SYSTEM DYNAMICS ANALYSIS ON MUNICIPAL SOLID WASTE MANAGEMENT UNDER FLOODING : CASE STUDY BANGKOK, THAILAND.

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SYSTEM DYNAMICS ANALYSIS ON MUNICIPAL SOLID WASTE MANAGEMENT UNDER FLOODING : CASE STUDY BANGKOK, THAILAND.) อ.ที่ปรึกษาหลัก : รศ. ดร.ชนาธิป ผาริโน

การจัดการขยะมูลฝอยเป็นการบริการสาธารณะที่สำคัญของเมืองที่สามารถบ่งชี้ความยั่งยืนของการพัฒนาเมืองดังที่ระบุเป็นเป้าหมายที่ 11 ในการพัฒนาที่ยั่งยืน (SDGs) โดยพื้นฐานของการจัดการขยะมูลฝอยเป็นระบบการทำงานที่ซับซ้อนและเชื่อมโยงกันเป็นเครือข่ายในรูปแบบของปริมาณและพื้นที่ภายในระบบ ดังนั้นด้วยลักษณะที่ซับซ้อนนี้จึงส่งผลให้มีความยากต่อการจัดการอย่างยั่งยืน โดยเฉพาะอย่างยิ่งเมื่อระบบนี้ถูกรบกวนด้วยภัยพิบัติ เช่น น้ำท่วม ซึ่งนับเป็นภัยธรรมชาติที่สำคัญในหลายภูมิภาคของโลกที่และมีความท้าทายต่อการบริหารจัดการขยะมูลฝอยภายใต้ผลกระทบจากการรบกวนจากภายนอกที่ส่งผลต่อทุกส่วนของระบบ ฉะนั้นการเตรียมแผนบรรเทาผลกระทบที่มีต่อระบบการให้บริการจัดการขยะมูลฝอยในช่วงการเกิดภาวะน้ำท่วมจึงมีความสำคัญต่อชุมชนเพื่อไม่ให้การให้บริการถูกชะงักลง

งานวิจัยนี้ได้ทำการประยุกต์หลักการของพลวัติระบบเพื่อใช้ในการทำความเข้าใจรูปแบบของระบบการจัดการขยะมูลฝอยและใช้ในการสร้างแบบจำลองความเข้าใจเพื่อประเมินผลกระทบของน้ำท่วมที่มีต่อระบบการจัดการขยะมูลฝอยของกรุงเทพมหานคร แบบจำลองแสดงแนวโน้มปริมาณขยะมูลฝอยที่จะเกิดขึ้นรวมทั้งรูปแบบเครือข่ายของขั้นตอนการเก็บขนและการขนถ่ายเพื่อศึกษาพื้นที่ที่ได้รับผลกระทบ โดยการประเมินผลกระทบจากน้ำท่วมในสถานการณ์จำลองทั้ง 11 บริเวณ ที่เป็นบริเวณที่มีโอกาสสูงต่อการเกิดภาวะน้ำท่วม ผลที่ได้พบว่าพื้นที่มีโอกาสสูงต่อการเกิดภาวะน้ำท่วมที่ตั้งอยู่ในเขตบางแค ซึ่งส่งผลกระทบสูงสุดต่อปริมาณขยะสะสมของระบบและจำนวนพื้นที่ให้บริการที่ได้รับผลกระทบ โดยผลกระทบที่เกิดขึ้นส่งผลเป็นลักษณะเครือข่ายทั้งในเขตให้บริการที่อยู่ในพื้นที่น้ำท่วมและนอกพื้นที่น้ำท่วม โดยผลที่ได้นำมาใช้ประยุกต์ในการหาแนวทางในการบรรเทาผลกระทบด้วยเทคนิคการตัดสินใจแบบหลายหลักเกณฑ์ (MCDA) ซึ่งแบ่งผลกระทบจากน้ำท่วมที่มีต่อขั้นตอนการทำงานของระบบการจัดการขยะมูลฝอย 3 ลักษณะ คือ 1) ไม่สามารถเก็บขนมูลฝอยจากแหล่งกำเนิดได้ 2) ไม่สามารถขนส่งสู่สถานีขนถ่ายและกำจัดมูลฝอยได้ 3) ไม่สามารถเก็บขนขยะจากแหล่งกำเนิดและขนส่งสู่สถานีขนถ่ายมูลฝอยและไปกำจัดได้ โดยมีปัจจัยในการวิเคราะห์ที่ครอบคลุมหลักการพัฒนาที่ยั่งยืน ได้แก่ ปัจจัยด้านสิ่งแวดล้อม เศรษฐกิจและสังคม ผลการวิเคราะห์พบว่าการปรับแต่งสมรรถนะรถบรรทุกมูลฝอยเพื่อให้สามารถขนส่งในพื้นที่น้ำท่วมได้เป็นทางเลือกที่ได้รับความสำคัญสูงสุด โดยปัจจัยที่มีความสำคัญต่อการตัดสินใจเลือกแนวทางในการจัดการมากที่สุด คือ ความเสี่ยงต่อสุขภาวะของชุมชน และความสามารถในการจัดการการคัดแยกมูลฝอย

