the north through the central plain to the Gulf of Thailand (Divakar et al., 2011).

Figure 3-1 (Left): Topographic Map of Thailand (Suksawang, 2012)

Figure 3-2: (Right): Map of the Chao Phraya River Basin (Suksawang, 2012)

In the lower catchment, downstream from the confluence of the four upstream tributaries commences at Nakhon Sawan and begins the Chao Phraya River, which is the main watercourse flowing southward through the alluvial plain, known as the Chao Phraya Delta (UNESCO,2003). The Chao Phraya River then splits into four branches: the Tha Chin River - also called the Suphan and Nakhon Chai Si River - the Noi River, and further downstream into Lop Buri and Chao Phraya Rivers. The Noi and Lop Buri Rivers then rejoin the Chao Phraya River at Bangsai, north of Bangkok, whereas the Tha Chin River discharges directly into the Gulf of Thailand (Vongvisessomjai, 2007; UNESCO, 2003). The main Chao Phraya tributary system passes through a number of large urban areas along with the capital, Bangkok, which is located at its downstream area (UNESCO, 2003).

In the CPRB, it is apparent that farmland is the primary land use in the catchment, which is dominated by rice (Tingting & Chuang, 2010). The appropriate alluvial soil, competent irrigation system, and floodplain conditions are benefits for the blooming of intensive agriculture for hundreds of years.

In the uplands, the primary plants are field crops, particularly maize, cassava, sugarcane, sorghum, mungbeans, soybean, peanuts and other upland crops. However, in these areas, the water shortage is the main issue in the dry season, which can support plantation only once a year; some high lands can also be cultivated short-growing season crops twice a year (Tingting & Chuang, 2010). Although double or triple crops of rice can be commonly grown each year, the shallow groundwater has also been required to support rice production specifically in the dry seasons (Divakar et al., 2011).

The lower catchment is generally a low-lying geographical region adjacent to the sea. This alluvial plain is very fertile for agriculture with extensive irrigation networks (UNESCO, 2003). Sufficient rainfall during the wet season provides for highly productive plantations without irrigation. However, in the dry season, crop production generally relies on irrigation as rain is inadequate to sustain agricultural production in this catchment (Tingting & Chuang, 2010).

In the lowlands, rice is the main crop, which has a total cultivation of roughly 90 and 40 percent in the wet and dry seasons respectively (Tingting & Chuang, 2010). However, the growth of urbanisation and industrialisation since the mid-twentieth century has resulted in the conversion of concentrated paddy cultivation in the floodplain of the lower delta (Emde, 2012).

3.3.2 Justifying the Case Study Area Selection: Bangkok City

This research focuses on the Bangkok area as a case study, in part because it has intense urban development and potential effects resulting from stormwater contaminants. However, the analysis on Integrated Catchment Management (ICM) covers the whole catchment of the Chao Phraya River Basin (CPRB) due to its influence on the water systems in Bangkok.

In order to understand the implementation of stormwater Source Control (SC) approaches, case studies in the lower CPRB were also selected for the interview research. These areas include the city, town, and municipalities where contamination issues potentially affected pollutant loads in Bangkok and the Chao Phraya River.

The criteria used to select these sites were guided by awareness of: (1) urbanisation particularly high density of residential area where there are high pollutant loads from non-point sources; and (2) ecological drivers especially water degradation from domestic water use, agricultural activities and transportation, with pressing and serious water quality problems around contamination of land and water resources. Within those research sites the perceptions of government authorities and experts were compared in an effort to capture the problems of catchments and to explore the potentials for and barriers to implement SC approaches in order to develop policy recommendations and guidelines to mitigate stormwater contamination in the catchment area.

Assessing catchment management planning has been helpful in drawing attention to the issues on the governance of water resources across physical, technological, and institutional barriers within geographic scales, and provides a diverse set of examples drawn from the CPRB to integrate new approaches into catchment management from the catchment level downwards. Due to environmental crisis, policy failure, and fragmented institutional structures, Bangkok case studies and their catchment provide a rich set of examples of the opportunity for transition to a new system.

3.3.2.1 Overview of the Bangkok city

Bangkok, the capital of Thailand, is located on the flat plain area of the CPRB covering a total area of 1,568.737 km^2 (BMA, 2011b). The Bangkok area is virtually flat, situated at an elevation of 2.31

metres above mean sea level at its highest point (ADB, 2012). The centre of the metropolis is located at a distance extended around 50 km. from the Gulf of Thailand (ADB, 2012). The economy in Bangkok is mainly driven by services and manufacturing systems. The city generated around 45% of the national GDP in 2012 (Matsumoto, 2015). Although Bangkok has achieved strong economic growth over recent decades, the growth appears to be exchanged with an environmental cost.

According to the Bangkok Metropolitan Administration (BMA), Bangkok had a registered population of 5,674,843 and 2,459,680 households (BMA, 2011b). The Bangkok Metropolitan Region (BMR), covering the area of 7,760 km^2 including five adjacent provinces, is home to 14.5 million people including unregistered residents, or over 20% of the national population. The highest population density can be observed in areas surrounding the central part of the city, the Rattanakosin and Chaopraya district groups, representing at 14,000 km^2 and 8,000 km^2 per person respectively (Thaiutsa et al., 2008).

An increase of population in Bangkok indicated a low growth rate, which is less than 1 percent from the last decade. However, estimated data by the Bangkok Metropolitan Administration revealed that there were slightly more than 10 million inhabitants in Bangkok, with a high nonregistered population rate of Bangkok representing almost 60 percent of total population (Panya Consultants 2008).

According to the study of existing land use in Bangkok by Warin (2010), it is evident that the uses of land and buildings are divided into three zones comprising of inner zone, contiguous zone or urban fringe, and suburban or outer zone. In terms of the inner zone, it has the highest rate of commercial land use, government institutions and educational institutions. Commercial and large residential buildings are densely concentrated in the centre of Bangkok, with high urbanity and high density of population. The west of the inner zone includes a residential area covering over 50 percent, and a commercial area covering 8.45 percent by area. With regard to the contiguous zone or urban fringe, the land use is mainly residential at about 25 percent and there are a lot of open spaces for development at about 25 percent of the area in the eastern contiguous zone. In contrast, most of area is used for agriculture at about 35 percent of the area in the western contiguous zone.

Considering suburban or outer zone, in the eastern suburb most of the area is in agricultural land use, representing at about 52 percent of the agricultural area in Bangkok and there are numerous industrial land uses including large warehouses. On the other hand, in the western suburb most of the area is for agriculture, representing about 40 percent of the agricultural area in Bangkok and there is a lot of land used for industry and large warehouses along the highways (Warin, 2010).

3.4 Research Methods and Research Design

3.4.1 Research Decisions: the Development of Research Topic and Method

My observations and experiences of the environmental and urban planning during the five years of my study and careers in Bangkok have inspired me to carrying out my research. Accordingly, at particular stages, my topic has altered, until it developed into the recent research topic. In the first stage, the study was conducted in regard to this following research topic:

"The Guidelines for Flood Hazard Mitigation in Bangkok"

As a result of analysis of the related works, I recognised that I did not have the strength to integrate the knowledge regarding engineering techniques on water quantity, rather than my potential on planning knowledge. Nevertheless, I realised that the focal point of the research needs to be narrowed down and ought to be used in practices for other tropical, high-density, or river-mouth cities. Consequently, my research is now developed to the following topic:

"The Challenges of Planning for Integrated Catchment Management and Stormwater Source Control for Environmental Improvement in Bangkok"

My knowledge of the local issues, my experience as an urban planner in Bangkok, and the sharing of my interest in land and water management topic were readily shared in the reflective semi-structured interviews. This also enhanced my interpretation and helped me to improve my research methods as well as assisting me to build relationships that were collaborative in nature. From this advantage, I had the chance to perceive and interact with related authorities in Thailand.

At the same time, with Thai being my first language, being part of Thai culture and tradition, and the opportunities to work in Thai government organisations for 4 years, I completely understand the culture of a Thai government. Overall, this built a level of trust between myself and the participants, resulting in honesty and mutual benefit.

3.4.2 Justification of Using Qualitative Research Methodology

Research methodology is a strategy that shapes the selection of particular research methods in order to allow the researcher to reach the desired outcomes (Ghauri & Gronhaug, 2005). Qualitative research is pragmatic and adopts the basis of lived experience of people (Marshall & Rossman, 2011).

'Qualitative research is a non mathematical process of interpretation, carried out for the purpose of discovering concepts and relationships in raw data and then organising these into a theoretical explanatory scheme.' (Strauss & Corbin, 1998, p.11). The term qualitative research means research results which are not succeeded by statistical method or other techniques of quantification (Marris, 2000).

This subjectivist research paradigm relying on the qualitative method and documentary research explored the residual contamination issues in floodplain areas as well as adopting social constructionism with the purpose of exploring the potentials for stormwater SC solutions and catchment management issues and how policies were established within the corporation, guideline and awareness of the government organisations. Interviews also allow researchers to obtain knowledge about interviewees' perception in view of the described phenomena.

Qualitative methods help demonstrate a common belief and offer a profounder perception of situations than can be gained from quantitative methods solely. This consequently leads to the choice of qualitative methodology which enables the researcher to investigate the authorities' experiences in the different organisational culture.

Cassell & Symon (2004, p. 11) claimed that qualitative research will help to gather the images of interviewees' life-world regarding interpretation of the meaning of the phenomena. Similarly, Easterby-Smith et al (2002, p. 87) stated that qualitative interviews allow researchers to conceive the way in which participants build the context of situations shaped from the complex personal structure of their understandings and beliefs.

3.4.3 Documentary Research

This research applied a qualitative method or empirical data collection technique through studying and analysing several documents that relate to the research question. Sources of information for this documentary research were compiled from various written sources using historical archival research.

As noted by Flick (2009), documents can be described as *"standardised artifacts, in so far as they typically occur in particular formats, as notes, case reports, contracts, drafts, death certificates, remarks, diaries, statistics, annual reports, certificates, judgements, letters or expert opinions"* and documents are useful for research as they provide *"a complementary strategy to other methods, the same as interviews or questionnaires"* (p.255).

The analyses are primarily based on the review of the various documents from relevant literature, scholarly journals, government reports, statistics, documents from university and public libraries, legal documents, thesis, and any public records including documents produced by outside consultants, public hearings, public forums, websites, media reports, and separate sources of related documents. Organisation agreement is required prior to gathering information from organisation publications.

In document analysis, an overview of the identification of contaminants and non-point sources of pollution in floodplain cities was initially gained to understand flows from their origin into the river system and to conceive existing problems of the CPRB. Non-Point Sources (NPS) pollution was addressed as the water quality problems worldwide now are associated with this source of pollution, known as polluted runoff from the land, whereas there have been steady advances in minimising water quality problems from point source pollution, particularly industrial effluents and sewage treatment plants during the last decades (Donlon & McMillan, 2004).

Information gathering regarding land use and water management policy, the role of government agencies, and land use and water legislation in Bangkok and CPRB also drew on articles available in academic documents and government and international agency reports. Effective strategies and measures to minimise stormwater contamination regarding SC and ICM approaches that have been applied in other parallel floodplain cities were also addressed.

The review of prior studies helped understanding water management and land use issues and identification of problems or questions in order to form the empirical research for this study, using the interview approach. Eventually, interviewing was used to gain information regarding potentials for and barriers to ICM as well as measures and strategies for enhancing environmental quality from experiences and knowledge of participants in the catchment areas.

3.4.4 The Interviews: Reason for Selecting a Semi-Structured Interview

There are various types of interview method. The most documented types of interviews include structured interviews, semi-structured interviews, and unstructured interviews. Qualitative interviews are vigorous and raise collaboration between researchers and participants and therefore make it the best way for gathering qualitative data (Bryman, 2004; Ghauri & Gronhaug, 2005).

In empirical survey research, researchers may often be limited by issues which simply result in unreliable or inconsistent conclusions and difficulties in gaining deeper insight into catchment management issues. The approach to work from an authority's perspectives includes numerous social issues and requests in-depth investigation and richness of understanding that cannot be accomplished by a statistical survey.

Moreover, acquiring a high response rate to a survey is among the most difficult of problems, particularly when the survey is carried out by post, also, the characteristics of the people surveyed in the sample is also hard to control (Zhao & Decker, 2004).

Considering all factors, a quantitative method based upon positivist approach is incompatible with this study as the exposure of catchment management issues and the perception of experts on the potentials and barriers of sustainable stormwater solution needs in-depth exploration and is not easy to accomplish via survey data.

Qualitative interview methods are applied as part of the data collecting approaches to unfold the meaning of representatives' experiences and to understand the potentials for and barriers to sustainable stormwater solutions and catchment management issues from their perspectives. Semi-structure interviews offer chances for insights perceptions to be explored.

The semi-structured interviews provide flexibility whereby detailed questions and an allowance for relevant topics to be raised by respondents, leads to more specific questions (Eyles & Smith 1988). According to Cloke (2004), semi-structured interviews also provide an open format to encourage involvement through a conversational focus in two-way communication. As supported by Crang (2002), the semi-formal structure contributes to an aspect of stakeholder participation, as respondents not only provide knowledge, but also exchange ideas with the researcher.

Based on the examination of the pilot interviews, a semi-structured interview was chosen instead of structured and unstructured interviews. To explore the research questions, rich data is necessary and essential. Semi-structured interviews seem the most appropriate way for conducting in this study in order to gain information from people who are specialised in environmental fields.

The structured and unstructured interviews are not appropriate for this research as the structured interview does not allow the interviewer to probe deeply to uncover new clues, while the unstructured interview is very complicated and difficult to control and provides applicants the chance to talk freely about the issues.

With being a new qualitative scholar, it is risky to implement an unstructured interview method to efficiently conduct and redirect the course of the interview towards the area related to my study. This would lead to enormous irrelevance information to my research topic. For that reason, it makes semi-structured interview the best options as it allows the researcher to gather in-depth information from a different perspective of experts.

To analyse the potentials and barriers of sustainable stormwater solutions and catchment management issues, semi-structured interviews were conducted with participants in the case study area to determine whether the sustainable approaches to stormwater management are appropriate to apply in Bangkok areas and its catchment. As the catchment management process is highly complex and requires the input from a wide range of stakeholders, the research design used in the case study was based upon an epistemological enquiry of knowledge from key informants.

The participants interviewed include experts with knowledge and experience in environmental planning in both government and academic sectors. Content analysis of institutional literature and semi-structured/open-ended interviews and predefined questions was used for data collection. A database was organised including documentation, the transcription from recorded interviews, notes and observations made during survey processes. Findings from the interview helped to clarify the research questions as several new topics and issues were raised to gain the perception of participants.

3.4.5 Research Design

Research design is shaped by the research strategy in accordance with the objectives and research questions in order to offer the guidance for the data collection method and data analysis and to help the researcher to conduct research consistently.

This research applies empirical data gathering methods from primary and secondary sources, involving documentary analysis and semi-structured interviews. The data collection and data analysis process follows a sequential exploratory research design strategy in order to understand the phenomenon.

Firstly, the case study was adopted and documentary research was used to explore the factors that provide understanding of sustainable stormwater solutions and ICM issues. Secondly, an inductive process of in-depth, semi-structured interviews was developed aligning the issues identified from the documentary findings and was cross-checked with established measurement variables as in the literature. The primary data collection techniques for the interviewing aim at exploring in-depth data and original viewpoints of the participants. The contribution of this research design fits into establishing research methods and topic.

Table 3-1 The research methods involved in research design for the interview

No.	Process	Action Taken
1.	Determining Interview Questions	• Reviewing literature, investigating issues and research objectives
2.	Ethical Clearance	• Obtaining ethics approval for research involving human participation
3.	Selecting Interviewees	• Selecting participants from various departments with experience in ICM planning and stormwater management • E-mails requesting designated interviewees to participate in the research • Time for discussion set-up for the responses. • Phone calls to ensure whether e-mail received • Met individually and requested for further related experts to take part • Set up interview schedule
4.	Pilot Interviews	• 3 interviews conducted as part of the pilot interviews, referring to unstructured and semi-structured approaches to interview • Field notes completed after the interviews
5.	Peer consultation on interview questions.	• Discussion with peers, then refined & reduced in categories, and specialist regarding interview questions & techniques
6.	Main Interviews	• Semi-Structure Interviews conducted in mostly government organisations • Some interviews recorded, mostly field notes taken

7.	Approach to Interview & questions modified.	• Reflexive • Approached further experts from same field
8.	Transcription and Translation	• Interview transcribed & reviewed • Interview translated to English

3.4.5.1 Data Collection

3.4.5.1.1 Interview questions

Data collection methods in relation to interpretive research frequently applies interview or/and observation. The guiding interview script was created from a literature review where questions were related to the principal barriers to and potentials for implementing SC solutions and ICM in the catchment areas.

The benefit of an interview-guided format ensures that "*the interviewer has carefully decided how best to use the limited time available in an interview situation. It helps make interviewing across a number of different people more systematic and comprehensive by delimiting in advance the issues to be explored"* (Patton, 1990, p. 283).

The application of the semi-structured interview was perceived as a means to guide the conversation in order to allow participants to reflect on their own personal internal experience in regard to the research questions. In addition, a secondary data source in the form of government and non-government records, which include environmental plans and publications on land use and water management, were collected to support the interview data collection method. Content analysis, based on these sources, focused on whether the documents present a consistent meaning and relevance in relation to the primary data interviewed.

Many documents for ICM planning for Bangkok and its catchment are increasingly available in the literature (Prajamwong & Suppataratarn, 2009; RID, 2010; World Bank, 2011; Suksawang, 2012). However, questions still remain as to how the city should change its strategies to be more sustainable, how urban rivers in Bangkok are being improved, and how its administrations and existing institutional arrangement need to be transformed to be more adaptive and effective to achieve environmental improvement when considering SC solutions and ICM planning.

The tools used in the research are open-ended questions created for semi-structured interviews. The interview questions were grouped into two parts as follows: The first part consists of the open-ended questions about barriers to the ICM planning and recommendations; the second part is the questions about knowledge and perceptions on the importance of SC measures to solve environmental problems in the CPRB.

3.4.5.1.2 Processes in development of the questions

The processes of creating and development of the questions in the research are as follows:

Step 1: Determined contents of the interview questions based on information and data from documentary study, as well as referring to environmental policies, land use and stormwater management plans of each organisation.
Step 2: Created questions based on the content and then reviewed by the thesis advisor in order to improve the accuracy, appropriateness, and consistency of the questions.
Step 3: Tested the understanding of questions with 3 pilot interviewees and examined the shortcomings of the questions before conducting the interview.

The questions were decided beforehand in order to answers the main research questions. Semi-structured interviews in a series of open ended questions allow researchers to list questions as a guideline that they could follow, and offer a proper environment for the participants to obtain a chance to expand their opinions.

However, the questions themselves did not follow a set pattern, rather emerged from the answers given to reduce the limitations of language barriers. Questions then were reframed and broken down into subsections in order to stimulate answers relevant the research. Due to such concerns, the interviews varied in length and time. There were 400 words on average for each interview and around 7,000 words for the complete set of interview. The interviews are rich in data and the government authorities are also from different departments and ministries and therefore the designation of work and beliefs is perceived from a different perspective.

3.4.5.2 Code of Ethics

In conducting this research, the code of ethics followed by the Human Participants Ethics Committee at the University of Auckland has been strictly adhered at several stages of this study throughout the finale of the research. According to the University of Auckland guidelines on research ethics, informed consent is essential when the research includes personal information or human participants. As described by Bryman (2004), a code of ethics established by professional committees offers ethical principles and confidentiality for research participants.

My effort has been devoted to create a credible and reliable thesis. Nevertheless, it was noted that there are some restrictions mostly relevant to ethical issues arisen in different processes while conducting the interviews. Some of these ethical issues are interviewees' consents, confidentiality, and recording of the interviews. Thus, other techniques particularly taking notes instead of recording have been carried out to reduce these constrains, which may possibly undermine the accuracy of the research.

The research objectives and the potential benefits were explained to the interviewees and organisations. I have provided reassurance that all interviews will be remained strictly confidential and information will not be shared without the consent of the interviewees. This helped the researcher to build the trust and allowed participants to share their opinions as well as giving accurately information relevant to the research objectives.

To ensure that participants could present their views securely and freely, the alternative locations were offered and mutually convenient places were chosen for some interviews. Easterby-Smith et al (2002, p. 91) stated that *"by conducting interviews in the manager's office adverse results were produced because the employees being interviewed were uncertain as to the confidentiality of what they might say".* Similarly, Steinar (1996, p.125) noted that *"the interviewer must establish an atmosphere in which the subject feels safe enough to talk freely about his or her experience and feeling".* Thus, some interviews were conducted outside their workplaces to create an atmosphere of mutual trust and confidence.

3.4.5.3 Pilot Studies

According to Babbie (2010), the aim of a pilot study is to avoid anticipating possible errors, or vague or unanswerable questions. In this research, pilot studies were conducted for the interview in the selected case study prior to the administration of the main interview in order to pretest the relevancy of the developed tools and to avoid vague questions that might be skewed from the original intention.

As a primary data gathering method, 3 pilot interviews were employed to gain confidence, adapt, and modify the questions from their perspective. To reach these purposes, the applicants were chosen in different groups of related criteria to the research issues. The interviewees were experts with environmental and urban planning based experience in Bangkok and its catchment. The selection of these participants was based on their knowledge, position, and experience at work.

The pilot tests were conducted for the interview in July 2015 with a mix of unstructured and semi-structured interview methods. These interviews were conducted in order to test whether the question terminology was understandable and to determine whether the flow and length was suitable for the one hour time limit. Moreover, this also allowed respondents to evaluate the structure and order of the questions, choice of answers and potentially vague contents. All of the participants were supportive and comfortable with the structure and format of the interview questions. However, some pilot participants tended to mention information not relevant to the research but occasionally an opinion reveals the matter which indicateds the merit of this research technique.

Overall, the pilot Interviews helped the author to recognise new matter arising, thus develop interview questions and improve the criteria of sample selection to achieve knowledge and contribute towards developing tactics for the main interview process. Finally, alterations were made based on their suggestions and prepared for the final interview instrument which was later submitted for approval to the University of Auckland's Human Participants Ethics Committee (UAHPEC).

3.4.5.4 The Main Study

3.4.5.4.1 Identifying Interviewees

In this research, a non-random sampling or a non-probability purposive sampling technique was implemented to identify the targeted participants for the semi-structured interview. The non-random sampling technique has commonly been used in qualitative research that requires targeted participants to be selected because of shared characteristics (Sullivan & Silverman, 2003). In contrast to random sampling employed in the quantitative technique, this approach allowed the recruitment of a sub-set of the population that was assumed to have experienced the phenomena (Creswell, 1998).

Stakeholders interviewed mostly consist of government officials in central and local organisations. Outside opinions from the local viewpoints were gained from local authorities in the social and environmental area who have experiences and good understanding of water resources management and land-use planning. The NGOs and experts from universities were also interviewed to gain a perspective of sustainable stormwater solution and ICM.

The interviewees include 18 participants from 16 institutional representatives of the following organisations: (1) City Planning Department of Bangkok Metropolitan Administration (BMA); (2) Department of Drainage and Sewerage of BMA; (3) Department of Environment of BMA; (4) Royal Irrigation Department; (5) Department of Public Works and Town & Country Planning; (6) Department of Environmental Quality Promotion; (7) Department of Water Resources; (8) Pollution Control Department; (9) National Housing Authority; (10) Thailand Environment Institute (NGO); (11) The Association of Siamese Architects (NGO); (12) Chulalongkorn University; (13) Kasetsart University; (14) Ang Thong Municipality; (15) Phra Nakhon Si Ayutthaya City Municipal and; (16) Pathum Thani Municipality. A summary of the status of ICM planning of related agencies and departments is given in Table 3-2.

NO.	Departments / Organisations	Main responsible for ICM planning
1	City Planning Department (CPD) of BMA	Land use planning in Bangkok
2	Department of Drainage and Sewerage (DDS) of BMA	Water drainage system, flood management and infrastructure in Bangkok
3	Department of Environment (DOE) of BMA	Environmental planning in Bangkok
4	Royal Irrigation Department (RID)	Water Resources Management, ICM planning
5	Department of Public Works and Town and Country Planning (DPT)	Land use planning
6	Department of Environmental Quality Promotion (DEQP)	Environmental quality improvement, natural resources and environmental management
7	Department of Water Resources (DWR)	Water Resources Management, ICM planning
8	Pollution Control Department (PCD)	Water quality control, pollution management
9	National Housing Authority (NHA)	Urban management in low-income housing areas, Environmental management

10	Thailand Environment Institute (TEI)	Environmental quality improvement
11	The Association of Siamese Architects (ASA)	Urban design and housing development
12	Chulalongkorn University (CU)	Environmental and urban planning
13	Kasetsart University (KU)	
14	Ang Thong Municipality	Environmental, land use, and water resources planning in municipality
15	Phra Nakhon Si Ayutthaya City Municipal	
16	Pathum Thani Municipality	

Table 3-2: A summary of the status of ICM planning of related agencies and departments

In bureaucratic hierarchies, governmental actors in formal institutions generally play the primary role in ICM and water resources management (Pahl-Wostl & Knieper, 2014). The interviewees were selected because of their experiences and knowledge regarding sustainable stormwater solution, ICM, planning, and water management. The parameters considered were accessibility and willingness to participate, a period of work experiences, knowledge and their present position and role in each organisation.

Since there is the large size of the research population, it is not practical to gather data from all population. I thereby selected a sample of the central and local staffs from environmental and planning experts. As the sample were obtained from the population, this information were applied to the rest of the populations, which the available samples were 18 participants. The sampling frame was created as following information:

Selection criteria for the interview
• Age above 30 • Education level • Gender • Civic capacity of occupation • Geographical distribution within the site • Length of residency in the CPRB from 5 years and above • Active role in water or land use management and environmental advocacy • Minimum of five years working experiences • Positions in their organisations, mainly middle management, technical, and administrative

Table 3-3: Selection criteria for semi-structured interviewees

From this sampling frame, a purposive, non-probability sample with 18 participants were drawn from a list of respondents of the available population in accordance with the selection criteria. Creswell (1998) addressed that eight to twelve interviews are sufficient for a phenomenological research. The interview is also based on understanding gained from the initial study of documentary research. The different components of the framework provide a focus for the analysis.

The consent forms were provided in the process of contacting to the individual applicants and organisations. This technique had confirmed to be applicable when the three pilot interviews were conducted. Therefore, prior to approaching some participants, institutional managers were contacted via telephone, email, personally clarified about the research, and asked for their consents for interviewing their employees. After this process was agreed, the same technique was followed to obtain the consent of the interviewees.

Figure 3-3: Map of stakeholders identified

Eighteen employees were contacted and they decided to participate in this research. Most of the participants concerned that the research is controversial and did not keen on conducting to the interview and particularly did not allow to record their opinions due to some effects on their occupations unfavorably. Most of the participants did not want to discuss regarding their organisations or their jobs as they concerned that any untoward attitude or misquoting might impact their standing in society as well as threaten their jobs.

The participants were divided into five groups including: the local employees from BMA; the municipal authorities in the lower CPRB; central government's authorities; researchers; private and real estate developers and; NGOs, and all of them had prior experience in their work on water resource management, environmental planning, or urban planning. Stakeholder groups are depicted in a stakeholder map in Figure 3-3.

3.4.5.4.2 Interviewee Characteristics

The aim of the participant selection was to provide rich insight from an extensive and representative number of five identified stakeholder groups. Interviews were conducted with a total of 18 participants (N=18) from November to December 2015. A number of participants representing each of the groups as outlined in Table 3-4 including participants who have lived in Bangkok or its catchment at least 5 years to their entire lifetime:

- Six participants for group [a] Central government's authorities (CG), mainly experienced social science, environmentalist, scientist, urban planner, and water engineer (*n*=6);
- Three participants for group [b] BMA's authorities (BMA), mainly urban planner, environmentalist, and water engineer (*n*=3);
- Three participants for group [c] Local government officials in the lower CPRB (LG), mainly municipal authorities in the fields of social science and environmental planning (*n*=3);
- Two participants for group [d] Researcher, ecologists, and planners (RE) working in universities and research institutions (*n*=2);
- Two participants for group [e] Private and real estate developers (D) (*n*=2); and
- Two participants for group [f] NGOs including urban designer and environmentalist (*n*=2).

Most participants were selected based on recommendations from key informants. Participant distribution was fairly equal in terms of age, sex, qualification level, and the number of years working experience. The participants consisted of 10 males (55.6%) and 8 females (44.4%). Five participants (27.8%) age from 30-39 years, eight participants (44.4%) age 40-49 years, and five participants (27.8%) age 50-59 years old. The highest level of education completed including: Diploma three participants (18.75%), Bachelor’s Degree eight participants (43.75%), and Postgraduate’s Degree seven participants (37.5%). Each participant is given a number that identifies the quotes applied to corroborate arguments in the remainder of the research. Table 3-4 provides an overview of the involved stakeholder groups in semi-structured interviews (n = 18) in the research.

No	Group	Sex	Age	Level of Education	Working Experiences (Years)	Organisation	Role
1	BMA (CP)	M	Late 30s	Bachelor’s Degree	14	City Planning Department (CPD) of BMA	Urban Planner
2	BMA (DD)	M	Late 40s	Bachelor’s Degree	18	Department of Drainage and Sewerage (DDS) of BMA	Water Engineer
3	BMA (DO)	F	Mid 50s	Diploma	25	Department of Environment (DOE) of BMA	Environmental officer
4	CG (RI)	M	Mid 40s	Bachelor’s Degree	16	Royal Irrigation Department (RID)	Water Engineer

5	CG (DP)	F	Mid 30s	Postgraduate	10	Department of Public Works and Town and Country Planning (DPT)	Urban Planner
6	CG (DE)	F	Early 50s	Postgraduate	25	Department of Environmental Quality Promotion (DEQP)	Senior Environmental Officer
7	CG (DW)	M	Early 50s	Postgraduate	26	Department of Water Resources (DWR)	Water Management Authority
8	CG (PC)	F	Late 40s	Bachelor's Degree	19	Pollution Control Department (PCD)	Scientist - Water quality
9	CG (NH)	F	Late 30s	Bachelor's Degree	12	National Housing Authority (NHA)	Community Development
10	NGOs (TE)	M	Late 50s	Bachelor's Degree	27	Thailand Environment Institute (TEI)	Environmental officer
11	NGOs (AS)	F	Late 30s	Postgraduate	12	The Association of Siamese Architects (ASA)	Urban designer
12	RE (CU)	M	Mid 40s	Postgraduate	15	Chulalongkorn University (CU)	Researcher - planner
13	RE (KU)	M	Mid 40s	Postgraduate	16	Kasetsart University (KU)	Researcher - Ecologist
14	LG (AT)	M	Mid 40s	Diploma	15	Ang Thong Municipality	Technical officer (municipal)
15	LG (PH)	F	Early 50s	Bachelor's Degree	27	Phra Nakhon Si Ayutthaya City Municipal	Environmental officer (municipal)
16	LG (PT)	F	Mid 40s	Diploma	18	Pathum Thani Municipality	Environmental officer (municipal)
17	D (PD)	M	Late 30s	Bachelor's Degree	15	-	Private developer
18	D (RD)	M	Late 40s	Postgraduate	20	-	Real estate developer

Table 3-4: List of stakeholders who participated in the research

3.4.5.5 Interview Process

3.4.5.5.1 Method of Selection

The head of each representative institution was functioning as moderator, or gatekeeper to allow me to gain access to stakeholders involved in interview processes, and approach the participants responsible for catchment management, land or water management, environmental or urban planning, based on their recommendations.

In order to ensure that the sampled participants represented a broad area structure, the snow-ball sampling technique was also implemented to place potential respondents from the initial list. The key informants obtained from the gatekeeper were asked to introduce related authorities and further participants in order to set potential informants who are able to disclose contextual information on subject matter. To secure a sufficient representation of participants, the same process was then employed with a following step of identification, through contacting the NGOs and related experts.

In the primary stage, the interviewees were initially contacted by telephone and email. The researcher was officially introduced to the interviewees, where they were briefed on the research outline and were asked whether they were interested in voluntarily being interviewed. Once they had agreed to participating, they were provided with the research's explanatory document via email or personally delivered. The document includes a letter of intent attached with detailed project brief and consent form corresponding to either individual or organisational capacity and a copy of the interview schedule. Approval from the University of Auckland Human Participants Ethics Committee (Ref. 2006/365) was gained prior to the interviews taking place.

The interview processes started by introducing the research, explaining the ethics guidelines, answering interview questions concerning the participant information sheet, and completing the consent form. The participants were fully informed of the aim of the interviews. The interviews began with an outline of the study, and the purpose of this research. The aim of providing the interview schedules to the interviewees prior to the actual interview was to offer them information and a clear picture in regards to the topic or issues. Interviews generally followed the interview guide reprinted in Appendix A unless they were time constrained. In order to avoid any trace of doubt, the interviewees had explained to them the potential outcome of the study for environmental improvement. The interview questions emerged towards the lines of the pilot interviews.

Documentary sources were reviewed prior to participation by each of the selected participants. This provided me the initial background information concerning planning issues and visions and in turn facilitated a shared learning process through exchange information during the interviews between the researcher and interviewees.

Participation in this interview required approximately one-hour for interview completion. The research involved a personal (face-to-face) interview. They were satisfied with the participation and dates and time were agreed on. Accordingly, during November and December 2014, eighteen semi-structured interviews were held in Bangkok and its catchment.

3.4.5.5.2 Field Notes

To ensure accurate representation of responses, a tape recording device was utilised during some interviews and the recording was transcribed. Some interviews were recorded as written consent was obtained at the beginning of the interview. The interviews were conducted mostly at government organisations and participant's workplace, although there were a few interviews conducted at coffee shops subject to their preference.

It was noted that most participants gave insights as the recorder sometimes had been switched off. The extensive comments and ideas mostly came out of these casual conversations, which allowed me to hear their views. My perceptions were to progress the interviews and to respond to the interviewees as the role of the researcher. This allowed me to understand the feelings that behind the words and the indifference of an opinion or view.

Handwritten notes were taken by the researcher to encourage preliminary thinking around the ideas. Most interesting field notes were happened when the recorder had been turned off. Post interview notes were completed instantly when the memory and awareness of interviewees remained fresh in mind. Some interviews were back to back so I wrote down the main points which were further explained as field notes.

Each interview contained 400 words on average and all of the interviews were conducted in Thai language as requested by the participant. In order to protect the participant's identity, randomly created pseudonyms were uniquely assigned to each participant and subsequently used throughout this research as per UAHPEC requirements. Confidentiality was assured as most of them required their names to be concealed and they objected to being quoted.

3.4.5.6 Transcription

The interviews were transcribed verbatim in Thai language and some excerpts of the transcripts were translated into English. There was no replacement of sentences or phrases written. For uncompleted sentences, information that might have seen in the different meaning were retained. My opinions and those of the interviewees were obviously separated.

Concern was taken to lessen interviewer bias by refraining from asking other leading questions, and by not introducing any ideas that may form part of the following responses. Only the emotions of the participants were absent in the transcription. These include pauses, reflective moments, and silences during the interview.

The whole situation of the interview has been an open enquiry into the apparent gap in knowledge. The research investigated a range of contamination issues and the potential for and barriers to implementing SC measures in the catchment context. The general opinion that certain races demonstrate lower levels of environmental concern also has been noted as inaccurate.

Responses were confidential with full rights for the participant to access, edit and withdraw their data. Quotes and excerpts from interview recordings and note takings are used throughout the research to demonstrate various findings. Upon their request as indicated in the consent form, the completed transcripts in Thai language were returned to those participants who wished to amend the script properly. Once the participants had validated the transcripts they were translated into English for this thesis by the researcher.

3.5 Summary

This chapter addressed the research methods and implementation strategies to explore the research questions in Chapter One that are central in understanding the barriers to ICM planning and the potential for SC solutions among actors. The mixed-methodology approach was applied to establish and identify their perspective in the case study, in Bangkok, Thailand. Five broad categories of actors were established as a unit of analysis in order to provide rich insight from identified stakeholder groups, which include the central government's authorities, BMA's authorities, the local government advocates, researchers, developers, and NGOs. The sequential exploratory design started with a phenomenological inquiry via documentary analysis and then followed with a semi-structured interview.

CHAPTER 4: STORMWATER RELATED ISSUES AND ENVIRONMENTAL EFFORTS IN THE CPRB AND BANGKOK CITY

4.1 Introduction

The traditional approach to urban stormwater management addresses urban stormwater as a nuisance rather than as a resource and treats it as a risk by collecting and conveying it via pipes or other infrastructure to mitigate flood events, with little regard for receiving waterways (van Roon, 2007). This results in degraded water quality, and loss of biodiversity in urban streams and coastlines (Segaran et al., 2014).

Combined sewers linked to traditional stormwater management systems have been applied in many urban areas to convey household sewage and stormwater runoff generated on impervious surfaces to water pollution control facilities for treatment. However, when stormwater runoff exceeds the capacity of these available systems, combined sewer overflows (CSOs) can occur resulting in discharge to receiving waters.

As older cities such as those in Europe and North America continue to grow and their population densities increase, they still use combined sewers to deal with both waste and storm water (Gasperi et al., 2010). In the U.S.A., combined sewer systems discharge roughly 3.2 million m^3 of untreated sewage from CSOs each year, and this is a primary cause of pollution in rivers, lakes, and estuaries (USEPA, 2002). CSOs are common and can occur even during small rainfall events (Olness, 1995).

In Bangkok, stormwater is usually either discharged directly into rivers, or drained via combined sewers into sewage treatment plants for purification. However, rapid drainage of stormwater from urban built-up areas to wastewater treatment plants, instead of its infiltration, has led to combined sewer overflows (CSOs) and the intensification of river pollution. The combination of wastewater and stormwater discharge in Bangkok represents approximately three million cubic metres per day (Leerasiri, 2010). Up to 75 percent of this wastewater effluent is generated from domestic sources (BMA, 2011a; ADB, 2012; Suriyachan et al., 2012). The growth of urbanisation associated with an inadequate water management system has resulted in the release of untreated water into receiving rivers.

Central wastewater treatment plants are still inadequate in Bangkok. Although seven central wastewater treatment facilities have been constructed, they do not cover the whole urban area and still have limitations. Currently, central wastewater treatment plants cover only 20 percent of the Bangkok area, serving around three million people or approximately half of the residents (ADB, 2012). Insufficient wastewater treatment facilities have led to high organic pollutant loads and lower dissolved oxygen than the water quality standards set for the lower Chao Phraya River (Suriyachan et al., 2012). Significantly, exceedance of the capacity of the system during heavy rainfall events results in discharges from the wastewater treatment system during the rainy season (Leerasiri, 2010). In this case, combined sewer overflows (CSOs) in Bangkok may impact on aquatic ecosystems of receiving waters.

As Bangkok has experienced rapid economic and population growth during recent decades, this has brought a vast inflow of migrants, rapid loss of farmland and a rapid deterioration of the urban environment. Evidence suggests that the growth of urbanisation and industrialisation since the mid-twentieth century has resulted in the conversion to urban use of concentrated paddy cultivation in the floodplain of the lower delta (Emde, 2012). These anthropogenic land-use changes along with coastal erosion of the delta also caused overflow and flood in Bangkok floodplain areas. Hence, a more sustainable approach is considered crucial in combination with the use of drainage pipelines, to resolve flooding and water quality problems in Bangkok and its catchment.

4.2 Climate Change Affects Multiple Water Issues

It is widely acknowledged among scientists that human activities have contributed to climate change and river deterioration over the past decades. This concern links to the threat to biodiversity and the ecological destruction as well as having a negative impact on humans' health, seeking stronger responsibility of government agencies to prevent ecological degradation and to reduce the consequences of the environmental harms.

Climate change has significant effects for multiple water issues, from water shortage, flooding, contamination of receiving rivers, to loss of catchment ecosystem services. According to Lebel et al. (2010), climate change drives the catchment hydrological cycle by influencing flows of water and sediments to streams. It could also affect higher water temperatures, resulting in lower dissolved oxygen levels and higher toxicity of contaminants in rivers.

4.2.1 Evidence of Warming Temperatures

Across monsoon countries, there is significant evidence of warming including increases in annual mean temperatures, more hot days, a longer hot season, and uncertain trends in precipitation under future climate (Lebel et al., 2010). In Thailand, average maximum and minimum temperature during 1961-2009 tend to have increased by 0.95 degrees Celsius. In the next 100 years, the temperature in the country is expected to increase continuously (Tantivasadakarn, 2011). Similarly, the study by DCP (2013b) found that in 2009 average temperature throughout the country was higher than temperatures in the last 5 decades by around 0.5 degrees Celsius.

Bangkok has a monsoonal tropical climate where average daily high temperature remains fairly stable within a range of 22–30°C on a yearly basis (Thaiutsa et al., 2008). However, Bangkok metropolitan area has been affected by the climate change as much as other major cities around the world. The temperatures of the city are likely to increase during the coming decades. The average minimum and maximum temperature of Bangkok during the years 1961-2007 indicated that the trends are increasing gradually, given the number of days with temperatures over 35°C are likely to increase (DCP, 2013). Moreover, it was suggested that mean temperature in Bangkok will increase by 3-3.5% by 2100 (Webster & McElwee, 2009).

Like many cities in a tropical climate, Bangkok has a 6-month wet season from May to October that can cool down the urban heat. However, with the high solar intensity during the dry season from December to April, the city becomes relatively hot, but less so in the first 3 months (Thaiutsa et al., 2008).

Various activities in Bangkok have caused significant environmental problems and intensified global warming. Increasing carbon emissions from the higher air-conditioning needs and the heat island effect from pavement and building areas also has the potential to aggravate high temperatures in the inner city of Bangkok.

4.2.2 Changes in Rainfall and Climatic Variables

Several studies indicated the increase of daily rainfall in Thailand (Thaiutsa, 2003; Lebel et al., 2010; Tantivasadakarn, 2011; ONEP, 2013; DCP, 2013; Takeda & Putthividhya, 2015). Changes in rainfall by altering stormwater regimes could heighten the challenges of water management. It is important to draw on understanding of how current climate variability influences on water management issues.

During the past 60 years, the amount of rainfall in Thailand is unstable but prone to increase in the long term. However, the average accumulated annual rainfall increased 10.5% during 2006-2011. In 2011, the annual amount of rainfall in Thailand reached the highest level at 932,722 million cubic metres, increasing from the average 48-year amount by 32.75% (ONEP, 2013).

Changes in rainfall in the past can be divided into 3 phases: 1955-1970 rainfall was more than usual; 1970-1990: rainfall was less than usual, and; 1990-present: rainfall increases more than usual. Such changes are related to the phenomenon of in El Niño Southern Oscillation (ENSO) in the Pacific Ocean (Tantivasadakarn, 2011). These changes in climatic variables and extreme weather may be regarded as a threat to adaptation.

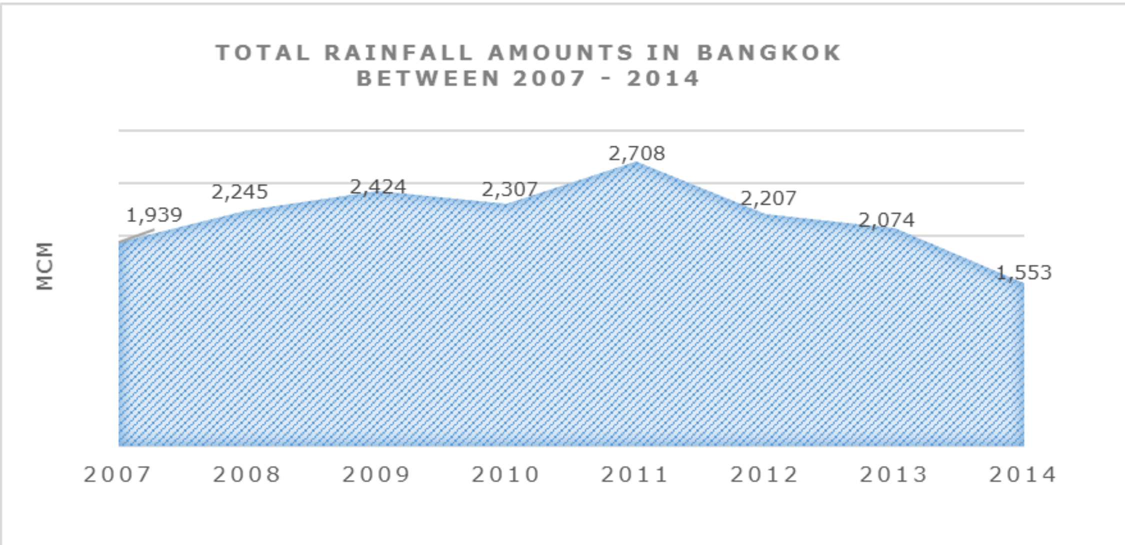

Figure 4-1: Total rainfall amounts in Bangkok between 2007 – 2014
(The Department of Drainage & Sewerage; BMA, 2008; 2009b; 2010; 2011b; 2012a; 2013b; 2014; 2015)

According to Lebel et al. (2010), total annual rainfall in Bangkok is likely to increase significantly. Daily rainfall in Bangkok has increased over the last four decades and the heavy rain is likely to occur more often.

The average annual rainfall in the catchment measured by the Meteorological Department is approximately 1,500 mm, 90% of which falls during the rainy season (Takeda & Putthividhya, 2015). Rainfall distribution in the catchment widely varies between the wet and dry seasons. DCP (2013) reported that the average rainfall in the summer over the last decades increased, while the data were varied in the winter and rainy season each year.

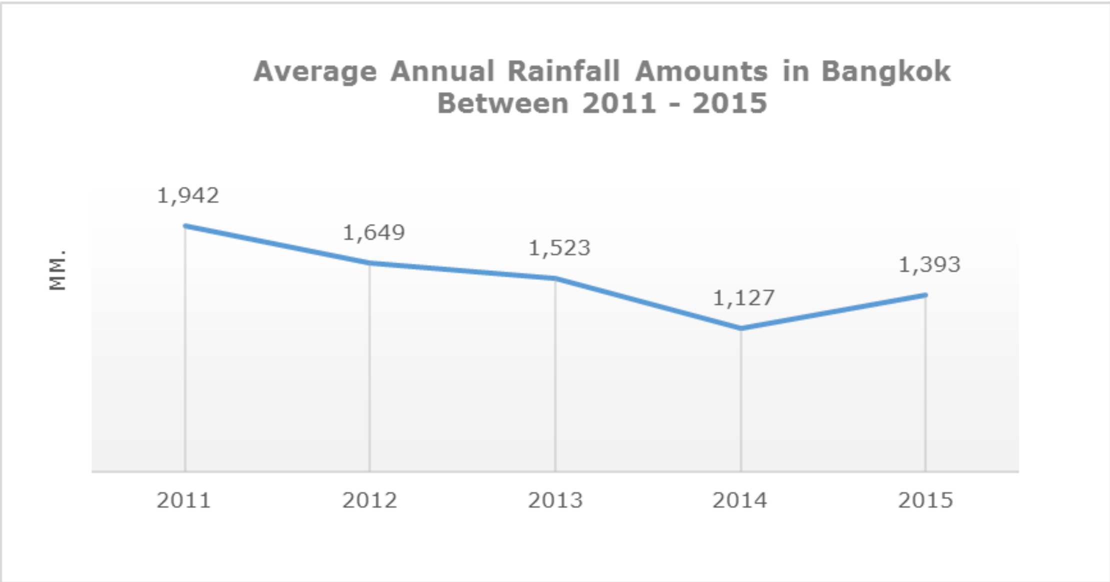

Figure 4-2: Average annual rainfall amounts in Bangkok between 2011 – 2015 (Meteorological Development Bureau, Thai Meteorological Department; BMA, 2012a; 2013b; 2014; 2015; 2016)

Thaiutsa et al. (2008) revealed that evapotranspiration rates represent a small range of variation parallel to average daily high temperature with the highest point in summer (April) and lowest in winter (February),varying between 4 to 6 mm during the day.

Due to fluctuations in rainfall and climate change, Thailand has been continuously affected by flooding especially in riverside and slope areas during the rainy season. In addition, climate change and global warming has resulted in unpredictable average annual rainfall, causing direct impacts of droughts and flooding especially for farmers whose farmland is outside the irrigated areas, and accounts for approximately 78% of the country's farmland (ONEP, 2013).

4.2.3 Flooding Issues

Due to the effects of climate changes, several countries have faced a major flood beyond their historic records during the last decade including Prague in 2002, the United Kingdom in 2007, Australia in 2011, Bangkok in 2011, New York in 2012, and Germany in 2013 (Thaiutsa et al., 2008). In October 2011, Thailand recently experienced extensive floods, resulting from the equivalent of a 100-year return period of rainfall in the CPRB (Saito, 2014).

Bangkok becomes vulnerable to areas of flooding as this area is periodically subjected to monsoons in addition to daily tidal variations. Localised heavy rainfall, high tidal surges, slowing down the flow of rivers, combined with peak river flow from the Chao Phraya river accelerate rapid local runoff and create difficulties in terms of water drainage from September to November each year (Marome & Asan, 2011).

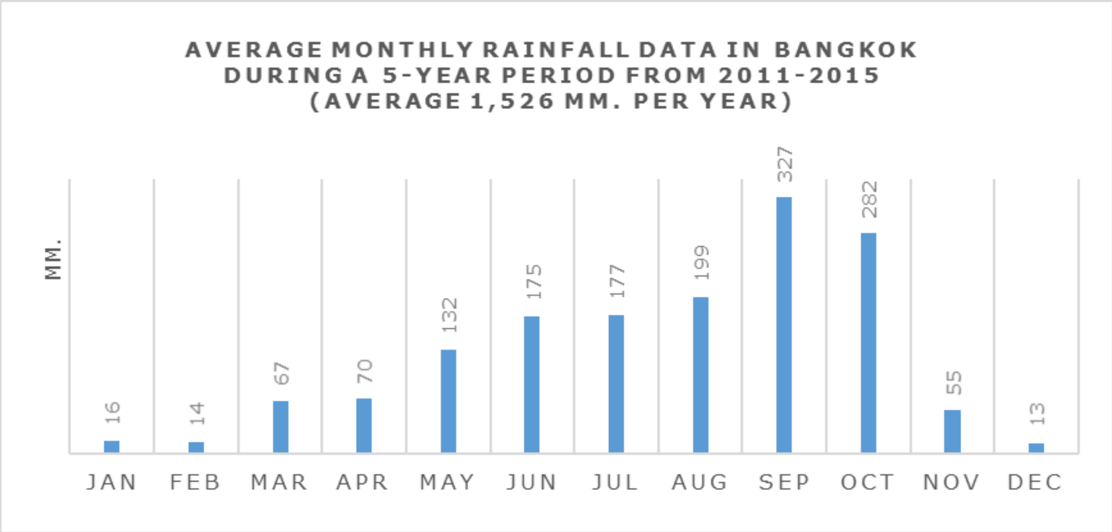

Figure 4-3: Average monthly rainfall data in Bangkok during a 5-year period from 2011-2015 (Meteorological Development Bureau, Thai Meteorological Department; BMA, 2012a; 2013b; 2014; 2015; 2016)

Flooding in Bangkok is also caused by the topography of the catchment, with the upstream part of CPRB having a relatively steep slope, while the downstream areas are less steep (Prajamwong & Suppataratarn, 2009). Bangkok located on low-lying areas at the mouth of the CPRB close to the sea, being only 30 kilometres from the coast and lying at just 2 metres above sea level. Bangkok is largely prone to natural flood cycles and heavily influenced by the tides, particularly when heavy rain meets high tides (Tanner et al., 2009).

Due to its location, the metropolitan area has been flooding from the Chao Phraya River, especially during the rainy season. The amount of water accumulated in the northern tributaries can reach about 4,000-5,000 cubic metres per second. However, with the ability to drain water of the Chao Phraya River at 2,000-3,000 cubic metres per second, the amount of rainwater is more than the river is capable of transporting and can eventually cause the river to overflow its banks into the metropolitan area, making it more difficult to drain (DCP, 2013).

In wet season, floodwater from catchments and tributaries are not be able to drain into the Chao Phraya River due to high water levels in the river. As a result, inundation areas regularly expand along the river. The river overflows usually occur in urban areas when the surface water exceeds the capacity of the river and, at the same time, when high tides meet the heavy runoff from upstream (Saito, 2014). However, due to the slow flow velocity of flood and the mild gradient of the CPRB, flooding rarely destroy properties and threaten human life and health (Komori et al., 2012).

Apart from river overflows, urban runoff in Bangkok can also be caused by more intense rainfall with increased frequency. Bangkok has the average annual rainfall of 1,400 mm, which is influenced by the southwest monsoon, the tropical storms, and depressions (DCP, 2013). Previous research has predicted more tropical storms, which intensify the risk of flooding. The frequency of intense precipitation and El-Nino and La-Nina events are expected to increase, as has been occurring every 4-10 years in Thailand (Marks, 2011). Thus, more runoff is projected in Bangkok due to an increase in intensity of rainfall events associated with sea-level rise. Due to a lake of pervious surface, the heavy rain in a short time has affected stormwater runoff in Bangkok inevitably.

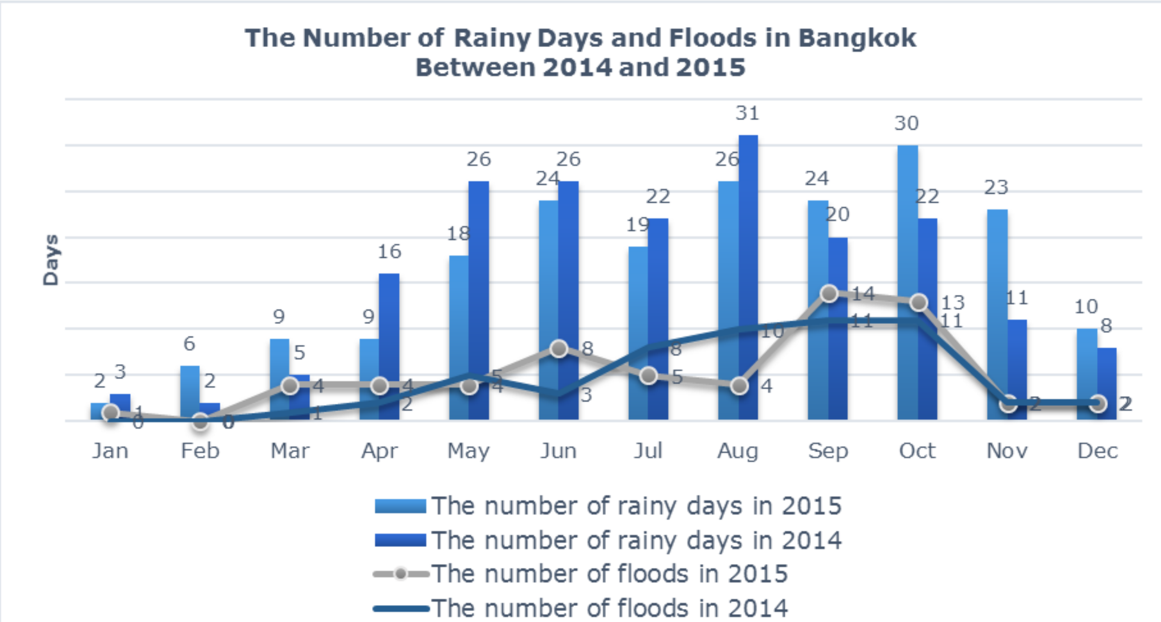

Figure 4-4: The number of rainy days and floods in Bangkok between 2014 and 2015 (The Department of Drainage & Sewerage; BMA, 2015; 2016)

4.2.4 Drought and Increasing Demand for Water Use

Climate change influences the weather pattern all over the year and plays a significant role in water demands in the country. Changes in climate regimes are a primary constraint in ensuring water security in the future. Thus, planning for future water management needs to take into account the impacts of climate change.

In Thailand, there is a relatively high risk for water shortage in the future. A survey of water consumption by the Royal Irrigation Department in 2011 showed that the water demand in the country accounts for 152,151 million cubic metres per year, increasing almost 3 times from 55,400 million cubic metres per year in 2001. Among these, is the water demand for agriculture up to 106,169 million cubic metres per year or about 65% of total water demand, followed by the use for maintaining ecosystem at 18 %, for consumption at 15%, for industries by 1.6 percent and 0.4 percent for livestock. This causes a shortage of water supply for the whole country of 4,737 million cubic metres per year, 98.5% of which is water shortage for agriculture. In 2016, the water demand for agricultural use was estimated to grow more than 10%, so the issue of water shortage will be more extreme in the future (ONEP, 2013). Thus, it is important to optimise the use of water in an effective and sustainable way.

The demand of water for domestic use in the CPRB has also increased gradually in recent decades causing the growing water scarcity particularly in the dry season (Pavelic et al., 2012). Likewise, Divakar et al. (2011) stated that although the water budget in the catchment has an excess during the rainy season, it still has an inadequate amount during the dry season. The study reported that the amount of water volume generated in the CPRB accounts for only 33,187 mm^3 for 24 million residents. Thus, the available water in the catchment occupied only 1,378 m^3/year per capita, which is still inadequate, compared to the average of 3,242.6 m^3/year per capita for the country.

It is noted that the conflicts of private and public interests in water use have remained unchanged and central to the debate. In the CPRB, Pavelic et al. (2012) noted that the agricultural sector represented the highest demand for annual water use of 71 percent, followed by ecological purposes 22 percent, domestic use 5 percent and industrial supply 2 percent. Similarly, GWP (2013) asserted that water demand in the country also demonstrated the highest use in the agricultural sector at around 70 percent. However, the trend of water use in both industrial and domestic consumption is expected to increase over the next 20 years due to rapid economic development.

With regard to water shortage issues, the catchment faces significant water shortages in the dry season. Marks (2011) stated that water shortages induced by climate change could affect the agricultural sector, industrial water consumption and domestic water uses. However, the study by Takeda & Putthividhya (2015) revealed that drought does not largely affect agricultural and industrial water uses in the lower catchment. Water scarcity becomes the main issue of rice farmers in the upper catchment.

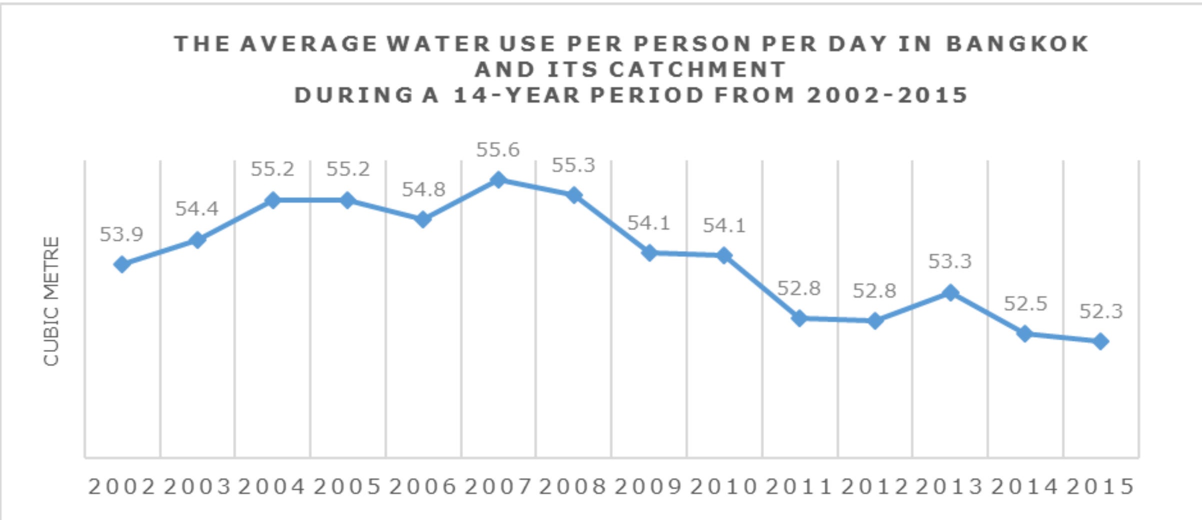

Figure 4-5: The average water use per person per day in Bangkok and its catchment during a 14-year period from 2002-2015 (The Metropolitan Waterworks Authority; BMA, 2007b; 2008; 2009b; 2010; 2011b; 2012a; 2013b; 2014; 2015; 2016)

In Bangkok, the demand for water consumption slightly increased and remained high compared to other cities in the region, which represent about 211 liters per capita per day in 2011 (ADB, 2012). GWP (2013) revealed that water required for rural areas is around 50 liters per person per day, while water demand in the urban area is 5 times higher and estimated to increase by 35 percent in the next decade due to rapid urban growth and economic development. The increase in water consumption can largely result from the concentration of industrial and commercial activities as well as the growth of population in Bangkok and its vicinities (ADB, 2012). Therefore, it is important to encourage water conservation especially at the household level in order to minimise the amount of water consumption in the future.

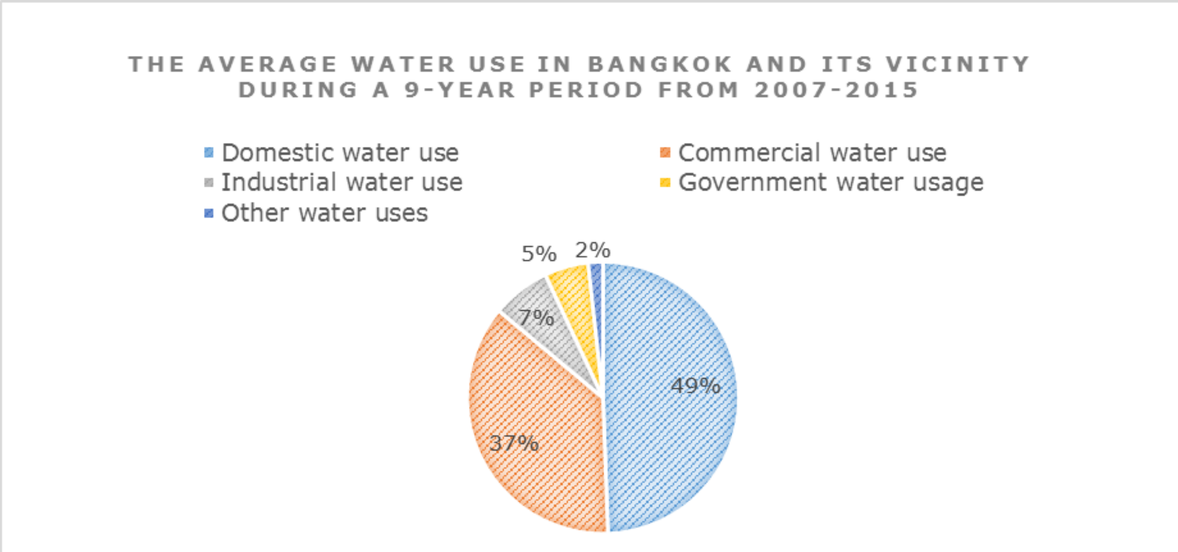

Figure 4-6: The average water use in Bangkok and its vicinity during a 9-year period from 2007-2015 (The Metropolitan Waterworks Authority; BMA, 2008; 2009b; 2010; 2011b; 2012a; 2013b; 2014; 2015; 2016)

Today's consumption and utilisation of water resources becomes a main factor to the economic growth that is accelerating the rate of use of the natural resource base. Considering the average water use in Bangkok and its vicinity, there is implicit evidence that during a 9-year period domestic water use represented the highest demand for annual water use of 49 percent, followed by commercial water use 37 percent, industrial water use 7 percent and government water usage 5 percent from 2007 to 2015 (BMA, 2007-2015). Nevertheless, the trend of water use in domestic, industrial, and government water usage increased over the recent decade due to rapid urban growth.

To deal with water shortages, the use of groundwater resources becomes an alternative water supply. Groundwater is an important source of water use of the country, with the amount of groundwater stored being up to 24 times the volume of surface water (ONEP, 2013). The groundwater, in addition to being an important water source for consumption, is also a potential water source for agriculture and industry. Currently, as the demand for water is rising, groundwater becomes an alternative water source. According to ONEP (2013), the amount of groundwater that can be safely used at the acceptable level, equates to a reduction of water level of 5 metres. It was found that groundwater of the lower CPRB and the upper CPRB have the potential to be developed for water use of up to 1,294 and 1,280 million cubic metres per year, respectively.

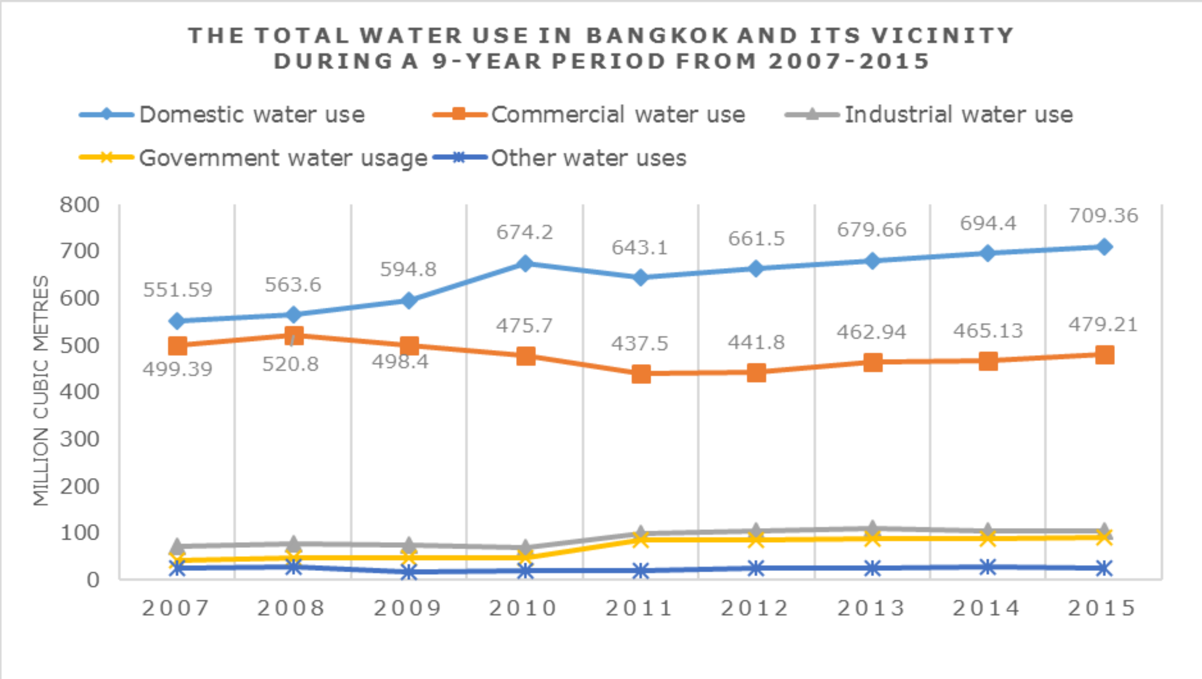

Figure 4-7: The total water use in Bangkok and its vicinity during a 9-year period from 2007-2015 (The Metropolitan Waterworks Authority; BMA, 2008; 2009b; 2010; 2011b; 2012a; 2013b; 2014; 2015; 2016)

It was clear that modern social-economic growth represented a strong argument. However, agreed upon goals must be dedicated towards sustainability and environmental improvement as a primary concern, rather than economic and social development. The result of high water use and unsustainable stormwater practices will cause very high risk to nature. In order to prevent the consequences of the environmental harms, it is necessary for the country to reuse their water and natural resources in a sustainable way.

4.3 Land Use Issues: the Lack of Green Space and High Impervious Areas

It is a well-known fact that Bangkok is a highly flood-prone area and mainly comprised of an extensive waterways system running through the city. In the early development of the city, this area was swampy lowland and had numerous canals that were regularly overflowed by the annual floods along the Chao Phraya River (ADB, 2012). Due to the rapid urbanisation during recent decades, various watercourses specifically canals and ponds have been filled and converted to streets and roadways (BMA, 2009a), the agriculture areas have been changed into housing and industrial estates (Prajamwong & Suppataratarn, 2009), and soil resources have been deteriorated through improper use and distribution of land areas (NESDB, 2012a). These not only have resulted in the reduction of large retention areas and an increase in the number of impervious areas in Bangkok (Marome & Asan, 2011), but also have led to increasing of severe floods which were apparent in 1983, 1990 and 2011.

Bangkok has a relatively small amount of total green space and park. It is apparent that a large area in Bangkok is covered by impervious surface including building, roads and constructed surfaces with more than 50% within its boundaries. The city has an area of around 1.5 thousand square kilometres, but the built-up area of Bangkok occupies around 834.37 square kilometres in 2009, or about 53.22 percent of Bangkok area. According to DCP (2013) the expansion rates of the built-up area and industrial facilities in Bangkok from 2000-2009 represented 2.41 and 1.66 percent per year, respectively, resulting in the reduction of open space and farmland of Bangkok.

Land use types of Bangkok	**Areas**	
	km^2	**Percent**
Residential Land Use	510.42	32.54
Commercial Land Use	72.28	4.61
Industrial Land Use	32.09	2.05
Warehouse	13.40	0.85
Institutional Land Use	38.28	2.44
Educational Institution	19.41	1.24
Religious Institution	9.00	0.57
Recreational Land Use	22.23	1.42
Transportation Land Use	117.25	7.47
Agricultural Land Use	453.09	28.88
Vacant Space Land Use	188.49	12.02
Water Sources	92.78	5.91
Total	**1,568.74**	**100.00**

Table 4-1: Land use types of Bangkok in 2009 (DCP, 2013)

Considering the proportion of each land use type in Bangkok, it is apparent that in 2009 housing land use represents the highest percentage of land use type at 32.54 percent or 510 square kilometres, and it continues to expand into the suburbs. The industrial land use in Bangkok occupies at 2.05 percent. However, the Metropolitan Region Development framework, as stipulated in the Thailand Plan, has promoted the distribution of industry from the metropolitan area to other regions of the country in order to reduce environmental pollution and to enhance air and water quality within the city. The vast majority of open space and agricultural areas including farmland and shrimp farms on the city fringe also decreased to 453 and 188 square kilometres, representing only 29 and 12 percent of Bangkok areas respectively.

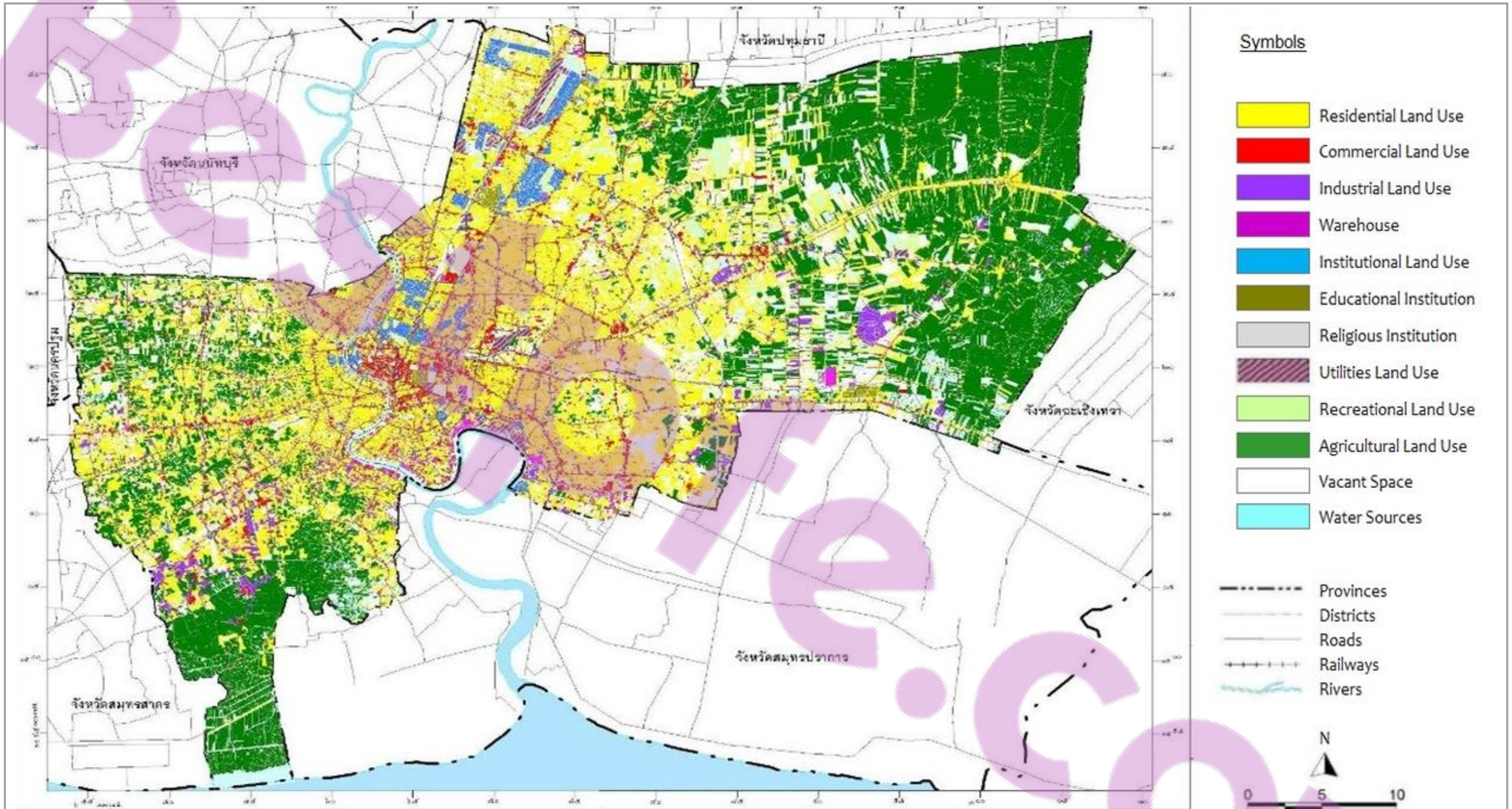

Figure 4-8: Land Use Map of Bangkok City 2009, Source: Department of City Planning [DCP], (2013b).

The green areas in Bangkok represent about 45,000 rai and are equivalent to 4.6 percent of the Bangkok's area, or 12.58 square metres per person (TEI, 2015), less than Seoul (14 m^2), while larger than other capital cities such as Singapore (10 m^2), Beijing (6 m^2), Mexico City (1.9 m^2), and New Delhi (0.12 m^2). However, according to the UN-World Health Organisation (WHO), the minimum urban green space per capita is recommended at 9 m^2 to improve urban environment as well as alleviating detrimental environmental impacts (Thaiutsa et al., 2008).

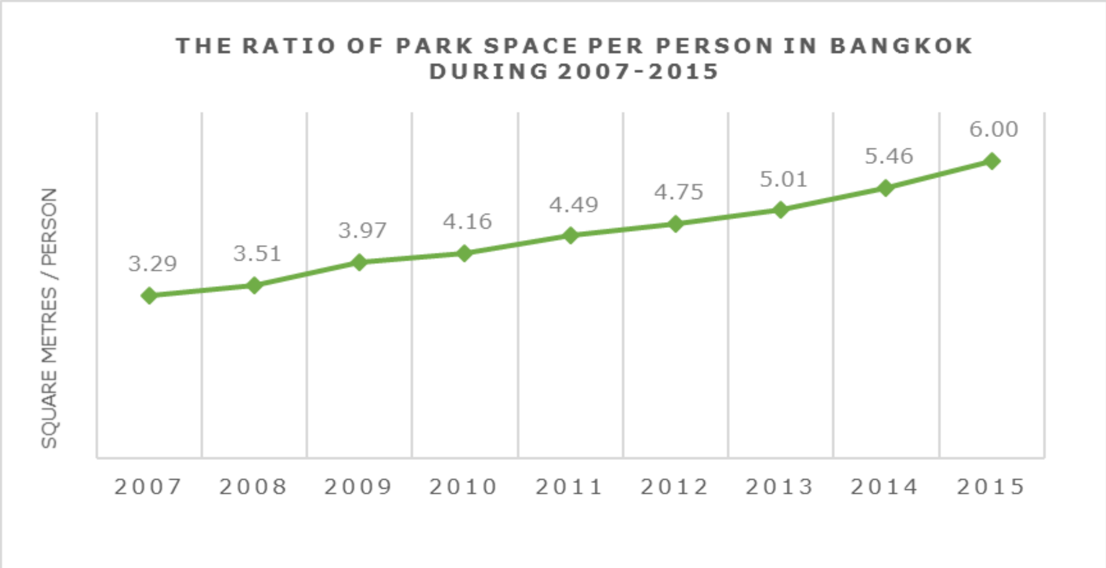

Figure 4-9: The ratio of park space per person in Bangkok during 2007-2015 (The Environment Department; BMA, 2008; 2009b; 2010; 2011b; 2012a; 2013b; 2014; 2015; 2016)

With regard to the ratio of park space per person in Bangkok between 2007 and 2015, it was observed that the trend of park space has been increased gradually from 3.29 to 6.00 square metres per person over the 9-year period (BMA, 2007-2015). The highest amount of park space in Bangkok can be seen in the categories of the pocket park and street park, while the community and city parks occupy the smallest amount in the Bangkok area.

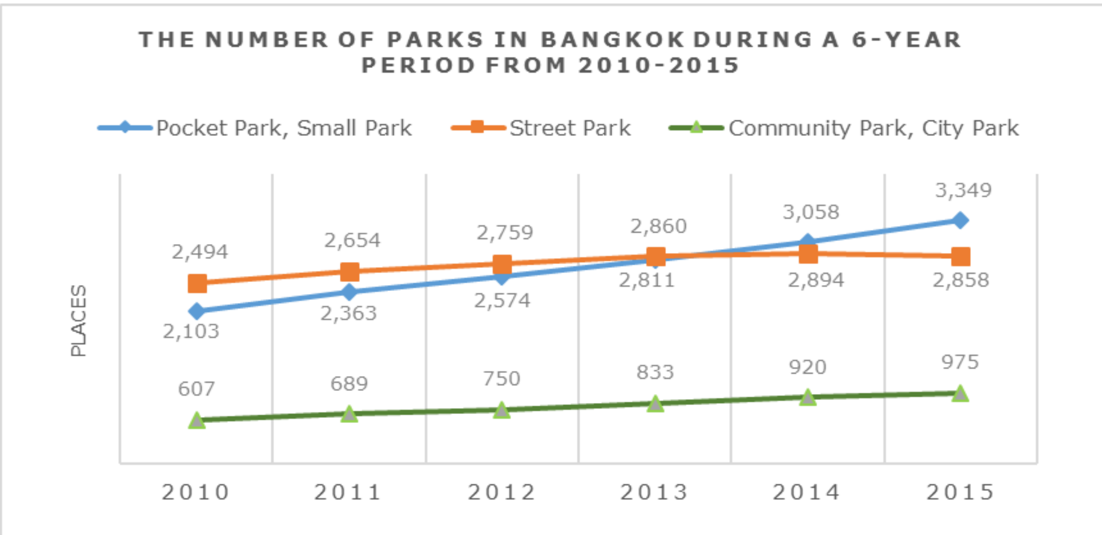

Figure 4-10: The number of parks in Bangkok during a 6-year period from 2010-2015 (The Environment Department; BMA, 2011b; 2012a; 2013b; 2014; 2015; 2016)

There is also a lack of public space and green area in several zones of Bangkok. It was revealed that the average green space per capita of CBD Bangkok represents only 2.8 m^2. According to the data on green area in Bangkok, it was found that among 50 districts, Bangkok has only 5 districts which have green areas that meet the standard of WHO including Laksi (16.39 square metres per person), Prawate (15.64 square metres per person), Pathumwan and Taweewattana (13.40 square metres per person), and Jatujak, respectively. Such districts mostly have large public parks including Lumpini Park, Wachira Benjatat Park, King Rama 9 Park. The area with very low green areas per person is the centre of the economy and business including Bang Rak with a green area at only 0.29 square metres per person. Such a ratio is lower than the criteria of WHO by up to 31 times; the largest green area of the district is Island in the middle of Silom Road (Wijitkosum, 2013).

Considering green space required for condominiums and large residential building projects, the Office of Natural Resources and Environmental Policy and Planning (ONEP, 2006; Warin, 2010) required the large building projects to provide green spaces for improving environmental quality, with the proportion of green space per resident of not less than 1 square metre per person. Moreover, the project shall provide a green space of no less than 50 percent of the total area with perennial plants at least 50 percent of green space.

The research results by Warin (2010) found that most condominiums and large residential building projects are located in the brown zone of the city plan, which is a high-density residential area. Most of the condominiums and large residential building projects provide green space at 1.2 and 1.53 square metres per person, respectively. This conforms to the Environmental Impact Assessment of the Office of Natural Resources and Environmental Policy and Planning that requires large residential projects with 80 rooms or more must provide green spaces for residents not less than 1 square metre per person. However, the project owners commonly provide the green space slightly exceeding the minimum requirement due to limited space and the high price of land in Bangkok.

It was argued that the preparation of the recent Bangkok Comprehensive Plan takes into account only the context of the Bangkok area, which is inconsistent with regional plans and catchment plans, resulting in inappropriate land use plans. National Reform Council (2015) claimed that a lack of strict enforcement of town planning laws also causes urban sprawl in Bangkok and the catchment. Although the recent Bangkok Comprehensive Plan have been implemented to control urban sprawl within the area of utilities service of the outer ring road to preserve the suburban agriculture, and natural environment, the growth of the city has continued to expand steadily to the Bangkok outskirts along the main road and industrial areas of the city.

The struggles between environmental protection and economic development have not yet been solved. It was observed that current Bangkok Comprehensive Plan is likely to be ineffective at controlling or restricting the urban sprawl within the Outer Ring Road and protecting agricultural areas in both the east and the west of Bangkok, and agricultural land use continues to decline steadily. As a result, the city is vulnerable to flooding due to rapid urbanisation sprawling into agricultural areas and converting them to impervious suburban lands.

Urbanisation, land-use change and increase in impermeable surfaces in Bangkok will heighten stormwater overflows in Bangkok making them more serious. In the rainy season, a high amount of rainfall is not absorbed into the land and flows over land and through urban areas before it reaches drainage systems or watercourses. This kind of flooding often occurs in urban areas, as the lack of permeability of the land surface means that rainfall cannot be absorbed rapidly. Thus, the need to create space for water is essential.

The challenges of stormwater management are likely to be more difficult under ongoing changes in urban land use. Much wider areas of Bangkok are usually flooded almost every year (Lebel et al., 2010). The city is extremely prone to stormwater overflows in the heavy rain events. Flood prone areas in Bangkok, occupying over 14% of the city area, obtain runoff from over 50% urbanised area during the wet season (Thaiutsa et al., 2008). However, due to the comparatively well-protected inner city area, the vulnerable areas along the railway lines from Hua Lampong station to the northward direction and long-standing slums and substandard housing areas in Klong Toey will not be largely affected by flooding (Webster & McElwee, 2009). In contrast, Lebel et al. (2010) concerned that new human settlements expanding into low-lying areas of rice fields around Bangkok result in the increase of stormwater management challenges in the areas.

Rapid urbanisation and infrastructure developments profoundly disrupt the natural waterways system and inevitably result in adverse effects on the ecology of Bangkok. As floods are a natural phenomenon in low-lying areas, it is necessary to require government authority to prevent the consequences of the environmental harms from the anthropogenic climate change. Moreover, management strategies regarding ICM and SC measures can be expected to reduce some of the negative impacts from climate change.

4.4 Water Quality Issues in the Chao Phraya River and Bangkok Canals

River water pollution can be caused by the anthropogenic climate change and other related human activities beyond Bangkok's administrative jurisdiction. It is strongly believed that urban stormwater runoff resulted in environmental problems in several river-mouth cities, so an integrated approach particularly sustainable stormwater practices and ICM planning in the sense of sustainable development is crucial to overcome water river pollution. Several cities around the world have taken a serious promise of sustainable stormwater practice as their agreed goal to prevent human activities that could have an impact on the river water quality.

In Thailand, the Chao Phraya River has widely been regarded as the heart of the country as its profound culture and history, also considered as the most significant cultivated areas in the country, and habitat for more than 300 species of fish (Greenpeace International, 2011). However, the river is currently faced with the problem of water quality especially in the lower river where most of the industry in Thailand is located. The on-going industrialisation has posted a strain on water pollution throughout the lower river and Bangkok area. As described by Greenpeace International (2011), Chao Phraya River has been classified as deteriorated based on the index of the Thai water quality.

The Chao Phraya River is important to the national's economy and represents about half of all water discharge into the Gulf of Thailand. The upper river is the primary source of surface water in Bangkok and its vicinities (Pavelic et al., 2012). Greenpeace International (2011) reported that the lower river is the location of more than 30,000 industries, including paper and pulp, dyeing and textile, and rubber industries as well as food manufacturers

Experts have described several causes arising from human activities that lead to river deterioration due to stormwater contaminants entering rivers. It has been found that the lower Chao Phraya River was considered the most degraded river in the country, which was contaminated by both natural and artificial sources. Natural sources include soil erosion and dissolution of soils from the upper catchment, while pesticides from surrounding rice paddies, discharges from pig and poultry farms and domestic and industrial wastewater are artificial sources of water contamination (Greenpeace International, 2011).

There are high distributions of particulates, nutrients and other contaminants in the river. According to UNESCO (2003), the river contaminates by heavy pollution including serious organic and bacterial pollution which harm to aquatic species. This is resulted from the combined contaminants of industrial, domestic and suburban discharges. Moreover, Pavelic et al. (2012) revealed that the distributions of nutrient concentrations mixing with groundwater also represent high levels at the catchment scale.

Likewise, Simachaya (2010) stated that the water quality in the lower part of river is in crisis. It has been found that a large portion of pollutant in Chao Phraya River (the whole catchment) resulted from community waste of about 70 percent particularly organic waste and coliform bacteria from household activities, followed by industrial waste 25 percent and agricultural waste about 5 percent. Moreover, in the industrial area in Samut Prakan, more than 70 percent of contaminant in river resulted from industrial waste (Simachaya, 2010). Although some factories have their own treatment facilities, the wastewater discharged from some industries still deteriorates the quality of water in receiving water.

Stormwater runoff may contain several pollutants from a variety of sources in the urban landscape. As described by EPA, (1999b) water quality in receiving waters can deteriorate as a result of stormwater runoff associated with contaminants in terms of oxygen-demanding substances, nitrogen and phosphorus, pathogens, solids, petroleum hydrocarbons, metals, and synthetic organics. These pollutants are often attributed to the decline in water quality particularly in receiving waters near urban areas. The major pollutants in stormwater and commonly found in the Chao Phraya River and the Gulf of Thailand are identified in the following paragraphs.

4.4.1 Oxygen-Demanding Substances and Dissolved Oxygen

The oxygen-demanding substances contained in water bodies are generally measured by Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC). EPA (1999) stated that the amount of oxygen dissolved in urban runoff is usually required to be 5.0 mg/l or greater. Low levels of Dissolved Oxygen (DO) in water bodies due to nutrient and sediment enrichment can pose a direct threat to fish and aquatic ecosystems.

The study by ADB (2012) during 2005 – 2008 also revealed that average dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the Chao Phraya River still meets the standards within Class 4 in terms of DO, but lower quality for BOD. However, the water quality in some of Bangkok's canals is lower quality than Class 4 (fairly clean fresh water resources) almost the whole year (ADB, 2012).

Similarly, recent studies reported that average dissolved Oxygen (DO) in the lower Chao Phraya River which runs through Bangkok was only 1.1-2.6 mg/l (Leerasiri, 2010), while Biochemical Oxygen Demand (BOD) exceeded 6 milligrams per litre (BMA, 2011a). This rate is still unsatisfactory according to the surface water quality standard class 4 which means fairly clean fresh surface water resources, but requires special treatment process before consumption. This condition points out that the water quality in the river needs to be improved.

Research conducted by the Pollution Control Department conclude that surface water qualities in the lower Chao Phraya have been deteriorated. The primary causes of problems are associated with Faecal Coliform Bacteria (FCB) contamination and wastewater draining from communities. These organic substances led to a decrease in dissolved oxygen (DO) and an increase in biochemical oxygen demand (BOD) (MPH & MNRE, 2012).

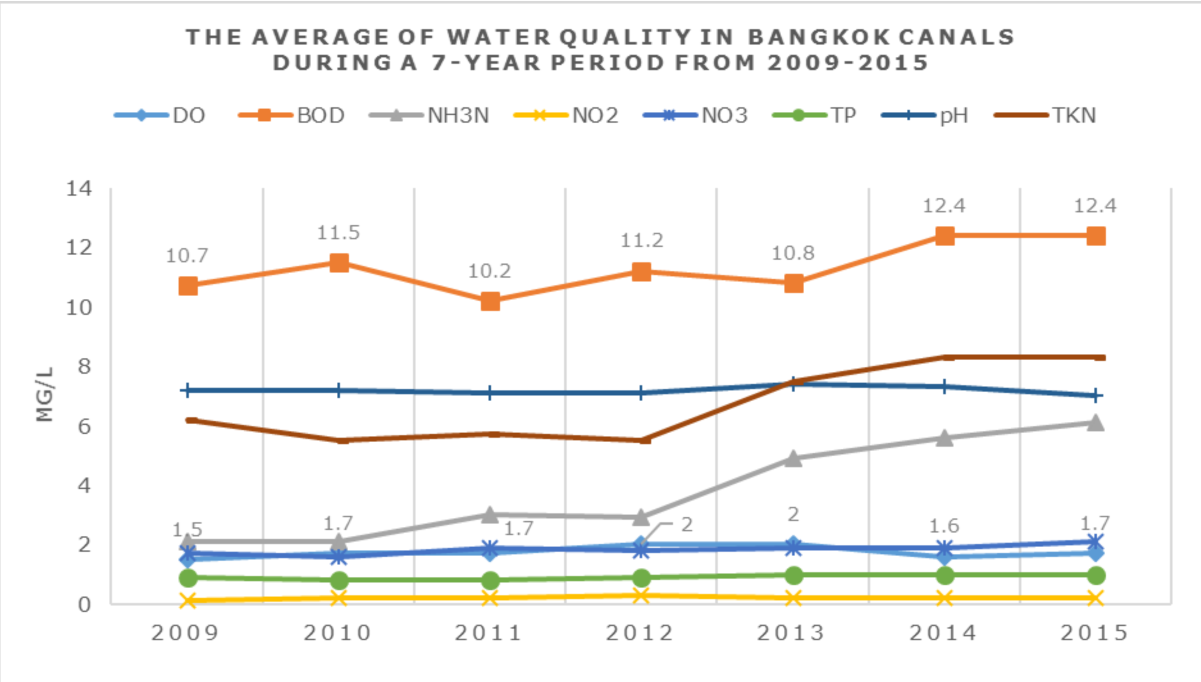

Figure 4-11: The average of water quality in Bangkok canals during a 7-year period from 2009-2015 (The Department of Drainage & Sewerage; BMA, 2010; 2011b; 2012a; 2013b; 2014; 2015; 2016)

4.4.2 Nitrogen and Phosphorus

Nitrogen in the form of Ammonia (NH3) nitrogen is typically the most acutely toxic to aquatic ecosystems. High degrees of nitrogen, phosphorus and other nutrient enrichments in a river lead to an excessive growth of biological productivity, particularly nuisance algae blooms. As a result, the decomposing algae in the form of sediment oxygen demand also cause dissolved oxygen depletions especially in waters close to the bottom streams. The important sources of nutrients in urban rivers include fertilizers, animal wastes, detergents, leaves and debris, and improperly septic systems (EPA, 1999).

A study by Burnett et al. (2009) indicated that there were high inorganic nitrogen, phosphate, and conductivities in the Chao Phraya River and many canals of Bangkok during the rainy season. These contaminants have caused by untreated wastewater from several domestic and industrial facilities or activities that discharge to surface due to inadequate wastewater treatment facilities in the urban area (Cheevaporn & Menasveta, 2003; Roomratanapun, 2001; UNESCO, 2003). Significantly, Burnett et al. (2009) revealed that these contaminants also related to high groundwater seepage into some Bangkok canals during the rainy season with the low tide stages and appears to be an important vector to imply that the seepage will distribute into surface waters of rivers and finally into the Gulf of Thailand.