ผลการศึกษาที่ได้สามารถใช้ในการพัฒนาแผนการบรรเทาผลกระทบระหว่างช่วงน้ำท่วมที่มีต่อการให้บริหารจัดการขยะมูลฝอยซึ่งเป็นระบบการให้บริการสาธารณะที่สำคัญของเมือง เพื่อเพิ่มศักยภาพและเตรียมพร้อมต่อการมุ่งสู่การเป็นเมืองที่ยั่งยืน

สาขาวิชา	วิทยาศาสตร์สิ่งแวดล้อม	ลายมือชื่อนิสิต ....
ปีการศึกษา	2561	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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KEYWORD: Municipal Solid Waste Management, Flooding, Mitigation, Planning, Multi-Criteria Decision Making (MCDM), Analytic Hierarchy Process (AHP)

Nuchcha Phonphoton : SYSTEM DYNAMICS ANALYSIS ON MUNICIPAL SOLID WASTE MANAGEMENT UNDER FLOODING : CASE STUDY BANGKOK, THAILAND.. Advisor: Assoc. Prof. Chanathip Pharino, Ph.D.

The municipal solid waste management service system has been one of the key service provisions to indicate the sustainability of the city as defined in Sustainable Development Goals - SDGs #11. Complex linkages of stock and flow within the system are impacted by waste quantities and spatial characteristics. The complex characteristics make it difficult to design a sustainable management system, particularly in case of a disaster. Flooding is a major natural disaster in many regions of the world and poses a challenge as an external disturbance that can affect any part of the waste management system. Flood mitigation plans are gravely important for mitigating the impact during crisis situation for communities to face no disruption of the waste management service.

The present research has applied the concept of system dynamics (SD) to understand and evaluate flood impacts on waste management system. The SD modelling approach has been designed to investigate management patterns of the system and evaluate the impacts of flooding on the waste management service in Bangkok, Thailand. The model illustrates waste generation trends and collection and transfer network patterns to predict potential flood-affected areas. The research analyzed different flooding scenarios and evaluated their potential impact. There are 11 flooding scenarios represented by 11 flood-prone locations. The vulnerable flood-prone area in Bangkae district is the most affected area with the highest accumulated waste amount. The flooding impacts have affected services within and outside the flooded areas to various degrees. The results have been applied to provide the mitigation impact approaches with the multi-criteria decision analysis (MCDA) technique. The flood impacts on municipal solid waste management are classified into 3 situations including: (1) cannot collect wastes from generating sources, (2) cannot transfer wastes to final disposal and 3) cannot collect from sources and transfer wastes to final disposal. The decision support system based on the principles of sustainable development considers the impacting criteria, namely, environment, society, and economic factors. The truck modification is the first

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Academic Year:	2018	Advisor's Signature ....

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Chapter 1

Introduction

1.1 Statement of the Problems

Municipal solid waste management (MSWM) is a significant service provision within any city (Hoornweg, 2013). In low- and middle-income countries, MSWM is the biggest single-budget item and comprises the largest number of public employees (World Bank, 2012). The two processes of waste collection and transportation are the main MSWM expenses and include complicated operations (Sukholthaman & Sharp, 2016). The amount of municipal solid waste collected correlates to a city's expansion, as countries urbanize, in terms of population structure and socio-economic development (Kollikkathara et al., 2010). The MSWM is a complicated system, in part because the stock-flow of waste varies over time. The dynamics of the system's individual parts, including waste collection, transportation, and disposal, are all interconnected to spatial management. Thus, the MSWM system is a combination network of quantitative and spatial management.