Previous study reported that the wastewater discharge from households is a major cause of nitrogen flow in rivers, which mostly use only primary wastewater treatment systems or septic-seepage tanks while some households situated by the river still drain wastewater directly into rivers (MPH & MNRE, 2012). Results of the Nitrogen flow in water and wastewater in Bangkok City indicated that sewerage system and onsite sanitation system OSS were the main sources of nitrogen flow for grey water and black water each. Wastewater from households in Bangkok was generated at around 872×106 m^3/year, with being treated at approximately 53 percent of total household wastewater (Buathong et al., 2013). Even though there has been construction of wastewater treatment facilities in many areas, Simachaya (2010) claimed that they do not cover the whole area and still have limitations, with wastewater treatment projects covering only 20 percent of the Bangkok area. This had led to high nutrients particularly nitrogen and phosphorus and low dissolved oxygen in the lower catchment.

In addition, the wastewater discharge from industries, livestock, and agricultural cultivation is also the main source of excess nutrients such as nitrogen and phosphorus and chemical pesticide contamination (MPH & MNRE, 2012). As the use of chemicals in the agricultural sectors is increasing, water contaminants resulted from leakage by transport, storage and misuse of chemicals have likely to increase (NESDB, 2012a). However, management proficiency including regulations, law enforcement, and policies have not been implemented efficiently.

4.4.3 Sediment and Floatable Solids

The number of suspended solid loads can significantly be affected by various geographic factors such as soil types, land slopes, types of land use and the amount of imperviousness of a catchment. The high levels of solids in receiving waters can contribute to increasing turbidity and sedimentation, reduce depth of light penetration, increase the accumulation of other pollutants, affect the growth of aquatic plants and eventually threaten habitat for fish and sediment-dwelling organisms. EPA (1999) reported that the various sources of solids include permeable surface erosion, dust, litter, stream bank erosion, erosion at urban construction sites, and other particles deposited on impervious urban surfaces from anthropogenic activities.

With the fast-growing urbanisation, the CPRB has faced various environmental problems. During recent decades, there have been some changes in the conversion of rice field and forest-covered land to use for growing fruit, economic crops, and several development activities, which could affect water quality in downstream rivers. The encroachment on a forest reserve and its transformation into economic plantations in the upper catchment has also become problematic. UNESCO (2003) revealed that deforestation has resulted in high soil erosion and an increasing large amount of solids in receiving streams.

The cause of clear-cutting rainforest was said in general to be due to the expansion of urbanisation. The deforestation can clearly be seen between 1961 and 2009. During the past four decades, approximately 20 percent of the nation's forested land has been lost. The primary cause of this reduction is land conversion to agricultural land (World Bank, 2011). The forest areas decreased from 53.3 percent of total area of the country in 1961 to 33.6 percent in 2009 (NESDB, 2012b). The lost much of forested area led to the diminishment of biodiversity and natural resource and resulted in affect water quality in downstream rivers.

The accelerating pace of forest degradation was high during the concession periods for logging operations from 1961 to 1989, and gradually declined after the ban came into effect in 1989 (World Bank, 2011). However, although logging concession was banned since 1989, the annual rate of deforestation still accounted for 1 million rai[1] (400,000 acres) and resulted in high soil erosion in the northern region (Bunnara et al., 2004). The National Economic and Social Development Board of Thailand (NESDB, 2012b) reported that the Northern region is the most vulnerable area of inundation and landslides due to degraded forests in the catchment. It is clear that forests are a home of biodiversity; massive deforestation causes the loss of biodiversity and environmental degradation.

It was noted that the biodiversity of forests represents the primary source of ecological integrity. Moreover, forests can be considered as a place of climate change mitigation through their role as carbon sinks. To enrich the natural resources and biodiversity, NESDB has set the targets for 11th national development plan to increase the proportion of forest areas to be 40 percent of total land area, and reforest mangroves in the coastal zone at least 5,000 rai (2,000 acres) per year (NESDB, 2012b). Moreover, successful efforts have been made in the northern sub-catchment. It became apparent that the participatory in catchment management has been successfully applied in several villages in the northern sub-catchment to reduce forest deterioration through emphasising participatory and holistic approaches over the past decades. Bunnara et al. (2004) reported that the coordination of community networking groups has led to an increase of upland natural resources and of forest and a reduction of environmental deterioration. Moreover, decentralised management by

[1] The rai equals 0.3954 acres.

coordinating of local communities in micro-catchment areas has contributed to the reduction of forest fire, illegal logging and upland erosion, and the increase of natural regeneration of forests.

Overall, deforestation is one of the main threats of biodiversity depletion and environmental degradation. Although the government, local communities, and private sectors make an effort to recover the loss of forest, the ecological restoration of degraded forest may take a lot of time and needs continuous strategies as well as the revision of the appropriate laws. Building resilience in the country will be important to reduce vulnerability and environmental impact.

4.4.4 Metals

Urban runoff concentrations of metals have potential impacts on human health and aquatic life. The substantial sources of metals in urban stormwater, waterways and sediments are discharges from domestic, agricultural and industrial wastewaters, and transportations (EPA, 1999; Wijaya et al., 2012).

Heavy metal contamination of the aquatic environmental systems can be quantified by analysing water, sediments, aquatic vegetation and animals (Hamed & Emara, 2006). The concentration of metals in sediments is typically higher than in water (Roussiez et al., 2006). The river sediment characteristics are crucial in evaluating the pollution impacts on the environment due to its potential to take up and segregate heavy metals, and to record the impacts of anthropogenic activities (Burton, 1992; Wijaya et al., 2012). Sediment associated contaminants may act as a source of chemicals which degrade water bodies and can be directly toxic to sediment-dwelling organisms (Roussiez et al., 2006).

The concentrations of heavy metals relatively vary in the environment, which is generally related to geological contexts and anthropogenic activities (Wu et al., 2011; Wijaya et al., 2012). The Chao Phraya River, which flows through Bangkok, has been significantly affected by various pollutants from human activities along its bank (Cheevaporn & Menasveta, 2003). According to the report ‘The situation in the water’ (Greenpeace, 2007a), the results of surveys during the past five years on water contamination near industrial areas showed that there was a high contamination of heavy metals such as nickel and zinc in wastewater discharged from Nava Nakorn Industrial Estate in PathumThani. Moreover, chlorine compounds - such as dichloromethane, chloroform, and trichloroethane - and other chemicals that affect the endocrine system used in manufacturing process could still be found in the rivers, though to a lesser degree than industrial wastewater quality standard.

Additionally, the assessment of the contents of heavy metal and Pb isotopic in the Chao Phraya River sediments by Wijaya et al. (2012) indicated that the high levels of heavy metal pollutions particularly Cd, Cu, Cr, Pb, Zn, and Pb isotope contents was found in the river close to the centre of Bangkok. Moreover, resulted showed that Pb isotope ratios in the Chao Phraya River sediments were transported by road-side dust and pond sediments.

With regard to the concentrations of heavy metals in the Gulf of Thailand, the study by PCD (2012) on the potential impacts of floods on the marine environment reported that there was Pb accumulations on sediment of the Gulf of Thailand. The study analysed two types of sediment samples in the inner Gulf of Thailand including: surface sediment (i.e 0-1 cm, representing the area influenced by the inundation); and subsurface sediment (i.e 5-9 cm, representing the area uninfluenced by the inundation) in rainy season 2012. Results showed that these sediments were moderately contaminated by Pb in adjacent areas of river mouth.

On the other hand, the study by PCD (2012) reported that the mean concentrations of heavy metals (Cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), mercury (Hg), arsenic (As) and chromium valence Hague Gonzaga ($Cr6$ +)) and polycyclic aromatic hydrocarbons (PAHs) in both sediment sources relatively low compared to the proposed marine and coastal sediment quality guidelines for Thailand. Concentrations of organochlorine pesticides in surface and subsurface sediments were not detected. Moreover, results show that there was no significant difference in mean concentrations of heavy metals, total organic matter and acid volatile sulfide (AVS) in both sediment samples ($p > 0.05$).

Overall, based on enrichment factors (EF) and geo-accumulation index (Igeo), PCD (2012) concluded that human activities, not inundation, are the primary factors of Pb accumulation in surface and subsurface sediments. However, the sediments were not contaminated by Cu, Zn, Hg, and As, which also have no influence by anthropogenic activities.

4.5 Source of Pollution in Urban Stormwater Runoff

Stormwater runoff generally contributes to various adverse effects on receiving environments and urban populations such as increased incidents of downstream flooding, increased rates of sediment transport, affecting habitat and biological resources (EPA, 1999). Stormwater runoff associated with contaminants can pose a threat to the integrity of aquatic ecosystems as well as potentially polluting water supplies and resulting in public health impacts. The degree of impacts can often be aggravated in urban areas related to a number of sources of contamination and environmental issues.

Water quality degradation has become an environmental concern in Bangkok as a result of population growth, urbanisation, the expansion of industrial land use, transportation activities, as well as climate change threatening to alter the hydrological cycle and river water quality. There is a wide range of pollutants being washed off from the catchment by stormwater runoff. The pollutants typically found in urban stormwater runoff are generated from either point or non-point sources.

Point source stormwater discharges are specific sites where contamination can occur, including sewer overflows and illegal discharges of trade wastes. Non-point sources or diffuse sources are difficult to identify and measure. Pollutant discharges from non-point sources may include nutrients, sediment, oil and grease, metals, debris, toxic pollutants, animal wastes, bacteria and organic matter (Gan, 2004).

4.5.1 Point Source Pollution

In the Chao Phraya River Basin, population growth, economic development, and unsustainable stormwater practices have led to some negative results to the urban ecosystem. While the sustainable stormwater source control methods have not yet been recognised, their implementation was clearly visible and more acceptable compared with the traditional stormwater management system. Conventional wastewater management has been broadly applied over several decades. ADB (2012) observed that organic pollutants from household wastewater have become the main source of the pollution, which accounts for 75 percent, while wastewater from industries represented 25 percent. This results from inadequate sewage treatment facilities for domestic wastewater as well as water quality legislation that are solely concentrated on industrial wastewater.

4.5.1.1 Pollution from Domestic Wastewater

Organic pollutants from household wastewater have become the major source of water deterioration in the lower Chao Phraya River. It was found that sewerage systems and onsite sanitation system (OSS) in Bangkok are the main sources of nitrogen flow for grey water and black water respectively (Buathong et al., 2013) as primary wastewater treatment systems or septic-seepage tanks have mostly been used in households (MPH & MNRE, 2012).

Currently, septic tanks or on-site treatment systems have been applied as a common pretreatment practice in urban and suburban communities in Bangkok. These systems are now required to be installed in individual or private houses, while groups of houses are required to use community wastewater treatment plants (Suriyachan et al., 2012). Tsuzuki et al. (2009) stated that on-site wastewater treatment systems are typically practiced even within WWTPs service areas. High proportions of pollutant loads in receiving rivers around Bangkok are caused by seepage and septage from on-site treatment methods including septic tanks and leachate from composting (SSL). The estimation data of Pollutant Discharges per Capita (PDCs) indicated that pollutant discharges to receiving rivers are still high even in the WWTPs service areas.

A combined sewer system for stormwater runoff and wastewater has been applied in the city (PCD, 2004; MPH & MNRE, 2012). This system collects both sanitary sewage and stormwater runoff in a single pipe system which requires a large pipe size and the high cost of construction. The wastewater collection pipe from households is linked to the public sewer to transport wastewater to the existing treatment plants (ADB, 2012). PCD (2004) reported that underground pipeline networks - including plumbing pipes, wastewater pipe, and wiring systems - are still unsystematic and disorganised, making a lot of obstacles in the construction of a new pipeline as well as maintenance the systems.

Study by Leerasiri (2010) revealed that to deal with water quality issues, a Master Plan on Wastewater Treatment in Bangkok was introduced by Japan International Cooperation Agency (JICA) in 1999. Central wastewater treatment projects were planned to operate to cover 20 zones in Bangkok (Figure 3.1), of which five Central Wastewater Treatment Plants are planned for construction in middle and outer zones of Bangkok in the near future. These projects will cover an area of 172.03 square kilometres and have a water treatment capacity of 773,000 cubic metres per day.

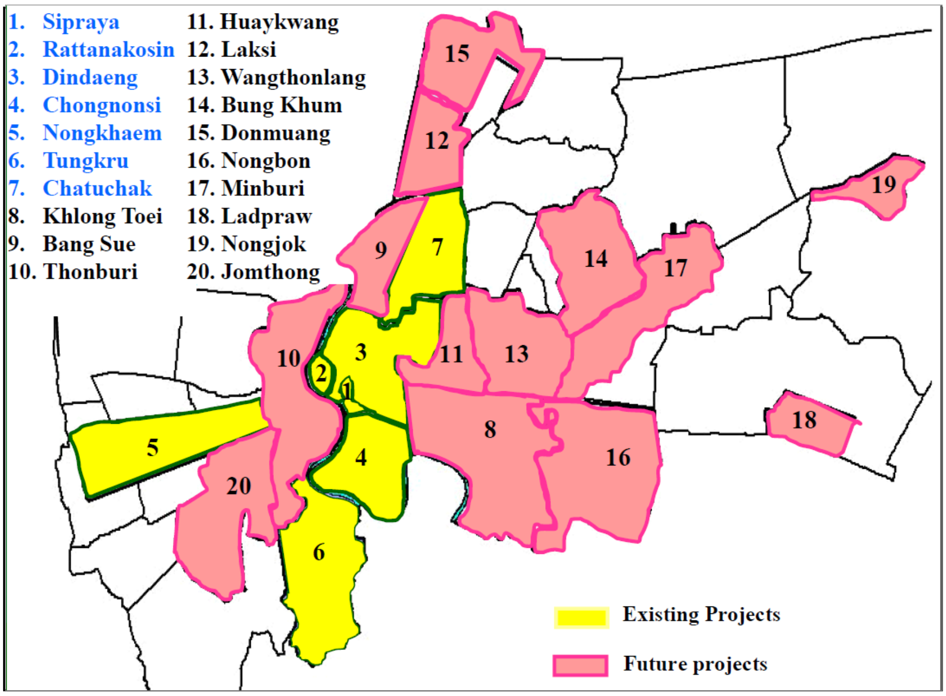

Figure 4-12: Wastewater treatment plants JICA master plan 1999 (Leerasiri, 2010)

According to Leerasiri (2010) and Suriyachan et al. (2012), currently, there are 7 central and 12 community wastewater treatment plants in Bangkok. Centralised WWTPs are more favored in inner zone, while Community WWTPS are more favored within the middle and outer zone. Seven central wastewater treatment plants being operated in Bangkok include Si Phraya, Rattanakosin, Din Daeng, Chong Nonsi, Nong Khaem, Thung Khru, and Chatuchak wastewater treatment plants. These systems are responsible for total service area of 191.74 km^2, providing capacity of treating water at 992,000 cubic metres per day.

Table 4-2: BMA central wastewater treatment plants systems (Leerasiri, 2010; Simachaya et al., 2010; Suriyachan, 2011; Suriyachan et al., 2012).

Wastewater Treatment Plant	Service area (Km^2)	Dry Weather Flow (m^3/day)	Service Population	Average BOD Effluent (mg/l)^a
Si Phraya	2.7	30,000	120,000	4.66
Rattanakosin	4.1	40,000	70,000	11.69
Din Daeng	37.0	350,000	1,080,000	4.20
Chong Nonsi	28.5	200,000	580,000	5.47
Nong Khaem	44.0	157,000	495,000	4.90
Thung Kru	42.0	65,000	203,000	4.82
Chatuchak	33.4	150,000	432,000	10.28
Total	**191.7**	**992,000**	**2,980,000**	

a) Average BOD effluent was calculated from 2005 to 2007 data.

Overall, the seven BMA central wastewater treatment plants have been implemented to collect and treat wastewater almost 1 million cubic metres per day in the area of 191.7 km^2. It was expected that 40 percent of BOD load from domestic wastewater will be reduced (Leerasiri, 2010).

Although seven central wastewater treatment facilities have been constructed in Bangkok, they do not cover the whole area and still have limitations. ADB (2012) reported that wastewater treatment plants in Bangkok cover only 20% of the Bangkok area, serving about 54% of the residents or slightly more than 3 million people. Overall capacity of wastewater treatment representing only 1 million cubic metres or one-third of the total wastewater per day (Leerasiri, 2010; Simachaya & Yolthantham, 2010; Suriyachan, 2011; Suriyachan et al., 2012).

The capacity of the interceptor system in Bangkok was set at 5 times of the average Dry Weather Flow (DWF) to remove discharges. However, the flow in the channel system during the rainy season can exceed 25 times of the average DWF (Leerasiri, 2010). Although the excess stormwater will be screened before discharge to the canals, the flows may exceed the capacity of the interceptors during a heavy rainfall event. In this case, the impacts on and health and aquatic ecosystems of receiving waters can be devastating.

With respect to community wastewater treatment plants, Leerasiri (2010) and Suriyachan et al. (2012) maintained that the facilities has been promoted for treating domestic wastewaters in a number of Bangkok communities. These systems are required to apply in large buildings or a group of buildings, such as Housing Estates (HE), National Housing Authority (NHA), commercial buildings, institutions, hotels, condominiums, and other communities in Bangkok.

Housing Estates (HE) are required to provide either onsite or community treatment systems (DWWM), or integrating both facilities, which its effluent has to meet the standards of National Environmental Quality Act (NEQA) 1992. National Housing Authority (NHA) communities usually apply treatment techniques similar to central systems such as activated sludge, but less capacity than central WWT systems (under 5000 m^3/day). The systems in NHA communities are now operated under the supervision of BMA to meet the water quality standards (Suriyachan et al., 2012).

Table 4-3: Wastewater treatment from BMA Community WWTPs (Suriyachan, 2011)

Treatment Plants	Designed Flow (m^3/day)
Rom Klao	3,800
TungSongHong1	3,000
Hua Mark	1,500
Huay Kwang	2,400
Tha Sai	1,400
Bang Bua	1,200

Bang Na	1,500
On Nuch	960
Khlong Toey	1,200
Ram Indra	800
TungSongHong2	1,100
Pibun Wattana	400
Total	19,260

In a slum community, Suriyachan et al. (2012) described that simple wastewater management techniques have been applied for wastewater management, particularly grease trap, filtering system, vegetative system, and trash removal, and natural circulation system for grey water purification, which have not met the quality standards yet.

Overall, it was evident that wastewater treatment facilities are still inadequate in Bangkok and improvements in wastewater treatment plants require very high investment. Insufficient wastewater treatment facilities for domestic wastewater have resulted in high organic pollutant loads and lower dissolved oxygen than the water quality standards in the lower Chao Phraya River.

4.5.1.2 Pollution from Industrial Wastewater

Industrial pollution is the major environmental effect on water bodies in several countries. The main sources of these pollutants are metal, paper and pulp, textile, food and beverage, and mining industries. In the USA, Karthic et al. (2013) revealed that industrial sources, particularly coking plant effluent, become major sources of nitrogen contamination in the Mississippi River and its floodplain in Louis Missouri. In Asia, Evans et al. (2012) reported that there were the highest industrial pollution levels in Central and Northeast Asian countries indicated by BOD (Biochemical Oxygen Demand) emissions per USD 1,000 of GDP, and followed by South Asian countries.

In response to the environmental concern, there have been potential efforts to improve water laws and implement wastewater treatment plants to prevent pollution and protect receiving waters in several countries including China, India, Thailand, the Philippines, Bangladesh, and Indonesia (Evans et al., 2012). However, insufficient enforcement of legislation still leads to difficulties in accomplishing environmental quality improvement.

Industrial pollution is also the major environmental effect on water bodies in the Chao Phraya River. Evidence suggests that the Chao Phraya River, flowing through Bangkok, has been significantly affected by various pollutants from industries along its bank as the river is the site of more than thirty thousand industries, including paper and pulp, dyeing and textile, rubber industries and food manufacturers (Greenpeace, 2011). In Thailand, MOE (1999) stated that the wastewater standards are also regulated under the Industrial Estate Authority of Thailand Act of 1979, which requires the individual factories located within industrial estates to establish their own central wastewater treatment plant for their operations as wastewater discharge into water sources is prohibited.

Although most factories have their own treatment facilities, the wastewater discharged from some industries still causes deterioration in the quality of receiving waters. Results of water contamination near industrial estates in Central Thailand by Greenpeace (2007) showed the contamination of heavy metals in wastewater discharged and in waterways.

Moreover, the leakage of chemicals and wastewater from wastewater treatment plants of industrial estates becomes a primary concern in the flood season. As described by EPA (1999b), contaminants in stormwater can contain various types of hazardous organic substances and heavy metals. These harmful chemical residues in flooded areas can potentially accumulate in the environment and food chain, contaminate rivers and flow into the Gulf of Thailand, and unavoidably affect human health.

According to the study on chemical contamination in ecosystems near the electronics industries in Central Thailand, Greenpeace Southeast Asia Foundation (Greenpeace, 2012) reported that the hazardous chemicals have been used and released into waterways and still contaminate sediments. The majority of these chemicals are non-biodegradable particularly toxic substances such as heavy metals, volatile organic compounds (VOCs), and other organic matter which can accumulate in the ecosystem and the food chain.

The report 'Pollution from the electronics industries: a study of environmental impacts during the production of electronic goods' showed that the several electronics companies are causing toxic contamination in rivers, groundwater, and wells in the central region of the country (Greenpeace, 2007b). This has primarily resulted from the wide use of various chemicals particularly copper and nickel in electronic industries, especially in the manufacture of Printed Wiring Board: PWB and semiconductor chips.

Samples associated with the manufacture of Printed Wiring Board: PWB were collected from five locations, including groundwater samples, wastewater samples, sediments and sludge samples (Greenpeace, 2008c). The five investigated sites include Elec & Eltek (EETH) in Pathum Thani; CKL Electronics Co. Ltd in Bang Pa-In Industrial Estate, Ayutthaya; KCE Technology in Hi-Tech Industrial Estate, Ayutthaya; PCTT Co. Ltd in Rojana Industrial Park, Ayutthaya; and Nava Nakorn Industrial Estate, Pathum Thani (Greenpeace, 2007b).

Analysis of this study showed that both water and sediment samples from four facilities were found to be contaminated with many harmful chemicals (Greenpeace, 2007b). The results of wastewater samples collected from the canal near site of 'the Elec & Eltek (EETH)', Pathum Thani showed the highest level of copper at 3710 µg/l (Greenpeace, 2007b; Greenpeace, 2008c) - which is double the standard quality of effluent from factories in Thailand. Moreover, according to the study by Greenpeace (2008c), a wide range of chlorinated volatile organic compounds (VOCs) was also present at a high level. Sediment samples collected from the same canal also contained a very high quantity of copper at 22,650 mg/kg. Other metals such as beryllium, lead, nickel and zinc were also present at higher levels than typically found in the environment. Copper and tin were found in high quantities in the canal nearby.

The analysis of untreated wastewater, treated wastewater, sediments, and groundwater samples from the 'Hi-Tech Industrial Estate', Ayutthaya, demonstrated that wastewater samples contained high levels of copper and nickel, accounted for more than 1,010 and 251 μg/l, respectively. Groundwater samples also consisted of a high level of zinc and nickel (the nickel at 96 μg/l., or about 10 times background levels) (Greenpeace, 2008c) - which is nearly five-fold higher than the Thailand's water quality standard (Greenpeace, 2007b). However, analysis for VOCs by Greenpeace (2008c) did not show them to be present in groundwater and treated wastewater from sewage treatment plants of semiconductor electronics factories.

The results of the study by Greenpeace (2008c) regarding contaminations near 'Bang Pa-In Industrial Estate', Ayutthaya, showed that wastewater samples consisted of copper at very high quantities of 1,780 μg/l, while the treated water present copper at 570 μg/l. Both wastewater samples also contained remarkable levels of nickel and zinc at 59 - 114μg/l, and 134 - 153 μg/l, respectively. With regard to 'Rojana Industrial Estate', Ayutthaya, it was found that the treated wastewater sample of surface water near the industrial estate contained some metals including chromium, copper, nickel, tin and zinc at high levels, while wastewater contained copper at the slightly high level of 73 μg/l. The relatively high levels of zinc have also been found in groundwater nearby Rojana Industrial Park. However, for 'Nava Nakorn Industrial Estate', heavy metals and volatile organic compounds (VOCs) in groundwater samples collected were relatively low and still met the water quality standards.

4.5.2 Non-Point Source Pollution

The amount of rainwater is usually converted into runoff when the level of impervious surfaces increases in a catchment. The increased imperviousness and the degree of catchment development lead to a high degree of hydrologic change particularly in volume and rate of discharge to a stream or receiving water (Prince George's County, 1999) as well as larger amounts of non-point source pollutants and sediments from industrial activities, construction, streets and parking lots to urban streams (EPA, 1999).

Potential nonpoint sources of river water pollution in urban landscapes may typically include lawn and crop fertilization, animal wastes, septic systems, and leaking sewage pipes (Collins et al., 2010). Additionally, stormwater runoff from urban impervious surfaces such as rooftops, streets, parking lots, storm drains, and compacted soil is also an important source of contaminants into urban rivers (Groffman et al., 2004). The major nonpoint sources of river water pollution in Bangkok including urban runoff, agricultural runoff, road runoff, and landfill leachate are addressed as follows.

4.5.2.1 Urban Runoff

As a result of urbanisation, anthropogenic water contamination has increased in receiving rivers around the world and degraded the majority of rivers in most cities. In the Orge River catchment, France, the heavy metal contamination measured in urban rivers indicated the increase in the contamination mainly resulting from urban activities, especially urban runoff and sewage releases into the river, which lead to the increase of bioavailability and toxicity of toxins in urban rivers (Le Pape et al., 2012). This research suggests that the Pb contamination and lead-bearing species in the Orge River were also observed as a result of urbanisation (Le Pape et al., 2013). In the Seine River basin, the main source of Pb used in the Paris conurbation was found to be associated with a mixture of lead from the Rio Tinto mine and lead from leaded gasoline released to the river, which can also be detected at the Seine River mouth.

The increase in this Pb concentration was mainly attributed to the urbanisation rather than industrial activities (Ayrault et al., 2012). In London, it is evident that the high contamination of submerged plastic pollution from urban activities has degraded the Thames and the ocean (Morritt et al., 2013). In Thailand, due to urbanisation along the Chao Phraya River and the intensification of industrial and agricultural development, Greenpeace International (2011) reported that the country currently face the problem of river water quality especially in the lower catchment.

Bangkok has intense development of urbanisation and has potential effects resulting from stormwater contaminants. A low-lying area like Bangkok is also widely recognised to be vulnerable to sea level rise and changes in runoff (BMA, 2009a). The growth of urbanisation and industrialisation since the mid-twentieth century has resulted in the conversion of concentrated paddy cultivation in the floodplain of the lower delta (Emde, 2012). The authors conclude that these anthropogenic land-use changes along with coastal erosion of the delta also accelerate overflows from upstream and adjacent riverbanks into the Bangkok areas (Emde, 2012; Prajamwong & Suppataratarn, 2009).

Intensification of economic activities has accelerated the urban sprawl in the city. The inner area continues to be the main employment zone, while the outer areas have been generally influenced by private developers as a result of ineffective land use planning (Perera, 2006). In the past, the Bangkok suburbs have been developed with a lack of city planning and the control of land use. The network of canals, rivers, and water storage areas has been considerably transformed by urban development. With the increase of high urbanisation rates, the remaining green areas have largely vanished in outer Bangkok (Office of the Ombudsman, 2011). As noted by Perera (2006), Tonmanee & Kuneepong (2004), and Srisawalak-Nabangchang & Wonghanchao (2000), around 75% by the suburban area has been used for industrial and commercial activities, given the deterioration in water pollution in the outer areas, while the remaining 25% of the land has been identified as residential areas.

The rapid population growth, expansions of industries and housing estates, and ineffective urban land use planning have exacerbated the water quality issues in Bangkok. Ineffective land use planning has contributed to uncontrolled horizontal expansion of the urban area. The expansion of impervious surfaces often prevents rainfall infiltration into the soil, challenges the drainage capacity of natural waterways and canals, as well as accumulating stormwater pollutants to impair water quality in the Chao Phraya River.

4.5.2.2 Agricultural Runoff

The contamination from agriculture becomes one of the main water quality issues all over the globe. In the UK, Neal et al. (2006) revealed that agricultural sources primarily resulted in the relatively high level of nitrate in the Thames Basin Rivers. This contamination is likely to be higher in catchments where there is a high proportion of impermeable surfaces and a combined influence of sewage and agricultural sources of nitrate.

In Asia, it is apparent that agricultural consumption of mineral fertilizer in the region increased steadily in the past decade. Receiving rivers are vulnerable to the negative effects of eutrophication including algal blooms that intensely deteriorate freshwater ecosystems. These resulted from high nutrient levels found in up to 50 percent of rivers across the region. Pesticide use remains a problem in many countries of Asia.

In China for example, although efforts have been made to improve regulation, nutrient discharge is also insufficiently controlled as the absence of good governance makes enforcement very difficult to achieve. In Central Asia, the small amount of unregulated pesticide use has also caused a human health risk. In Southern Asia, a river in Sri Lanka has been polluted by pesticides from agricultural discharges resulting in surface water deterioration. In India, pesticide use increased by more than seven hundred percent over the last five decades from the mid-1900s, and prohibited pesticides were still detected in the Ganga River (ESCAP, 2005; Howarth et al., 2007; MoEF, 2009, as cited in Evans et al., 2012).

A study of nitrate contamination in Asian megacities by Umezawa et al. (2009) showed that high nitrate contamination occurred in dry fields of Jakarta in the suburban areas. However, results revealed that nutrient contaminants of the aquifers in Metro Manila, Bangkok, and Jakarta was not excessive, implying low risk of drinking groundwater to public health.

In the CPRB, the contamination from agricultural runoff is one of the main water quality issues. The high fertility of the lower Chao Phraya alluvial plains together with the competent irrigation systems has resulted in the intensification of agriculture and rice production (UNESCO, 2003), which contributed to water quality pollution in the river. Several studies (Vongvisessomjai, 2007; Simachaya, 2010; Greenpeace, 2011; Komori et al.,2012; and Pavelic et al.,2012) reported that wastewater from intensive agriculture has degraded water quality in the Chao Phraya River and affected the ecosystems' health particularly from the rice growing area in Nakhon Sawan, Suphan Buri and Ayutthaya provinces (Office of Agricultural Economics, 2012).

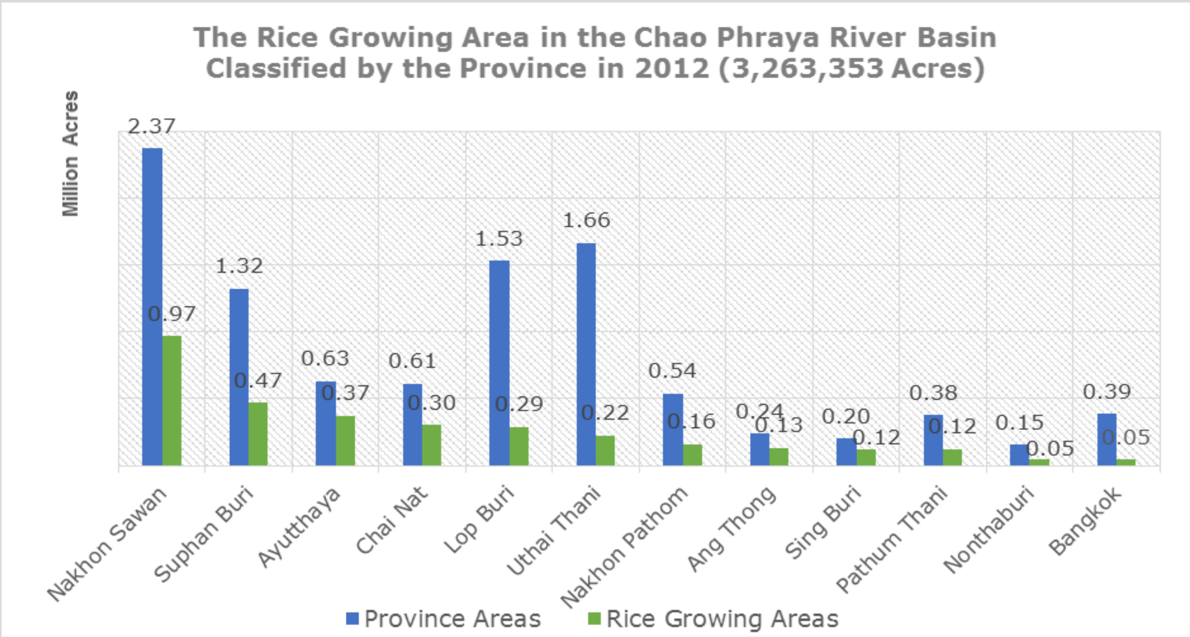

Figure 4-13: The rice growing area in the Chao Phraya River Basin (CPRB) classified by the province in 2012 (3,263,353 Acres, representing 33%of the catchment areas) (Office of Agricultural Economics, 2012).

BOD and High-nutrient loads from agricultural fertilizers, mainly nitrogen and phosphorus, become one of the most prevalent water quality problems in the lower Chao Phraya River. The contaminants in the river also have an influence on Bangkok areas as the majority of stormwater usually inflow from the upper catchment into the lower river where Bangkok is located.

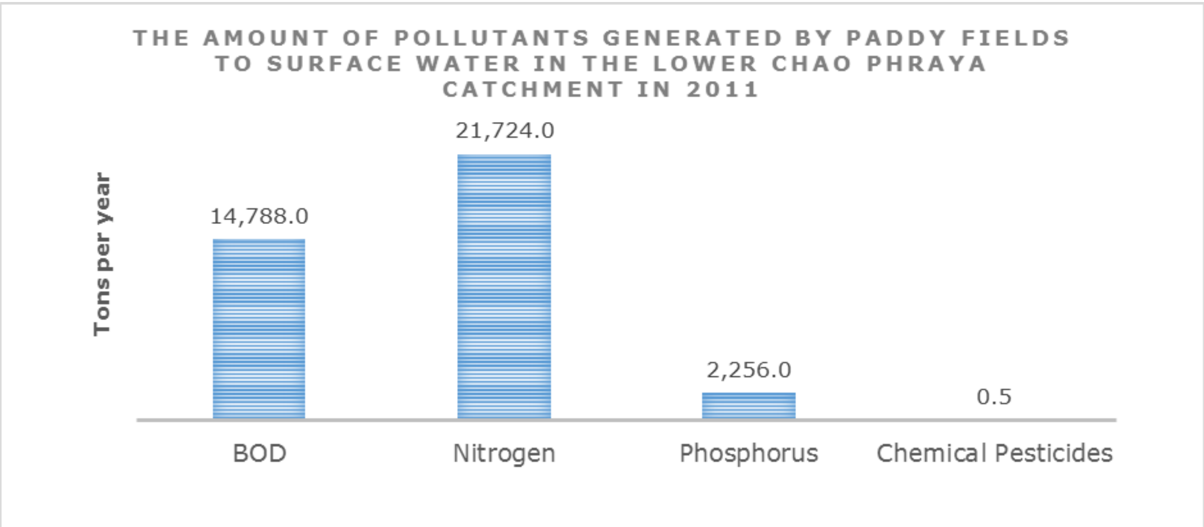

Figure 4-14: The amount of pollutants generated by paddy fields to surface water in the lower CPRB in 2011 (The Pollution Control Department, 2011)

Recent studies have found that the amount of nitrogen and phosphorus present in urban water is steadily increasing. As described in 'Agrochemical disclosure: The overuse of fertilizers and pesticides in Thailand and its environmental impact', the use of chemical fertilizers in the country increased from 18,000 tons in 1961 up to 2 million tons in 2004. This has resulted in the increase of nitrate contamination in water resources and poses a risk to human health and the ecosystems (Greenpeace, 2008a).

Water pollution from nitrate contamination often results from the excess fertilizer which reaches to rivers and groundwater and eventually flows into the coastal area (Greenpeace, 2008b). According to the Greenpeace's report 'Nitrate and the quality of groundwater' (Greenpeace, 2008a), the use of fertilizers for agriculture in very high volumes has contributed to nitrate contamination in groundwater and surface water in central Thailand. The results of the survey showed that 55 percent of the groundwater in central Thailand near the cultivated asparagus areas (Kanchanaburi and SuphanBuri) contaminated with nitrate at higher levels than the level of drinking water standard set by the World Health Organisation. In Kanchanaburi, the contamination of nitrates in groundwater is almost 3 times higher than the standard. This contaminant is related to fertilizer use in high levels beyond the needs of the plant and ultimately impact on the environment.

4.5.2.3 Road Runoff

Contamination from transportation becomes another environmental issue of concern in urban areas. In New Orleans, The USA, a large number of artificial organic compounds and contamination by polycyclic aromatic hydrocarbons were found in Mississippi river (Zhang et al., 2007). In Beijing, China, a study by Schleicher et al. (2011) demonstrates that particulate matter from road traffic is the main source of atmospheric and water pollution. Results showed that a high concentration of heavy metals including Zn, Cd, Mn, As and Pb were detected in the water-soluble fraction, which can be harmful to the environment and to human health. In Shanghai, a study by Wang et al. (2013) indicated that polycyclic aromatic hydrocarbons (PAHs) in urban soils mainly resulted from vehicular emissions and anthropogenic activities may possibly pose potential impacts on groundwater water quality and human health from carcinogenic effects of PAHs.

Water runoff from roads and highways is another environmental issue of concern in urban areas. The rapid vehicle growth in Bangkok and its vicinities has contributed to lowered urban water quality. According to the Department of Land Transport (DLT) (2013), the total number of registered vehicles in Bangkok was up to 7.5 and 8.2 million in 2012 and 2013, respectively, with a rapid growth in number of vehicles during recent years. Increasing vehicles in the city not only become the major sources of greenhouse gas emissions in Bangkok, but also contribute to the contamination of polycyclic aromatic hydrocarbons (PAHs) and heavy metals in urban rivers (BMA, 2009a).

As described by EPA (1999), the major sources of petroleum hydrocarbons (PAHs) are generally found along transportation corridors, parking lots, leaking storage tanks, and improperly disposed oils. Effects of PAHs can cause acute toxicity even at low concentrations. The maximum of PAHs concentrations for fishery protection is in the range between 0.01 - 0.1 mg/l.

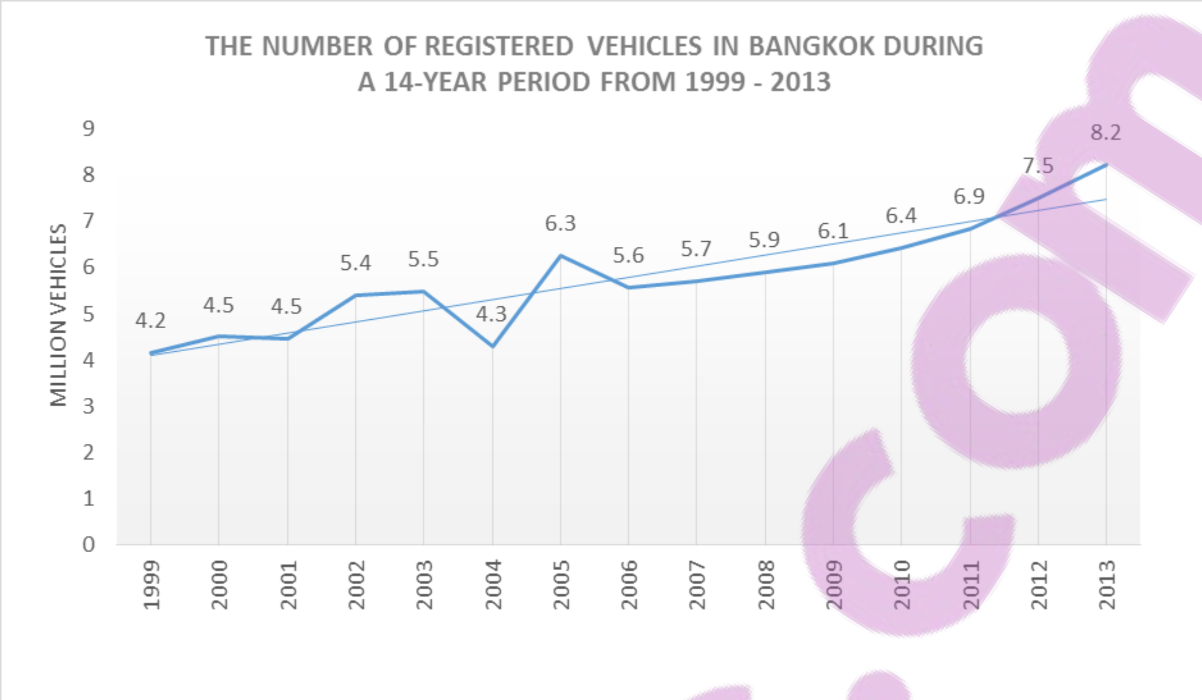

Figure 4-15: The number of registered vehicles in Bangkok during a 14-year period from 1999 – 2013 (Department of Land Transport, Ministry of Transport; BMA, 2007b; 2008; 2009b; 2010; 2011b; 2012a; 2013b; 2014)

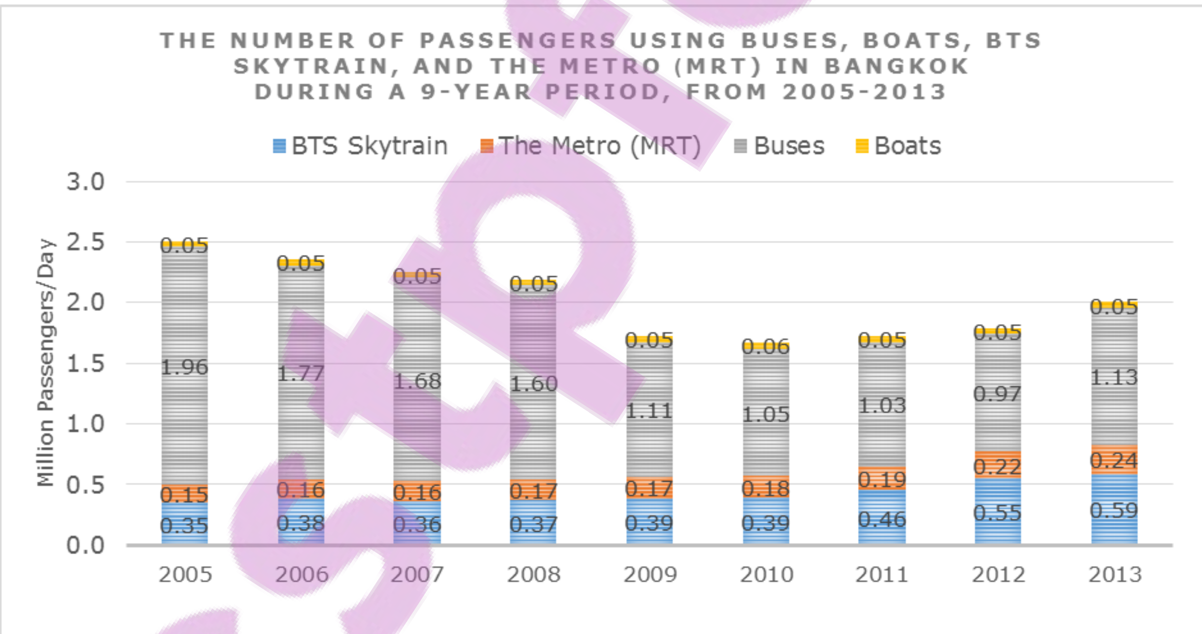

Figure 4-16: The number of passengers using buses, boats, BTS Sky train, and the metro (MRT) in Bangkok during a 9-year period, from 2006-2013 (Bangkok Mass Transit System Public Company Limited, Bangkok Metro Public Company Limited, Bangkok Mass Transit Authority, the Harbour Department; BMA, 2007b; 2008; 2009b; 2010; 2011b; 2012a; 2013b; 2014)

In Bangkok, Boonyatumanond et al. (2006) suggests that street dust has become an important non-point source and the major sources of the petrogenic PAHs. It has been of concern that traffic-derived PAHs that contaminate street dust in Bangkok will be transported to aquatic environments.

The evidence of intensive inputs of PAHs concentrations were also detected in sediments from urban canals in the city, while middle and lower reaches of the Chao Phraya River, the river mouth, and the upper Gulf of Thailand showed intermediate concentrations of PAHs.

Although the use of public transport has been promoted during the recent decade, it is apparent that the numbers of passengers using buses have decreased from 1.96 to 1.13 million passengers per day between 2005 and 2013. Nevertheless, the trend of passengers using BTS Sky train and the Metro (MRT) in Bangkok has increased from 0.35 to 0.59 and 0.12 to 0.24 million passengers per day during the 9-year period, respectively.

4.5.2.4 Landfill Leachate

Ineffective waste management activities may cause high contaminants in urban runoff and potentially affect river water pollution. Study in 2010 by Pollution Control Department revealed that the quantity of solid waste has increased significantly over the decade. In 2010, the amount of solid waste in the country had roughly 15.16 million tons or 41,532 tons per day, which was generated in Bangkok around 8,766 tons per day (21%) of the total solid waste in the country (MPH & MNRE, 2012). BMA (2006) reported that the majority of solid wastes in Bangkok are disposed by sanitary land-filling at 88%, and by composting at around 12%.

Solid wastes in Bangkok have been collected more than 99% of the area covering across 50 districts (BMA, 2006). However, MPH and MNRE (2012) observed that only 3.91 million tons or 26% of all solid waste were recycled or reused through various recycling mechanisms, including junk trade, community recycling centres, recycle bank waste, operators' recall of used containers, organic fertilizer, and generating biogas, electricity and alternative fuel.

Wastes in Bangkok are generally conveyed to three transfer waste stations: Bang Khen, On Nut, and Nong Khaem district before being disposed at landfill sites in Nakhon Pathom and Chachoengsao Province (BMA, 2006). Regarding these three solid waste management centre in Bangkok, On-Nut Centre is the largest centre which receives solid waste from eastern Bangkok at about 42% of the total solid waste in Bangkok or around 3,500 tons per day. Facilities of these waste disposal centres involving composting plant, infectious waste incinerators, night-soil treatment plant, and organic fertilizer plant. However, BMA (2007) revealed that these waste management activities also result in various environmental problems, especially water and air pollution from transportation processes. It can be argued that those potential risks may cause negative impact on both the marine environment and human health.

4.6 Other Water-Related Issues

4.6.1 Groundwater Depletion

The increasing demand of water use has led to the decrease of groundwater levels in the catchment. According to ADB (2012), although water supplies for domestic and industrial use in Bangkok are generally provided by surface water, and groundwater extraction has been restrained since the late

1990s, some private households and industries still use groundwater particularly in the urban hinterland of the city.

Many industries around Bangkok consume a large amount of groundwater in their manufacturing processes although the government has promoted the use of water supply due to land subsidence (UN, 1997). Groundwater was largely employed by industries around 9 percent of the water demand in Bangkok under permission of the Department of Groundwater Resources (Polprasert 2007; ADB, 2012). As descriped by BMA (2009), land subsidence has occurred due to over pumping of groundwater from the thick layer of clay. In some part of southeastern and southwestern Bangkok areas, the subsidence rate has reached to 30 mm per year.

To mitigate groundwater depletion and land subsidence, raw water sources for MWA's water supply in Bangkok rely solely on surface water, particularly from Chao Phraya and Mae Klong rivers, with groundwater being restricted to produce water supply since 2005 (ADB, 2012). In 2006, piped water was provided by the Metropolitan Waterworks Authority (MWA) for 91 percent of the total areas of Bangkok in order to resolve groundwater depletion and land subsidence issues. Water supply coverage reached 98.8 percent of the total registered city population in 2008. However, MWA's service area for water supply in Bangkok did not encompass the whole area of responsibility, covering only 75 percent of the city area (ADB, 2012). Therefore, it is necessary to encourage water saving, and the reuse and recycle of water to reduce demand on water consumption and minimise groundwater depletion in the area.

In response to supply freshwater in more equitable allocation and minimise land subsidence in Bangkok, industrial sectors extracting water from groundwater sources and irrigation canals are charged a fee in higher rates than the rates charged to the agricultural sector (UN, 1997). For slum dwellers, MWA applies a particular regulation for providing piped water to the urban poor in order to discourage pumping of groundwater and wastage and high consumption of water. With regard to groundwater use in agricultural sector, irrigation water has been applied in various area instead of groundwater, with small rate charged and usually being ignored in practice, excluding raw water used for tap water production (ADB, 2012).

4.6.2 Groundwater Contamination

A gradual decline in the levels of groundwater in an artesian aquifer beneath Bangkok and an unbalancing of groundwater recharge has led to the accumulation of contaminants in groundwater (UNESCO, 2003). According to Onodera et al, (2009) intensive urbanisation and groundwater overpumping in the urban areas lead to the reduction of hydraulic potential which bring groundwater flowing downward below sea level and result in seawater intrusion in shallow and deep groundwater.

Although most of groundwater sources in Thailand meet the good water quality in accordance the standards for human consumption, Onodera et al. (2009) found that there is brackish water in some areas of catchments and hard water in the limestone aquifers. Moreover, evidence suggests that there are diffusions of the Cl^- concentration and δ18O, Mn, and NO_3−N in groundwater and can be transferred from shallow groundwater into deep aquifers.

Study by UNESCO (2003) reported that sodium and chloride were the primary chemical component contaminating groundwater. In addition, there is a general increase of the groundwater salinity in the unconfined aquifers of downstream path, while the concentrations of nitrate in entire catchments are mostly unvarying low.

4.6.3 Land Subsidence

Another problem related to stormwater issues is land subsidence. The Bangkok city is built on saturated soft clay in the Chao Phraya River delta, which along with the heavy pumping of groundwater from household and industrial estates, which has led to land subsidence of 2-15 cm/year in Bangkok (Polprasert, 2007), particularly in the industrial zones in the southeastern and southwestern parts of Bangkok (Marome & Asan, 2011). Moreover, it has been found that the ground surface has also sunk below sea level, which exacerbates the difficulty of localised drainage during the rainy season (BMA, 2009a) and results in a reduction of the flood embankment level (Prajamwong & Suppataratarn, 2009).

4.6.4 Sea Level Rise and Coastal Erosion

Apart from land subsidence, rising sea levels also pose a threat to the catchment in terms of flood vulnerability. There is evidence to suggest that the average sea level is raising roughly 25 mm per year (BMA, 2009a). Unfortunately, UNEP reported that approximately 70 per cent of the Bangkok area would be affected by flooding if the waters in the Gulf of Thailand increased by just 1 metre (Marome & Asan, 2011). Clearly, these impacts would lead to adverse effects on human life and the economic system of the country.

According to Organisation for Economic Co-operation and Development (OECD) report, there has been found that Bangkok ranked seventh on the list of 136 coastal megacities around the world[2], which a coastal flood would affect population exposure by the 2070s. Moreover, BMA (2009) indicated that the numbers of people suffering from severe floods in Bangkok are expected to increase to more than 5 million by 2070, as a consequence of climate change and land subsidence.

Marine and coastal resources in the lower catchment are under pressure and gradually deteriorating as a result of infrastructure construction, tourism and coastal erosion. Some coastal areas of the inner Gulf of Thailand have experienced severe erosion up to five metres per year (NESDB, 2012b). In the case of Bang Khun Thian seaside coast, Bangkok's connecting area to the Gulf of Thailand, BMA (2006) indicated that areas of the mangrove forests covering a total area up to 2,735 acres in the past have been encroached by coastal erosion and human activities.

The coastline and canal system in Bang Kun Thien District have already been affected by sea level rise. The western Bangkok, suburban Bang Kun Thien District, and the main industrial provinces in

[2] with populations greater than 1 million people

Samut Prakarn and Samut Sakorn Province appear to be the most at risk areas affected by major potential climate changes associated with sea level rise due to the site which fronts on the Gulf of Thailand (Webster & McElwee, 2009). This is a low-lying area as Bangkok is widely recognised to be vulnerable to sea level rise and coastal erosion. The undergoing land subsidence also intensifies the impacts of sea level rise in Bangkok.

4.6.5 Saline Intrusions

The lower catchment contains a very flat land area, with the slope barely exceeding 1 percent, causing the reduction of drainage to the sea and the reach of the tide up to 60 km along rivers in the dry season, around 10 km in the wet season (Pavelic et al., 2012), and occasionally extending up to 175 km upstream of the seashore during the dry season (Divakar et al., 2011). This leads to saline intrusions in the Chao Phraya River and areas in the south of Bangkok which greatly threatens crop cultivation and the water utilisation for domestic and industrial water supply (Divakar et al., 2011). A minimum freshwater flow from the river to the estuarine is required to protect the saltwater transported from downstream through upstream (Pavelic et al., 2012).

During the dry season water flows from several dams are needed for supplying water, preventing saline water intrusion from the Gulf of Thailand, sustaining terrestrial ecosystems and preventing environmental impacts (Pavelic et al., 2012; Divakar et al., 2011). Moreover, Divakar et al. (2011) stated that a minimum amount of water of 181 mm^3 per month has also been released from the Chao Phraya dam into the Chao Phraya Rivers for salinity control, navigation, and municipal proposes.

4.7 Current Trends on Environmental Efforts and Policies in Thailand

The urban development and economic growth has led to anthropogenic impacts and socio-ecological changes in the CPRB, which can be observed in both local and catchment levels. The encroachment of the natural resources-based economy has led to the destruction of the ecosystems. Although several national policies and plans aim to balance the socio-economic dimensions of development, their benefit to the society in terms of quality of life and environmental improvement has been skeptical.

To date, several environmental management plans have been undertaken in Thailand. These suggest that the government has undertaken preliminary initiatives to improve the country's environment, although currently there is no comprehensive plan, legislation, or single statutory body administering water resources management in catchment areas. Additionally, the achievement of the comprehensive environmental plans has also been limited which is attributed to the disempowerment of authorities in capacity building. However, it is noted that an integrated physical plan for land use planning at the national level has been prepared to strengthen the spatial framework and to create sustainable development through synergies between socio-economic and ecological aspects of the resources.

To enhance environmental improvement in Thailand, several policies, plans, and laws have recently been introduced to provide best practices and recommendations. Some examples of environmental policies, plans, and legislation are described as follows.

4.7.1 The Agenda 21

The Agenda 21 is important national document to specify guidelines operation in economic, social, and environmental development focusing on sustainable development in the 21stcentury. It was established in the United Nation Conference on Environment and Development (UNCED) also known as the Earth Summit or Rio Conference in 1992 in Rio de Janeiro, Brazil.

Thailand adopted the concept of sustainable development and adopted the Agenda 21 concept as a main strategy for the country's development since 1992 after participating in UNCED in Rio de Janeiro (Jarusombat & Senasu, 2014). The Agenda 21 concept has been used as a guideline for both national and local plans in order to promote participation among the public, government and private sectors to take part in the environmental management plans (Bejranonda & Attanandana, 2010). The national plans were introduced under the concept of Agenda 21, giving precedence to management of natural resources and environment in order to maintain the economic activities that are not harmful to environment, natural system and the lifestyle of locals (Dheeraprasart, 2008). This can be seen in several national plans, such as the National Economic and Social Development Plan no. 8 B.E. 2540-2544 (1997-2001), no.9 B.E. 2545-2549 (2002-2006), no.10 B.E. 2550-2554 (2007-2011), no.11 B.E. 2555-2559 (2012-2016), and National Promotion and Maintenance of Environmental Quality Policy and Plan 1997-2016.

4.7.2 The National Economic and Social Development Plan

The sustainable development principle has been raised in a wide range of environmental policies. It aims to support ecologically sound activities in environmental improvement at the national level in order to achieve long-term environmental solutions. The National Economic and Social Development Plan No.8 B.E.2540-2544 (1997-2001) is considered as the first national development plan that focused on green area management. The plan defined the strategy of management of natural resources and the environment that "...*management of environmental and community green areas, with the clear policies and guidelines to preserve the natural environment, green spaces, open space and parks in the urban areas to be proportional to the population, and in order for enhancing urban landscape*..." (NESDB, 1997).

The National Economic and Social Development Plan No. 9 B.E.2545-2549 (2002-2006) focuses on development of healthy cities by defining in the strategy of the sustainable rural and urban development that "... *Strengthening the development of healthy cities and liveable communities based on the principle of participation and self-reliance*..." (NESDB, 2002; Ruthirako, 2013). The National Plan No.9 provided an opportunity for several agencies to participate in several policy processes. However, the insufficient participation was still the major problem preventing achievement of good governance due to the centralisation of decision making in policy processes. Jarusombat and Senasu (2014) asserted that the centralised power by central government in specifying policies and plans resulted in inadequate budgets as the budgeting process had to be done only through ministries of central government.

The National Economic and Social Development Plan No.10, B.E. 2550-2554 (2007-2011) has specified the goals and strategies to enhance the capability of local organisations and to promote good governance in local administrative organisations (Jarusombat & Senasu, 2014). Moreover, there are strategies on the development of human and society quality on the basis of biodiversities by building good environment in order to enhance the quality of life (Bejranonda & Attanandana, 2010). The policy mandates responsibility to the states to fulfill their implementation to alleviate land and water degradation resulting from various factors including climate variations and human activities.

The National Economic and Social Development Plan No. 11 B.E. 2555-2559 (2012-2016) was introduced by the Office of the National Economic and Social Development Board (NESDB), with goals towards the *"Happiness, equality, and fairness society, as well as people have immunity for the changes"*. The national plan takes into account the extensive participation of all stakeholders and the public at all levels from community, regional to national levels in the development of the country through applying the philosophy of a sufficiency economy as a guideline for development. The plan also gave a priority on economic development based on existing knowledge, innovation and environmentally friendly production. To enhance environmental quality, the plan also focuses on the preparedness of the eco-town with low-carbon society. It also focuses on the enhancement of environmentally friendly agriculture, the potential of alternative energy from the agricultural sector, the sustainable management of natural resources and the environment through developing the potential of all levels, and promoting public participation in all policy processes (NESDB, 2012b). However, it was observed that whilst the sufficiency economy is mainly a governmental policy, it lacks the legal identity to support and back it up. Moreover, although the numbers of green areas in the nation's report may show an increase, environmental improvement policy without proper concern related to sustainable stormwater practices still exists and does not qualify.

It is evident that the National Economic and Social Development Plan No.11 B.E.2555-2559 (2012-2016) is consistent with the plan No.8, 9 and 10, defining the creation of good environment through increasing green spaces in urban areas to enhance the quality of life and sustainable development. The plans also aim to enhance the environmental sustainability by reducing greenhouse gases from human activities. However, although there are efforts to improve river water degradation, this attempt may be voiceless as long as the sustainable stormwater practices are not be recognised by national environmental policy.

4.7.3 The Enhancement and Conservation of National Environmental Quality Act, B.E. 2535(NEQA, 1992)

In response to environmental issues in the country, a number of legal measures for environmental protection have been implemented for several decades. The most important national environment law is the Enhancement and Conservation of National Environmental Quality Act (NEQA) B.E. 2535 (A.D. 1992) (ADB, 2012; Knight et al., 2010; MOE, 1999). This act is regarded as the comprehensive environmental law, which aims to provide primary framework provisions for environmental protection and pollution control (Sunee Mallikamarl, cited in MOE, 1999).

The existence of the NEQA B.E. 2535 (1992) is a positive sign for the management of natural resources and the environment at national level. NEQA (1992) stated that the Act required the development of institutional arrangements with measures of environmental protection and pollution control, as well as specifying the rights and duties of the public to jointly promote and maintain the quality of the environment. The Act intends to involve people and private organisations together with the government to promote and maintain environmental quality, and arrange the environmental management system in accordance with the principles of environmental quality management.

The major feature of the Act is to provide opportunities for public participation in environmental management. Section 6 states that … *"a person has the right to be informed by the government in regards to environmental promotion and preservation, receiving indemnity or compensation from the state in case of damage from pollution caused by the activities and projects of the government, and complaining against those breaching environmental laws"* (NEQA, 1992). In practice, the policy can be recognised as a people-based centre development. In addition, Section 7 also certifies the status of each private organisation or NGO to be registered as a private enterprise in the field of environmental protection. Devakula (2007) maintained that this allows those organisations to request assistance from the government in various activities related to environmental protection, including giving assistance for grants or loans from the Environmental Fund for their activities. The challenge of the Act is to interpret, embrace, and implement them in a practical context related to the ecocentric approach at all levels. However, the present measures seem to not fully support the improvement of river water quality in a manner related to sustainability.

The NEQA also defines authorities of the government, state enterprises and local authorities to coordinate the promotion and preservation of environmental quality. The Act came into force as a tool for the planning and management of natural resources and environment of the country. The Act is the comprehensive environmental law, with the main principle to distribute the power in environmental management from central to local government. This allowed the local agency to anticipate monitoring, protecting, and resolving environmental problems in their jurisdictions, which is corresponding with the Determining Plans and Process of Decentralisation to Local Government Organisation Act, B.E.2542 (1999) (Thailaws.com, 2016). However, the law had not clearly stated that sustainable stormwater management and ecosystem management are a part of climate change mitigation. Therefore, most human activities are lacking careful and considered ecological consideration at the local level.

4.7.4 The Wastewater Management Legislation for the Maintenance of River Water Quality and Canals

The management of river water quality in Bangkok has been regulated by several statutes. The Enhancement and Conservation of National Environmental Quality Act (NEQA) of 1975 (revised in 1978, 1979, and 1992) is a comprehensive law for maintaining natural resources and water quality. ADB (2012) stated that NEQA contains significant provisions involving provision on water quality standards, wastewater treatment and effluent standards for domestic, industrial, and agricultural sources in order to prevent water resources from becoming polluted. Based on NEQA, the standards of water quality for the Chao Phraya River were also set in 1986.

The NEQA (1992) also requires those who cause pollution to treat wastewater at a common wastewater treatment plant provided by the government. The act also empowers government agencies in central, provincial and local levels to construct and operate a common wastewater treatment plant in their jurisdictions as well as having the authority to charge fees for wastewater treatment (DWR, 2014a). In Bangkok, the legal framework for wastewater tariff collection has been enacted since 2004 under the authority of Ministry of Interior (MOI) to penalise for non-compliance under the requirements of wastewater treatment and wastewater disposal from point sources of the NEQA (Act) 1992. However, ADB (2012) pointed out that the decision to implement wastewater tariff collection has been supervised under the authority of the Bangkok governor.

In order to control the water quality from wastewater disposal, the National Environmental Quality Act of 1992 regulated 3 decrees including control standards for sewage released from some sorts and certain sizes of building, from allocated land, and fuel stations. Thus, sewage discharged from these pollutant sources must be treated to the wastewater disposal standards before release into the environment. However, PCD (2004) claimed that with the lack of strict and efficient enforcement, many entrepreneurs still avoided operating the wastewater treatment system, and illegally discharged untreated wastewater into the environment. It is argued that the concept of such policy seems to allow poor performance and to be treated as a minimum obligation of the political parties. Thus, government agencies should take sustainable stormwater practices and ICM planning into account, via expressing it in law and policy to enhance an environment of long-term sustainability.

4.8 Policies on the Increase of Green Infrastructure in Bangkok

4.8.1 Bangkok Agenda 21

In response to global development agenda, the Millennium Development Goals (MDGs), Bangkok has set the ten points of Bangkok Agenda 21 to achieve the strategy for a sustainable Bangkok, within which environment, culture and tourism are main priorities. Bangkok Agenda 21 was initiated in 1998 as the development guideline to improve economic, social and urban environmental issues of the city for the next 20 years (Cities Alliance, 2007). The agenda is the driving force for environmental, social and economic sustainable development, and provides basic principles for the various activities in Bangkok.

The Agenda also aims to invest in green urban areas and create a clean city to deal with environmental degradation in Bangkok, while increasing a level of good governance in the BMA and promoting public involvement in the city development (Cities Alliance, 2007). The creation on a five-year Bangkok Comprehensive Plan under the goals of Bangkok Agenda 21 ensured that urban development places environmental improvement as a primary concern.

4.8.2 Bangkok Healthy City Policy

BMA has performed environmental tasks under the framework of Agenda 21 since 1995 with the Project of Environmental Strengthening of Bangkok Metropolitan Administration. To improve the quality of environment, Bangkok Healthy City Policy has been applied since 1995 by the BMA. According to Bejranonda and Attanandana (2010), the policy aims to improve Bangkok to have safe environment, create an appropriate environment for residing, promote good management, education, and health care, and encourage Thai cultural activities, as well as increasing community gardens, parks and flood retaining ponds. In 1998, BMA had performed work on Agenda 21 by preparing the ‘Bangkok Agenda’, which aimed to improve the city environment and quality of life in Bangkok within 20 years (1998-2018).

In 1994, the concept of a healthy city was introduced by the Ministry of Public Health, supported and operated by the World Health Organisation for the implementation of healthy cities including Bangkok and another four pilot cities. The development of the healthy city was carried out by the Office of National Economic and Social Development as the coordinating organisation. In 2000, the Board of the National Urban Development was established in order to set policy, to coordinate and operate the healthy cities, and to prepare a framework for sustainable urban development of a healthy city (Wijitkosum, 2011).

To promote the policy on Bangkok Healthy City’, the BMA made an effort to increase green spaces in Bangkok, of more than 4 square metres per person, through increasing the areas of parks and green space, including community parks, retaining ponds, street trees, and rain gardens (BMA, 2011b). However, Wijitkosum (2011) claimed that in some cities in England, the government planned to increase green spaces for more than 40 percent of total areas, while many countries are also building the new eco-town as well as redeveloping old cities to be an eco-town.

Moreover, the Bangkok Action Plan on adaptation for climate change had been implemented during 2007-2012, though specifying 5 measures to reduce global warming issue including; the development of transportation system and traffic system; the promotion of the use of alternative energy; the improvement of electrical appliances in buildings (Green building); the management of wastes and the wastewater treatment; and the increase of green area including increasing public parks, and promoting the planting of trees (Bejranonda & Attanandana, 2010).

4.8.3 The 25-Year Master Plan for Bangkok Green Area

The environmental problems of Bangkok have been improved with the cooperation from all sectors including the government sector, BMA, private sector, and society. In 2003, the 25-year master plan for Bangkok green area was established, which aimed at providing the long-term master plan for Bangkok green area for developing Bangkok to be the sustainable green city. To develop more green areas in the form of a public park, the green area master plan of Bangkok has been set to develop 41 public parks covering areas of 10,510 rai, consisting of flower gardens, ornamental plants, wetland plants, and perennial plants with 13.35%, 21.54%, and 65.11%, respectively. The budget used for the area of development excluding the cost of land is 5,594 million Baht. In the end of the master plan in 2027, Bangkok will have the areas of public parks covering 15,751 rai or equal to 4.050 square metres per capita (ONEP, 2006). The Project for the increase of green areas and public parks aims to increase green area in Bangkok by developing small parks, community gardens, green areas along the side of the canals, along the main road and the local road, and the decoration and renovation of landscape in the 50 districts.

The policy-based action plan on management of sustainable urban green area was introduced by the Office of Natural Resources and Environmental Policy and Planning in 2012 through the integration of relevant authorities and all sectors. The policy-based action plan requires the sustainable green area[3] in a university and a religious place of at least 30% of the land area for recreation and benefit to the environment in terms of filtering dust and reducing temperature of the city (Kithivechanon & Khongouan, 2012). However, it was found that many universities and religious places still also lack implementation as specified in the plan, such as using most of areas for buildings, concrete patio, and parking lots and development or improvement of the sustainable green areas. Considering such implementation, a very few temples and universities in Bangkok have provided the green area to meet the standards as defined.

4.8.4 The Green Government Buildings Policy

The green government buildings project was introduced by the Pollution Control Department in 2010. During the initial stage, the project focused its application through the one representative building of each Ministry, for 20 buildings in total. The project then would expand to 750 other government buildings including improving of the old buildings and creating criteria standards of new government buildings in the near future (PCD, 2011a). The criteria of the environmental management for green building also include implementing green infrastructure and water reuse practice (PCD, 2011b).

However, a survey by Chulalongkorn University regarding the conditions of the government's green infrastructure practices (PCD, 2011a) revealed that only 10 % obtained an excellent condition, while around half of government's buildings did not pass the standard assessment. It was noted that buildings that were built before 1996 had not been designed and constructed under the consideration

[3] Sustainable green area refers to the green area with large trees (the trees living many years, when fully-grown, have the canopy of not less than 5 square metres, with a height of not less 5 metres and circumference of not less than 50 cm) as the main component, and under maintenance for sustainable living (Khongouan & Sitachitta, 2010).

of the environmental impacts. However, the buildings of foreign private sector is directly affected by the requirement of foreign investors in that the new buildings must meet green infrastructure practice standards involving energy saving and environmentally friendly ways.

It is noted that there are increasing concerns with environmental improvement from the government agencies, with a new movement appearing in the policy outcome. According to PCD (2011b) Samples of good operation of the pioneering buildings under the criteria of environmental management for green office buildings can be seen in the practices of the office building for the National Development of Science and Technology with trees planted alongside the building; Mahatheerachanusorn Building, Library of the Chulalongkorn University with around 130 trees being planted in the area including the large size of grass field; Fifty-Year Building, Sathit School, Chulalongkorn University of the Primary Education Division with a lot of large trees inside the botanical garden; Mechanical Office and Communication Building, Highway Department with the large areas of impervious surface, small trees used on the roof deck, and large and small trees around the building covered by grass fields and use of rain gardens to infiltrate rainwater through the soil; Thai Airway Operation Centre Building with the large areas of impervious surface include the corridor in front of the building, covered with the grass field to drain water into the soil; Romklao Library office of Bangkok with large trees and gardens around the building and; Radio and Television Station Building of Thailand, the Department of Public Relations with numerous large trees to provide shades for the building and reduce heat from the hard surface around the area.

It was observed that most buildings in the urban areas have limited areas to provide open space or green area. However, considering the samples of good operation, PCD (2011b) found that some buildings are surrounded by large trees, permeable surfaces, pervious pavements, and grass fields which the water can be absorbed into the soil easily to reduce the volume and slow down water runoff from the hard surface. Although most pioneering buildings reused the water for gardening and cleaning ground surface, there is still a lack of regular practice and maintenance. It can be noted that the weakness of this policy clearly occurs because the core enforcement not depends upon legal mandate to support.

4.9 Current Practices of Sustainable Stormwater Source Control in Bangkok

In Thailand, it has also been widely recognised that water resources management has been implemented by a number of Royal Projects over the past 40 years (World Bank, 2011). The application of detention ponds for storing and treating stormwater as well as flood protection is relatively widespread.

There are six research centres established in several regions to remedy specific situations in those mountainous, flood plains and coastal areas. In Northern Thailand, the King's Projects take into account conservation of forest, soil, water, and catchment management. Vetiver grass has been used as a living wall to prevent soil erosion and to increase evaporation of soil moisture in forest areas. In Central Thailand, vetiver grass has been promoted to grow in alternating rows alongside other plants in order to increase moisture to the area and create a forest firewall. The ability of vetiver roots to penetrate deep into the soil in vertical range rather than horizontal direction makes this grass possible to grow without affecting other plants' growth. Moreover, the King's projects also encourage organic farming methods to minimise the use of chemical pesticides and fertilizers in the country (World Bank, 2011).

The Monkey Cheeks Project (Kaem Ling Project) was launched by His Majesty the King Bhumibol Adulyadej in 1995 to provide stormwater detention systems for minimising stormwater issues of Bangkok and other cities (Suksawang, 2012). To resolve water quality issues in Bangkok, several water treatment projects have been introduced including the Makkasan Pond Royal Project and the Rama IX Pond Royal Project. The natural mechanisms have been applied through a number of Royal Projects to clean up water in canals. The native plants particularly Water hyacinth, Umbrella grass (*Cyperus Corymbosus Rottb*), Elephant grass (*Typha angustifolia Linn*), Cogon grass (*Imperata cylindrica),* Coastal grass (*Sporobolus virginicus*) and Indonesian Vetiver grass have been used as natural water filtration for absorbing pollutants including organic materials, chemicals, lead and suspensions in canals, ponds and rivers (BMA, 2011a).

The Makkasan Pond, a 36-acre pond situated in central Bangkok and known as the city's kidneys, has been used to treat polluted water from the Lat Phrao Canal and adjacent communities, with the capability of efficient collecting and treating wastewater in Bangkok around 260,000 cubic metres per day. In the past, polluted water from surrounding areas, including wastewater from more than 700 slum households adjacent the pond and used lubricants from the Makkasan railway work shop, was drained into the Makkasan Pond. His Majesty emphasised the urgent need to restore and clean up the Makkasan Pond in 1985 by using water hyacinths as a natural water filter. Later on when the expressway was built and reflected sunlight away from the pond surface, Chaipattana Aerators were installed in the pond to increase the water oxygen levels and to support the water hyacinths and microorganisms in treating wastewater. The Makkasan Pond Royal Project has been adopted by the Bangkok Metropolitan Administration to plant 20,000 clusters of Vetiver grass in 2007 in order to create a natural wall in the pond and to protect landslides, absorb nutrient and heavy metals, and catch sediment covering an area of 440 square metres (BMA, 2011a).

The Rama IX Pond has been used to collect and treat dirty water from the Lat Phrao Canal. Several aerators have been set up to further increase the potential of water treatment. Rama IX Pond Royal Project is now able to treat wastewater around 28,000 cubic metres per day (BMA, 2011a).

The Chaipattana Aerator, the ninth aerator patented in the world, was initiated by the King and received five honors at the Brussels Eureka 2000: 49th World Exhibition of Innovation. An important feature of this aerator is its ability to accelerate the natural water treatment process through enhancing the proficiency of decomposition process by microorganisms. Currently, this technique has been applied extensively by BMA in canals and several ponds in public parks throughout Bangkok to increase the level of oxygen in the water (BMA, 2011a). The canal water quality has been improved during last 2 decades through several aerator systems to oxygenate the water in canals. Water from the Chao Phraya River is commonly pumped to the canals during the dry season. The water is then treated and pumped back to the river from Phra Khanong Pumping Station, located at downstream of the river (Leerasiri, 2010).

However, the application of SC approaches by private and public sectors is not widespread in Bangkok. In 2009, the National Housing Authority funded King Mongkut's Institute of Technology, LatKrabang, Bangkok to study and initiate the SC practices with a view to the reduction of long-term flooding in a housing project of the National Housing Authority. The focus of this SC practices is on flood protection and sustainable water management in consideration of the environmental aesthetics for this housing pilot project (National Housing Authority, 2009).

Overall, most environmental policies and plans in Bangkok mainly focus on increasing green areas or promoting recreational and landscape features. However, such policies and practices are still not focused on the benefit for improving water drainage and reducing stormwater problems. It is apparent that the application of green roofs, bioretention systems, swales, and constructed wetlands is relatively new and not widely used in Bangkok and its catchment.

4.10 Conclusion

During the last decades, Bangkok has experienced a rapid economic growth and extensive urban and industrial development. The development of manufacturing has resulted in a large-scale influx of new inhabitants, creating a demand for water resources and subsequently generating a large amount of wastewater. The water quality of the lower Chao Phraya River has continued to decline. The main sources of water pollution in the river are mostly generated from domestic waste as well as urban runoff flowing through high-density urban areas.

Economic development and uncontrolled land use change are likely to impact loss of natural areas. The pattern of urban growth in Bangkok has shifted from agricultural to residential land use (Swangjang & Iamaram, 2011). During the last decades, urban population has increased steadily on the eastern and northern parts of Bangkok, while the sprawl on the western part has primarily caused the loss of agricultural land (Perera, 2006). Agricultural areas have been converted mostly into industrial and residential developments (Ann Marome, 2013; Srisawalak-Nabangchang & Wonghanchao, 2000). These anthropogenic land-use changes along with coastal erosion of the delta intensify overflow and inundation in the floodplain areas.

Rapid population growth and industrialisation have also led to degradation of natural resources and environmental quality. It has been observed that untreated wastewater released to waterways and urban runoff is the main sources of the water quality problem in the Chao Phraya River and the Gulf of Thailand. World Bank (2011) indicated that about two-third of the rivers in the country have acceptable water quality, while degraded rivers are experienced especially in the lower river near Bangkok with low dissolved oxygen (DO), high demand by microorganisms to consume oxygen (BOD) and high ammonia concentrations (NH3).

Currently, the wastewater effluent discharge in Bangkok is mostly generated from domestic uses up to 75 percent (Leerasiri, 2010; BMA, 2011a; ADB, 2012; Suriyachan et al., 2012). The rapid changes of urban population associated with an inadequate and inappropriate water management system have contributed to the discharge of untreated water into rivers. The results of a water quality monitoring programme reported by several studies (Emde, 2012; MPH & MNRE, 2012; Pavelic et al.,2012; Suriyachan et al., 2012 Greenpeace, 2011; Leerasiri, 2010; Simachaya, 2010; BMA, 2009a; Tsuzuki et al., 2009; Greenpeace, 2007; and UNESCO, 2003) also showed that the river was contaminated by wastewater discharges from several point sources and non-point sources. Moreover, land use change particularly paddy rice conversion downstream has led to serious impacts on water quality in the Bangkok area.

The implementation of sewerage systems to service Bangkok's population has become the main approach to addressing the water quality issue over the last few decades. Pollutants generated from anthropogenic activities are often washed out to downstream catchments and water bodies during storm events. Domestic sewage is considered as a significant source of organic and nitrogenous pollution in the city. It was noted that the centralised wastewater treatment systems have been developed for more than two decades to capture all wastewater and stormwater inflows under a wide range of flow, ranging from a minimum to a peak daily discharge. However, wastewater treatment plants in the city are still insufficient (BMA, 2011a; ADB, 2012). The excess stormwater may exceed the capacity of the treatment facility during a heavy rainfall event resulting in overflows.

Considering the flooding issue, as Bangkok located in the tropical climate, the city faces a challenge with annual heavy rainfall, flash floods, and impacts of climate change. Moreover, Bangkok is located in the lowlands near the river mouth of the Gulf of Thailand. Stormwater runoff in Bangkok is mainly caused by river overflows, heavy downpours in the rainy season, as well as the tidal inundation effect. Flooding and sea level rise in Bangkok are likely to be serious and will possibly increase a number of secondary problems during the next few decades.

Furthermore, flooding is also attributed to the forest degradation accompanying the conversion of agricultural lands into residential, industrial and commercial areas, as well as encroaching on conservation areas resulting in conflict over land use (NESDB, 2012). The expansion of the community, the change of land use into housing and industrial areas, and the construction of transport routes cause barriers to the water way and destroy the drainage areas. Additionally, the soil also has less capacity to absorb and slow down rainwater to mitigate the effect of floods, as well as preventing the recharge of groundwater for water use in the dry season.

With regards to the water scarcity issue, the Chao Phraya River Basin often faces significant water shortages in the dry season (Tanner et al., 2009) due to an extended season of a long dry period (Jacobs et al., 2010). However, the rainfall pattern in Bangkok indicates the increasing uncertainty in weather in relation to both flood and drought situations. Hence, a more sustainable way is considered necessary to combine with the use of drainage pipelines, to solve flooding, drought, and water quality problems and to restore landscape degradation in Bangkok.

It is clear that human activities have contributed to a negative impact on environmental problems associated with stormwater runoff. Similar to many floodplain cities, rapid urban growth, and economic development in Bangkok are the major causes of water quality deterioration in rivers and canals. Conventional stormwater drainage systems often direct runoff to impair streams and rivers, resulting in the degradation of ecosystem function.

Under urban expansion scenarios for the case of the flood-prone area of Bangkok, the population is estimated to increase and city growth patterns appear to heighten vulnerability. Although several plans and strategies on environmental management have been promoted for both national and local levels, strategies on land use planning, ICM, and creation of green facilities and sustainable stormwater practices have still insufficiently been addressed.

The recent development projects for dealing with stormwater issues in Bangkok include the provisions for increasing the capacity of drainage systems such as elevating flood barriers, flood walls, drainage tunnels, developing pumping stations, using sand bags for flooding prevention, and increasing landfill projects for raising the elevation of infrastructure. Up to date, most actual measures of adaptation are likely to be hard measures with massive capital investments. In response to future climate change, calls for even the construction of large flood protection infrastructure have become the main focus.

The structure of policy and legal frameworks in Thailand was addressed in this chapter to understand the planning processes operating for environmental planning and stormwater management. It is evident that there has been a number of recent policies, plans and actions particularly in Bangkok aimed at the implementation of green infrastructure and associated sustainable urban solutions. The Agenda 21, the National Economic and Social Development Plans, the Enhancement and Conservation of National Environmental Quality Act (NEQA), Bangkok Healthy City Policy, and the 25-Year Master Plan for Bangkok Green Area give priority to the consideration of socio-economic and ecological conditions devoted to minimising the demands on energy, water, and output of waste and water pollution.

However, it can be noted that while the existing environmental policies and practices can be an ideal model, it is not sufficient to capture the aspects of ecocentrism and sustainable stormwater solutions. A lack of coordination among central and local agencies, and lack of linkage between national environmental policies, environmental quality management plans, and local administrative development plans also results in inappropriate environmental management, ICM, and SC practices.

Considering issues regarding environmental policies, it was evident that the responsibility and obligation for the urban ecosystems are less of concern than the control of nature and other resources for human welfare and wellbeing based on anthropocentric views. This has possibly eroded the ability of governments to uphold environmental policies and plans. Several national environmental policies do not express ecocentric linkages of ICM and SC approaches associated with ecological sustainability. It is argued that existing environmental approaches are insufficient to protect the nation's waterways from ecological destruction resulting from anthropogenic environmental pollution.

Many cost-effective soft instruments and adaptation policies such as the use of green facilities and SC measures to reduce both urban stormwater runoff as well as enhancing environmental improvement often lack advocates. Engineering design based on historical flood events without acknowledging SC measures may be irrelevant under future climate regimes. The narrow focus on traditional inflexible urban planning without considering environmental aspects is a barrier to ICM planning in the country.

Thus, the paradigm shift from anthropocentric to ecocentric should be promoted, so sustainable stormwater solutions will have a chance of becoming a core standard to improve river water quality. Promoting the application of source control devices including green roofs, bioretention systems, pervious pavements, swales, and constructed wetlands may significantly reduce the load of stormwater contamination and combined sewer overflow (CSO) as well as reducing contaminants entering rivers and streams.

The challenges for policy and plans are in part within integrated catchment management. As policies and plans are the basis for budget decisions to initiate and enable adaptation, planning mechanisms should intervene by addressing an integrated adaptation strategy to national and local administrative development plans in order to increase and reallocate funds for improving SC solutions to promote environmental improvement in the country. To date, integration of adaptation policies has been rare. Thus, these development policies and plans could be the main strategy documents within which to incorporate cross-sector policy integration.

CHAPTER 5: CHALLENGES IN IMPLEMENTING STORMWATER SOURCE CONTROL SOLUTIONS AND ICM PLANNING

5.1 Introduction

The most persistent challenges for dealing with the sustainable stormwater management can be attributed to governance failures rather than resource-based issues, particularly corruption, the lack of civil society, inefficiency of governance structures, fragmented responsibilities, and over-regulation by rigid bureaucracies (Pahl-Wostl et al., 2012). To deal with these problems, effective governance for water resources management requires integration of social and physical processes within catchment boundaries (Lebel et al., 2005). Thus, there is a need to raise the understanding of the stormwater source control (SC) practices jointly within socio-economic and ecological dimensions.

This chapter explores the challenges in implementing ICM and sustainable stormwater SC practices through analysing existing knowledge and literature on its practices in Bangkok and the Chao Phraya River Basin (CPRB). Apparent gaps in the literature are explored and the chapter then continues by outlining the data collection and analysis. An effort has been made to review related studies generally published as journal articles, research or government reports.

The numbers of barriers were identified through the literature review and the findings were then compared with the interviews. The qualitative findings are discussed which reveal the perspectives among the participants related to the barriers investigated. The implications arising from the participants' interviews were also described and discussed in detail. Finally, specific recommendations were made on how to overcome or achieve effective reduction of some of these barriers. The understanding of barriers to ICM and potential for sustainable stormwater practices is crucial in order to develop strategies that diminish barriers and to increase the implementation of alternative urban stormwater solutions.

A range of barriers for implementation of ICM and SC measures has been explored. Most scholars believe that these are institutional barriers rather than concerned with technical challenges (Jacobs et al., 2010; Marks, 2011; World Bank, 2011; Lebel et al., 2010; Lebel et al., 2012; GWP, 2013). To identify the barriers, results from comprehensive reviews and the interviews were subsequently distilled into the following nine major categories of the challenges: fragmented roles and responsibilities; technocratic path dependencies; challenges of centralised systems and hierarchical administration; limits of regulatory framework; financial barriers, constraint of land use and available spaces; conceptual and performance barriers; challenges of integrated knowledge; uncoordinated institutional framework; and limited community and stakeholder involvement.

5.2 Barriers in Stormwater Management

5.2.1 Institutional Barriers: Fragmented Roles and Responsibilities

During the last two decades, growing concerns regarding the need for environmental protection have emerged as public interest issues in the country. In response to water-related isues, the application of the ICM principle first appeared in the 1990s (Takeda & Putthividhya, 2015). However, the ICM approach by experts has been focussed on supporting the public interest in, overcoming flood and drought issues only, rather than also addressing clean water protection. Catchment based institutions have emerged over the last 15 years, from a relatively centralised structure at the national level, to a decision-making structure that has expanded citizen engagement and the development of participatory processes (Jacobs et al., 2010). The establishment of a regulatory agency, The Department of Water Resources (DWR) of the Ministry of Natural Resources and Environment (MoNRE) in 2002, with core activities to promote the ICM concept (Anukularmphai, 2010), may be considered as the most significant institutional reform for overcoming fragmentation problems. The formation of a catchment organisation with a specific environmental mandate can be seen as an opportunity for water resource management that reflects the catchment context.

Although ICM has been developed to address and resolve issues of water governance, the responsibilities of government agencies under the laws often overlap. This has often resulted in complications and confusion in catchment management. There are more than 30 government agencies at all administrative levels, involved in water resource management. Each agency typically works separately and operates based on their own objectives and priorities. This has frequently resulted in conflict between agencies. Institutional fragmentation is considered as one of the main barriers to achieving Integrated Catchment Management.

Participant 4 (CG): *There are too many agencies in charge of water management and working separately under their own missions. The change of structure in the bureaucratic system in the last decade resulted in more agencies in managing water resources; this increases the work procedures and sometimes the operation of water management is not in the same direction* (RI1)*.*

Participant 7 (CG): *The management of rivers and canals in the catchment is still confused and several agencies overlap, including local government authorities, communal systems, and the irrigation department. So, the water system is almost unmanaged and extensively used by farmers, households, and industries in the catchment through pumps and wells* (DW1)*.*

Participant 8 (CG): *Water pollution is not the responsibility of the Pollution Control Department alone, but there are many agencies involved. Practically, when an issue is the responsibility of several agencies, it is likely that the issue is not resolved in a timely and appropriate way because they believe that they are not the main agency in charge* (PC1)*.*

The separation of the management of individual natural resources, has mostly resulted from legislation that relates to management of each natural resource such as land, water, forests, coastal, fisheries and marine resources, and the environments there by empowering each agency to be responsible for each resource absolutely. A lack of coordination between different agencies frequently causes conflict, inefficient management, and destruction of natural resources in the catchment areas. As such issues and matters are not of particular concern, the consequence has led to fragmentation, omissions of performance, or failures to implement certain obligations or expected actions.

Participant 4 (CG): *Implementation on catchment management in the past has been a separate operation. There has been overlap between the agencies, both at the policy and operational levels, with a lack of integration in different aspects. So, this makes water management of the country become a crisis, with respect to drought, flooding, and wastewater management* (RI2).

Participant 7 (CG): *There have been many agencies involved in the management of water in the catchment, implemented according to responsibilities of each agency in order to solve immediate problems. There is clearly no practical way to change, and it may continue the same way in the long term* (DW2).

The increase in the separation of institutions was due to the lack of cooperation and coordination among organisations. Thus, expert suggested that the central government institution would remain in charge to determine the main decisions in overall water issues. Moreover, the planning system should accept the principle of sustainability as a fundamental norm at both the local and national levels in order to avoid fragmented problems.

Participant 13 (RE): *There should be establishment of a single water management unit to supervise overall water issues by those in charge of making decisions. This unit or person has absolute power; such as the Prime Minister or a Committee. There should be an appropriate organisation for managing water resources at the national, catchment, and local levels, and promoting public participation from all water users* (KU1).

At the National level, the Ministry of Natural Resources and Environment (MoNRE) and the National Water Resources Committee (NWRC) are responsible for formulation of policies and plans (GWP, 2013). Moreover, there are a variety of government agencies involved in water resource management, with water resources being managed by four main Ministries: Interior; Industry; Agriculture and Cooperatives; and Natural Resource and Environment. To date, each ministry is developing its own plans for water management, land use planning, and environmental improvement without coordination with other specific ministries. Each ministry frequently implements policies and plans under their own jurisdiction and budgets, with a lack of coordination and sharing information among government agencies (Marks, 2011). Table 5.1 illustrates the agencies responsible for water resource management in Thailand.

The Ministry of Natural Resources and Environment (MoNRE) has a wide responsibility for management of several natural resources and the environment, including surface water, groundwater, marine and coastal resources, forest management, protected area, mineral resources, wastewater management, and pollution control. However, GWP (2013) suggested that insufficient cooperation among subsector agencies within MoNRE becomes a major concern. Thus, cooperation and coordination among separated institutions and regimes are significant for dealing with the consequences of fragmentation. Moreover, in order to seek the stronger responsibility, government agencies should attempt to link state responsibility with environmental sustainability.

Table 5-1: The key functions and legal frameworks related to water resources management of government agencies (World Bank, 2011).

Primary functions	Ministries	Agencies	Regulations
National plan	Prime Minister's Office	NESDB	
Hydropower development and operations	Ministry of Energy (MOE)	EGAT, Department of Energy Promotion	EGAT (2511)
Irrigation development	Ministry of Agriculture and Cooperatives (MOAC)	Royal Irrigation Department (RID), Department of Land Development (DLD), Department of Agriculture (DOA), Royal Fisheries Department (RFD), and Office of Land Reform	Irrigation Canals (2483) and related regulations
Agriculture development and land use, and Land reform			Land Reform (2517)
Fisheries			Fishery (2490)
Permanent Secretary Office	Ministry of Natural Resources and Environment (MoNRE)	Including 76 provincial offices on natural resources offices on natural resources and	
Natural resource policy and plan, EIA		Office of Natural Resources and Environmental Policy and Planning (ONEP)	National Environmental Quality Act (NEQA)(2535)
Surface water resources management		Department of Water Resources (DWR)	
Groundwater management		Department of Groundwater Resources (DGR)	Groundwater (2520)
Marine and coastal resources management		Department of Marine and Coastal Resources (DMCR)	
Forest management		Royal Forestry Department (RFD)	
National Protected Areas		Department of National Parks, Wildlife and Plant Conservation (DNP)	National Forest Reserves (2504); Wildlife (2505)
Mineral resources management		Department of Mineral Resources (DMR)	
Water management and pollution control		Pollution Control Department (PCD)	NEQA (2535)
Public education and outreach		Department of Environmental Quality Promotion (DEQP)	NEQA (2535)
Pollution control from industries	Ministry of Industry (MOI)		Industrial act (2535)
Pollution control from industrial estate			Industrial Estate Act (2522)

Public health	Ministry of Public Health (MOPH)	Department of Public Health, etc	Public Health (2535)
Local administration and people wellbeing	Ministry of Interior (MOInt)	BMA, Pattaya, DOLA, etc.	BMA Act, Pattaya Act, Local Gov. Act
Water supply		MWA, PWA, Tambon, etc.	Metropolitan Water Supply (2510); Provincial Water Supply (2522); Water Supply Canals (2526)
Disaster Prevention and Mitigation		Department of Disaster Prevention and Mitigation	
Meteorology	Ministry of Information and Communication Technology (MICT)	Thai Meteorological Department	
Water transport	Ministry of Transport (MOT)	Marine Department	River Traffic (2456); Pier (2494)

The Department of Water Resources (DWR) under the Ministry of Natural Resources and Environment (MoNRE) is the principal agency responsible for overall water resource management, policy formulation, the water resources management plan and implementation in the catchment area, as well as administrating the 25 River Basin Organisations (RBOs) (World Bank, 2011; GWP, 2013; Takeda & Putthividhya, 2015). Moreover, the department still has responsibilities in supervising, coordinating, following up, assessing, and solving problems concerned with water resources, and also in developing guidelines and specifying standards and disseminating technology related to water resources, both at national and catchment level, in order for unity and sustainability of water resources management (Office of the Ombudsman, 2011). In response to flood and drought problems, various centres have been established by government institutions including the Water Crisis Prevention Centre organised by the Department of Water Resources (DWR) (GWP, 2013).

Although catchment organisations and a new Department of Water Resources (DWR) were established in 2002 to implement catchment governance practices and to transfer ICM reforms, Lebel et al. (2013) argued that much of the capacity, mandate and power to manage water resources is rarely delegated to catchment authorities, but instead remains within the Royal Irrigation Department (RID) in the Ministry of Agriculture.

Participant 7 (CG): *There are many agencies responsible for solving the problems of water resources, but they are not unified and management is under those ministries. Although DWR has a duty about coordinating management of water, it is not its core mission or beyond obligations of the agency* (DW3).

It was noted by interviewees that although many government agencies have shared responsibility for environmental improvement, they do not always share the same goal to protect the ecological integrity of the river. Furthermore, difficulties are likely to arise, as government agencies would do routine works such as annual reports without addressing stormwater SC practices and ICM planning.

Thus, it can be argued that government agencies fail to maintain environmental sustainability under the ecocentric system, rather heavily rely on an anthropogenic regime.

5.2.2 Technocratic Bureaucracy

Stormwater management is frequently seen as largely a technical issue and current practices mainly emphasise structural measures. Longer-term measures that could reduce stormwater generation or build resilience, like land use planning, ICM, and SC measures are not addressed in most climate change adaptation reports. The analysis of documents and interviews revealed that although several stormwater management measures are being implemented, most of the current practices such as heightening flood walls, drainage, and pumping capacity are not being implemented in a sustainable way and not explicitly taking catchment management into account.

Traditionally, the human-centred approaches derive from techno-centrism. Infrastructure is broadly perceived as the best solution, to overcome the impacts of floods most of the time. In trying to reduce risks of exposure from floods, Lebel et al. (2010) stated that the emphasis on infrastructure in conventional stormwater management has been promoted by politicians and experts to protect Bangkok and neighbouring provinces from flood risks. Although technology provides humans with a great power to dominate nature and disturb environments through human activities, it comes hand in hand with huge responsibility as well. Misjudgement of the government in exercising its authority leads to ecological degradation within its jurisdiction, such as dam construction that can potentially harm and alter the ecosystems of the entire catchment.

Most structural measures such as heightening flood walls, drainage, and creating pumping capacity in Bangkok fall under the jurisdiction of the Department of Drainage and Sewerage (DDS). However, the construction and management of dams, dykes, and pumping systems is the specific responsibility of the the Royal Irrigation Department (RID) of the Ministry of Agriculture and Cooperatives, to reduce floods and water shortages at national and regional levels (Lebel et al., 2010). It seems the government agencies have chosen an unsustainable stormwater practice based on an anthropocentric regime. Although it becomes an environmental improvement responsibility of the government agencies, the main concerns of government are still addressed using unsustainable practices in order to carry out economic development.

Bureaucratic and cultural norms persist that regard stormwater management as mostly a technical practice in which stakeholders have a restricted role as recipients of advice and assistance (Lebel et al., 2012). Decisions regarding a large infrastructure project are likely to rely on reports proposed by consultant companies with close relationships to government agencies rather than based on the public agendas or decision-making process of the catchment organisation (Jacobs et al., 2010). Lebel et al. (2010) stated that water-related infrastructure to prevent Bangkok from flooding frequently has significant effects on vulnerable groups. Moreover, dams can interfere with the river ecology and cause overflows in sensitive areas (Pavelic at el., 2012). To reduce flood risk in CPRB and Bangkok areas, the mitigation measures are as follows.

5.2.2.1 The Construction of Dams and Reservoirs in the Catchment

In the case of the Chao Phraya River Basin (CPRB), it was argued that most of the floodwater is generated in the upper catchments, flows into the lower catchment and discharges into a large area of the downstream parts along the Chao Phraya River in Bangkok and its vicinities (Komori et al., 2012). To reduce flooding in the downstream area during the wet season, the floodwater level is generally managed by the dam reservoirs in the upstream area to store rainwater and runoff. UNESCO (2003) stated that over the last sixty years, 3,000 reservoirs have been constructed to minimise the impact of flood risks, to store the water for discharge in the dry season, to supply the water for industrial and urban use, and to take advantage of the agricultural potential of the country.

The Bhumiphol and Sirikit dams, the two largest dams located on the Ping River and the Nan River respectively, are constructed to provide fresh water for domestic consumption, industrial purpose, irrigation, inundation control, and hydroelectricity generation (Komori et al., 2012). Additionally, the Bhumiphol and Sirikit dams also control the floodwater up to 22 percent of the whole catchment area. Bhumiphol dam contains a live capacity of 9.7 billion cubic metres (bm^3) compared to the average annual inflow of 6.6 bm^3 from a catchment area, while Sirikit dam represents a live storage of 6 bm^3 compared to the average annual inflow of 5.9 bm^3 from a catchment (UNESCO, 2003). Furthermore, the other three reservoirs were constructed in the upper catchments, creating the total storage capacity of combined reservoirs up to 24.7 billion m^3 (Komori et al., 2012).

5.2.2.2 Dykes and Flood Walls for Protecting Bangkok CBD

To minimise the risk of flooding in Bangkok, dykes were built to protect further floodplain development in high flood-risk areas. These flood protection systems have been constructed by the Department of Drainage and Sewerage (DDS) including the dykes from the northern to eastern parts of Bangkok and flood barriers along the Chao Phraya River and canals to protect the city from overflows with height ranging from 2.5 to 3 metres above sea level and extending around 77 km (ADB, 2012).

In the east of Bangkok, flood walls have been used to prevent flooding including in Khlong Sam Wa, Min Buri and Lat Krabang districts. Furthermore, in the west of Bangkok, flood walls have also been constructed along the riverbank of the Chao Phraya River, Bangkok Noi Canal, and Maha Sawat canal. Overall, flood protection systems through building levees enclosing the Bangkok area are divided into three areas of flood protection, as follows: enclosed area on the east of Chao Phraya River within the Royally-Initiated Flood Dyke with an area of about 650 square kilometres; enclosed area on the west of river (Thonburi side) with an area of approximately 450 square kilometres; and the eastern area of Bangkok outside the Royally-Initiated Flood Dyke with an area of about 468 square kilometres. These areas have been used as a flood way to drain water runoff from the fields into the sea to prevent flood risk at the enclosed areas within the Royally-Initiated Flood Dyke, which are the high population density areas and the main economic centre of the country (Thaiutsa, 2003; DCP, 2013).

5.2.2.3 The Use of Drainage System, Canals, Pipes, and Pumping Stations

To solve the problem of water drainage in the enclosed area, drainage systems have been constructed to drain runoff from Bangkok areas into the Chao Phraya River and the Gulf of Thailand. ADB (2012) reported that the current capacity of the drainage system can handle the volume of rain accumulated up to 80 mm in 1 day or a rainfall intensity of up to 60 millimetres per hour. The system consists of ditches and 1,682 drainage canals, with a total length of about 2,625 km. In the near future, BMA will improve the capacity of the drainage system to be able to support a volume of accumulated rainfall of up to 104 millimetres in 1 day or rainfall intensity at 80 mm per hour.

Moreover, several drainpipes or sewer lines have also been installed with 6,368 kilometres in length, divided into 1,950 kilometres along main roads and 4,418 kilometres in several communities to enhance drainage capacity from streets and households into rivers and canals. Furthermore, 174 pumping stations, 227 floodgates, and 259 pumping wells were constructed to drain water runoff into Chao Phraya River (ADB, 2012). According to DCP (2013) the drainage capacities of pumping stations have recently been increased to more than 360 main pumping stations. Hundreds of pumps and further preventive measures have recently been installed in the metropolitan areas to prevent flooding and support the drainage of stormwater.

5.2.2.4 Drainage Tunnels to Accelerate Stormwater into the River and the Sea

Large drainage tunnels were constructed to improve the efficiency of the drainage system in the Bangkok areas and to direct stormwater from flooded areas into the underground drainage system and into the Chao Phraya River. Drainage tunnels are at present being enlarged, with seven tunnel projects being constructed by BMA with a total length of 24 km and total capacity of drainage of 50.155 cubic metres per second (ADB, 2012). In the future, 6 more large drainage tunnels with a total length of 40.25 km, and total capacity of drainage of 360 cubic metres per second will be constructed. Three drainage tunnels are projected to be completed by 2017 (DCP, 2013). Overall, the drainage structures in Bangkok consist of a number of canals, drainage tunnels and sewer lines, which have a total length of 2,625 km, 24 km and 6,368 km respectively (ADB, 2012).

Considering the budget for stormwater management, NESDB (2012c) noted that the government has implemented the action plan on ICM for flood mitigation for the CPRB, with the budget of 300,000 million baht in 2012. This includes restoring, repairing and improving efficiency of existing infrastructures such as dikes, dams and drainage systems to prevent and mitigate flooding, scraping canal, and removing obstructions in drainage ditches. The project also includes the preparation of floodway or water diversion ways, the improvement of land use plans and major waterways, the construction of enclosed spaces (dikes) in the housing, commercial and industrial areas, and the implementation of the royal projects within the amount of 177,000 million baht. Such conventional viewpoints still have shortcomings in providing solutions that can effectively address the challenges posed by climate change.

Participant 2 (BMA): *Drainage systems in areas such as gutters, ditches, and canals have limited capacity to drain the flood from the area to the river. Therefore, it is necessary to construct the large underground drainage tunnel to speed up drainage of water into the rivers and the sea without passing the traditional canal system with limited capacity. The drainage tunnel can also help to dilute the polluted water in the canals in the inner community areas in the dry season* (DD1).

5.2.2.5 The Use of Monkey Cheeks or Stormwater Ponds in Bangkok

Apart from these drainage systems, Monkey Cheeks[4] (retention ponds) have also been established in 21 locations in Bangkok by DSS to contain water runoff. These ponds have the capacity to contain water volumes of approximately 12.7 million cubic metres (million m^3), retaining stormwater water at around 6.7 million m^3 and 6 million m^3 on the east and west of Bangkok respectively (ADB, 2012; DCP, 2013).

In the near future, several monkey cheek areas are planned for construction under the responsibility of the Ministry of Agriculture and Cooperative, the Ministry of Natural Resources and Environment and the Ministry of Interior, which are projected to cost 60,000 million baht. The projects include restoring and developing the monkey cheek areas in the upper and lower CPRB, defining measures to compensate damages in the designated water drainage areas, and developing agricultural and irrigation areas, and large wetlands to be the monkey cheek areas for about 2 million rai in the CPRB, and to be able to plant double-crop field twice a year (NESDB, 2012c). According to the interviews, some authorities suggested that ponds or water storage systems should be provided temporarily in order to retain water before drainage into rivers or seas as soon as possible, regardless of water quality or environmental issues.

Participant 2 (BMA): *Government should construct ponds and floodway to drain stormwater into the sea as soon as possible in order to reduce human impacts. If the drainage can be done quickly, the flooding would not take long time and this would reduce or eliminate the impact on the people life and agricultural plants* (DD2).

Participant 3 (BMA): *The local agencies should cooperate with the Royal Irrigation Department (RID) and the Department of Public Works and Town and Country Planning to acquire techniques of design and construction in their operation in order that the ponds or the water storage areas could lead to maximum benefit to the people both in the dry and wet season* (DO1).

Participant 1 (BMA): *The construction of ponds at the household scale under the New Theory is the effective way of managing a small land area and water resources for agriculture for maximum benefit.*

[4] 'Monkey Cheek' is a retention pond launched by His Majesty King Bhumibol Adulyadej. The project is located in Bangkok and vicinities under the authority of the Royal Irrigation Department (RID). The Monkey Cheek can be classified into two patterns; lowland as a large retention area, and ponds or canals. The former can be considered as natural floodplain area not cultivated during the rainy season. These lowlands will be vacant areas prepared to supply coming rainwater. Another type of Monkey Cheek can be regarded as canals or ponds which have a free storage and are feasible to contain the next runoff and local rainfall (Prajamwong & Suppataratarn, 2009).

Based on a self-sufficient economy, this can be done by allocating land into 4 parts; and using 30% of the land for ponds for storing water use for the whole year (CP1)*.*

Participant 13 (RE): *There should be the consideration of specifying target areas for public parks especially for floodplain areas in order to alleviate flood problems, focusing on specifying the sizes of parks, density of population, and geographical criteria of the city* (KU2)*.*

It was noted that although some sustainable stormwater practices have been recognised in several environmental plans, they are poorly implemented. Unsustainable stormwater practices or large projects are not associated with strong sustainability rather they weaken and decrease the ecological sustainability. As discussed previously, unsustainable stormwater practices lead to ecological destruction and negative impacts to human health. Thus, to achieve environmental sustainability, all members of society must place the value of nature and ecological responsibility at the top-level priority.

5.2.3 Challenges of Centralised Systems and Hierarchical Administration

5.2.3.1 Ineffective Distribution of Function and Authority across Levels

Although there has been an ongoing effort by the government to decentralise power and authority on environmental management, the central government still has a major role unilaterally, while the role of local governments is also limited. The Constitution of Thailand, B.E. 2540 (1997) and Constitution of Thailand, B.E. 2550 (2007) tend to reduce the role of central government and distribute roles and powers to local government to perform the tasks that affect local communities. One of the important missions that was transferred to the local administration organisation is environmental management through the participation of local communities in reserving, restoring, and sustainable utilisation of natural resources.

Additionally, although there are several laws that empower local governments in environmental management, the laws still require the central government to operate in the areas that are the responsibility of the local governments. These responsibilities include decision making on environmental policy, financial contribution in various environmental projects, pollution control, pollution control zone declaration, defining standards for controlling point source pollution, and declaration of environmentally protected areas.

Due to the promulgation of the the National Environmental Quality Act (NEQA), the National Environment Board has declared several provinces in metropolitan areas to be pollution control zones, particularly in densely populated areas such as Bangkok, Samut Sakhon, Samut Prakan, Nonthaburi, Pathum Thani and Nakhon Pathom. The law on pollution control covers environmental management in terms of air, water, noise pollution and other hazardous wastes, allowing public participation in environmental protection activities in their local communities. However, even if there is the decentralisation of power and duties on environmental missions to the local government, Jarusombat and Senasu (2014) noted that the roles of local governments in such missions still increase slowly due to limitations of knowledge, budgets, local administrators, as well as policy on environmental management.

As environmental investment is often beyond the financial and fiscal capacity of local governments, Jarusombat & Senasu (2014) suggested that central government should provide subsidies for the local governments. However, as budgets are still limited while there are several project proposals, local politicians often lobby the government officers at higher levels to have the project approved.

The mission on wastewater management requires high investment and operational expense compared to the fee charged by the local authorities, and needs large open spaces for water storage areas. Therefore, subsidies from central government and a long-term plan for large open areas are required in advance. Jarusombat and Senasu (2014) suggested that in some cases, the local governments might require subsidy for operating expenses of wastewater treatment, which is not consistent with economic principles of Polluter Pays Principle (PPP). This allows the local governments to obtain the subsidy for fixed costs, rather than the subsidy for operating costs. If the polluters receive subsidies, they would have an incentive to cause more pollution without being aware of environmental effects. In the case of Bangkok, a lack of enforcement of the Bangkok Ordinance on Charging for Wastewater Treatment B.E.2547 (2004) becomes another environmental issue as the local government leader and governor of Bangkok are usually elected by the local people in the area, so they do not dare to enforce such an ordinance as it might affect the voter base. Thus, the BMA has to bear the costs of wastewater treatment alone.

5.2.3.2 Centralisation and lack of Transparency in Water Allocation

Serious concern has been expressed in terms of the dominanting power of the central government to set a national agenda that supports government interests. Considering the centralised systems for water allocation among different users, it is apparent that the lower catchment particularly Bangkok's water supply has been prioritised for water allocation in the catchment. Water resources decision in national development is usually affected by national-level agencies, operated by centralised coordination, command, and control to ensure adequate water supply and fair allocation. Water management decisions previously relied on centralised authorities. In the case of water allocation, the distribution of water among sectors previously remained in the hands of the departments of the responsible ministers through a process of negotiation before each rainy and dry season (Takeda & Putthividhya, 2015). With the capital in the catchment, the politics of water allocation is given the highest priority to Bangkok's position. It has been critiqued by Lebel et al. (2005) that the ICM planning processes lack transparency.

The amount of water from the Bhumiphol and Sirikit dams is usually controlled by the Electricity Generating Authority of Thailand (EGAT), then allocated and distributed by the Royal Irrigation Department (RID) to irrigation projects. Among different users and economic sectors, highest priority of the water allocation from the dams is given to Bangkok's water supply, followed by an allocation to control pollution and saltwater intrusions, to orchards and shrimp ponds. On the other hand, the inland transport, rice, and farming downstream have been given the low priority for water allocation (Lebel et al., 2005). Similarly, the survey on water allocation decisions at RID and at the dam operation offices of EGAT by Takeda & Putthividhya (2015) also reported that the order of sector priority in the CPRB relies on the water needs for municipal use and industry, followed by environmental conservation (prevention of saltwater intrusion), agriculture, and inland waterway navigation.

Although central government has gained more influence over the implementation of water allocation, there are ongoing arguments focused on the consequences of central government practices. Bangkok City provides a case of highly centralised urban planning that impedes ICM programmes. The lower catchment has been prioritised for water allocation in the CPRB due to centralist political influence in favour of short-term economic interest. Lebel et al. (2005) stated that when a shortage occurs, water and electricity are given to industry and urban areas of the capital Bangkok first.

Participant 10 (NGOs): *The conflict always happens when the downstream people require the Electricity Generating Authority to release water in reservoirs to dissolve salt water during the dry season, but the authority also needs to maintain the water level to generate electricity for the Bangkok city* (TE1).

Highly centralised systems and hierarchical administration reduce capacities to implement ICM in the agricultural sector and local communities as the plans and budgets are often generated from Bangkok (GWP, 2013). The pressure between agricultural and urban interests is central to catchment management. Although irrigation water demand is the largest share on average, the irrigated area still gets only a small amount of water, which is left after demands from other sectors have been allocated. Due to inadequate water flows by gravity in the dry season, Lebel et al. (2005) noted that the use of pumps to access groundwater for rice cultivation is widespread by farmers in the lower CPRB.

Due to centralist political influence in favour of short-term economic interest, it is difficult to argue that the government has created environmental improvement based on sustainable stormwater practices and ICM planning. This might have resulted from unsuccessful governance in maintaining the balance of economic development and the environmental improvement in the catchment. As ecological destruction is recognised as a common concern of humanity (UNEP, 2011b), the government cannot deny their responsibilities. Thus, to achieve sustainable goals it is necessary for the government authorities to be in solidarity and unity to commit to sustainable stormwater practices and to call for a new social contract for water governance in the country.

5.2.4 Limits of Regulatory Frameworks

Although ICM planning already exists, the fragmented government and legal systems are still lacking a hierarchical role to pursue it. As discussed, the fundamental principle in terms of stormwater management and ICM planning has been dominated by a technocratic government. The current ICM planning regime has also been applied flexibly to include the various institutions and structures of authority engaged in environmental management. This also involves inappropriate legal principles related to it. Moreover, as the government bureaucracy with high corruption has subsumed society, the legal force underpinning today's society has continually weakened.

5.2.4.1 The Fragmentation of Water-Related Laws and the Delay of the National Water Act

In recent decades, there has been ineffective laws to support water resources management. The current water related law might not be enforceable by judicial action, as the obligation has been freely performed. As a result, river water pollution and the loss of environmental sustainability may not be reclaimed. To deal with water management, DWR (2014b) noted that the government has adopted the Regulations of the Office of the Prime Minister on National Water Resources Management, first promulgated in 1989, and amended (No. 2) in 2002. Such regulation has been implemented for a long time and some content is not consistent with the current situation. Recently, the Regulations of the Office of the Prime Minister on National Water Resources Management B.E.2550 (2007) has been revised, requiring the National Water Resources Board (NWRB), River Basin Organisations (RBOs), and the Department of Water Resources (DWR) to supervise the water management of the country.

It was noted that the legal aspect of integrating water and land use planning, has not yet been fully implemented, although the long-term comprehensive plan under the Town and Country Planning Act has been adopted by the Senate Committee on Natural Resources and Environment (GWP, 2013). According to Marks (2011), the catchment management has not progressed due to insufficient technical training and with no single regulatory framework on water management in place, to monitor policy implementation, which has reduced the government's ability to manage water.

ICM policy has been declared a key part of the National agenda since 2007. Several projects have been carried out to increase public awareness on water resources management, and legislation governing the use of natural resources such as land, forestry and minerals has been enacted over several decades. However, according to World Bank (2011), the comprehensive water legislation, a specific National Act, or Statute has not been released yet. Although the concept of ICM has been included in a number of National policies, legislation to implement the water policy remains inefficient.

Participant 7 (CG): *The DWR has no absolute power in supervision and management of water resources, especially the work relating to the Royal Irrigation Department (RID), as there is no law specifying the powers and duties of the DWR since the National Water Act has not been enacted by the parliament. So, law on water management should be urgently enacted in order to determine the role and duties of the DWR* (DW4).

Participant 12 (RE): *The DWR still cannot pass the water management law under the intention to improve the structure of national administration in 2002 due to a lack of power and duties of the Department* (CU1).

Participant 7 (CG): *In recent times there have been several agencies responsible for the management of water resources. If the Water Resources Act is enacted, the main organisations for water management will remain only the National Water Resources Board, the River Basin Commission, and the River Basin Sub-commission, with clearly determined compositions and authorities* (DW5).

Participant 4 (CG): *The government should speed up to enact the National Water Act that is important for preventing and solving stormwater problems and to increase unity in managing water resources at all levels* (RI3).

There is also a redundancy of laws in enforcement, especially in the fines, sanctions and obsolescence. Some laws have been promulgated for a long time, without revision to make them appropriate to the current situation, thus causing problems in enforcement (DWR, 2014b). Currently, there are a large number of separate water-related laws implemented by several government agencies within nine ministries, but those laws still do not cover all aspects of water resources management.

Participant 3 (BMA): *There is a variety of laws but lack of a master law or National Water Resources Act. Although the provisions relating to water management are embedded in many laws, their contents are not comprehensive. So, enforcement does not cover all cases. There are problems of obsolescence and gaps in the law. This is because some of the laws on water in force today have been promulgated a long time ago without updating the content to suit the current situation* (DO2).

Table 5-2: Water pollution legislation and responsible ministers (WEPA, 2013)

Legislation	Responsibility Ministries	Regulated Activities
Enhancement and Conservation of National Quality Act (NEQP 1992)	Ministry of Natural Resources and Environment (MoNRE)	Regulates wastewater discharges from point sources into water sources based on effluent standards.
Factories Act of 1992	Ministry of Industry (MoInd)	Regulates effluent discharged and restricts concentration levels of chemical pollutants
Navigation in Thai Waterways Act (Volume 14) as amended in 1992	Ministry of Transportation and Communications (MoTC)	Prohibits dumping of any waste into waterways that may pollute the environment or disrupt navigation in Thai waterways
Public Health Act of 1992 (Decentralised implementation to LGAs)	Ministry of Public Health (MoPH)	Regulates nuisance activities and wastewater discharge of buildings, factories or farmlands that cause water pollution and harmful health impacts
Cleanliness and Tidiness of the Country Act of 1992 (Decentralised implementation to LGAs)	Local Administrative Organisations (LAOs)	Prohibits dumping of waste in waterways

Canal Maintenance	Ministry of Agriculture & Cooperatives (MoAC)	Prohibits dumping or discharging of wastewater in canals
Building Control Act of 1979 (Decentralised implementation to LGAs)	Ministry of Interior (MoInt)	Regulates discharges of wastewater from building
Penal Code of 1956	The Office of the Attorney General (*OAG*)	Prohibits adding harmful substances in water resources reserved for consumption
Fisheries Act of 1947	Ministry of Agriculture & Cooperatives (MoAC)	Prohibits discharging of chemical hazardous waste into water resources reserved for fishing
Royal Irrigation Act of 1942	Ministry of Agriculture & Cooperatives (MoAC)	Prohibits dumping of refuse or releasing contaminated water into irrigation canals

It was found that most water management controls have focused solely on regulating each water resource individually, contributing to a lack of comprehensive law enforcement. In addition, with a lack of integration among responsible agencies for water resource and environmental management, this also has resulted in the fragmented operations and inefficiency.

With respect to legislation related to stormwater management, there are no direct and immediate legal sanctions to prevent environmental harms caused by unsustainable stormwater practices. Instead there is a general responsibility under general environmental laws. It is evident that there is still no specific legislation, regarding stormwater and drainage systems, for the permitting of the construction of infrastructure and buildings in Bangkok and its catchment. The requirements were mostly focused on the connection between the drainage system and the sewer network under the Building Control Act B.E. 2522 (1979). As described by DWR (2014a), although there are more than 200 ministerial regulations under the Act, the requirements for drainage systems and stormwater management, have not been recently discussed in the Bangkok ordinances on building codes under the Building Control Act.

Participant 14 (LG): *It would be hard to implement the sustainable stormwater SC practices consistent with the catchment context because there is a lack of core agency to take action and to be in charge of monitoring laws and standards. It is very important to set the core agency to implement water related laws, so that the water management would be efficient* (AT1).

At this point, the fragmented legal governance refers to the separation of an agreed upon goal, such as climate change, land, and water resources management, resulting in losing sight of the long-term core objective. Due to the fact that so many individual laws exist, the problems of conflicts, institutional problems and poor enforcement have occurred. Moreover, there is no single law regarding ICM planning, and sustainable stormwater practices. The lack of a proper legal instrument to hold such guidelines and standards cause significant failure for the stakeholders to perform and follow through the implementation. The unity and coherence of the stormwater SC practices should be governed by the Water Resource Act. Enacting the Water Resources Act will not only uphold the

Nation's responsibility in water resources management, but will also ensure and enhance ecological sustainability for long-term success. Thus, if we expect that the sustainable stormwater practices will be achieved, the urgent need is to establish a legally binding water quality protection instruments and increase the size of protected areas within catchment.

5.2.4.2 Ineffective Land Use Legislation

The Town Planning Act B.E. 2518 (1975) and B.E.2535 (1992) is considered to be the most important law for specifying frameworks for urban development. It addresses comprehensive urban planning and development in all aspects, including processes as specified in a Town and Country Plan for developing a new town and urban renewal, to promote the economy, society, and the environment. However, the concept of sustainable stormwater practices and ICM planning has not yet received recognition under the Act.

The Act intends to promote land use planning in both urban and rural areas through requiring the preparation of a comprehensive and specific land use plan for the purposes of city planning. According to DCP (2016), the aim of land use planning is *"to promote and develop economy, society and environment, to maintain natural resources, beautiful landscape or value of the nature, to develop the city to be clean, hygienic, comfortable for safety and welfare of society, as well as maintenance of places or valuable objects in terms of arts, architecture, history, and archaeology".* To achieve these objectives, the city planning is set into two types: 'comprehensive land use plan' aimed to provide a broad outline plan, and 'specific land use plan' aimed to provide details of specific areas.

A lack of comprehensive land use plans is one of the main problems that hinders the success of city planning. Although the Town Planning Act B.E.2518 (1975) requires the preparation of a comprehensive plan as a framework for urban development, and is enforceable by its enactment as a ministerial regulation for a period not exceeding 5 years, DPT (2006) noted that the land use plans prepared at the provincial, and municipal levels are in the form of development plans, not the comprehensive plan to be implemented as a framework.

The content of a comprehensive land use plan, usually includes general information of the municipality, the future land use maps, transport networks, but strategic plans or development plans do not exist in the Plan. The future land use maps which are usually prepared by the Department of Public Works and Town and Country Planning (DCP), apply only to major municipalities, and generally cover only some parts of administrative areas as viewed appropriate by the committees. Although land use plans have been enacted and prepared, most local agencies fail to enforce and implement the plans. The increasing urban land use and housing construction results in undersizing and the obstruction of the water drainage system and causes inevitable flooding.

Participant 12 (RE): *The land use plan prepared by the DCP has been ignored by other government agencies and it cannot be enforced or implemented efficiently. Without a land use plan for new housing constructions, this eventually causes problems in water drainage and flooding* (CU2).

Participant 15 (LG): *The mission on land use planning that the central government assigned to the local administration organisation seems to be unsuccessful as many land use plans have expired and there are no new plans or laws to enforce and implement. Many drafted ministerial rules are still not examined due to a lack of authorities and staff on city planning to set the new ministerial rules of the local community* (PH1).

Participant 9 (CG): *People who live near rivers and canals sometimes encroach over the borderline zone of the river. This leads to the obstruction of water drainage. BMA should strictly enforce the law concerned with the encroachment of rivers and drainage areas and should control the expansion of the housing community to reduce the encroachment near rivers or other public areas* (NH1).

Participant 2 (BMA): *There has been an attempt by a group of people to change the use of land for their own benefits, beyond those specified in the land use plans. This also leads to a water drainage problem* (DD3).

Participant 10 (NGOs): *Due to the lack of land use plans associated with water drainage systems, ditches have been filled in for the expansion of roads, pipes were constructed at an inadequate size, and the canals were created so narrow, leaving no other choice but to build a concrete dam to drain water* (TE2).

At this point, if one looks at the general principles of comprehensive land use planning, one would realise that most of those principles in fact attempt to determine only future land uses, without the details of current land use plans and measures to implement the plans. The future land use maps are the only measures in force for land use control. The map does not cover sufficient elements of the plan, which provides only three elements: land use map, transportation map and open space map, rather than covering key issues of urban development, such as public utilities, commercial and housing planning, and natural resources planning. DPT (2006) asserted that there is still no zoning map that controls buildings and land developments in each zone in detail, such as the issue of density, building sizes, open space and setback distances of the building.

Considering the issues of the specific land use plans, it is argued that most specific plans have not been made for urban areas. Although the specific plans are required to be prepared, enacted, and promulgated under the Act in accordance with the comprehensive plan, in practice, almost no specific plans have been prepared after the comprehensive plan has been enacted. Moreover, the Town Planning Act also allows the preparation of a specific plan for any area even when they have never had the comprehensive plan before, resulting in an ineffective specific plan.

DPT (2006) suggested that the law should require the preparation of the comprehensive plan (the structure plan) as a framework for the urban development before the preparation of specific plan with details of development in accordance with the framework set out in the structure plan. The law should not allow the preparation of a specific plan for any local community without the preparation of the structure plan. Also, the law should require the structure plan and specific plan to be consistent with the policy framework for urban development at the national and regional levels.

With regard to environmental protection, land use planning has often been managed without legal enforcement. Moreover, there are not yet any land use related laws concerned with protecting the ecosystem of rivers, at the same time as implementing future land use. Thus, it can be noted that legal instruments, until recently, have had no relationship with SC practices to promote environmental protection.

5.2.4.2.1 Challenges of Local Administrative Organisations for the Implementation of Building Control Act, B.E. 2522 (1979) and the Town Planning Act, B.E. 2518 (1975)

According to the Building Control Act, B.E. 2522 (1979), the Act authorises local governments in building control to have the power in mandating building owners to restrain or demolish the construction within a specified period if they are illegally modified. The provisions of the Act are brought into consideration of the executives of local administrative organisations in respect of permission for construction, modification, relocation or demolition of the building, using or changing the use of building. Therefore, the building owners need to receive permission from the local officials to issue a license under Section 21 or inform the local officials before constructing, modifying, or relocating a building. To examine for licensing, the local officials will determine whether those buildings are contrary to the building control laws and ministerial regulations on comprehensive city plan. If it is contrary to the regulations, the license application must be rejected without considering details of the floorplan as defined in the Act.

As mentioned above, it can be assumed that the Local Administration can issue local law for development of the green area in their jurisdiction as long as it is not in conflict with the ministerial regulation. Moreover, ONEP (2006) noted that Local Administration may issue a local law, which is contradictory with such ministerial regulation if approval is obtained from the Building Control Committee and from the Minister of Interior.

Under the Town Planning Act B.E.2518 (1975), the preparation and implementation of the comprehensive and specific town plans is still the responsibility of the Department of City Planning (DCP). However, the law also empowers local authorities to carry out comprehensive plans as well. The comprehensive plans prepared by local authorities must be approved by the Town Planning Commission as local authorities lack the skills and are not ready to take such responsibilities. The National Reform Council (2015) noted that although there has been transfer of responsibilities in city planning to localities, the Central Government still lacks a clear policy regarding town planning, ICM planning and SC practices. As a result, it lacks momentum and support for local governments to prepare comprehensive town plans.

Participant 5 (CG): *The small local authorities still have insufficient capacity and are not ready for the preparation of a comprehensive plan. However, a large local authority such as the Provincial*

Administration Organisation that has experts and knowledge in planning and environmental management should prepare a comprehensive plan, while the other local governments in lower level including municipalities and Sub-district Administrative Organisations should prepare a specific plan in accordance with the comprehensive plan (DP1).

Participant 15 (LG): *Due to a lack of availability and ability to prepare a comprehensive town plan by most local governments, such plans should be prepared by a central agency as a guideline for the local government to prepare a specific town plan specifying details of development based on the framework of the comprehensive plan* (PH2).

Participant 12 (RE): *Many local organisations lack systematic information and coordination between organisations. There is a lack of policy, plan and strategy to apply sustainable stormwater practices in most municipalities. Although the Town Planning Act B.E.2518 (1975) has identified development of parks and green spaces in the urban areas, most municipalities have not applied them* (CU3).

Participant 7 (CG): *As the measures under the Town Planning Act B.E.2518 (1975) may take much time to increase SC facilities, the local administration should take part in increasing practices and encourage public participation to increase green areas and SC practices in their lands. Moreover, the government should issue land use and water-related laws at catchment and local level as soon as possible* (DW6).

It was argued that most local organisations are not capable of implementing the mission on town planning assigned by the DCP. Although the Town Planning Act B.E.2518 (1975) allows the local governments to prepare the comprehensive town plan, most plans are still prepared by the central government, which may not reflect the needs of local areas. Moreover, it is important to accept that because the local government could not guarantee legal enforcement and establish the authority for land use planning, the government must rely on its own skills and capacity to perform their environment related duties and obligations.

5.2.4.2.2 The lack of Integration between the Implementation of the Building Control Act B.E. 2522 (1979) and the Town Planning Act B.E. 2518 (1975)

According to DPT (2006) there is still a loophole in the Building Control Act B.E. 2522 (1979) as it is applicable only to the construction, renovation, change of building use but, not including lands, which is not favorable to enforcement in accordance with the Town Planning Act. The building control officials perform their duties under the Building Control Act B.E. 2522 (1979), which sometimes is inconsistent with the Town Planning Act. This may cause inefficiency in land use planning. Thus, DPT (2006) suggested that the building control laws should be amended to cover the changes of buildings and land uses as well, and should be implemented under the permission of the town planning authorities in order to supervise the development projects and not to affect land use and the environment of communities.

Furthermore, there is a lack of regulation requiring the building owners to provide stormwater SC facility, either indoors or outdoors, or on the rooftop. The ministerial regulations and local ordinances define the utilisation of the open spaces broadly such as for planting, water storage areas or parking areas. According to the interviews, obstacles in the implementation of Building Control Act B.E. 2522 (1979) mostly occur as a result of enforcement issues.

Participant 1 (BMA): *The landowners have choices to take advantage of such open space without the necessity or requirement to use the space for sustainable stormwater devices or green facilities, as those facilities come with a cost to provide care and maintenance. As seen, mainly it is just arrangement of a garden on the terrace or mezzanine, with the purpose of recreation and beauty of the building* (CP2).

Participant 11 (NGOs): *The open space often appears and created properly during construction of buildings because a local official comes to inspect regularly. However, when construction is completed and the buildings have been used for a while, the local authority rarely monitors it due to not enough workers to do so. Many building owners make additions to the buildings without permission and change the use of open space* (AS1).

Participant 5 (CG): *The construction of large buildings must obtain a license from the government under the Building Control Act B.E. 2522 (1979), so the licensing agencies come to inspect those buildings one time per year, mainly to check for fire protection, building plans, and wastewater quality. There is a rare case of inspection on the management of green areas and green facilities* (DP2).

Several participants suggested that to enhance sustainable stormwater practices on government and private lands, the ministerial regulations, the building control law, the local ordinances, and land use policy need to be improved through adopting the compulsory measures instead of the optional measures.

Participant 9 (CG): *The Building Control Act B.E. 2522 (1979) and the Town Planning Act B.E. 2518 (1975) should be the main mechanism to increase stormwater SC practices through requiring the development of SC devices in the setback distance and space between the buildings* (NH2).

Participant 18 (D): *The implementation of SC facilities should be specified under the Building Control Act B.E. 2522 (1979) under the compulsory measure instead of the alternative measure. This can be done by requiring the building owners or occupants to provide green areas and SC facilities in their open space with perennial trees* (RD1).

Participant 13 (RE): *The Building Control Act B.E. 2522 (1979) and the ministerial regulations applicable to the Bangkok Comprehensive Plan 2006 require building owners to provide open space, but the regulations do not specify the need to provide a green facility. So, there should be measures for the requirement of the green spaces and SC practices with strict enforcement* (KU3).

Participant 12 (RE): *The BMA land use plans should focus on the preservation of agriculture land use as much as possible in order to maintain canals, rivers, and drainage areas, to reduce stormwater runoff, to treat contaminated runoff, and should enforce the plans strictly* (CU4).

Participant 14 (LG): *The land use plans must require water storage areas or reservoirs to store rainwater for domestic consumption and for agricultural use. The SC facilities for a new development project, especially large size commercial projects and government projects should be required under the laws* (AT2).

Even though the consequences of fragmentation and a multilateral legal system have not been recognised as legal norms, it is a challenge for government to reform its comprehensive law to bring coherence and unity to the law and governance. Although the existing land use law has been enacted, the legal principle itself becomes a huge obstruction to preventing ecological degradation as seen in today's anthropogenic land use issues and the depletion of urban ecosystems. Thus, the need for environmental protection requires agreement to ensure that land use related laws are binding. Furthermore, the sustainability approach should be undertaken in the face of irreversible outcomes in particular, if such consequences could cause harm to the environment and human health.

5.2.5 Financial Barriers

One of the main barriers for implementing stormwater SC practices is related to the high and upfront costs. Economic comparisons for SC practices are presented in a number of publications (Bettess, 1996; FHWA, 2000; Barbosa et al., 2012). Bettess (1996) examined the distinction between economic and financial consideration. Costs for the conventional system consist of high construction costs and high enhancement of downstream systems, whereas costs for infiltration systems include construction costs and lower enhancement costs of downstream systems. According to Barbosa et al. (2012), economic aspect of stormwater management practices is difficult to measure, such as the groundwater impact from infiltration, whereas financial aspect considers the cost arising from the system.

In conventional centralised sewage treatment system, 80% of the total costs is attributed to a pipeline and transportation of sewage. Thus, the whole life costs of a conventional treatment plant compared with the sustainable stormwater practices were observed to be more costly. For example, an example of economic assessment between conventional treatment systems and constructed wetland systems is presented using the literature data. Non-technically trained staff can operate constructed wetland while technically trained recruits are essential for the maintenance of conventional treatment systems. However, the design of some sustainable stormwater practices such as a constructed wetland may involve extra costs for harvesting and electricity, which is required for pumping, and aeration (Burkhard et al., 2000). Thus, Zalewski (2002) and Li (2012) suggested that sewage treatment plants were recommended to combine with constructed wetlands in order to enhance the potential of water purification and reduce pollutants from sewage overflows.

In the case of the Bangkok area, some experts believed that the expenses of stormwater SC practices are high. The government sector and local people may not be able to afford SC practices, so the implementation of those green facilities becomes challenging to achieve.

Participant 8 (CG): *The cost of SC is high compared to the income of people, so the quality of most infrastructures is low. Most local governments lack funding and personnel who have knowledge and understanding of SC practices. Local governments do not have enough environmental budgets and funds, so some public parks are left abandoned and SC practices lack maintenance* (PC2).

Participant 14 (LG): *Local governments do not have enough allocated budget to deal with stormwater SC management, so we have to use the budget from other missions, which makes it inefficient in its operation. The allocated budget should be increased consistent with the costs of SC practices to cover the whole life cycle costs rather than focusing on only initial cost for the constructions* (AT3).

However, some experts suggested that SC practices are still worth to invest, as economic development cannot be accelerated by ignoring the depletion of the environment.

Participant 15 (LG): *It would be worthwhile for government to invest in stormwater SC extensively, as the damage and environmental effects, which are equivalent or more than the cost of construction, could be prevented* (PH3).

Participant 13 (RE): *Environment values should be considered as one part of the economic values of the SC practices as the practices would result in reducing the cost of environmental management, electricity, water supply, and wastewater treatment* (KU4).

Participant 10 (NGOs): *BMA should invest in the development of the SC practices, especially in small areas not requiring much investment or along the streets in order to reduce environmental impacts of traditional infrastructure practices* (TE3).

Participant 17 (D): *Sustainable stormwater practices are value factors for real estates. A green area that applies perennial planting as the main composition would significantly save maintenance budget. Apart from the land price, buyers tend to be mostly concerned about the amenity and landscape value of an area* (PD1).

5.2.5.1 Insufficient Budgets for Environmental Management

Considering the budget for environmental management and although environmental issues are recognised as the important ones, which affect the well-being of the wider public, the budget allocated for environmental development remains low, which makes the operations associated with the conservation of the environment and natural resources not fully successful. This is because environmental budgets are separated from, for example, drainage budgets when the latter could be spent in such a way that it resulted in environmental quality improvement as well as drainage capacity. Combining budgets can increase financial efficiencies rather than environmental costs being an addition.

In fiscal year 2012, the Central Government set a total budget of 2.38 trillion Baht based on nine national development strategies. However, it is found that the budget for the strategy of conservation of natural resources and environment was allocated only 45,182.4 million baht or 1.9% of the national budget (In 2011, it was at 1.8 %). In terms of the budgets related to environmental issues, there is a very small proportion, accounting for 211,477.3 million baht or only 8.9% of the total government budget (ONEP, 2013).

Insufficient budget also becomes the major cause of ineffective environmental management at the local government level. Although the amount and proportion of local revenues is currently increasing steadily, it is still considered very low compared to the total revenue of the Government, and does not meet the minimum requirement of the Determination of Plan and Steps in Decentralisation of Authority to the Local Administrative Organisation Act B.E. 2542 (1999) that requires a proportion of local revenue not less than 35% of total revenue of the Central Government.

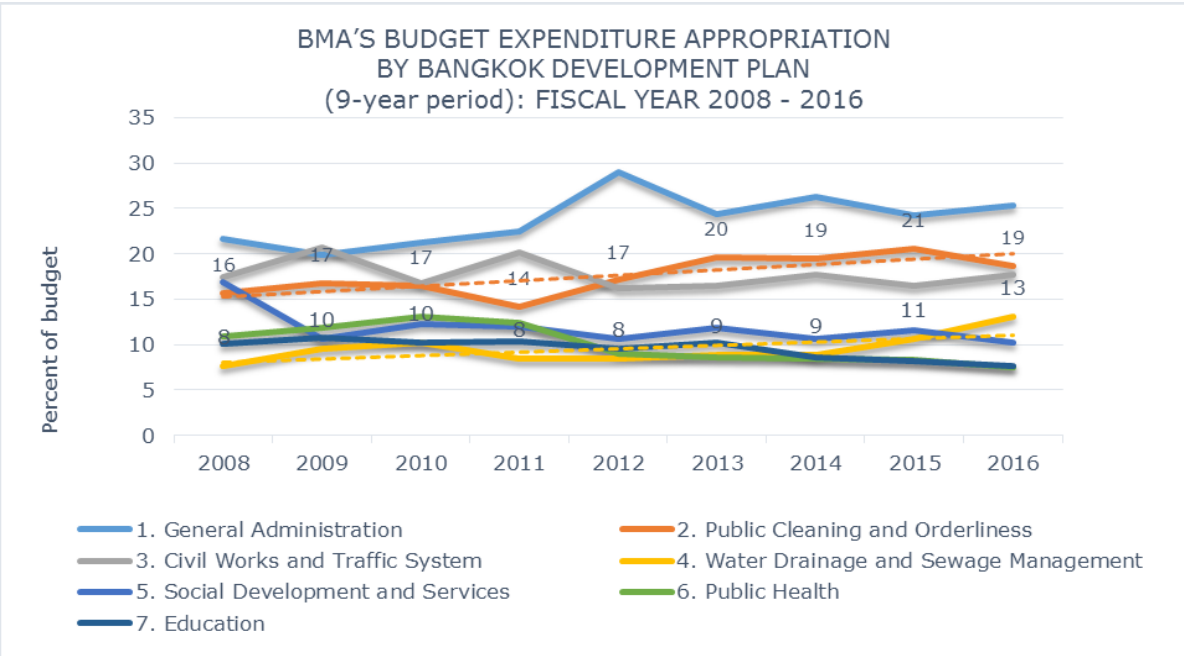

Figure 5-1: BMA's budget expenditure appropriation by Bangkok development plan (9-year period): Fiscal Year 2008 – 2016 (The Bangkok Metropolitan Administration Budget Department; BMA, 2009b; 2010; 2011b; 2012a; 2013b; 2014; 2015; 2016)

It is also found that allocation or subsidies from the Central Government for environmental management are usually in the form of grants to solve problems, rather than focusing on prevention. Moreover, the grant is usually provided for the investment of large-scale construction, and being transferred to local governments to further administer. This has often resulted in ineffective management by the local governments to maintain large infrastructure due to a lack of local funding.

Participant 16 (LG): *Local Budgets are still limited and most of the budgets have been spent on community infrastructure such as roads, buildings, floodwalls, and purchasing equipment rather than environmental improvement, training workers, and developing local knowledge* (PT1).

Participant 10 (NGOs): *The local plans usually focus on the building of a pumping station, a floodgate and a number of large water storage areas, which demand a high investment* (TE4).

Jarusombat and Senasu (2014) noted that most local governments in metropolitan areas have environmental plans and have allocated a budget for environmental management of less than 10% of the total budget in recent years, and more than 75% of local governments have insufficient environmental management budgets. However, some local governments in metropolitan areas have financial potential and adequate budget in environmental management due to high income and revenue.

Participant 15 (LG): *Although some local governments have a policy and a campaign for green infrastructure practices, most local agencies still have not enough budget being allocated for their operations and there is no such action at all. Local Budgets have been allocated for only traditional infrastructure practices and determined at the fixed rate, so this led to the failure to support the long-term environmental improvement* (PH4).

Overall, the local environmental budget is still inadequate, resulting in unsolved environmental issues. To enable the local governments in environment management, the actions on environmental taxes and fiscal tools should be taken into account. Jarusombat and Senasu (2014) suggested that the central government should increase subsidies to local organisations for environmental activities, which should take into account the conditions and severity of environmental problems in each local area rather than considering only the proportion of local income and population.

In the case of Bangkok, there seems to be insufficient funding and land for the creation of large green areas or public parks which can facilitate stormwater management. It was observed that the green areas are mostly built as of two types including gardens along the roadside and vertical parks. Considering the funding allocated for developing green areas in Bangkok, the operational budget such as wage and utility costs is more than those costs for the development of a green area. ONEP (2006) claimed that the budget was mostly used for developing city landscape rather than increasing open space or parks. However, the budget allocated for Bangkok green areas tends to increase since BMA recognises the importance in improving landscape and the environment.

Bejranonda & Attanandana (2010) revealed that during 2005-2010, expenses concerned with the improvement of green facilities and green areas tend to increase at the rate of 22.4 percent per year, which seems to be the good sign for green area development in Bangkok. However, the authors reported that the budget for green area development was allocated from BMA for 873,688,700 Baht in 2009, but it is used to develop and improve green area for only 330,430,300 Baht, or equal to 37.82 percent of the budget for developing green area.

To increase the budget for SC practices in Bangkok, the government should consider a tax incentive for seeking funds from the private sector, which is probably the source of most funding of green areas. ONEP (2006) suggested that the measures to promote the green fund include providing the deductions of corporate income tax and personal income tax for property owners who maintain green areas, green infrastructure, as well as donating to the green fund. Besides, the government shall determine an appropriate tax rate for the optimum charge to increase participation from the private sector involved in increasing the SC practices.

5.2.5.2 The Financial Incentives for Green Facility Implementation

Financial incentives and public subsidies are the main influence on the probability of sustainable stormwater systems adoption. Public financial support to promote sustainable stormwater approaches installation also creates a cost-effective opportunity for communities to consider in their efforts to minimise CSOs. Financial incentives to promote SC installations have been introduced in some municipalities in the US such as Portland (PBES, 2006; Greenroofs, 2014), Washington D.C., Philadelphia, and New York (Garrison & Hobbs., 2011). It was argued that the limitation of the financial support would cause ignorance of some sustainable stormwater practices that are valuable for the investment. Thus, economic incentives would be a good solution for their implementation.

In Portland, Oregon, financial incentive had been promoted to reduce urban runoff from individual land parcels. In 1993, the Portland Downspout Disconnect Programme offered inhabitants a US $53 incentive to redirect stormwater runoff from roofs to gardens and lawns. As a result, more than 47,000 households have responded to this strategy in 2005, resulting in the reduction of stormwater drained into combined sewer systems at approximately 4.2 million m^3 per year (PBES, 2006). Furthermore, to accelerate the installation of green roofs in Portland, the city allocated the eco roof incentive grants of up to $5 per square foot in 2010 for new green roof projects for all residential, commercial, industrial, and mixed-use projects. With the City of Portland's Grey to Green effort, more than 90 buildings have installed green roofs in 2010 (Greenroofs, 2014).

In Washington D.C., the District Department of the Environment (DDOE) recently adopt a River Smart Rewards Programme for offering residents to obtain a discount of up to 55 percent of stormwater fees when installing SC practices (Garrison & Hobbs, 2011). As described by Greenroofs (2014), Washington was the first state in the U.S. that required publicly funded buildings such as new offices, schools, and colleges to install green roofs over 5,000 square feet in 2005 in order to meet a national green building environmental standard.

In New York, a considerable tax credit has been offered to building owners who install green roofs and other SC facilities in the city. Green Infrastructure Grant Programme has been promoted to reduce CSOs and increase the installation of sustainable stormwater facilities in private property. The programme has promoted a new performance standard for allowable runoff discharge rate and increased green roof tax credit. The new performance standard, presented in 2012, aims to reduce the runoff rate allowed for discharges from new development and redevelopment properties into the combined sewer system. The technical design guidelines were also created to enhance the application of sustainable stormwater approaches such as green roof and infiltration systems. Under the Green Infrastructure Grant Programme, around \$11.5 million has been allocated to 29 green infrastructure retrofit projects on private property since 2011. To subsidies building owners, in 2013 the city increased the tax credit value for the installation of green roof up to \$5.23 per square foot, with a maximum credit value of \$200,000 each project. Green infrastructure efforts also include the increase of on-site retrofits at public facilities, initially focusing on schools and public housing projects (Garrison & Hobbs, 2011).

According to Greenroofs (2014), financial incentives have been provided under the bill passed by the New York legislature in 2008 for enhancing green roof implementation, which building owners will receive a maximum annual property tax credit of up to \$100,000 when installing green roof covering more than 50% of rooftop space. This credit is equivalent to \$4.50 per square-foot of (0.093 m^2) roof area, or approximately 25 percent of the operating costs.

In Singapore, there has also been an effort to accelerate the implementation of green roofs in the country. The Green Roof Incentive Scheme has been launched by Singapore National Parks (NParks) to heighten the retrofit with extensive green roofs by owners of existing buildings. Greenroofs (2014) reported that under the incentive project, the building owners will be subsidised up to 50 percent of installation costs of green roofs in Singapore's downtown and adjacent areas.

In the case of Bangkok, several experts suggested that social acceptance of sustainable stormwater practices would be particularly high if government promotes financial incentive to support SC practices in old and new buildings.

Participant 12 (RE): *The government should encourage the private sector to invest or co-invest using tax incentives to increase the SC practices. The laws related to taxation may need to be revised and promoted the use of tax incentive to land owners to provide green facilities* (CU5).

Participant 15 (LG): *the government needs to establish an environmental fund to promote the increase of CS practices. The use of economic incentive in stimulating the development of green areas should mainly consider the needs of local people* (PH5).

Participant 17 (D): *There should be financial incentives, bonus, tax reduction, subsidies or rewards for building owners to increase CS practices in their properties for a large project, especially along the recession area of the project* (PD2).

Participant 18 (D): *BMA should support housing entrepreneurs in management of SC practices in terms of knowledge, plant varieties and services to reduce costs in management of the project*. *Financial incentives should be promoted for design and construction processes for entrepreneurs* (RD2).

It was argued that the limitation of the financial support would cause ignorance of some sustainable stormwater practices that are valuable for the investment. As those participants have pointed out previously, although some of them seem to ignore the consequences of ecological degradation and the implementation of SC due to a lack of budgets as discussed previously, the economic incentives would be a good solution for its implementation.

5.2.5.3 The Promotion of FAR and Bonus System for Increasing Green Area

There was a major change in Bangkok land use planning in 2006 due to the implementation of the Bangkok Comprehensive Plan B.E. 2549 (2006), which defined Floor Area Ratio (FAR) up to 10: 1 and decreased in descending order, coupled with requiring open space ratio for landowners in a residential and commercial areas in Bangkok CBD. The Bangkok Comprehensive Plan also defines measures to control density of land use through FAR and Open Space Ratio (OSR) in order to increase open space and improve landscapes of Bangkok.

As described by Pongphun (2007), the purposes of FAR are to *"control density of the population to comply with the infrastructure and public utilities, to reduce traffic congestion in areas where the road network does not meet standard, to prevent the construction of large or tall buildings obstructing views and environment of residential areas, and to prevent the urban sprawl in agricultural areas".* Moreover, the purposes of OSR are *to "provide sufficient open space in the case of unforeseen disasters such as fires, to promote a better environment for buildings, and to promote beautiful landscape"*. Considering the incentive measures for increasing green areas, the regulations of the Bangkok Comprehensive Plan B.E.2549 (2006) also provides a bonus to increase Floor Area Ratio (FAR) up to 5 times of the open space provided, with not more than 20% of the FAR for the building owners who provide open space in high-density residential and commercial areas.

Moreover, the establishment of rainwater retention areas for private buildings has been promoted through a higher Floor Area Ratio (FAR) in designated zones. Measures to promote green space and natural waterways provide a bonus of up to 5-20 percent of FAR for property owners who apply rainwater harvesting techniques and retain rainwater from 1 to 4 square metres for 50 square metres of land (DCP, 2013). Furthermore, the 2013 Bangkok Comprehensive Plan has also introduced a new provision that requires a pervious surface of at least 50% of the open space ratio of each land use type to increase green space and reduce runoff overflows in Bangkok.

For rural and agricultural land use, DCP (2013) described that Bangkok city has also set the rules to reduce the floor area ratio of total land area (FAR) from 1:1 to 0.5:1 to create a water diversion channel for preventing and mitigating flooding in Bangkok and its vicinity. This rule has been set for those areas in order to increase open space with permeable surfaces (Biotope Area Factor or BAF) for not less than 50 percent of the land areas. The rule aims to provide drainage retention areas for preventing stormwater runoff as well as increasing green space.

5.2.5.4 Environment Tax from Sources of Pollution for Offsetting the Cost of Green Facilities

Taxation mechanisms have still not been widely used in environmental management in the country, especially at the local level. An establishment of a fund for development of green facilities would offset the revenue the community may lose. Community acceptance to this environmental tax system is an important step to create a fund from these environmental issues. An environment tax from sources of pollution would also be the easiest way to increase tax revenue to offset subsidies of increasing green areas in municipalities.

Participant 13 (RE): *The taxation system is applied to those who work, those who add value and those who have saving, but not applied to those who cause stormwater pollution. The pollution tax is still new. So, the imposition of a stormwater pollution tax in an urban area should be considered to apply urgently in each municipality* (KU5).

Participant 10 (NGOs): *It should levy those who generate pollutants such as from housing estates, shopping malls, gas stations, industrial plants and vehicles. The tax collected could be used to develop green space or SC infrastructure to promote a better environment* (TE5).

The impact of pollution on the environment is an external impact that entrepreneurs tend to pass on the costs to society to reduce the environmental cost. In managing natural resources and the environment, the principle of 'polluter pays principle' or PPP and 'beneficiaries pay principle' or BPP need to be considered (TEI, 2015). Thus, communities should develop the fund supporting on environment of the community through environmental taxation on those emitting pollution, harm to the environment or have inefficient use of natural resources in the area such as sources of poisonous smoke emission, source of discharge of wastewater, on improper use of land. The revenue from the taxation of those emitting pollution would be used to support environmental activities, such as increasing green facilities and green areas.

It was noted that the most extensive use of economic measures for increasing and managing green facilities in the OECD (Organisation for Economic Co-operation and Development) countries are charging for pollution, followed by deposit-refund system, fines, and subsidies. In European Union countries such as Denmark, Finland, France, Germany, Italy, Netherlands, Sweden and Britain, environmental taxes applied to those who cause environmental impacts have been introduced to prevent and reduce pollution. This environmental taxation is found to increase steadily, and has accounted for 6.71% of total tax revenue of the European Union. In Denmark, its government reforms the tax structure through compensating the value-added tax and income tax with various types of pollution tax. In Canada and Australia, the revenue from the taxation of those emitting pollution has been implemented to improve the environment. In Thailand, Forestry Research Centre (2004) noted that the fiscal tool has been used to improve the environment including oil tax reduction for unleaded petrol. Moreover, fees for wastewater treatment have also been applied for the service of pollution control in the country.

5.2.5.5 The Use of Economic Incentive through Tax Deduction and Tax Exemption

To promote the increase of green space, currently there are two laws related to taxation: the Property Tax Act B.E.2475 (1932) and the Local Maintenance Taxes Act B.E.2508 (1965). However, it was seen that both laws have no positive effect on the increase of green space because there is no tax exemption or reduction for those using the land for such purposes.

As described by Forestry Research Centre (2004), the rate of property taxes is divided into 2 categories: tax of house, related buildings and land used in relation to such house and other buildings at 12.5% of annual pay[5]; and local maintenance tax at 7% of annual pay. The local maintenance taxes are generally lower than property tax rates. Rates of local maintenance taxes in Bangkok are different in each district. The rates also vary with distance from the main road. All kinds of land to be calculated in the local maintenance tax will be based on the tax rate set by stages of fair price of land at present, divided into 34 stages, each showing tax the amount per rai at fair price of land. The area which is paid for property tax is unnecessary to pay local maintenance taxes.

However, there is no tax deduction mentioned in the Property Tax Act B.E.2475 (1932) whether the land is planted with seasonal plants or perennial plants. With respect to the Local Maintenance Tax Act B.E.2508 (1965), the tax deduction is provided only for agricultural land in a type of seasonal plants. Forestry Research Centre (2004) suggested that it is necessary to revise the list annexed to the Local Maintenance Tax Act B.E. 2508 (1965) for tax deduction to the agricultural land in type of perennial plants as same as that of the seasonal plants.

Moreover, in order to create incentives for landowners to increase green areas and CS practices, legal measures should be improved to include exemption or reduction of the Property Tax Act B.E.2475 (1932) and the Local Maintenance Taxes Act B.E.2508 (1965). Forestry Research Centre (2004) suggested that the ministerial regulation under the Property Tax Act B.E. 2475 (1932) should be issued to offer the exemption of property tax for the landowners who provide perennial trees with a circumference of at least 20 cm at a ratio of not less than 1 tree within 32 square metres, or 50 trees per rai.

To support the creation of green areas in a commercial area, Khongouan and Sitachitta (2007) suggested that companies or registered partnerships should be exempted for income tax for twice the amount of expenditures in construction and maintenance of playgrounds, public parks, or private stadiums that are generally opened for public free of charge.

Incentive mechanism through reducing Local Maintenance Tax and property tax would result in changing the land use in favour of green facilities and green space and the value of the tax cut would be offset value of opportunity costs. The successful case of implementing SC through tax deduction can be seen in Malaysia. Thani et al. (2012) stated that the Malaysian Government has launched the National Policy of Climate Change in 2009 through providing financial incentives including exemptions

[5] Annual pay is the rent or opportunity to be obtained (Forestry Research Centre, 2004).

from stamp duty and income tax deduction for the owners of land and buildings who obtained Green Building Index (GBI) certification in order to promote urban resilience at a national level. The evidence shows the major increase of SC practices in the country.

To increase the SC implementation, the Building Control Act B.E.2522 requires open space for at least 30% of the housing area, which is not necessarily a green area (Forestry Research Centre, 2004). However, the tax incentives through reducing property tax and local maintenance tax for landowners to increase green areas and SC practices more than required by laws is necessary to enhance the better environment.

5.2.6 Physical Barriers: Constraint of Land Use and Available Spaces

Another cause of low implementation of sustainable stormwater approaches is related to the constraint of land use, drainage areas and available spaces. Although the idea of stormwater SC practices has been increasingly grounded in the research and science of sustainability in several countries, these practices have not been extensively adopted or applied in highly urbanised areas in Thailand. This is partly because of a belief that there is inadequate open space and land costs are too high thereby acting as a disincentive to install or retrofit devices into urban landscapes.

Participant 6 (CG): *Bangkok is the centre of the economy with crowded construction and commercial buildings, so it is hard to find land to develop to be a green area as the price of land is high. As there is little open space to increase the green area in urban areas, various forms of green spaces and SC facilities including vertical garden inside buildings and roof gardens should be promoted* (DE1).

Participant 18 (D): *The main problems to implement SC measures in the residential projects are the limited land areas because land prices are relatively high, so the space allocation is mainly focused on functions of activities. However, Budget for long-term implementation of SC should be allocated from Common fund for utilities management of the projects* (RD3).

Participant 9 (CG): *There are limited sustainable green areas in the city, which are mostly hard paving watertight areas. Moreover, there is a lack of green area development in each land use to join as a green corridor, so the concept of community green area should be promoted to increase green areas between urban and rural areas to be buffer zone. The project should promote walking tracks, biking tracks and parks for public use to meet the needs of the community* (NH3).

The Building Control Act, B.E. 2522 (1979) is the law regulating or defining measures in construction, alteration, demolition, relocation and using land in the urban community for the benefit of safety and good environment in the community. In regards to city planning, the Act allows the use of buildings to be based on the city plans, with defining conditions on size or group of buildings, density of buildings, the parking areas, as well as defining the area prohibited for construction, modification, demolition, movement or change of use of certain building types (Office of the Juridical Council, 1979).

Thus, in order to promote the use of SC practices, the regulation should address and classify land use activities that will be permitted or not permitted, including specifying other requirements such as open space ratio (OSR) or building coverage ratio (BCR), as well as setback distance between buildings in each land use type. The law should also specify the ratio of open space outside the building, which could be used for plantation and SC devices, with issuance of ministerial regulations requiring buildings to leave the open space at the specified proportion.

The role of land use, drainage area and the constraints on available space are major controlling factors in the implementation of SC measures. Several participants suggested that the promotion of SC practices can be facilitated by the use of devices in small spaces, including setback distance areas, along roadsides, urban voids, road islands, spaces under bridges, toll ways, deck space of a commercial buildings, rooftops, and recessing areas by all parties including public and private sectors.

Participant 16 (LG): *The small green spaces have the advantage on giving shade, scenery or recreation to those who use the land and travel around, and as a source to absorb toxic fumes in the air because it does not need a large area, so investment to increase SC measures in the small areas can be done easily* (PT2).

Participant 17 (D): *There should be measures to promote SC measures in the open space of infrastructure development, including areas in the setback distance along the roadsides and public waysides space* (PD3).

Participant 1 (BMA): *There are several potential areas to increase SC measures and green corridors such as near open spaces, roadsides, and areas along the urban voids. The installation of sustainable stormwater devices in these small areas would improve quality of environment; alleviate stormwater runoff; as well as reducing temperature in the hot season to some extent* (CP3).

Participant 13 (RE): *SC measures should be developed and applied to open spaces along transportation routes such as the side of footpaths, roadsides, road islands, interjections, spaces under bridges and toll ways to create beautiful landscape, pleasantness, and filter dust, air, and water pollutants from cars. There can be shrubs and trees that provide shade, but climbers should be avoided because their branches may affect the traffics. However, shrubs should be planted in public utilities zone of the city such as electrical lines and railway, but there should not be large trees within the distance that can harm or dangerous for traffic or people* (KU6).

Participant 17 (D): *In addition to install sustainable stormwater devices in the large space, increasing SC devices in many small areas at roadsides is also important to improve the urban environment, to treat the contaminated water before it flows into rivers, and reduce the temperature in the city* (PD4).

Participant 3 (BMA): *To apply the sustainable stormwater devices for a large building, the deck space of a commercial building, which usually has a flat multi-purpose roof, can be used as a rooftop* *garden. The gap between the buildings can be used to construct a rain garden; especially with an open space of commercial buildings* (DO3)*.*

Participant 17 (D): *There should be grasses planted on the rooftop, especially of high buildings with flat roof or deck. During rainy season, it can slow down or retain rainwater that would gradually flow into the drainage systems* (PD5)*.*

Participant 5 (CG): *It is important to promote green areas and rain gardens outside the building, especially the recessing area for the large building and the special large building under the Building Control Act B.E.2522. However, large perennial plants or wide shrubs may damage buildings' structure. Rain gardens should also be applied into public parks, open spaces around parking lots and along rivers and canals, and along corridors and footpaths* (DP3)*.*

Participant 18 (D): *The fields in front of department stores were mostly built with the hard concrete surfaces, often used for selling goods for business purpose, and used as the parking areas. However, such area should be replaced by porous paving for at least the half of total area, covered by shady trees or grass to create value for the area* (RD4)*.*

Participant 6 (CG): *There should be narrow shrubs or perennial plants with grass covered to provide shade along recession area of the riverbanks and to protect the banks. There should be the plants with branches and shrub that provide shade along pavements* (DE2).

Participant 11 (NGOs): *To increase SC practices, there should be a green space in the form of vertical garden for high buildings in order to save utilising space. Such vertical garden brings about a beautiful shade and reduces hardness of the hardscape materials. The areas recommended for the vertical garden include walkway along the fence, areas at significant spots inside the building and waterfront areas* (AS2).

Mixed land use approach can also be regarded as a sustainable urban land use practice to reduce impervious areas, stormwater runoff and negative impacts on water resources. According to Carmon and Shamir (2010), mixed-use zoning through the incorporation of employment, commercial, and residential zoning will serve to increase land use efficiency as it reduces the area of pavements and impervious surfaces - particularly roads, sidewalks and parking lots – which typically take up a lot of space and consume almost one-third of developed urban land.

Furthermore, the authors suggested that vertical mixed-use development is also considered as one of the sustainable urban land use practices as it consumes less land and creates less impervious cover in the catchment. The vertical development may further reduce water quality impacts compared to horizontal development, which impacts more runoff per individual housing unit. Thus, reducing imperviousness through land use planning and a balanced mix of housing may reduce runoff and create urban water quality improvement.

The combinations of parks and a series of sustainable stormwater devices are important to reduce urban runoff and improve stormwater quality. The potential role of retrofitting SC approaches into existing parks and network of land has been shown in the improvement of stormwater quality particularly nitrogen removal in an urbanised catchment in Adelaide, capital city of South Australia.

Segaran et al. (2014) described that the land use characteristics of the upper catchment of Adelaide range from highly urbanised residential and light industrial to agricultural conservation reserves, rural and protected reserve areas. The large area of parks in the upper catchment provides the potential to reduce the nitrogen load up to 62%, which is greater than the 45% target demanded for new developments in the country. In addition, in the eastern area of the catchment where the impervious surface areas (ISAs) are predominantly disconnected (80–100%), the current distribution of parks also offers great potential to reduce nutrient load generated from ISAs by up to 83%. It was found that large parks located in the lower catchment, and distributed small and medium sized parks located in the higher catchment along the stormwater network are effectively sited for improving stormwater quality. Evidence suggested that the annual nitrogen removal efficiency is generally positive for all of the parks, with the mean removal efficiency of 42% and a peak of 68%.

As described by Segaran et al. (2014), existing parks in an established urban catchment are reserved for stormwater filtration by networks of bioretention devices and an explicit treatment train covering 16% of park areas. The results show that the efficient combinations of parks and these SC devices play significant roles in stormwater pollutant reduction. The potential for nitrogen removal from stormwater was demonstrated by a decrease of up to 62% or 7.8 tonnes per year. In the past, the loss of coastal seagrass meadows and inshore sediment transport has contributed to a large nutrient load from the urbanised areas to the coastal waters (Fox et al., 2007; Segaran et al., 2014). The combinations of parks and stormwater devices including the use of vegetated swales, detention ponds and constructed wetlands implemented in existing public parks showed the improvement of urban stormwater quality.

It is apparent that the combination of the retention ponds and parks in Adelaide is an example of a successful case, which provide several benefits to the urban area. Public parks provide opportunities for integrating SC approaches for medium to high-density residential developments. As the constraint of high prices for competing urban land uses poses threats to and resistance against the adoption and implementation of SC strategies, introducing SC strategies within parks may mitigate public resistance due to lower public costs of storm water management. Establishing SC devices off site at nearby parks can not only improve river quality in an urban catchment but can also provide the additional benefit of reducing urban stormwater runoff.

5.2.7 The Challenges of Integrating Knowledge

Due to the challenges of rapid urban growth associated with limited knowledge and experiences of adaptation measures, the country confronts the challenge of integrating knowledge of ICM and SC practices from western countries. This has resulted in difficulties in integrating adaptation on technical measures and governance systems for planning agencies in both national, catchment, and local levels.

5.2.7.1 Challenges at the National Level

At the national level, the government has recently launched several policies and plans on water resource management. For example, the Department of Water Resources (DWR) conducted pilot studies in several catchments and sub-catchments to enhance understanding on ICM, and developed a strategic map on each catchment in 2009, involving detailed activities to be operated at the catchment and sub-catchment levels (World Bank, 2011). However, GWP (2013) argued that most programmes on water management have focused on the sufficient use of water in the agricultural sector and water quality control in the industrial sector, while sustainable measure for stormwater management have not been taken into account.

With regard to policy on climate change adaptation at the national level, although the government has launched climate change policies to mitigate environmental issues, its implementation so far has been limited due to shortcomings in the planning processes. In response to the World Summit on Sustainable Development 2002, the National Sustainable Development Strategy was developed in 2008. However, there seems to be inadequate information in the climate change report regarding the adaptation measures on SC management for the country.

Lebel et al. (2011) noted that although the Five-Year Strategy on Climate Change (2008–2012) was developed to reduce vulnerability to climate change impacts, the adaptation measures on stormwater management did not appear to be a high priority and were not even mentioned in its report. The national policy under the National Sustainable Development Strategy 2008 mentioned ‘climate change’ in only two pages out of 96 pages. Many existing environmental policies and plans were not formulated taking into account climate change adaptation.

Rural and urban development planning also have a different emphasis on climate change adaptation. Lebel et al. (2012) argued that in rural areas, the centre of attention is likely to focus on reducing poverty and increasing access to public services, while the emphasis on improving infrastructure becomes the main focus in urban areas.

Jacobs et al. (2010) also claimed that the research on water management and water policy studies is prominent by academic institutions, external consultants, and overseas development agencies, while there is very little research published by the bureaucracy and the catchment organisations. Consultant companies also have more in-depth data and better knowledge about water resources than line agencies (Olsson et al., 2006). Moreover, Lebel et al. (2010) addressed that there seems to be a lack of information-sharing and coordination within each government agency; most of them have their own data and information, and always keep it to themselves.

The Director of Environmental agency revealed that traditional urban planning that ignores the issue of environment and climate changes is the major barrier to adaptation policies on environmental improvement: *“There are only three factors in these planners' minds: land utilisation, expansion of* *road networks, and recreation areas as required by law. Environment and global warming have yet to enter their minds"* (Tangwisutijit, 2007; cited in Lebel et al., 2012).

The implementation of ICM planning and stormwater SC practices has not been promoted extensively in Bangkok due to a lack of shared knowledge in the various sectors, lack of continuity of networking and cooperation, associated with inadequate support, personnel and funding. Some stormwater SC system lack ongoing maintenance, making them dilapidated and non-functional.

Participant 12 (RE): *There is still a lack of integration of knowledge and information of each agency. Stormwater management was traditionally the responsibility of the RID, later on, the DWR was established in the last decade for managing water resources, but it appears that personnel in the DWR still lack knowledge, expertise and experience on stormwater SC management* (CU6).

Participant 13 (RE): *The SC practices were also not practiced appropriately in terms of energy and water saving and wastewater management in the way that would reduce the environmental impacts. One factor that causes inefficient practices of SC is a lack of knowledge in the government sector* (KU7).

Furthermore, to deal with the impacts of global warming, there has been establishment of a national committee on climate change policy and the establishment of the Thailand Greenhouse Gas Management Organisation (TGO) at the national level. However, Jarusombat and Senasu (2014) revealed that due to a lack of clear policy and plans on climate change adaptation, their operation is still relatively ineffective.

A low level of institutional awareness in climate change adaptation is one of the main issues. Although the government has introduced national policies on adaptation to climate change, there has been a marginal impact due to inefficient institutional arrangements and fragmented politics, which impedes its capacity to adapt to climate change and environmental issues (Marks, 2011).

For example, the Office of Natural Resources and Environmental Policy and Planning (ONEP) within the Ministry of Natural Resources and the Environment (MoNRE) is the main agency responsible for climate change policy (Lebel et al., 2010). However, ONEP does not have sufficient authority, with only 11 staff, to monitor other agencies in the implementation of environmental policies on climate change (Marks, 2011). Moreover, Lebel et al. (2012) argued that the Ministry of Agriculture and Cooperatives and the Ministry of Industry have not given high priority to environmental policies on water quality improvement and climate change. Additionally, responsibilities for climate change adaptation policies also lie within other ministries, including the Ministry of Interior and the Ministry of Natural Resources and Environment. The lack of coordination between ministries makes adaptation responsibilities much more difficult.

Several methods of stormwater solutions still rely on agency specific strategies that fit within their areas of responsibilities. Climate change has mostly been seen by the Government as an environmental issue and has only marginally been taken into account in water resource management.

There is only a vision and a National Water Policy, but no strategic plans on water management at the National and catchment levels, leading to a lack of concrete action. The lack of unity in water management policy and plans resulted from various laws, which overlap but are not comprehensive and lead to enforcement or control difficulties. This causes confusion in law enforcement because it takes much time in diagnosis and interpretation and threatens the opportunity to deal with water problems. DWR (2014b) noted that the different and unsystematic data and information of many agencies also resulted in difficulties in plan implementation.

Bangkok is still in the early stage of planning for urban resilience, while practical application in an integrated and holistic manner is still limited. Integrated approaches to stormwater management will need to take into account changing stormwater regimes under climate change. Several strategic and action plans for climate change adaptation have been proposed. For instance, plans on climate change adaptation, Bangkok 12-year development plan (AD 2552-2563), has addressed the role of Bangkok as a green city in order to adapt to climate change, with a focus on maintaining and enhancing green spaces, green buildings, and supporting environmentally friendly transportation such as mass rail transit systems (DCP, 2013). However, the current adaptation measures in Bangkok have a hard engineering bias and it is not clear that those strategies will be the most effective approach, or will reduce the planning issues that currently exist.

Most of the primary responses to stormwater pollution mitigation within the Bangkok bureaucracy were to push for solutions by the Department of Drainage and Sewerage (DDS) of the Bangkok Metropolitan Administration (BMA). Stormwater management planning has until recently paid very little attention to environmental issues, whereas the strategies regularly refer to water quantity or risks of flood-related disasters (Lebel et al., 2010). Although early concerns have been addressed about technical solutions to resolve flooding issues, not much attention has been given to alternative stormwater solutions and adaptation measures.

Participant 2 (BMA): *Agencies concerned with water management such as municipalities should speed up the construction of ponds for large-water storage areas, especially in the area where there has been frequent floods in order to slow down the water flooding in rainy season* (DD4).

Participant 4 (CG): *In order to solve the flooding problem, we need to accept that flooding is a natural phenomenon that can occur. The long-term solution may have to deal with providing a detention pond or a sport's field to retain floodwater and to reduce the impact of floods on society* (RI4).

Participant 13 (RE): *The government has recently been concerned about the impact of climate change and promoted the urban green area development and recreation sites in order to absorb carbon dioxide, heat, and reduce air pollution in the Bangkok city* (KU8).

Participant 18 (D): *Building owners should use porous paving to reduce a hardscape area, and reduce reflected heat of the concrete and the risk of flooding in parking lots and courtyards* (RD5).

The lack of concerns and knowledge on climate change adaptation and standards on SC practices can be seen as significant barriers to ICM planning. Several experts suggested that the government sector should develop appropriate guidelines, standards, and criteria for SC practices to use as a model for other sectors.

Participant 3 (BMA): *The concept of SC practices is still new, and there are, as yet, no specific standards on its practice concerned with geography, weather, and physical environment of Thailand. BMA should improve and revise policy, law and regulation regarding SC practices to be guidelines for action and operation* (DO4)*.*

Participant 16 (LG): *There is no long-term successful result of SC practices, so the people have not much awareness and still hesitate about the worthiness of SC investment. It is essential to promote a campaign to boost understanding of public on SC practices and to train staff of local agencies to follow up and assess under the criteria of the practices* (PT3)*.*

Participant 11 (NGOs): *There are no standards for SC practices and no clear assessment mechanisms. There should be a study on measures to improve SC practices in communities, including a master plan for defining the percentage and size of development land to use for SC practices, encouraging the community to provide the area for SC devices, and assigning the host agency to be in charge* (AS3)*.*

Participant 18 (D): *Rules, regulations, standards, and criteria for SC pilot projects should be set up in order to improve the efficiency of the SC practices in both the old and new buildings. Government agencies should take action using government buildings as the pilot project to be the role model for private buildings* (RD6)*.*

Participant 13 (RE): *The government should prepare criteria and standards of the Thai SC practices in efficient and sustainable way. The related agencies should increase the number of the SC practices through applying such criteria in all stages of constructions and operations* (KU9)*.*

Participant 14 (LG): *The government agencies should develop and improve the assessment system of the SC practices, participate in the assessment process, promote the best model of SC devices, and develop materials and technologies that support SC practices* (AT4)*.*

Overall, water resource management has been seen as an isolated issue rather than focusing on a holistic water system that could be managed as part of catchment development. The potential impacts of stormwater runoff, on water quality in receiving rivers are not yet well understood (Lebel et al., 2010). Insufficient knowledge of ICM by National Ministries may hinder creativity of adaptive responses for sustainable stormwater practices. Thus, the need for capacity building in government agencies is important.

5.2.7.2 Challenges at the Catchment Level

In the CPRB, advocates have played a critical role in creating new knowledge that challenges the fundamental basis of catchment management. Emerging River Basin Committees (RBCs) in Thailand offer opportunities for enhancing public awareness on adaptive water resource management, particularly with regard to integration of land and water-use planning in dealing with significant shifts in water governance regimes.

It is highly expected that the catchment areas must be protected under the responsibility of catchment organisations. In the past, an interpretation of a catchment territory was widely recognised, but still became uncertain due to the fact that it was difficult to clarify spatial extent within its jurisdictions. In response to ICM policy, the Department of Water Resources (DWR) under the Ministry of Natural Resource and Environment (MoNRE) established River Basin Committees (RBCs) for the 25 catchments in 2004 (World Bank, 2011).

As described by Anukularmphai (2010), the major focuses of the RBCs consist of preparation of catchment plans, maintenance of catchment information, and conducting public relations. RBC memberships mainly comprise of government officials and community stakeholders at an equal number of representatives, while academics, and NGO representatives comprise 10-15 percent of total membership. The members of the stakeholders were not nominated, but were selected by each representative group. At present, nine members of the RBCs are representatives of the National Water Resources Committee (NWRC). This allows stronger connection between national and catchment agencies.

However, Lebel et al, (2013) argued that the lack of awareness in ICM planning and variety of members with responsibilities for top-down processes of national government agencies has resulted in too little progress in implementing ICM. Moreover, most experts have focused on tools like building large infrastructure to deal with flooding issue and scarcity of water, while only a few emphasised the importance of implementation of SC practices and ICM.

Considering the implementation of the catchment plans, the plans were formulated by the Department of Water Resources (DWR) of the Ministry of Natural Resource and Environment in 2003 with stakeholder participation in the process (GWP, 2013). A catchment plan is a tool that provides a statutory framework within hydro-geographical boundaries for promoting the natural resource improvement as well as reducing stormwater runoff. As described by GWP (2013), the water resources management plans for each catchment were developed by the River Basin Committees (RBCs) in 2005 through local communities' involvement and the participation of RBC mechanism. These plans have addressed the integration strategies for upstream and downstream operation, stressing land and water preservation in the upper catchment and ensuring fair water allocation for several purposes in the lower catchment and floodplain areas. Additionally, these measures also take into account the maintenance of water quality, and the mitigation of water-related disaster.

However, limitations are also observed in the development and implementation of catchment management plans. Anukularmphai (2010) argued that a loose strategy for ICM was proposed, and the need for an ICM plan tends to be ignored and was not the main focus from the beginning, while evolving later based on need. It is not clear what lessons have been learned from implementation of the previous catchment plans. Moreover, the ICM principle adopted had no fixed plan and no time frame given, but rather depended on the consequences of the previous activities. The implementation processes of catchment management have relied on a flexible time frame and work programme which helped to change processes among the involved stakeholders. Without targets and time-frame setting, succeeding processes largely depended on the outcomes of early steps (World Bank, 2011)

It was suggested that ICM plan has not been fully developed (GWP, 2013). Although catchment plans have been introduced for the 25 catchments since 2005, most of the plans have not been implemented due to an inadequate budget, knowledge, and disagreement with local public. The World Bank (2011) reported that the water budget for implementing ICM has been fluctuating and insufficient over the last decade. Only about 0.5-2% of the government budget has been allocated for water resources management, under the strategy of natural resources management. This contributed to difficulties in the catchment management in the country. Additionally, although the local government budget can be an alternative source to support water resources management, the water budget is still limited as there is no clear water management sector at the local levels: instead, there are fragmented water responsibilities in the agricultural and community development sectors.

With regard to a long-term catchment plan, the Twenty-Year Perspective Plan (1997-2016) was also developed by the Office of Natural Resources and Environmental Policy and Planning in 1996 in order to set the goals of Enhancement and Conservation of National Environment Quality, and policies for a Water Pollution Management Plan. This plan aims to control water pollution generated from community activities, agriculture and industry, to increase clean water resources, and to direct policy for all involved government agencies for protecting the natural environment (UNEP, 2011a). Moreover, the plans also address ecological functions of catchments including maintaining water quality in receiving waters (GWP, 2013). However, the mitigating measures to minimise pollution from stormwater runoff have still not been taken into account in catchment plans.

Based on the consideration of existing catchment plans, it is argued that BMA should play a major role in formulating an integrated stormwater management plan that takes into account water and land use issues in the catchment boundary. Additionally, the plan should offer strategies for preventing stormwater downstream by decreasing flows from developed upstream areas of the catchment. The useful requirement in the plan for stormwater management may contain specific protected areas for water sources, delineated flood plain areas, and a suitable location for detention and retention storage basins.

Participant 6 (CG): *Water resources management needs to be planned and implemented at catchment level, including upstream, midstream and downstream. At the upstream area, it should focus on reducing the volume and speed of the water. At the midstream area, it should focus on water storage and water diversion. At downstream area, it should focus on accelerating water drainage and mitigating the damage caused by flooding* (DE3).

To enhance the awareness and knowledge of ICM planning, champions or advocates are seen as important. Champions are considered as a group of people who strongly believe in the value of the ICM practice and serve as the driving force to achieve the ICM identified goals (Anukularmphai, 2010). Moreover, the champions also have the responsibilities to ensure external funding for sustainable water practices in catchments (Bos & Brown, 2012). Anukularmphai (2010) noted that experience-based knowledge from advocates is critical to support decisions about water resource management. The needs for consistency, patience, and continuous efforts by advocates or campaigns are equally important in the lengthy process of pursuing goals through an effective implementation of ICM process and to avoid derailment. Prominent and respected persons as advocates and champions are important to accelerate the ICM process and to be able to link community stakeholders, decision makers, and other relevant networks in complex and bureaucratic systems.

Actors have played an important role in coalescing around shared interests and considering alternative perspectives to reinforce social and political values and institutional responses. As described by Lebel et al. (2005), the capacity to create links with actors across bureaucratic hierarchies is a significant mechanism for maintaining or increasing power and influence for coordinating both upward and downward administrative levels in the network.

5.2.7.3 Challenges at the Local Level

At the local level, local governments are crucial to environmental improvement and have authority to implement environmental regulations. However, Marks (2011) argued that there seems to be inadequate technical, knowledge, and financial support from the Central Government to enforce environmental quality control and natural resource management in local communities. At present, it is clear that the local administrative organisations are not able to overcome the environmental degradation alone.

Local Administrative Organisations (LAOs) including the BMA are the main agencies responsible for natural resource management and environment in their jurisdictions. Local governments have authority to issue ordinances on environmental management. Several laws also allow local governments to issue environment regulations in the local areas. For example, local governments are able to propose their environmental plans to the province to be included as part of the provincial plan as well (Jarusombat & Senasu, 2014). Although several LAOs already make an effort to improve environmental quality, many of them also need a lot of technical support from other agencies.

Although local communities are aware of environmental issues, most local authorities do not understand their overriding importance and give no priority to environmental issues and no long-term context plan is provided, especially in areas which are politically contentious. The research on the Role of the Local Administration Organisation in Environmental Management by Patamasiriwat & Rayanakorn (2009) (cited in Jarusombat & Senasu, 2014) stated that the mission on environmental management is still not the priority task for local administration organisations due to a lack of awareness and low net-working co-operation.

Considering the three aspects of sustainable development administered by local government, the environmental pillar can be considered as the weakest part due to the lack of experts, knowledge, and budget compared to Central Government organisations. In terms of stormwater management, it was noted that most local administration organisations still have insufficient knowledge and understanding, with no dedicated personnel responsible for its implementation. Therefore, it can hardly be expected that by empowering the local government, the implementation of sustainable stormwater practices and ICM planning could be achieved. Additional personnel who have expertise in environment and stormwater management, sufficient knowledge and funding are still needed for local government, especially those with specific knowledge regarding local problems.

Participant 8 (CG): *There is a lack of information on integrated SC practices. Water shortage is a new thing for most people in floodplain areas and they are not familiar with it. The issue of stormwater quality and its impacts are also new matters of the society. In many cases, it is the responsibility of the officials in the local government who have no technical knowledge related to the SC practices, such as for gardening and maintenance staff* (PC3).

Participant 14 (LG): *Although there was an operation in training local staff about green infrastructure practices, and a manual for its management has been provided, the policies have not been implemented appropriately as we have technical problems and a lack of knowledge and experts for green infrastructure practices related to the local context* (AT5).

Participant 17 (D): *Problems in sustainable stormwater practices arise from a lack of knowledge and expertise, in terms of variety of plants suitable for the geography and buildings* (PD6).

Participant 8 (CG): *Government should train the personnel of the government sector and increase technical knowledge and capability of local government agencies to understand the SC practices. Local government should also improve materials, equipment, and database, and promote academic institutes to take part in developing staff in designing, and constructing the SC practices of local communities* (PC4).

Participant 3 (BMA): *The local governments should develop guidelines and manuals regarding practice of SC provided to each government agency using Thai and international standards to make it possible to follow up. Guidelines for sustainable stormwater practices including porous paving and rain gardens should be developed to be appropriate with particular characteristics, environmental conditions and limitations of each area and the uniqueness of each community* (DO5).

Participant 12 (RE): *Before assigning any mission concerned with water management to the local organisation, the DWR should provide guidelines and knowledge on water management and train staff. It is essential to increase knowledge and understanding of local agencies to maintain SC practices as it would reduce the environmental impact in terms of energy and water saving and wastewater management in the long run* (CU7).

Participant 16 (LG): *In assigning power to the local administration organisation, it is needed to prepare the staff and personnel to have knowledge and understanding as well as creating knowledge and research on SC practices that is consistent with the context of local society* (PT4).

The shortage of personnel skilled in the environmental field is also one of the main issues in most local governments. Most personnel working on environmental management in local government are not qualified in an environmental field, and even not related to water management. Although most local governments particularly PAOs and municipalities have established the public health and environmental division to be responsible for environmental management, the personnel working under this division are not qualified or knowledgeable in the fields. With regard to sub-district administrative organisations, Jarusombat and Senasu (2014) noted that they also have no specific environmental division. The workload in the environmental area is the responsibility of the civil division. The local governments often rely on external environmental personnel, such as experts from Regional Environmental Office, Provincial Environment and Natural Resources Office, or even educational institutions and universities.

It was argued that the large local governments have more potential in environmental management because they have qualified personnel, adequate budget and specific mission on environment, especially in stormwater management and wastewater treatment. The large local governments usually have the Division of Environmental Health responsible for the environmental management, which does not appear in small local governments. However, as the understanding of environmental management has been promoted by central and regional authorities, the environmental knowledge and awareness of most local officials is enhancing. For example, Jarusombat and Senasu (2014) described that there has been the preparation of local development plans, the maintenance of parks, and the development of community forest by local authorities.

It was noted that local people were sustainable in their own way of living, which was unlike urban communities. Wungaeo (2008) noted that strengthening community participation in the rural areas can raise the development of local knowledge and increase local awareness on natural resources and environmental management more than the urban community. To solve these environmental problems in urban communities, public participation, local knowledge, techniques, and legal are necessary.

Overall, the restriction in environmental personnel with ability to convert the policies into practice often results in ineffective implementation of environmental policy in local governments. Thus, the local governments need to have the personnel with expertise in environmental management to carry out environmental issues and to provide understanding of environmental management to the public. In addition, the number of personnel in environmental field must be adequate to perform the works, rather than assigning it to those in other positions to be responsible for the environment management in addition to their main duties. With the holistic and integrated approach, we could set sustainable stormwater practices as the highest priority and could extend ecocentrism to the local community, based on the ecological sustainability framework.

5.2.7.4 Supporting Factors for Enhancing Awareness and Knowledge

Sustainability can be the fundamental knowledge of actual human civilisation as it has the capability to form a bridge between the natural environment and human development in terms of environmental protection. Due to increasing concerns about important process of public participation in Bangkok, stakeholders gain control of the process and thereby become fully supportive of directing it forward. According to Cities Alliance (2007), Bangkok Agenda 21 has paved the way for greater public participation. The Communities Love Canals Project has been promoted to prohibit garbage dumping and wastewater discharge in the Bangkok canals with the community involvement. Moreover, the BMA Environmental Protection Volunteers from schools and communities have been established to enhance environmental awareness and environmental projects.

To deal with stormwater-related issues in Bangkok, it is important to increase the opportunities for more meaningful local participation and cross-scale interactions. Local communities which are likely to be affected by floods and drought should be meaningfully involved in decision making. Local consultation should be undertaken in infrastructure planning projects to reduce local problems. For example, some good traditional water management practices should be considered such as the use of water tanks designed to receive rainwater from roofs and swales for trapping water along the edges of farms (Anukularmphai, 2010). Moreover, the local knowledge and practices particularly the Thai house on stilts also reflects traditional unique amphibious architecture (Lebel et al., 2011). Local knowledge on housing styles such as two storey homes or houses on stilts can deal with prolonged periods of flooding (Lebel et al., 2010). Existing local capacities, practices and strategies that contribute to resilience to seasonal climate variability may need to be taken into account.

Learning processes or adaptive management are also important to increase ICM implementation. Jacobs et al. (2010) described that adaptive management was primarily evolved in the context of managing ecological resources, and has lately been regarded as the learning by doing approach to increase efficient policies in decision-making processes. According to Pahl-Wostl (2012), the needs in social learning processes for changing in governance systems are thought to require open, more flexible, and informal networks. Social learning provides opportunities for interactions in open and flexible networks, while learning in closed networks may not result in changes to policies, objectives and implementation.

Facilitating learning processes is important to deal with complex issues of catchment management. The availability of information is important to promote participation in decision-making, monitoring and evaluation. The transparency and accountability of the municipal authorities can be enhanced by providing essential information through mechanisms such as websites (Tanner et al., 2009). Knowledge should be shared across government planning and implementation agencies within both catchment and sub-catchment organisation and among other stakeholders.

5.2.8 Uncoordinated Institutional Framework

5.2.8.1 Ineffective Vertical Coordination

Effective co-ordination at all levels of the bureaucracy and cross-sectoral agencies is necessary to deal with the complex issues of urban stormwater management. Closed organisational cultures or lack of coordination between organisations are likely to be a barrier to involvement of staff in policy formulation and ongoing monitoring. According to the interview, several participants believed that there is a lack of coordination among central and local agencies, and lack of linkage between national environmental policies, environmental quality management plans, provincial action plans, and local administrative development plans. This results in inappropriate environmental management, ICM, and SC practices.

Participant 14 (LG): *Most of environmental plans are made without a clear goal, with lack of connection to policy, lack of accurate environmental data, and no clear indicators of performance. This becomes the main barriers to environmental management and SC practices between national and local level* (AT6).

Participant 8 (CG): *Most of local governments do not have environment department nor have not enough personnel. Most government agencies are also not under the Building Control Division of the Ministry of Interior, so the design and construction of those SC practices are unproductive due to lack of coordination* (PC5).

Participant 4 (CG): *Flood prevention measures have been carried out by both central and local authorities through measures deemed appropriate by individual agencies, such as building dikes to present floodwater drained into the area, and expanding canals to increase efficiency of drainage systems. However, there is no coordination between agencies on flood prevention. Therefore, the RID or the DWR should be assigned to be the primary agency responsible for enhancing coordination* (RI5).

Participant 15 (LG): *The local organisations should not be allowed to work solely in environmental and water resource management. The representative of each local organisations who have a role in being the member of the catchment committee should take part and jointly perform with related agencies in SC practices in their local communities to solve stormwater problem in the same direction* (PH6).

Participant 7 (CG): *To establish the ICM in each catchment, it should be carried out by the smallest part of the relevant groups through local organisations. The catchment organisations need to have enough budget and personnel to support local agencies for the operation of sustainable stormwater facilities* (DW7).

Participant 12 (RE): *Most NGOs have freedom and flexibility in their operations, which is conducive to creativity. However, they do not allow the cooperation to take place among different groups. Most*

NGOs also cannot earn an income on their own. They still need funding from outside and inside the country (CU8)*.*

5.2.8.2 Ineffective Horizontal Coordination

In Thailand, the major roles in water resources management fall under the responsibility of the RID including providing sufficient water, equitably allocating water for all water users, preventing river water pollution, balancing water source uses within the catchment, encouraging public participation in the process of development and management of water at all levels, and preventing and relieving flooding. The Office of the Ombudsman (2011) stated that in the past, RID has been the initial agency in charge of water management especially for agricultural use. Due to economic growth and industrial expansion under the National Plans for Economic and Social Development, the responsibility of RID has become wider and more complex in order to balance the water management for industrial and agricultural uses, as well as maintaining ecosystems.

Lebel et al. (2010) noted that the RID and municipalities have responsibilities to manage stormwater issues for the most part. RID also has a significant role in catchment management, which has been supported by the Department of Water Resources (DWR) under the Ministry of Natural Resources and Environment. However, the Office of the Ombudsman (2011) claimed that the obligations for water management of the DWR and the RID are also a duplication. Before 2002, the RID alone had responsibility for water management. At present, it is the responsibility of the DWR, the RID, and the Institute of Water Resources Information to be in charge of water management. Without the unity and coordination among agencies, as well as clarification of exact roles, stormwater management and flooding issues are difficult to resolve in both the short and the long term.

Participant 7 (CG): *As there are many government agencies responsible for water resources management, all agencies should work together in their operations; for example, the DWR shall cooperate with the RID in managing surface water and stormwater, and jointly with local agencies in each catchment in SC practices* (DW8)*.*

In response to stormwater management in the lower catchment, Lebel et al. (2009) argued that a lack of coordination between the RID under the Ministry of Agriculture and Cooperatives and the Bangkok Metropolitan Authority (BMA) regularly results in unsolved issues for operational decisions and stormwater infrastructure in the overlap jurisdictions. The Department of Drainage and Sewerage (DDS), a local government agency of the BMA, and RID have different stormwater management policies. The BMA is powerful and principally pursues a zero-tolerance flood policy, to keep inner Bangkok dry through its dyke infrastructure within BMA boundaries, making it difficult for national departments especially the RID to manage stormwater in upstream and surrounding areas.

As described by GWP (2013), the RID is the main department responsible for the provision of irrigated water for agriculture and deals with floods and droughts in the rural and irrigated areas. In contrast, the Department of Drainage and Sewerage (DDS) under the BMA has responsibility for solving all stormwater issues and administrating flood protection facilities and monitoring in urban Bangkok areas. The DDS is the independent authority for the operation of stormwater drainage in Bangkok under the Decentralisation Act 2006. However, they also need to have permission from the Ministry of Interior (MOI) for the operation of mega projects (ADB, 2012). Without a law giving authority to designate stormwater receiving areas, the RID has regularly struggled with flooding in peri-urban areas adjacent to Bangkok (Lebel et al., 2011). Conflicts between RID and BMA over diversion and redirection of floodwaters to protect Bangkok during high water periods result from institutional constraints and as well application of accepted criteria.

With regard to issues of co-ordination across sectors within the Bangkok Metropolitan Administration (BMA), there is evidence suggesting that a lack of coordination results in the fragmentation of responsibilities. The BMA performs a diversity of governmental roles including water management and environmental improvement in Bangkok. Each environmental and water-related organisation in Bangkok also works in isolation.

Participant 2 (BMA): *Several authorities are responsible for the water resources system in Bangkok, so the practice may be unclear. Moreover, they may be powerless to competently carry out the tasks assigned. For example, the wastewater collection systems and wastewater treatment plants have been managed as one system involving the PCD together with the DDS taking part in water quality control* (DD5).

Participant 1 (BMA): *Mission on drainage system was assigned from various agencies to the DDS of the BMA, but the power and duty to manage public utilities including SC practices has not been transferred yet* (CP4).

The Department of Drainage and Sewerage (DDS) under the BMA is the main agency responsible for planning and controlling the drainage system, flood protection and wastewater treatment in Bangkok. However, green facility improvement in Bangkok has been worked out by the Environment Ministry (Saito, 2014), without the coordination of the DDS, the City Planning Department (CPD), and the Department of Environment (DOE) under BMA.

The lack of coordination between land and water government agencies, such as the DDS and the CPD in providing green spaces for stormwater runoff or detention, increases urban runoff significantly. Lebel et al. (2010) asserted that with a lack of cooperation between technical expertise and urban planners, approaches to dealing with stormwater management seem to focus on promises of building a large stormwater infrastructure rather than introducing a long-term planning strategy.

5.2.8.3 Strengthening Coordination and Empowering Network among Stakeholders

Successful coordination among various actors mainly relies on the important role of formal institutions through increasing cooperation within networks (Pahl-Wostl & Knieper, 2014). By doing so, enhancing ICM planning will require a transformative change through strengthening cross-sectoral collaboration and changing the way each government agency operates. Therefore, strengthening collaboration and coordination among agencies can be enhanced by integrated management across land and water-related agencies within BMA. The changes could be led by DDS and the CPD and increase coordination with members from other departments under the BMA.

The CPD is responsible for specifying measures for increasing green areas in Bangkok under the principle of city planning (Bejranonda & Attanandana, 2010). In dealing with stormwater management, Saito (2014) suggested that the CPD should formulate a land use plan in relation to stormwater management, promote permeable land surface, and integrate a series of SC facilities into public parks. At the same time, DDS should take account of SC measures in their stormwater drainage system designs to mitigate runoff and enhance water quality. Moreover, the Public Works Department (PWD) should further enforce building codes to increase the implementation of the land use plan created by the CPD.

Furthermore, Saito (2014) noted that the PWD and the DDS can work together to implement SC devices in low-income communities. PWD should ensure functionality of the building codes and promote improvement of SC devices in low-income communities. DDS should also promote community development programmes to address the needs of vulnerable communities affected by stormwater overflows. The Department of Environment (DOE) should monitor environment plans of each department and ensure sufficient drainage capacity of canals and waterways through regular removal of solid waste to strengthen resilience of the city.

Thus, the coordination among relevant agencies including those of central government responsible for land and water resource management, local governments located in the catchment and the needs and support from different agencies and all related departments within the BMA is important to make sustainable stormwater measures more effective.

5.2.9 Limited Stakeholder Involvement and Public Participation

ICM planning plays a significant role in binding all participants together, strengthen and support strong policies in ways that enhances and promotes ecological sustainability. Rather than relying on central government taking absolute environmental responsibility, Tippett (2001) noted that the ICM planning refers to a network system with all multi-participants including the government sector, civil society, NGO, experts, and business to work together towards the transformative parts of governance for sustainability.

The essence of public participation regarding sustainable development, which was proposed at the conference on the Rio Declaration on Environment and Development in 1992, is treated by several countries as guidance for environmental improvement in their nations. As described in TEI (2007), Principle 10 of the Rio Declaration states that environmental issues are best handled with participation of all stakeholders at both the national and local levels. In this regard, each individual shall be able to access information, participate in decision-making processes, as well as being able to access judicial and administrative processes.

Principle 10 of the Rio Declaration was renegotiated 10 years later in a meeting organised by the United Nations, under the title of the World Summit on Sustainable Development (WSSD), held in Johannesburg, South Africa in 2002. This emphasised of the vital role of public participation in development. According to TEI (2007), Principle 10 required States to support public participation in environmental matters on access to information, participation in decision-making, and access to justice in order to contribute to the sustainable development. The concept of participation has been accepted and widely used as guidelines in environmental management in several countries.

Researchers at Burapha University (2013) stated that participation in activities and development processes is necessary to reduce conflict. Meaningful public participation will help prevent conflict, particularly with respect to public policy, which needs to get feedback from the public to support decision making. Thus, a public hearing must be held from the beginning of a project, as this participation will be a tool to create an effective solution.

Thailand has realised the importance of public participation and implemented it in several aspects. The Thai Government has given priority for participation in both national and local administration organisations. This can be seen in the Constitution of Thailand B.E.2540 (1997) and B.E.2550 (2007) that require the process of participation in several sections. The consideration of Environment Quality Management Plan, B.C. 2540-2554, also focuses on the process of public participation in planning processes to enhance effective implementation. However, the understanding and implementation of participation processes is still varied and patchy.

Public participation in ICM practice at the local level, with local communities has been seen to be at the receiving end rather than at the giving end. This eventually leads to increased conflict, confusion and misunderstanding. Without multi-stakeholder engagement, implementation of ICM planning at the local level will remain challenging for resolving local issues. For instance, Lebel et al. (2011) argued that a floodwall built to protect commercial areas has often resulted in runoff and riverbank overflow floods on the opposite bank of the river, as runoff and riverbank overflow floods in Bangkok are significantly affected by upstream catchments. Thus, it is argued that the voice of each individual who is affected by from anthropogenic environmental issues should have an opportunity to contribute to the process of governance for sustainability.

There still seems to be a lack of co-operation and learning from local expertise. GWP (2013) revealed that construction plans are often prepared from Central Government perspectives in Bangkok, especially by consultants and the City Planning and Public Works in each province. The planning of a stormwater protection system such as a dyke, flood ways, or a water diversion system is typically the effort of Government Agencies, while local people are not involved. Moreover, Tanner et al. (2009) noted that although civil society in Bangkok is active and dynamic, there still have been difficulties in obtaining participation in urban development programmes, due to an ingrained culture of bureaucracy, a lack of available information, and low levels of knowledge and interest.

Overall, the co-operation of local people is a priority, in integrating traditional environmental management, into the creation of a more sustainable and adaptive approach. Although the importance of local government and community-based management has been recognised by Central Government Agencies, there has been a lack of public participation in planning processes. According to the interviews, it was noted that the participation and implementation on stormwater practices and appeared to be limited and difficult.

Participant 5 (CG): *There are rare people get involved in the planning process, especially when the opportunity is given to the public for comments on environmental and land use plans prepared by the central government due to a lack of knowledge and understanding of the plan. Also, local people do not participate in SC practices as they do not have enough knowledge in land use planning and stormwater management* (DP4).

Participant 11 (NGOs): *The role of public participation today is a form of notice and asking for feedback, rather than participation in determining the issues and needs, and policy formulation processes. People often take part in the last stage of planning after the environmental and land use plans have been drafted, so the campaign and education on environmental and land use planning is important* (AS4).

Participant 12 (RE): *People rarely participate in every process of SC practices. Barriers to public participation have been caused by the domination of political power, which has been monopolised by three groups: high-ranking military, capitalists and bureaucrats. If there is no structural change to such monopoly, it is difficult to develop the public participation* (CU9).

Participant 15 (LG): *The bureaucracies are major obstacles to the public participation. As the government policies often are top-down and budget allocation often comes from the centre, the stormwater management activities are set only by the central government. In such a system, local government has to choose to implement only the main policies of their agencies* (PH7).

Participant 10 (NGOs): *There is a hierarchical relationship of superior to inferior. Authorities like to work in office bureaucracies, granting benefits or disadvantages, being seen to be satisfying their superiors. They do not truly perform their duties on sustainable stormwater practices for rural people* (TE6).

To be able to better deal with issues in public participation processes, norms in planning will have to shift away from technical conventional instruments, towards sustainable stormwater management, and local organisations need to co-operate with higher administrative levels and vice versa. Reforming education, raising learning activities and workshops, and heightening strong water-related institutions are very useful tools in enhancing learning processes and pushing for ICM implementation.

To increase the implementation of ICM, stakeholder involvement and collaborative work as a team of all relevant authorities including urban and regional planners, landscape architects, water systems engineers, and ecologists is also important. As sustainable stormwater management is a relatively new approach for many decision-makers, strengthening links with these experts is crucial to gaining acceptance about new sustainable stormwater infrastructure.

It was noted that the implementation of ICM planning and sustainable stormwater practices appeared to be limited in the catchment. These following ideas may allow participation in the decision making process and the building of opportunities for joint work among different groups.

Participant 10 (NGOs): *To increase collaboration, there should be the promotion of networks of various parties to build teamwork in increasing SC practices such as the group of entrepreneurs for green business, the group of young planners, and the group of domestic and international academic networks* (TE7).

Participant 13 (RE): *There should be the promotion of the use of media in various forms such as printing media, radio, television, and websites to present data and information to increase public participation, and to broadcast academic knowledge and other information. The management of water resources should consider local problems. Local communities and local organisations should be allowed to take part in SC practices and ICM* (KU10).

GWP (2013) suggested that, ICM guidelines and regulations should clearly address multi-stakeholders engagement, at local and catchment levels, to support the sustainable water resource management. Technical assistance is also crucial for assistance in the creation of a legal framework and guidelines on sustainable infrastructure. Moreover, Bos & Brown (2012) stated that as a governance approach involves much more interaction processes, it requires a very diverse dynamic within societal networks or innovation networks rather than relying solely on technical experts on water management.

Therefore, dealing with persistent governance issues requires clear purposes to support and strengthen formal and informal societal networks. This could be achieved through a number of multi-stakeholder partnerships to share their perspectives and knowledge on the issues. A large group of diverse stakeholders is critical to put ICM into practice at various levels.

5.3 Analysis of Interview Findings

This section identifies the findings of the interview regarding the implementation of ICM and alternative stormwater SC practices. Research participants were asked for their perceptions on barriers and offering some suggestions to the implementation of SC solutions in Bangkok and its catchment. Interview participants covered a wide range of stakeholder groups including central and local government authorities, experts in relevant disciplines, NGOs, and developers.

Some barriers and suggestions were listed and then clustered according to emergent barrier categories. Findings from the interviews were consolidated and substantiated with insights from the literature review in order to provide supporting argument and evidence as well as to show similarities and differences between research results and those of other academic literature. Critically, in the discussion of Chapter 6 specific suggestions were made to overcome barriers through considering recommendations from documentary analysis and various stakeholders. This process is required to deal effectively with the complexities and barriers that have been perceived in ICM planning and urban stormwater management.

5.3.1 Barriers in ICM and sustainable stormwater management

Exploring different perspectives can emphasise and expand our understanding of these barriers and provide the opportunity for further discussion. The perspective on the barriers to implementing ICM and sustainable stormwater practices emerged as the main themes were highlighted differently by each group. Although the potential impact of stormwater on water quality are generally not well understood from Bangkok participants' viewpoints, an analysis of responses on underlying mindsets showed that there was substantial agreement on the implementation of SC management.

A negative explanation that associated with the ineffective land use plans were weighted heavily by participants in the group [d] researcher and planners, and group [c] local government officials (CU2, PH1, and DP4). The problems include unenforceable and expired land use plans, lack of authority and staff on city planning at local level, it is rare for people to get involved in the planning process, and there is a lack of knowledge and understanding of the plan. This vision was linked to the sprawling development and its effects on stormwater drainage problems due to rapid urban growth. Similarly, many participants under group [a] central government's authorities, group [b] BMA's authorities, group [f] NGOs also described the sprawling pattern of urbanisation dominated by the land use change from agricultural areas to residential and industrial estates, and also commented negatively on stormwater drainage problems (DD3, TE2).

Considering the perspective on knowledge in land use and ICM planning, the typical responses of participants in several groups were that there is a lack of capacity, knowledge, and awareness in both central and local levels (DP4, DD5, and DO4), a lack of personnel who have knowledge and understanding of SC practices. (PC2), a lack of integration of knowledge and information of each agency (CU6, KU7), and a lack of knowledge and experts for green infrastructure practices related to the local context, particularly in terms of variety of plant species (AT5, PD6). Sustainable stormwater practices are the new things (PC3), and their priority and concerns were totally restricted and ignored. As most respondents had minor understanding of a non-point source pollutant from urban stormwater and sustainable SC solutions, scientific knowledge and technology should be applied as appropriate with social and economic conditions and ecology of Bangkok.

Additionally, participants in group [c] local government officials, group [a] central government's authorities, and group [d] researcher and planners revealed that it is hard to implement the SC measures due to a lack of staff and personnel with technical skills as well as knowledge and expertise in stormwater management and ICM planning in local organisations (PC3, CU3, CU6, PC2, and AT5) and a lack of authority and staff on city planning (PH1). Participants in several groups also highlighted a lack of standards and guidelines and no clear assessment mechanisms as the main concerns for the implementation of sustainable stormwater practices (DO4, AS3, and PT3). Thus, they suggested that rules, regulations, standards, and criteria for SC pilot projects should be set up in order to improve the efficiency of the SC practices in both the old and new buildings (RD6, KU9, DO5, and AT4). Moreover, ability and knowledge in managing water of the related agencies should also be developed, so that they could apply their skill efficiently in the actual field.

With respect to the perspective on financial issues, a lack of budget is also the main barrier in implementing integrated catchment management. Participants still have insufficient knowledge regarding costs associated with implementation, unforeseen administrative costs, and maintenance costs, which tend to be higher for SC devices in the short term than for a standard device. The responses among those in the group [c] local government officials are skeptical about the implementation of sustainable SC practices, which is exemplified by the cumulative issues related to cost, budgets, funds, and land available (AT3, PH4, and PH7), particularly insufficient allocated budget for stormwater SC management for local governments.

However, for participants under group [e] private and real estate developers, their viewpoints to increase the sustainable stormwater practices were primarily subjected to matching their area of interest and belief, and in order for enhancing the implementation, financial incentive and bonus should be supported for building owners (PD2 and RD2), especially the incentive for installation and maintenance costs, which may offset the costs of environmental degradation. Moreover, some suggested that the provision of ready-made designs by local governments may reduce costs of SC devices for individuals and local government.

As anticipated, the participants in the group [a] central government's authorities also discussed their specific interests regarding the construction of large infrastructure to overcome flood problems (DD1, DD2, and DD4), especially floodway and large underground drainage tunnels to speed up drainage of water into the rivers and the sea, giving less priority to river water quality issues and the environment. Likewise, the typical responses of a number of participants in group [b] BMA's authorities and group [a] central government's authorities group [d] researcher, and group [e] real estate developers appeared to prioritise flooding issues as the major goal (KU2, RI4, RD5, and DE3), such as focusing on reducing the volume and speed of the floodwater using detention ponds or sport’s fields, while water quality issues seem not to be a main concern. It can be argued that these perspectives still lack understanding of integration for ecosystem health.

In contrast, only a few participants in group [e] private developers, group [b] BMA's authorities, and group [d] researcher gave a high priority to river water issues and degrading environmental conditions (PD4, DE2, and CU4), which they were interested in implementing SC practices and believed that the BMA could be able to provide this effort in the near future.

With regard to institutional arrangement issues, some participants in groups [a] central government's authorities emphasised a fragmentation of government, and struggled with the overlapping government powers in numerous agencies responsible for water resources management between the central and local government (RI1, PC1, DW1, DW2, and DW4). For example, they believed that there are too many agencies involved in water management and working separately under their own missions, resulting in overlaps in the management of rivers and canals in the catchment. However, the participants in group [a] central government's authorities were keen on putting forward their responsibility in ICM, but felt powerless because of a lack of the Water Resources Act to support their missions, so they suggested that the comprehensive water law should be urgently enacted (DW5 and RI3).

Most of the local participants who worked in the governmental agencies reported their constrained capability to perform in environmental planning due to their restricted roles, hierarchical institutional arrangement, and disempowerment. Participants across group [a] central government's authorities, group [c] Local government officials, and group [d] researcher and planners consistently identified institutional constraint and top-down decision-making as the core factor that reduces their ability to overcome issues (PH7, CU9, PC5, and DP4). For instance, they believed that the government policies often are top-down and budget allocation for stormwater management often comes from the centre of government. Moreover, people rarely get involved in the planning processes as they do not have sufficient knowledge in land use planning and stormwater management.

Participants generally stated that the planning at the local level is just a matter of implementing policies from a higher administrative organisation, which tends to reach specific interests and unavoidably results in an imbalance in sustainability of socio-economic and environmental development. Although integrated bottom-up approaches have been a focus of catchment management plans, most local communities have not participated in operations through ICM approaches. Therefore, complementarities between top-down and bottom-up approaches are necessary and need to be given greater emphasis.

The ineffective planning processes were also the major concerns for both groups [a] central government's authorities and group [d] researcher and planners due to a lack of inter-agency coordination and public participation in land use planning, stormwater management, and ICM planning at all levels (CU3, PC5, RI5, DP4, AS4, CU9, and PH7), particularly lack systematic information and coordination between each organisation. It was noted that calls for cooperative movements from the local to the institutional levels are important in order to resolve issues comprehensively. Network governance and strengthening the capacity of local communities are essential for improving inefficient bureaucratic hierarchies and governmental performance.

Overall, it is argued that the participants generally expressed their ecological awareness based on their own particular visions as a common concern. Some participants remarked on the role of reductionist thinking, and believe that existing stormwater management practices manifest a disconnection from the natural world. However, most of these participants seem to agree that SC management could reduce river water pollution as well as enhancing environmental improvement.

5.3.2 Recommendations for Stormwater Source Control Practices from the Interviews

According to the interview, typical of the responses among those in the group [c] local government officials, group [d] researcher and ecologists, group [e] private developers; were observed to comment on the worthy and feasible implementation of SC practices, mainly addressed the priority of environmental values, and highlighted their capacity to resolve environmental issues as a mission of professional and institutional scope (PH3, KU4, and PD1). However, variability in terms of attitudes for SC practices were observed across groups that are rationalised based on values, belief, and motivations.

In response to the land constraint issue, the positive viewpoint regarding the potentials for installing green roofs emerged as the main concern emphasised by participants in both group [e] private developers and group [b] BMA's authorities, especially for large buildings with flat roofs (DO3 and PD5). Participants in group [a] central government's authorities, group [d] researcher, ecologist, and planner, group [c] local government officials, group [e] private and real estate developers; and group [f] NGOs also suggested that the implementation of SC development in small areas, along roads and streets, and setback distances are crucial to overcome the stormwater issue (PT2, TE3, PD3, PD4, CP3, KU6, DE2, and NH2).

Moreover, for group [a] central government's authorities, and group [e] real estate developers, the results suggest that the perspective toward the importance of perennial trees along roads, rivers, and in real estates were emphasised to be among the main concerns (DE2, DE2, RD1, and PD1). The professional and administrative understanding by group [a] central government's authorities, group [b] BMA's authorities, group [d] researcher and ecologist, group [e] private and real estate developers suggested that they are convinced that the SC development could overcome the effects of air pollutions, heat events, and climate change (NH2, KU8, RD5, CP3, PD4).

Furthermore, participants in group [e] real estate developers were also capable to expressing their opinions regarding water quality issues and the potential implications of SC development through installing porous paving (RD4, RD5), and the expanding of parks for retaining stormwater (NH3, DP3, and KU2). The participants in group [b] BMA's authorities while addressing their professional capacities, held the opinion that flooding issues can be improved if ponds, floodwalls, and floodgates are promoted extensively (DD2, DO1, CP1, and DD4). Therefore, it can be argued that flood problems are the main focus to the exclusion of stormwater quality issues.

5.4 Conclusion

Managing water resources in a catchment, for the purposes of sustainable development, is both a technical and a governance challenge. A shift towards more sustainable water management practice has become a major concern in Thailand, due to ongoing river degradation and technology-based approaches. However, support for ICM and SC practices is unlikely to be a high priority within catchments as there is limited Government directive to respond to stormwater management concerns.

Additionally, there is a large variety of Government Agencies involved in water resource management. Several measures are being implemented as stand-alone interventions by single departments. Existing development plans still lack integration and coordination with plans and projects in the upstream areas of Bangkok catchment. The lack of cooperation between agencies has become the primary problem for achieving ICM planning in the country. Holistic and integrated land and water management planning beyond a single local government is necessary, and points to the need for a regional catchment based approach.

It was apparent that responses to stormwater management are often based on technical practices without giving attention to catchment management regarding land-use changes upstream, rapid transformation of building in downstream flood plain areas, and changes in stormwater regimes. However, structural measures are not adaptive to future uncertainties due to a lack of flexibility and reliance on their operations. Although there are enormous opportunities to minimise environmental problems, too little attention has been paid to sustainable management approaches. A policy on SC measures through the creation of green facilities for environmental improvement has not yet been launched in the case of this flood-prone city but could lead to great improvement.

A major shift in implementation of non-structural measures including institutional arrangements, land use planning, building capacities of local authorities and communities for proposing and implementing adaptation measures through ICM planning is required. To achieve the goals of sustainable management, institutional arrangements will require a transformational change through promoting a collaborative mechanism among relevant agencies in the catchment.

A transition to a new system needs to include clarifying responsibilities and accountabilities of existing authorities, especially of local government, groups of water users, and catchment organisations. Sustainable stormwater management requires more than technical quick-fixes; long-term adaptive planning approaches particularly SC measures should also be considered to provide an opportunity for enhancing resilient ecological systems.

Incorporating structural measures into an adaptive practice, rather than focusing on an optimal engineering design is necessary. Central and local government, NGOs, experts, and relevant private sector actors need to play important roles in integrating adaptive practices, and enhancing awareness programming and education for local communities. Stakeholders will need to be proactive in adaptation, through determining sustainable stormwater practices and incentive program for urban green facilities. The policy-makers will also need to create long-term policies and allocate sufficient resources to invest in adaptive stormwater solutions in the catchment areas.

CHAPTER 6: DISCUSSION

6.1 Introduction

The key aspect of this research is to indentify the barriers to ICM planning and explore how the concept of stormwater SC practices have potential for implemention in floodplain cities, using Bangkok and its catchment as a case study. More specifically, how these concepts could provide guidelines and shape future changes based on existing policies, plans, laws, and authorities' perceptions.

Discovering the barriers to ICM planning and the potential for SC practices can provide a critical basis for decision-making processes to alleviate any potential impacts of stormwater runoff on ecosystems. Accordingly, for this reason this research addresses the theoretical framework based on the ecocentric paradigm, holism, systems and complexity philosophies through the integrative concept of sustainable development, ICM planning and stormwater source control approaches. Holism and system approaches have brought a sense of unity for the earth environment instead of separation. These frameworks aim to provide understanding of the alternative methods for minimising the impacts of anthropogenic activities on the natural environment and to seek proper solutions for environmental improvement.

This research has presented knowledge regarding water quality issues in Bangkok through clarifying concepts in interdisciplinary literature that may support an understanding of complex socio-ecological issues. The study suggests the wisdom of rethinking the concept of sustainable stormwater management in the country that should consider the environment and river water improvement. The approach of the human domain that once dominated nature should be shifted to the ecological domain that links to the resilient system.

6.2 Thematic Comparison of Qualitative Findings

The findings highlight that urban water quantity and quality issues are closely related to the city's development. Population growth and urbanisation have caused several environmental impacts, and resulted in increased impervious surfaces, stormwater runoff and non-point source pollution by nutrients, metals, suspended solids, and other pollutants. To deal with water issues, many cities around the world still use combined sewers to treat both wastewater and stormwater. However, this conventional water system does not fit with the new era of river environmental problems and cannot prevent global environmental harms. The process of unsustainable stormwater practices may destroy urban ecosystems within one human generation. As those cities continue to grow and their population densities increase, combined sewer overflows (CSOs) may cause adverse effects on receiving waters. This is because sewer capacity has not been increasing at the same rate as population and impervious surface area increase. Although such activities occur within local boundaries, the harm may result to the whole ecological systems in the catchment and the ocean.

The analysis suggested that the urbanisation associated with increases in impervious surfaces has led to a high degree of contamination, increased water runoff, and decreased water quality in Bangkok. The urban landscape has changed rapidly during the last few decades due to high population growth. Various canals and ponds have been filled and converted to streets and roadways (BMA, 2009a), the agricultural areas have been changed into housing and industrial estates (Prajamwong & Suppataratarn, 2009), and soil resources have been degraded through distribution of land areas (NESDB, 2012a). Moreover, there has been concern that stormwater runoff from urbanised areas causes negative impacts on the aquatic ecosystem of receiving waters. The way in which humans had altered the natural environment may lead to ecosystem depletion.

Stormwater is usually either discharged directly into rivers, or drained via combine sewers into sewage treatment plants for purification. However, rapid drainage of stormwater from urban built-up areas to wastewater treatment plants, instead of its infiltration, has led to CSOs and the intensification of river pollution. With the large amount of rainfall during the wet season associated with overflows from the Chao Phraya River and upper catchment, the sea level rise, and a low flat plain area, the city has been threatened by stormwater runoff. Moreover, as the climate changes, extreme weather events with more heat waves, droughts, and floods are expected to be more frequent and intense in the tropical region, the practice of stormwater source control solutions in the catchment context is important to minimise these impacts and will lead to achievement of sustainability within urban environments. Table 6-1 shows water and land use related issues in Bangkok and its catchment.

Table 6-1: Water and land use related issues

Water and land use related issues in Bangkok and its catchment
- Inadequate wastewater treatment facilities - High-nutrient loads in rivers from CSOs and intensive agriculture - Climate change affects higher water temperatures and lower dissolved oxygen levels - Water runoff from roads and highways - Increasing daily rainfall, river overflows, and sea-level rise - Water shortage due to high water demand for domestic use - Water scarcity in the dry season - Groundwater depletion due to over pumping of groundwater - Urban sprawl resulting in increasing impervious surface and built-up area - Small amount of green areas and parks in Bangkok - Loss of biodiversity

The most important element to improve river water quality is the principle of sustainability that has been underpinning management over a long history. The idea of ecological sustainability and living harmoniously with nature has existed in effect to hold a balance of the human-natural relation. Being a sustainable city could refer to the capability to maintain a balance between environmental protection and economic development in the context of natural environmental governance. It can be noted that the philosophical root of sustainable stormwater approaches is somehow similar to the concept of sustainability. This means the SC management is properly related to sustainability and environmental protection. Its practices are applied to natural technology and devices, which help to create environmentally friendly actions that we can adopt to live harmoniously with nature.

Recognition of the need for a paradigm shift should lead to a shift from conventional approaches to alternative approaches in stormwater management. The examples from other countries clearly illustrate significant advantages in runoff reduction and contaminant removal achieved by stormwater source control technologies. These solutions also promote the use of urban stormwater as a valuable resource rather than an urban nuisance.

The qualitative findings reinforced the sustaibable stormwater approaches by identifying them from the documentary analysis and the attitudes among actors regarding sustainability. The analysis indicates that stormwater SC approaches seem to be promising approaches to apply in floodplain cities as they provide high performance in urban runoff reduction, pollutant removal, and display a good efficiency for improving water quality in several countries. These practices also offer reclamation of urban runoff through converting the waste of the urban nuisance into a valuable water resource, through techniques such as rainwater harvesting. Treated stormwater also allows for the minimisation of demand for water supply as it can be used for various non-potable purposes.

The findings revealed that source control facilities are not only designed to capture and treat pollutant runoff from stormwater but also have promising potential for reducing urban temperature. The role of vegetation on environmental improvement varies and can be applied at a building-scale, street scale or urban and catchment scales. The use of vegetation offers many urban cooling mechanisms from its evapotranspiration process and morphological characteristics (Thani et al., 2012). The advantages of this vegetation may consist of providing shade and shelter, minimising ground and air urban temperature, and lessened solar infiltration.

The interview findings support the suggestion regarding the SC practices that most participants commented on as being worthy and feasible for implementation based on values, beliefs, and missions of professional and institutional scope. They were capable of expressing their opinions regarding water quality issues and the potential implications of SC development through installing green roofs, porous paving, ponds, expanding parks, and implementing those devices in small areas, along roads and streets, and setback distances for retaining stormwater.

However, the finding highlights that the government authorities mainly addressed their perspectives on the importance of ponds, floodwalls, and floodgates to overcome flooding issues. This view was framed in terms of social-economic benefits. Besides, the use of SC devices to overcome the effects of air pollution, heat events, and climate change were also the main concerns. Therefore, it can be argued that flood problems and other environmental issues are the main focus to the exclusion of stormwater quality issues.

Overall, the documentary analysis and the interview findings consistently indicated that the implementation of SC measures within urban areas improve environmental quality. In addition to their abilities in runoff reduction and contaminant removal benefits, SC approaches enhance the reuse of harvested rainwater, resulting in the decrease of water supply demands and CSOs overflows. The practices also provide the potential for promoting infiltration and evaporation, recharging aquifers, minimising soil erosion, reducing energy demands for building and the urban heat island effect, as well as enhancing biodiversity in an urban area.

The ongoing urbanisation associated with increases in impervious surfaces in many floodplain cities has led to a high degree of contamination, increased water runoff, decreased water quality, and ecological degradation. As ecological and environmental issues have become more complex, sustainable solutions need to be incorporated to deal with the inherent complexity of urban issues. Stormwater source control approaches provide a significant ecological service to mitigate contaminants from water discharge or other impacts and disturbance caused by urban development.

6.3 Potential for Source Control (SC) Measure Implementation in Bangkok and Its Catchment

As discussed in the previous chapter, stormwater SC measures are being implemented in different parts of the world, from North America and Europe to Australia, New Zealand and Asia. The scientific results and understandings of SC approaches have been acknowledged and promoted in many developed nations. The approach improves stormwater quality through the co-operative performance of stormwater treatment facilities as treatment trains ranging from roof gardens to constructed wetlands. These measures are considered as an alternative method to minimise the negative impacts of urbanisation on water systems. As river water resources should be perceived as a part of the environmental system which belongs to every life form, it must be time for a sustainable approach to maintain river ecosystems and environmental sustainability in the country.

The trend of sustainable stormwater practices has become one of the main focusses of the existing international ICM planning regime. The SC practices have been widely used for many purposes as they provide a significant ecological service to mitigate contaminants from water discharge or other impacts and disturbance caused by urban development. These techniques use natural processes of plants and microorganisms to purify the water. In addition, the systems also promote stormwater runoff reduction, restore habitat for native and migratory birds and other wildlife, and encourage the reuse of the treated effluent for landscape irrigation and other non-potable uses.

The approaches maximise natural drainage features at site rather than directing stormwater offsite though a pipe system in order to avoid negative effects on physiochemical, biodiversity, social and urban amenity (van Roon & Knight, 2004; van Roon, 2005). An analysis of source control techniques and key research findings highlighted the potential of green roofs, bioretention devices, permeable pavements, swales, detention ponds, and constructed wetlands.

Green roofs as the examples described in many countries show great opportunities for application in Bangkok and its catchment to achieve multiple benefits of substantially reducing stormwater runoff and minimising urban water pollution problems as vegetated roofs provide benefits for promoting urban cooling, decreasing energy consumption, and moderate temperature around and within buildings. Thus, reduced energy consumption and thermal reduction may offer significant benefits in Bangkok and other tropical cities.

Additionally, green roofs are appropriate for highly urbanised cities like Bangkok, as they require existing space with no additional land area. Without additional maintenance, sediment and nutrient concentration on runoff from green roofs may be high especially during wet seasons due to high rainfall associated with mass loading. Thus, to sustain green roof performance, the systems may require more maintenance effort in hot climatic regions than that required in temperate climate regions, particularly additional irrigation to maintain water levels.

Rain gardens are the most commonly used stormwater control devices in several countries. They provide substantial results in detaining stormwater flows, absorbing and filtering pollutants before stormwater flows into rivers. It was found that a fine sand or sandy loam filter media for bioretention provides a substantial nutrient removal (Henderson et al., 2007). However, as the soil in Bangkok consists mostly of low permeability soils such as clay (Polprasert, 2007); the underdrain is needed in place to slowly drain the base layer of the rain gardens. Rain gardens could also be constructed using media or suitable soils from other locations.

Swales are generally used for treating urban and road runoff in gently sloping terrain in several countries. The use of swales along with conventional pipes in Bangkok may provide substantial removal of high influent concentrations in the first flush, as well as reducing the runoff contaminants through sedimentation and filtration processes.

Most areas in Bangkok are impervious surfaces, including numerous commercial offices, apartment buildings, houses, roads, impervious pavements, and car-parking areas. The installation of permeable pavements instead of impervious surfaces on pedestrian walkways, courtyards, parking lots, and low-traffic roads would be effective in reducing surface runoff volumes as well as urban contaminants in Bangkok. However, as Bangkok clay soils may not provide a good infiltration rate, underdrain systems may be important to enhance the performance of the systems and prevent surface flooding during heavy rainfall.

Constructed wetlands (CWs) seem to be a promising practice in Bangkok as they provide high performance in reducing pollutant loads and demonstrate a good efficiency for improving water quality. CWs provide a comparative benefit over conventional techniques, as they are low cost, environmentally sound, energy efficient, easy to operate and maintain, and promote the conservation of water and nutrient resources compared to end-of-pipe or traditional systems. Substantial cost savings of CWs are feasible in terms of long-term operation and the cost of maintenance. CWs are a potential alternative or supplementary system for wastewater and stormwater treatment.

As wastewater treatment facilities in Bangkok are still insufficient, wastewater can be a threat to both human health and the environment through water runoff. The application of CWs and reclaimed water may significantly reduce the load of combined sewer overflows (CSOs) on natural receiving waters in Bangkok. However, insufficient land area for CWs is also a concern. As land may be limited in Bangkok areas, it seems to be a feasible alternative in medium density areas but may not be suitable in the high-density areas where a large area is required to store and infiltrate stormwater runoff. However, the devices may be suited to communities where open space surrounding public places is still adequate.

Stormwater ponds can play an important role in storage runoff volume and attenuating peak flows due to the retention and detention capacity of the systems. In Bangkok, the application of stormwater source control approaches is relatively new; however, detention ponds for storing and treating stormwater as well as flood protection are relatively widespread under the operation of Royal Projects to treat polluted water and resolve water quality issues in Bangkok (World Bank, 2011). It is argued that the combined use of a retention pond and park may result in great potential for enhancing river water quality through retention of stormwater by ponds, and infiltration and purification runoff by plants as well as increasing biodiversity, providing an aesthetic purpose, and reducing runoff pollutant loads or CSOs in the city. Table 6-2 shows the possible implementation actions for stormwater SC practices in Bangkok and its catchment

Table 6-2: Possible implementation actions for stormwater SC practices in Bangkok and its catchment

SC Devices	Implementation Actions	Locations
Green roofs	Use intensive (deep bed) green roofs with a thickness soil covers of more than 15 cm and regular watering for large plants / Outflow water from green roofs is suitable to be reused only for non-potable applications, such as toilet flushing and landscape irrigation.	Intensive green roofs can be placed on the roof top of a building, a large apartment and a commercial building with sufficient structural strength and moderate slopes.
	Use extensive green roofs with little soil cover of a few centimetres and can be placed on slopes up to 40–45% to minimise stormwater runoff, to reduce heat, to decrease energy consumption, and to moderate temperature in and around buildings	Extensive green roofs can be applied for existing buildings where the weight of the roof is limited. As the soil layer is thin, it can usually be placed without structural reinforcement.
	Apply additional irrigation to maintain water level for green roofs in the dry season to sustain green roof performance as the systems require more maintenance effort in hot climatic regions than that required in temperate climate regions	Use green roofs for highly urbanised areas like a residential and a commercial area of Bangkok's downtown as they required existing space with no additional land area.
Rain gardens	Use bio-retention systems to minimise stormwater runoff and to filter and absorb pollutants / Use native plants to provide better tolerance of extreme wet and dry conditions	The systems can be used for absorbing pollutants in densely populated areas, industrial, commercial, and residential areas, parking areas, small areas where not requiring much investment. This includes areas in the setback distance along the roadsides, public waysides space, the recessing area for large buildings, in open space between buildings, urban voids, road islands, spaces under bridges, toll ways, public parks, open spaces around parking lots, along rivers and canals, and along corridors and footpaths
	Use a fine sand or sandy loam filter media for biofiltration to increase the performance of nutrient removal and increase depth in biofilters to support phosphorus removal. The underdrain is needed in place to slowly drain the base layer of the rain gardens. Rain gardens could also be constructed using media or suitable soils from other locations to provide a substantial nutrient removal as they support plant growth.	

	Avoid fertilizers, herbicides or pesticides for raingardens to minimise polluting downstream water quality. Use mulch, pebble and rock layer to maintain soil moisture and preventing weeds	
	Use overflow system to convey runoff flows in excess of designed filtration capacity / Install the water saturation zone of rain gardens to reduce peak flow and runoff volume through a retaining process	
Permeable pavements	Use sandy soils for permeable pavements to provide good infiltration / As the soil in Bangkok consists mostly of low permeability soils, rain gardens could also be constructed using media or suitable soils from other locations	Use permeable pavements for most areas of impervious surfaces, including commercial offices, apartment buildings, houses, surfaces on pedestrian walkways, pavements, courtyards, parking lots, residential driveways, and low-traffic roads to reduce runoff peak flow
	Use underdrain systems for low permeability soils such as clay to slowly drain the base layer of the permeable pavement, to enhance the performance of the systems, and to prevent surface flooding during heavy rainfall	
Swales	Use swales for removing high influent concentrations in the first flush through infiltration and sedimentation processes	Swales can be placed along with conventional pipes alongside low-slope roads and highways to treat urban and road runoff in gently sloping terrain and to increase the percentage of contaminant removed
	Use swales with moderate lateral slope or domed shape lined with grass to capture stormwater from adjacent areas, and to filter it through a soil media before conveying into drainage systems or receiving waters	
	Use grass swales to provide primary treatment for road runoff	
Detention ponds	Use detention ponds to attenuate peak flows through the retention and detention capacity of the systems, especially for the low frequency storms or high intensity rainfall events	Install ponds to be a central part of each new development for both residential and industrial land use, in public park, large open areas, and agricultural areas to reduce runoff pollutant loads or CSOs in the city. Stormwater ponds will receive inflows of polluted water from urban areas, parks, and agricultural areas, and finally purify water for local water supply and river discharges in upstream and downstream catchments
	Empty the water in the retention pond before a coming rainstorm event to enhance the storage capacity for runoff reduction during the flood season	
	Apply the combination of ponds and public parks to reduce runoff volume and pollutant loads, and increase biodiversity / Use ponds to divert runoff away from waterways and spread out to irrigate adjacent fields to increase agricultural production as well as minimising flood risks in the downstream catchment	
	Use stormwater ponds to store and filter water runoff for domestic supplies in water-stressed basins / Use the harvested rainwater for irrigating decorative gardens, toilet flushing	
Constructed wetlands	Use constructed wetlands for nutrient removal in treating wastewaters, particularly sewage, urban and agricultural runoff / Use the wetlands as a potential supplementary system to reduce the load of combined sewer overflows (CSOs)	Constructed wetland can be used for absorbing pollutants including organic materials, chemicals, lead and suspensions in canals, ponds and rivers. The systems can also be installed in medium density area, public parks, large open areas, industrial, and urban areas where open space surrounding public places is still adequate to store and infiltrate stormwater runoff.
	Use native plants particularly Water hyacinth, Umbrella grass, Elephant grass, Vetiver grass, and tropical plants in a constructed wetland to purify wastewater and to enhance runoff removal through transpiration process	

	Use tropical wetland plant species, particularly cattail and reed as they provide high degrees of nutrient removal.	

Overall, stormwater SC measures seem to be promising approaches to apply in Bangkok and other floodplain cities as they provide high performance in urban runoff reduction, pollutant removal, and display a good efficiency for improving water quality in several countries. SC practices are appropriate to install in Bangkok and other floodplain cities as they require a small amount of investment, operation and maintenance costs, and less operating skills compared to conventional systems. Substantial cost savings of SC practices are feasible in terms of long-term operation and maintenance cost consideration. These practices can be regarded as environmentally friendly facilities as they provide high treatment performance for treating and reusing water.

Moreover, it is necessary that sustainable water use must be realised subject to the framework of environmental sustainability. The practices offer reclamation of urban runoff through converting the waste of the urban nuisance into a valuable water resource. Water reuse strategies provide several benefits for ecological health, such as decreased stormwater runoff and pollutant loads. Treated stormwater also allows for the minimisation of demand for water supply as it can be used for various non-potable purposes such as landscape, gardening, and toilet flushing. Landscape planning could consider the benefits of water reuse (van Roon, 2007). Environmental problems are strongly associated with human behaviour. Therefore, environmental policies need to include strategies to change behaviour in order to mitigate these problems. As mentioned, river water quality, environmental depletion, and human health is linked, human activities must be maintained within a framework of eco-carrying capacity to be resilient.

6.4 Barriers to Implementing ICM Planning and SC Solutions in Bangkok and Its Catchment

To identify the barriers, results from the documentary analysis and the interview consistently indicated that effective planning barriers are the major concerns rather than technical challenges. This includes the four main barriers: fragmented government issues; ineffective knowledge management; limits of regulatory framework; and financial barriers.

6.4.1 Fragmented Government Issues

The expanding a growth in the number of institutional arrangements becomes driving forces behind institutional complexity in ICM planning. It is evident that there are several organisations dealing with the similar policies and issues, which lead to overlapping responsibilities. With the fragmentation of planning processes, various subsector government agencies have established implementation methods to support the intentions of their sector with insufficient cooperation of other water sectors and a lack of consideration of holistic management of the water resource. The fragmentation of related organisations often leads to the consideration of the management of water shortages and stormwater as completely separate issues. This fragmented consideration may contribute to isolated and ineffective policy on water management.

It was noted that a lack of horizontal and vertical coordination are associated with low adaptive capacity of government (Pahl-Wostl & Knieper, 2014). Several measures are also being implemented as stand-alone interventions by single departments, especially within the Royal Irrigation Department (RID) of the Ministry of Agriculture and Cooperatives. For example, the RID has administered irrigated water for agricultural purposes and stormwater drainage system at the national level (GWP, 2013). The water related departments have been said to be independent institutions with their own responsibilities.

A lack of cooperation between agencies has become a primary problem in the achievement of ICM. These barriers may result in a lack of enforcement through policy and insufficient integration from related authorities. To create effective policy implementation, vertical and horizontal coordination across different levels is particularly significant in overall policy processes, including policy formulation, plan development, and implementation.

As we can see, cooperation can be considered as conspiracy, if the main purpose does not serve the common interests of the public rather than the particular intention of the specific group. Thus, under the current cooperation and coordination, escape from the anthropocentric paradigm is impossible. The existing catchment organisation responsibility lacks a specific obligation to prevent environmental harms related to stormwater pollution caused by human activities. Moreover, it was found that the government never intended to cooperate to improve environmental degradation and river pollution, rather to focus on its interests in commercial and economic development (RID, 2010). However, the consequences of economic development in return have caused overexploitation and created adverse effects on environments.

As discussed above, it is argued that this circumstance will contribute to ecological destruction. Failure to meet the river water quality target is associated with the environmental depletion that has gone beyond the capacity of the individual local community to handle it. The risk is overlooked and ignored by local governments to apply unsound environmental management particularly transportation, consumption, over-exploitation of the natural resources, and substantial deforestation. Although local people currently have a better understanding of the protection of natural environment, human unsustainable activities are placing the world under unprecedented pressure. However, it would not be easy to stand for environmental protection to keep a strong political accountability without the responsibility of both central and local governments. Due to certain fragmentation related to governance regimes, there should be a call for closer cooperation to share expertise and information for environmental improvement.

Urban river restoration requires an integrated systematic solution and involvement among local and catchment administrative agencies that combines knowledge of urban planning, landscape ecology, environmental science, and hydrology for urban stormwater management (Jia et al., 2014). Moreover, the need of the champions for enhancing collaboration among stakeholders across the catchment is important. The champion may facilitate and direct the process to build new governance structure, municipal officers, executive and political leaders to support the changes in existing governance structures. Better cross-level coordination of land and water-related agency, establishing community-based capacity, and coordinating these agencies with existing governmental hierarchies is important to reduce fragmented organisations.

6.4.2 Ineffective Knowledge Management

Considering issues regarding public awareness and knowledge on ICM planning, it was noted that the public knowledge and participation in policy formulation and plan implementation was still limited. The public involvement in water resource management is mostly associated with the responsibility for treating their wastewater, operating and maintaining the sewerage network as well as dredging retention ponds and canals. Stormwater practices seem to be limited to anthropocentric responsibility.

Technocratic government has dominated the area of stormwater management based on an anthropogenic regime. This worldview can be seen in various national policies that focus on natural resource management based on socio-economic development. Several local governments have also performed the traditional practices and failed to improve river water quality through sustainable stormwater practices. It is argued that local communities should develop shared understandings that enable SC practices to be managed in a sustainable manner.

As discussed in previous chaper, the environmental management usually relies on the role of central government agencies which consist of ministries, bureaus, and several departments while the local organisations are assigned to be responsible for only some tasks (Jarusombat & Senasu, 2014). Although the environmental responsibilities regarding land use and stormwater management are carried out by local actors, they are often affected by supportive relations with the central government.

It is noted that stakeholder participation is important for sharing knowledge and monitoring alternative response measures in ICM regimes. However, several water-related agencies still view participation as a training and sharing responsibility rather than sharing knowledge (Lebel et al., 2010). Although the principle of public participation was well designed in the water policy framework, it seems the practices of people and agencies involved in ICM planning and SC implementation are still little. Stakeholders still view participation as traditional and convenient public participation processes. Lebel et al. (2010) revealed that stakeholders have not been involved in strategic planning for ICM management, they are mainly involved only in a governmental plan and project when they need to be aware of its consequence.

The findings revealed that local knowledge is important to enhance the implementation of sustainable stormwater management. Local knowledge is greatly applicable to building adaptive capacities and larger-scale adaptation planning. Thus, broad engagement with multi-stakeholders can be an integral part of adaptive governance in order to explore alternative response solutions and develop effective institutions for ICM and SC management.

6.4.3 Limits of Regulatory Framework

The problems of laws relating to water resources and land use planning are one of the main causes of ineffective ICM planning. DWR (2012) argued that there was a lack of the National Water Resources Act or the comprehensive water legislation. Although the provisions relating to the use of water resources are latent in many laws, there is still a lack of comprehensive contents and the enforcement does not cover all cases.

The absence of a national legislative mandate to manage stormwater runoff is also the main barrier to maintaining stormwater SC management, contributing to inconsistent management policies of SC practices. Several current water related laws have been enacted to focus on separate aspects. However, there is no single law relating to sustainable stormwater practices and no specific obligations relating to the prevention of environmental harms caused by stormmwater issues. Thus, the augmentation of stormwater management at a large scale is needed to contribute to urban runoff reduction and contamination removal. The need to consider legislative intervention by relevant authorities should be taken into account at an early stage of urban planning.

Although, substantial improvement has been made to improve water management during the last decades particularly extending structural measures, water supply and wastewater treatment services. The presence of legal frameworks and the adoption of ICM plans are weak in overall performance. As mentioned above, management proficiency including policies, regulations and law enforcement have not been implemented efficiently. Thus, the potential for further improvements of water related laws and appropriate policies should be considered in order to achieve ICM planning in the country.

The fragmented legal governance in relation to climate change, land use, and water resources management has resulted in losing sight of the long-term core. Whereas some environmental issues and ecosystem resilience require a long-term solution to continue, political authorities have preferred a short-term approach. Due to the fact that so many individual laws exist, the problems of conflicts, institutional problems and poor enforcement have occurred. As there is no single law regarding ICM planning, and sustainable stormwater practices, the lack of a proper legal instrument to direct the use of such guidelines and standards cause significant failure for the stakeholders to perform and follow through the implementation. Thus, the unity and coherence of the stormwater SC practices should be governed by the comprehensive water legislation. Enacting this comprehensive law may not only uphold the nation's responsibility in water resources management, but will also ensure and enhance ecological sustainability for long-term success.

In regard to land use planning, it was observed that land use practices have often been managed against legal enforcement. Moreover, there are not yet any land use related laws concerned with protecting the ecosystem of rivers, while implementing future land use. Thus, It can be noted that legal instruments, until recently, had no relationship with SC practices to promote environmental protection. Since the ecological crisis is vigorous, it is undeniable to refuse SC practices and ICM planning accountability. It is important to note that land use planning is deemed as a significant instrument to regulate and control the use of SC measures in catchment areas. Therefore, it becomes a legal obligation of all related agencies to boost a strong enforcement to land use policy and regulation in order to uphold the sustainable stormwater practices and ICM planning.

6.4.4 Financial Barriers

Another main challenge for implementing ICM and SC practices include economic constraint and inadequate financial support. Although the policy on financing for sustainable development and environmental improvement is clearer, it is argued that the budget allocated for environmental improvement remains low, which make the operations associated with the environmental improvement not fully successful (ONEP, 2013). It is also found that allocation or subsidies from the central government for environmental management are usually in the form of grants to solve problems, rather than focusing on prevention (Jarusombat & Senasu, 2014). Moreover, the grant is usually provided for the investment of large-scale construction, and being transferred to local governments to further maintain.

The limitation of the financial support would cause professionals to ignore some sustainable stormwater practices that are valuable for the investment. However, the reform of stormwater management through SC measures for the restoration and protection of pre-development flow regimes in Bangkok could be promising if financial support and some efforts were made. For instance, financial incentives should be encouraged for increasing the implementation by building owners. The institutional capacity to design and manage stormwater source control systems should be enhanced. Moreover, the use of public parks and public spaces in Bangkok should be taken into account. As a result, the application of source control measures and reclaimed water may significantly mitigate the stormwater pollutants and runoff in the city.

To increase public implementation of source control technologies, financial incentives can be used to create a public subsidy program for property owners for installing the technologies. Public subsidies are also a main influence on the probability of the adoption of source control systems. In several cities, financial Incentives and subsidies of source control device installations have been introduced such as in Germany, Toronto, New York, Singapore (Greenroofs, 2014), Portland (PBES, 2006), and Philadelphia (Garrison & Hobbs, 2011). As the subsidy amount would be regressive in time, and properties would potentially be valuable when they change hands (Montalto et al., 2007), financial Incentives might be the most cost-effective way to encourage individual property owners to replace conventional facilities.

Moreover, to increase the budget for SC practices in Bangkok, the government should also consider a tax incentive for seeking funds from the private sector, which is probably the source of most funding of green areas (ONEP, 2006). The measures to promote the green fund may include providing the deductions of corporate income tax and personal income tax for property owners who maintain green areas, green infrastructure, as well as donating to the green fund. Besides, the government shall determine an appropriate tax rate for the optimum charge to increase participation from the private sector involved in increasing the source control practices.

6.5 Analysis of Qualitative Findings on the ICM Planning

Considering the ICM implementation in Thailand, as in many other developing countries, a policy response to ICM issues is just beginning to emerge. However, most water policy attention has focused on mitigation of stormwater quantity, and rarely taking into account stormwater pollutants, ICM planning, and land use issues. Adaptive measures to stormwater management are relatively new approaches, most water government policies and plans remain unclear. Moreover, efforts to respond through ICM planning still have been slow to emerge. Although the ICM approach has been broadly promoted, the authorities have paid only little attention to sustainable stormwater management. Additionally, the integration of long-term strategic planning for ICM and stormwater SC practices has not yet been realised.

According to the analysis of interview findings as discussed in the Chapter 5, the authorities' perspective indicates that a lack of knowledge and awareness in land use and ICM planning, and sustainable stormwater practices is the main concern of the local and central government's authorities. They still believed that it is hard to implement the SC measures due to a lack of staff and personnel with technical skills as well as standards and guidelines for these practices. This finding implies that issues such as professional constraint have been disempowering their role in responding with sustainable stormwater practices.

The qualitative findings revealed that although the issues regarding financial support are of concern, local government officials are skeptical about the implementation of sustainable SC practices due to their perceived high cost and the lack of budgets and funds to support the operation. Financial incentives seem to be a promising measure to support building owners seeking to enhance implementation.

Clearly, most interview participants demonstrated a high level of awareness towards water quantity issues. Central government interviewees also discussed their specific interests regarding the construction of large infrastructure and prioritised flooding issues as the major goal, giving less priority to river water quality issues. Their motivation and aspiration seems to be concerned with the socio-economic values. However, the concern for ecological impacts, river water issues, and degrading environmental conditions can be seen to be a main concern of some authorities and researchers, which is framed deeply from their personal viewpoints.

Interestingly, the interview results indicated contrasting findings compared with the documentary research, regarding the attitudes towards institutional arrangements. This finding highlights that this issue is likely to be the main concern of the central government, which they felt struggled with the overlapping government powers in numerous agencies responsible for water resources management. Nevertheless, they would be keen on putting forward their responsibility in ICM if the draft of Water Resources Act will be enacted to support their missions.

Most of the interviewees from local government agencies described their constrained capability to perform in environmental planning due to their restricted roles in top-down decision-making and disempowerment as the core factor that reduces the ability in their operations. Moreover, central government's authorities, a researcher, and planners also commented on the ineffective planning process in terms of a lack of inter-agency coordination and public participation in land use planning, stormwater management, and ICM planning and suggested calls for cooperative movements and network governance at all levels to resolve the planning issues.

It can be argued that the government agencies have chosen an unsustainable stormwater practice based on anthropocentric regime such as the construction of dams, ditches, drainage systems and the large underground drainage tunnel to speed up drainage of water into the rivers and the sea. Although it becomes a responsibility of the government agencies in the environmental improvement, the main concern of government is still based on unsustainable practices in order to carry out economic development. Although technology provides humans with a great power to dominate nature and disturb environments through human activities, it may come hand in hand with our huge responsibility as well. Misconduct of the government in exercising its authority to the ecological degradation within its jurisdiction such as huge dams constructed can potentially harm and alter the ecosystems of the entire catchment.

Due to centralist political influence in favour of short-term economic interest, it is difficult to argue that the government has created environmental improvement based on sustainable stormwater practices and ICM planning. This might have resulted from unsuccessful governance in maintaining the balance of economic development and the environmental improvement in the catchment. As ecological destruction is recognised as a common concern of humanity, the government cannot deny their responsibilities. Thus, to achieve sustainablility goals it is necessary for the government authorities to be in solidarity and unity to commit to sustainable stormwater practices and to call for a new social contract for water governance in the country. Table 6-3 displays the possible implementation actions for ICM practices in Bangkok and its catchment.

Table 6-3: Possible implementation actions for ICM practices in Bangkok and its catchment

ICM issues	Possible implementation actions for ICM practices in Bangkok and its catchment
Limits of Regulatory Framework	
- No comprehensive water legislation to implement the water policy. - Fragmented environmental law implemented by several government agencies - No specific legislation regarding stormwater management for urban areas and no strategic plans on stormwater quality improvement.	- Urgently enact the comprehensive water laws and the Water Resources Act - Enhance the unity and coherence of the stormwater SC practices through Water Resource Act. - Issue land use and water-related laws at catchment level - Formulate the comprehensive land use plan and the specific plan to be consistent with the policy framework for SC practices

- Lack of comprehensive land use and specific land use plans prepared and implemented for urban areas. - lack of land use plans associated with water drainage systems - Ineffective catchment plans with no fixed plan and no time frame given for implementation - Lack of concerns on environmental impacts from stormwater runoff in ICM plans	- Amend the building control laws to cover the changes of buildings and land uses through adopting the compulsory measures instead of the optional measures - Establish guidelines and measures for the requirement of the SC practices for government agencies and building owners with strict enforcement - Require the development of SC devices in the setback distance and space between the buildings under the compulsory measure. - Require the implementation of SC facilities for a new development project under the laws - Formulate an ICM plan by addressing water and land use issues in the catchment boundary and promoting the use of SC practices
Issues of fragmented government and limited stakeholder involvement	
- Overlapping responsibilities of government agencies - Lack of coordination between government agencies for water management and land use planning - Lack of coordination among central and local governments - Lack of linkage between national environmental policies, catchment plans, and local administrative development plans. - Fragmented policies and plans on climate change adaptation and water management - Insufficient government authority in stormwater management - Isolated management of each natural resource and lack of cooperation of technical expertise and urban planners - Centralist political and top-down decision-making influence in favour of short-term economic interest	- Establish single water management unit to supervise overall water issues in each catchment - Promote cooperation and coordination among separating institutions and strengthen cross-sectoral collaboration - Enhance collaborative work as a team of all relevant authorities including urban and regional planners, landscape architects, water systems engineers, and ecologists - Encourage local administration to take part in SC practices and enhance public participation
Ineffective knowledge management and technocratic path dependencies	
- Lack of understanding and awareness of the impacts of stormwater runoff on water quality of receiving rivers - Lack of sustainable stormwater SC measures mentioned in national environmental policies - Government paid very little attention to environmental issues; strategies regularly refer to water quantity or risks of flood-related disasters - Inadequate technical knowledge and no long-term plans on stormwater SC practices provided for local government - Lack of available information and low levels of knowledge and interest on SC practices related to the local context - The shortage of personnel skilled in the environmental field, no specific environmental division, and no clear	- Reform education, raising learning activities, workshops and promote a campaign on stormwater SC practices to boost understanding of public - Develop appropriate guidelines, standards, and criteria for SC practices and the pilot projects to use as a model as well as assigning the host agency to be in charge - Increase technical knowledge and train staff of local agencies to monitor and follow up under the criteria of the SC practices - Establish advocates or champions who have experience and knowledge in stormwater management to accelerate the ICM process, to ensure external funding, and to create links with actors across bureaucratic hierarchies - Share knowledge across government agencies and among stakeholders through mechanisms such as radio, television, and websites to broadcast academic knowledge regarding SC

- Lack of awareness and skills of local authorities in preparing land use plans - Current adaptation measures in Bangkok and its catchment rely on having a hard engineering bias, focusing on building a large stormwater infrastructure - Stormwater management frequently seen as a technical issue with a lack of learning from local expertise - Lack of concerns on climate change adaptation and SC practices among authorities and lack of awareness of the environmental impacts of stormwater runoff in catchment plans. - Lack of information sharing and lack of continuity of networking within each government agency on stormwater SC practices - Lack of standards and guidelines for sustainable stormwater practices	- Promote local knowledge on housing styles such as two storey homes or houses on stilts and require local consultation in infrastructure planning projects - Support housing entrepreneurs to implement SC practices in terms of knowledge and plant varieties - Promote academic institutes to take part in educating future staff in designing, and constructing the SC practices
Financial Barriers	
- Inadequate budget for the environmental mission of local governments to deal with stormwater SC management - The budget allocated for local government mostly for improving city landscape rather than increasing green areas - High relevant costs related to SC practices - No tax exemption or reduction measures for the increase of green areas and SC practices - Lack of Environment tax from sources of pollution for offsetting the cost of green facilities	- Allocate insufficient environmental budgets, subsidies, and funds for local governments for long-term implementation of SC practices - Establish an environmental fund, bonus, tax reduction, subsidies, or rewards for landowners in the CSO drainage areas to promote the implementation of SC retrofits. - Offer the deductions of corporate income tax and personal income tax for property owners who maintain green infrastructure - Provide a maximum annual property tax credit for building owners who install SC facilities to minimise CSOs - Provide financial incentives including exemptions and reduction of property tax and local maintenance tax for landowners to redirect stormwater runoff from roofs to gardens and lawns where soil type is appropriate. - Consider a tax incentive for seeking funds from the private sector to be the source of most funding of SC practices. - Allocate the greenroof incentive grants for new green roof projects for all residential, commercial, and industrial projects and public buildings. - Offer residents a discount on stormwater fees when installing SC practices - Apply environmental taxes to those who cause environmental impacts, emit pollution, and harm the environment

6.6 Conclusion

Stormwater quality issues in this thesis are viewed as a link of environmental problems in the catchment. It is evident that the water quality of river-mouth cities is continuing to deteriorate in response to the persistent urbanisation. Growth of anthropogenic land-use change has resulted in the conversion of natural areas into impervious surfaces. This change accelerated the amount of rainwater converted into runoff as well as increasing the concentrations of various contaminants from overflow into the lowlands. The stormwater runoff carrying various contaminants has also led to deteriorated water quality in receiving rivers and had adverse effects upon urban environments.

The negative consequences of ignorance of environmental degradation can also be seen in terms of climate change, floods, droughts, biodiversity loss, and ecosystem decline. The consequences of downstream progressive pollution confirmed that unsustainable human activities are a main driver that threaten such degradation. It can be critiqued that the anthropocentric view has been accepted in traditional stormwater management, as most stormwater policies are based on an anthropocentric perspective.

It can be argued that the anthropogenic viewpoint is not concerned with environmental sustainability, as its main objective is to promote development that includes unsustainable practices. Thus, it is urgent that the urban environment should be improved because it affects natural ecosystems and humankind as a whole. Beyond anthropocentric reductionism, it is important to note that it is necessary to shift traditional stormwater management to sustainable stormwater practices. Sewage treatment plants sufficient to service the whole Bangkok population are recommended to combine with SC practices in order to enhance the potential of water purification and reduce pollutants from sewage overflows. Stormwater SC measures seem to be promising approaches to apply in Bangkok and other floodplain cities as they provide high performance in urban runoff reduction, pollutant removals, and display a good efficiency for improving water quality in several countries. The practices could serve as the fundamental principles for environmentally sustainable solutions.

This study suggests reconsidering the concept of sustainable stormwater management in Thailand to reflect environment and river water improvement. The practice of SC on a catchment scale through localisation of stormwater runoff in upstream parts of the catchment will be important to downstream improvements and improve ecosystem sustainability. SC facilities may be an essential practice for responding to the urgent need for improving and monitoring water-quality and wastewater treatment in Bangkok and other floodplain cities. The true sense of human development must be in harmony with nature to an appropriate extent with holistic awareness. As the climate changes are expected to be extreme in the region, the practice of SC is important to minimise these impacts and will result in improvements in sustainability within urban environments.

CHAPTER 7: CONCLUSION

7.1 Introduction

The aim of this exploratory study was to develop a planning policy framework and guideline to mitigate stormwater pollution and to promote environmental quality improvement in floodplain cities, using Bangkok as a case study. The research provides the understanding of the complexities of the environmental issues in relation to the stormwater management that has not yet been fully investigated in the country.

The study applied qualitative methods through documentary analysis and semi-structure interviews to explore the barriers to ICM planning and the potential for applying stormwater SC approaches in Bangkok and its catchment. This was also done by examining the existing policies, plans, measures, and planning processes that have been applied to minimise stormwater contamination in the study area and by exploring adaptive stormwater approaches implemented in other countries.

The core argument of the thesis is that the nation fails to protect river water quality as it heavily prioritises economic development that lacks specific standards and enforcement mechanisms for sustainable stormwater practices to improve the quality of water in the rivers. Comparing the findings from the interview analysis with the literature review, it was found that there were various similarities of case characteristics. The findings from addressing the first research question suggested that water pollution from non-point source is one of the major causes of the impurity of urban receiving water and environments in Bangkok. Moreover, it can be argued that current stormwater practices and ICM planning in the country is still limited within scope of anthropocentric view. The conceptual problems of human-centered approaches have an impact on the urban ecosystem and its complexity.

Based on the idea of the holism and ecocentric approaches, the thesis proposes a paradigmatic shift to environmental protection. The findings from documentary research and the diverse ideas among the multiple actors as indicated in previous chapters reinforced the role of government in the implementation of sustainable stormwater solutions in the CPRB. The chapter concludes with a discussion of the way in which SC practices and effective ICM planning could promote environmental quality improvement. These findings warrant further research to consider an in-depth policy frameworks and guidelines that need to be provided to reduce stormwater contaminants in specific areas of the metropolitan in order to promote environmental quality improvement in the floodplain city.

7.2 Contribution to the Stormwater SC Implementation in Bangkok and Floodplain Cities

Recognition of sustainable approaches to urban stormwater management has grown over the last few decades. The shift in recognition of stormwater as a nuisance to being a resource resulted from the rising environmental awareness. Green practices such as stormwater SC approaches, which adapt the principle of restore, reduce, reuse, and recycle of water, have been promoted extensively in several regions, especially the United States, Canada, Australia, New Zealand, and parts of Europe. In Asia, several countries are embarking on a project of SC practices as an aid to mainstream sustainability in urban development at the catchment level in their flood-prone cities such as in China, Taiwan, Malaysia, and Singapore. The findings of the effectiveness of SC implementation from those countries provide information for their adoption and design in Bangkok and other river-mouth cities in solving flooding and river water quality problems.

As discussed, the argument of this study is based on the presumption that sustainable stormwater practices are significant for the future of humanity. This SC concept is presented taking into account an ecocentric perspective of the paradigm shifting towards sustainable development. Stormwater SC approaches emphasise the use of holistic and long-term methods to provide sustainable urban stormwater management. The practice mainly emphasises integrated land and water use on individual to catchment scales through an ICM practice. It also promotes water reclamation through the integrated management of water supply, wastewater treatment and stormwater drainage systems. It is evident that these methods reduce both the amount of stormwater runoff from urban areas and the pollution entering a river through increasing travel time, and encouraging infiltration into the ground. Additionally, infiltration systems also reduce peak runoff rates in sewer systems and thus reduce the number of combined sewer overflows (CSOs).

Stormwater SC practices may be an effective method for purifying polluted urban runoff in Bangkok and other floodplain cities through physical, biological and chemical processes. The systems have demonstrated effectiveness in reducing runoff and achieving removal of both suspended and soluble contaminants such as nutrients, suspended sediment and associated runoff contaminants.

Similar to other floodplain cities, in the low-lying Bangkok areas, climate change especially the influence of sea-level rise, saltwater intrusion, storm surges, and irregular precipitation will impact on urban drainage systems unavoidably. Implementing SC infrastructures at the catchment scale may become more effective to enhance drainage capacity and water storage to alleviate stormwater related issues and drought impacts.

Existing limitations to adoption of SC practices for water treatment in Bangkok and other rivermouth cities may include limitations on land supplies and prevalence of contaminants in wastewater and stormwater runoff. Thus, these alternative approaches need to take account of sensible investment, local based applications, and environmentally friendly techniques.

Insufficient land area for source control facilities is a major concern in high-density areas where a large area is required to store and infiltrate stormwater runoff. As land may be limited in high-density floodplain cities, the use of public parks and public spaces should be considered in order to reduce space constraints in private land. It is apparent that public parks provide opportunities for integrating source control measures for medium to high-density residential developments. As the constraint of high prices of competing urban land uses poses threats to and resistance against the adoption and implementation of stormwater quality management strategies, introducing source control strategies within parks may mitigate public resistance due to lower public costs of storm water management.

The combined use of source control devices through the retention ponds and parks may provide the great potential for enhancing river water quality. For these systems, ponds may design to receive inflows of polluted water from the park and finally purified water for local water supply and rivers discharges. However, the water in a retention pond should be emptied shortly before a large expected rainstorm event to enhance the storage capacity for runoff reduction during the flood season.

Moreover, stormwater runoff in Bangkok may convey mixed inorganic and organic pollutants and the prevalence of contaminants, so this may cause a reduction in the devices' treatment efficiency. Sustainability may not be achievable when these approaches have limitations to maintain river and stream ecosystems, for instance, if pollutant loads exceed the capacity of these facilities. Thus, the tropical macrophyte species and type of contaminants to be treated should be considered in the design.

The SC decentralised practices may provide more sustainable solutions if applied at a catchment scale. These approaches enhance the potential for runoff reduction and pollutant removal through retrofitting the hydrological regime in association with various green facilities. It is a neutral practice that can guide people to balance the way of living or the harmony of living through considering ecocentric values and sustainable use in order to protect ecological integrity. Restoring the natural hydrologic regime is an essential component of sustainable development in urban landscapes.

Considering these SC facilities, it is argued that the use of green roofs, rain gardens, permeable pavements, swales, detention ponds, and constructed wetlands as open series may be appropriate in Bangkok and other flood-prone cities, particularly potential for implementing in brownfield developments and retrofits. Substantial cost savings of these facilities are feasible in terms of long-term operation and maintenance cost consideration. These practices can be regarded as environmentally friendly facilities as they provide high treatment performance for treating and reusing water. The disconnection of stormwater from the combined sewer and drainage through an array of open systems within private and public properties may contribute to a substantial reduction for stormwater reaching the piped systems and CSOs in the catchment.

Despite the issue of the stormwater runoff, impervious surfaces tend to store heat and exacerbate the high temperatures in urban areas. The use of natural vegetation in SC approaches may contribute to the urban thermal improvement especially in a tropical environment and promote a pleasant living environment. For others who may not be interested in sustainable stormwater solutions, the implications of green infrastructure for reducing urban heat effects may become promising. However, it is noted that a sufficient quantity of vegetation should be incorporated into a design to optimise its ambient temperature and geographic environment. The size of green spaces should be balanced or in the right proportion to offset the area of urban imperviousness. Moreover, the use of native vegetation may facilitate the adaptation to local climate and require less cost of maintenance rather than ornamental types. This will provide opportunities for planners and landscape architects in the design of a new development and redevelopment for both individual and catchment scales. To enhance biodiversity in the city, urban gardens should contain diverse shrub and tree species.

Furthermore, to avoid damaging drought and the potential for water stress during the monsoonal dry period, dry evergreen species or plants well-adapted to drought should be carefully selected to achieve adaptation to the monsoonal dry season in Bangkok and other tropical cities.

Overall, most source control systems provide practical methods for reclamation of urban runoff through converting an urban nuisance into a valuable water resource. The reclaimed water can be used for irrigating landscapes, and for groundwater recharge. Thus, these measures can be applied not only in the low-lying areas of Bangkok, but also within its catchment and the adjacent cities to minimise the volume of stormwater inflows into Bangkok areas. As the sustainable SC approaches has already witnessed, such practices must be kept and promoted.

Whereas environmental sustainability becomes the common concern of humankind, governments could be obliged to take a duty of care to enhance environmental improvement. Moreover, to increase the long-term effectiveness of the system, upstream residents and farmers, downstream landowners, and local government should also implement stormwater SC solutions from small scale to larger scale systems for the benefit of their communities. Small-scale distributed water harvesting systems that capture water for local uses can have a significantly positive impact on larger scales, particularly in terms of hydrologic conditions, minimising stormwater runoff, as well as improving water quality before the runoff reaches downstream areas.

7.3 Contribution to Effective ICM Planning in Local Context

In Thailand, the changing governance of urban stormwater processes pressures by embracing more sustainable forms of water management, such as the ICM concept. However, the transformation in planning processes was perceived as ineffective due to complexities of the catchment contexts. The main factors influencing the failures of an effective water governance system in the country are typically associated with managing urban water with various potential source of diffuse water pollution, geographical mismatch between hydrological and administrative boundaries, different levels of government and many stakeholders involved in water management, insufficient appropriate authority, the delay of water legislation, ambiguous catchment policies and strategies, and conventional engineering viewpoints. Overcoming such constraints, there is a need for significant changes in approach that would integrate knowledge for ICM planning through combined with both hard and soft adaptation measures.

The attitude towards human/social boundaries often affects stormwater management practice and catchment management. The view of ecological connectivity seems to be ignored by governments. From an ecocentric perspective, it is crucial to pose a question to query whether catchment boundaries, which we inhabit, influence urban ecosystems beyond the political boundaries. As an administrative boundary aims to separate the catchment's ecosystems and biodiversity within an individual political boundary, implementing SC measures and ICM planning within a catchment boundary is necessary to protect its ecosystems and biodiversity from the anthropogenic environmental pollution and climate change.

Additionally, the policies and plans on stormwater management clearly indicate its emphasis on structural measures. Building infrastructure has been reinforced by institutional rigidity based on technical bureaucracies which often persist with structural measures and rely solely on controlling water flows and making only small changes in policy practices. Operational planning norms based on building infrastructure such as dams, dykes and diversions for flood protection without considering changes in catchment context may increase environmental problems and even risks of flooding. Based on purely technical aspects, water issues have a primarily focused on resolving either a flooding problem or a stormwater quantity problem, which required an end-of-pipe solution.

Thus, calls for an alternative solution to stormwater management should arise from planning norms and organisational interests in order to envisage modifications to the traditional focus on existing infrastructure. More non-structural measures of sustainable stormwater management such as land-use planning, strict regulations and adaptation practices of state agencies are vital to make the overall intervention more effective in ICM planning.

Considering institutional arrangement issues, although catchment organisations were expected to support planning improvement and water resources management, there seem to be large gaps between numerous policy initiatives in response to water-related issues, given conflicting organisational mandates and responsibilities. Due to the isolation and overlap in water management between the agencies in both policy and operational levels, the management of drought, flooding, and wastewater issues is inefficient and becomes more of a catastrophe. Moreover, concern about stormwater management was unlikely to be a high priority at the catchment scale as there was limited catchment organisation directive to respond to stormwater management. Those various institutions established have accountability for isolated water resources management issues.

To overcome the fragmented issues, empowerment networking among stakeholders or water users through their own practice in water resource management is important. It is important to co-operate with all partners beyond the territory of administrative jurisdictions to achieve goals of sustainability. The strengthening of relations and interactions of relevant actors may potentially provide coordination mechanisms for sharing knowledge and experiences for resolving environmental issues, contributing to socio-technical change in the transitions of complex systems of the catchment. Finally, this will help to make the approach work for their own benefit and help relevant actors to learn and firmly understand the ICM and SC systems.

To improve environmental performance and resolve unsustainable environmental issues, fundamental changes in governance regimes are needed to require structural change of established socio-technical arrangements that form the behavioural practices and decision-making of actors that will in turn filter up and transform socio-technical structures. Institutional arrangement would be one of the greatest challenges in integrating catchment management. As climate change is likely to increase the frequency and intensity of rainfall events in the region, the effects of stormwater on water quantity and quality become challenges for both formal and informal institutions to define roles and responsibilities for guiding social practices.

The paradigm shift from anthropocentric to ecocentric may have possibly occurred by enhancing the awareness of the public for the implementation of SC principles into the urban catchment and introducing policy that recognises the need for improving the urban stormwater quality. The efforts in improving the urban environment for long-term purposes requires an interdisciplinary approach that depends not only scientific elements of landscape knowledge but also cooperation under the jurisdiction of planners and other relevant parties.

Responding to shifting stormwater regimes under climate change will require better cross-level coordination of local people, municipalities, and other levels of authority, as well as coordinating established community-based capacities with administrative hierarchies. Thus, the coordination among related agencies including central governments responsible for land and water resource management, local governments located in the catchment and the needs and support from different agencies and all related departments within the BMA is important to make sustainable stormwater measures more effective.

Furthermore, the champions from different practitioner and scientific backgrounds in the field of environmental planning and stormwater management with high levels of position power should play an important role in gathering the information on stormwater SC management focusing on the attributes of social processes instead of purely technical aspects that challenged conventional practice of urban stormwater planning.

Overall, it is very important to strengthen the capacities of stakeholders' participation at all levels through providing and sharing of knowledge, learning, information, and financial support. Meaningful public participation in planning and decision-making is a basis for increasing transparent policies, building trust, allowing stakeholders to identify local problems and to understand the existence of plans and best practices, and empowering a social group.

The sustainable stormwater strategies must be flexible and multidisciplinary, adapting to the changing nature. Planning of integrated water management requires a holistic approach to deal with the complexity of the methods. Therefore, it requires multiple perspectives and the participation between different stakeholders. Spatial and administrative factors such as land-use planning, legal, administrative and institutional implementation also need to give greater priority for sustainable stormwater practices. Broader public participation is crucial to local adaptation to monitoring changes in stormwater regimes, and gaining acceptance for stormwater SC solutions.

Stormwater SC measures have great significance for future stormwater management policy. The economic measures are important instruments that should be applied for increasing SC practices and green areas in floodplain cities. The budget and expertise for the SC practices should be provided and enacted by government agencies and this should be specified to be in both short-term and long-term plans. Measures in economic incentives may include tax reduction, tax exemptions, financial subsidies, and environmental SC technology investment. The public financial support and strict legislations are important to create opportunities for communities to consider in their efforts to minimise the load of stormwater contamination and CSOs in Bangkok and other floodplain cities.

For today's globalisation, civil societies should play a significant role to drive forwards beyond the routine activity of governments related to environmental obligations through the proactive movement of public support for the government policies. Public and institutional resistance to the adoption of stormwater SC principles can be gradually mitigated by enlightening the public through education and engagement. Training environmental programs for staff of local organisations are also important to set up an adequate legislative and policy framework for ICM planning. As sustainable stormwater management is a relatively new practice for decision-making in government, strengthening links of knowledge and practice on SC approaches between technical experts, planners, local legislators, developers, and decision-making authorities would help address the governance issues.

As regards the big picture, the governance for sustainability holds the ecosystem integrity as a core essential to be protected. Thus, the existing water and land use policies and design guidelines for ICM and SC management in Bangkok should be revised to promote environmental improvement. Additionally, the management of land and water resources should be integrated in all aspects and considered holistic approach of urban ecosystems including biotic and abiotic components and the association with policy, legislation, and institutional arrangements.

It is a priority of this thesis to highlight a sustainable stormwater practice that can maintain resiliency of urban ecosystem. As discussed previously, unsustainable stormwater practices are not associated with strong sustainability rather they weaken and decrease the ecological sustainability and could lead to negative impacts on human health. Thus, to achieve the environmental sustainability, all members of society must place the value of nature and ecological responsibility at the top-level priority so that it cannot be diminished.

Appendix

Appendix A. Interview Guides

The interview questions: Overviews of the barriers to and potential for implementing Integrated Catchment Management (ICM) planning and stormwater source control (SC) practices

1. What have strategies and measures been applied in the area to minimise stormwater contamination and to promote environmental quality improvement?
2. What are the barriers to implementing Integrated Catchment Management (ICM) and stormwater source control (SC) in the CPRB?
3. What are the strategies and measures of effective ICM planning and stormwater SC practices that should be provided to promote environmental quality improvement in the catchment areas?
4. How can government organisations promote the implementation of ICM planning and SC practices in the catchment areas?

To clarify these main questions, the interview will include the following variables of barriers to and potential for ICM and stormwater SC implementation in the CPRB

- Challenges of fragmented government
- Challenges of technical bureaucracy
- Challenges of integrated knowledge and learning
- Challenges of coordination among relevant agencies
- Challenges of legal enforcement
- Challenges of budget implementation
- Challenges of public participation and stakehoder involvement
- Potential for implementing stormwater SC practices in the catchment areas

The stormwater source control (SC) management is part of an urban design concept to create the greening of cities and community environment using local plants and stormwater treatment trains (from green roofs, rain gardens, permeable pavements, to detention ponds) from the individual and neighbourhood level to the whole catchment level. At the individual level, stormwater SC practices take into account managing household water runoff through green infrastructure such as green roofs, rain garden, pervious pavement, and rainwater storage tanks. At the neighbourhood level, the primary focus of the stormwater SC approaches is on managing street pavements, bioretention swales, and detention basins in terms of stormwater quality and quantity. This approach also creates green habitats for native species, increases biodiversity, and promotes water balance for the whole catchment level.

Please use the photos of stormwater SC features and a range of their benefits to answer the following questions

Green roofs: *"Stormwater reduction, retention, transpiration and filtration; Cost savings in heating and air conditioning due to the insulating effect of the growing medium and plants; Protection of the roof from UV damage; Habitat for insects, plants, birds, and even lizards; Moderation of the urban heat effect; Noise reduction (inside the building);and they look interesting and pleasant."* (Ignatieva et al, 2008, p.18-19)


Source: www.blackdiamondnow.net


Source: www.scgh.com


Source: baybridgehouse.org

Rain gardens: *"Raingardens are usually under-drained and always have an overflow or bypass through which the majority of runoff from large storms passes. With the appropriate species for the area, rain gardens are self-watering and self-fertilising once established, and particularly suitable for supporting street trees in dry urban environments."* (Ignatieva et al, 2008, p.27)

Source: texaslid.org

Source: greatecology.com

Source: www.inblackdiamond.com

Vegetated swales: *"A swale is an ephemeral watercourse for overland flow of stormwater. It is a shallow, linear depression in the ground that is designed to collect and channel stormwater runoff along gentle slopes, and in the process allows settling and filtering of coarse sediments and contaminants. Some evaporation and subsurface filtration may occur, but generally most stormwater is transported to a raingarden, infiltration basin, wetland, pond, or piped infrastructure."* (Ignatieva et al, 2008, p.23)

Source: dottarchitecture.com

Source: greatecology.com

Source: aubreyshepherd.blogspot.com

Pervious pavements: *"Permeable paving is best used where there are low traffic loading, light vehicles (cars, not trucks), and relatively clean stormwater – this limits compaction and sealing of the surface with sediment."*(Ignatieva et al, 2008, p.21)

Source: www.lastormwater.org

Source: greatecology.com

Source: www.ens-newswire.com

Detention ponds: *"The detention pond or retention basin allows biological or chemical treatment to occur in retention time before the water is released into the receiving streams, which can be beneficial use for the downstream habitants."* (Auckland Regional Council, 2003).

Source: www.rwmwd.org

Source: city.milwaukee.gov

Source: www.rwmwd.org

Challenges of fragmented government

- In your opinion, do administrative boundaries fit with ecosystem boundaries in terms of water resource management?
- Are responsibilities for management of rivers in the catchment still confused or overlapped across several agencies?
- Are the management of water shortages and stormwater considered as separate issues under different jurisdiction and their own budgets?
- Do governments have sufficient authority to monitor other agencies in the implementation of environmental policies on climate change and water resource management?

Challenges of technical bureaucracy

- How satisfied are you with the hard adaptation measures such as storm drains and dikes along roads constructed to prevent flooding?
- Do building infrastructure such as dams, dykes and diversions for flood protection increase environmental problems or even risks of flooding in vulnerable areas?
- Are decisions regarding a large infrastructure project likely to be based on public agendas or decision-making processes of the catchment organisations?
- Are longer-term measures like SC practices, land use planning and good water governance addressed in goverment reports?
- Are local or regional councils responsible for sustainable stormwater operations or the management of environmental impacts?
- Does stormwater management planning pay more attention to either environmental issues or water quantity/risks of flood-related disasters?

Challenges of integrated knowledge and learning

- In your opinion, is the understanding of the impact of urbanisation on water quality very limited?
- Is there any research on water management and water policy studies published by the bureaucracy or the catchment organisations?
- How satisfied are you with information-sharing and coordination within other government agencies?
- How satisfied are you with cooperation between local practices and central agency officials in learning processes?
- Is there inadequate technical-knowledge support from the central government to enforce environmental quality control in local communities?
- Is reforming education, raising learning activities and workshops, and heightening strong water-related institutions indicated in order to enhance learning processes?

Challenges of coordination among relevant agencies

- Are there any problems arising between professionals of different disciplines which lead to difficulties in developing a common language, perspectives and knowledge?
- Is there coordination between the Royal Irrigation Department (RID) and the Bangkok Metropolitan Authority (BMA) for operational decisions about stormwater infrastructure in the overlap jurisdictions?
- Is there adequate learning from local expertise in stormwater construction plans such as a dike, flood ways, or a water diversion system?
- How often is your organisations time spent in collaborative activities with other organizations in catchment management?

Challenges of legal enforcement

- Is the legal aspect of integrating water and land use planning fully implemented?
- Does a large number of separate water-related laws contribute to ineffective law enforcement?
- Is there strict relevant legislation and adequate enforcement of it to prevent illegally discharged untreated wastewater into the environment?

- Is there specific legislation regarding stormwater and drainage systems for the building construction permit in the catchment area?
- Are there any measures in controlling urban sprawl to preserve the suburban agriculture and natural environment indicated in environmental plans?
- Are there clear timelines, goals, and objectives in stormwater management plans?
- Do land use measures explicitly take stormwater management, ICM, and climate change into account?

Challenges of budget implementation

- Is there inadequate budget in the implementation of catchment plans?
- Is the local government budget an alternative source of finance to support stormwater management?
- Are the costs of the construction and maintenance of SC devices a major barrier in its implementation?
- Do perceptions of high capital and maintenance costs and low profit influence developers and consultant decisions on SC solutions?
- Are the financial incentives and public subsidies a main influence on the probability of source control systems adoption?
- How can financial incentives be used to create a public subsidy program for property owners for installing the source control technologies?
- Is tax credit, financial incentive, or a public subsidy program offered to owners of building, new offices, schools, and colleges who install green roofs and other source control facilities to increase willingness to pay?
- Will a financial incentive be promoted and offered to properties' owners to install green roofs to reduce urban runoff from roofs to gardens and lawns?

Challenges of public participation and stakehoder involvement

- Are all stakeholders including government agencies, professionals, local communities and vulnerable groups participating in decision making for stormwater management?
- Are champions or advocates involved in enhancing the implementation of ICM and SC practices?
- What improvements are possible/desirable in the management of catchment networks?
- Is information on websites available to promote participation in decision-making, monitoring and evaluating processes?

Potential for implemntaing stormwater SC practices in the catchment areas

- Are there any measures to reduce combined sewer overflows (CSOs) when stormwater runoff exceeds the capacity of wastewater treatment systems?
- How satisfied are you with the implementation of stormwater SC features in the catchment areas?
- What are the potential for and barriers to implementing stormwater SC approaches in the areas?
- How can the implementation of SC approaches be increased in the catchment areas?
- Is the use of public parks and public spaces considered to combine with a series of sustainable stormwater devices in order to reduce space constraints in private land in high-density residential developments?
- Is the installation of permeable pavements suitable for pedestrian walkways, courtyards, parking lots, and low-traffic roads in Bangkok and its catchment?
- Is the implementation of vegetated swales instead of curbs and gutters applicable to save the developers in construction cost, reducing paving width of the road, and reducing paving cost?
- Are greenroofs, raingardens, stormwater ponds, and constructed wetlands appropriate to prevent stormwater overflows and reduce contaminants in the catchment areas?

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