The depth and breadth of a network connection can become quite a challenge on the path to achieving sustainable management. If any part of a waste management system is disturbed by a natural disaster, it can affect the other parts (such as emergency operations). Therefore, MSWM is among the most pressing issues and a major management challenge for many cities worldwide (Habitat, 2010; Hoornweg, 2013).

Besides global development towards urbanization, the management of intense climatic conditions such as storm surges, heat stress, and extreme precipitation is another challenging problem (IPCC, 2014). Particularly, flooding is a major natural disaster in many regions of the world. From 2001 to 2010, floods and other hydrological events represented over 50% of all global disasters (Guha-Sapir, 2011); in 2012, 53% of global natural disasters were floods. Asia, in particular, most frequently suffered hydrological disasters, causing 52.1% of all natural disaster damage in 2011 (Guha-Sapir, 2012). Rapid and unplanned urbanization processes in hazardous areas exacerbate vulnerability to disaster impact (IPCC, 2012). The pressure for urban areas to expand into floodplains and coastal strips has resulted in an increase in populations' exposure to riverine and coastal flood impacts (McGranahan et al., 2007). Urban floods often occur when rain overwhelms drainage systems and waterways, making its way into basements and streets (CNT, 2014). Thus, the impacts of disasters significantly affect the development and management of a city.

Urban flooding not only impacts flooded areas, but also those outside the flooded area when a network system, such as the MSWM system, is located. It is critical to conduct an MSWM systematic impact evaluation under pressure of extreme external conditions to provide a better understanding of the interlinking of a sophisticated and dynamic waste management system. There are many studies on sustainable MSWM, but most are conducted under normal circumstances, such as the cycling of solid residues, management of electronic waste, and investigations into forecasting, planning, and management of collection and transport routes (Vitorino de Souza Melare et al., 2017). There are many studies on sustainable MSWM with disaster waste management, which are mostly focused on the after-disaster phase but lack analysis of MSWM during the crisis phase. Therefore, the study of the impact of natural disasters, such as flooding, on the municipal solid waste system is important to investigate approaches for the mitigation of the impact situation.

Bangkok's MSWM was affected by the massive flooding in Thailand in 2011; the flood impacts were widespread and affected areas both inside and outside the floodplain. The emergency response from waste management systems in case of such crises is only a temporary solution for an unexpected problem. This parallels other developing countries that give waste management low priority (Brown et al., 2011). Data about impact evaluation for appropriate MSWM planning during flooding is severely lacking. Moreover, the planning facility still does not have an appropriate strategy or measures to prepare for possible flooding (BMA, 2015c). Therefore, the flooding mitigation of MSWM services is intensely important to the move towards sustainable cities and communities. This poses the challenge of obtaining complex spatial and quantitative impact data both inside and outside the disturbed area in order to apply mitigation plans during floods.

System dynamics (SD) is a fundamentally interdisciplinary method to enhance learning in complex systems (Sterman, 2000) and facilitate understanding of the relationships between variables in a system in a specific situation over time and under specific conditions (Wolstenholme, 1990). SD is used to optimize system performance while grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering (Sterman, 2000). Problem analysis is a set of supporting tools that offer a useful modelling approach to simulate scenarios in a wide array of disciplines, such as finding appropriate decisions for agricultural development (Saysel et al., 2002), sustainable management of coral reefs (Chang et al., 2008), business systems (Sterman, 2000), the desertification of the Ordos region of China (Xu et al., 2016), and the determination of buildings' technical system energy performance (Horvat & Dović, 2016). It also involves important features for studying the survival of a system in case of interference from external conditions (Coyle, 1996).

In the area of waste management, SD has been extensively applied to forecasting of municipal solid waste (Dyson & Chang, 2005), optimization of solid waste scheduling and routing (Johansson, 2006), evaluation of municipal solid waste generation, landfill capacity and related cost management (Kollikkathara, Feng, & Yu, 2010), reduction of construction and demolition waste (Ding et al., 2016; Yuan et al., 2012), collection schemes for portable battery waste (Blumberga et al., 2015), evaluation of municipal solid waste source separation (Sukholthaman & Sharp, 2016), and prediction of waste generation (Johnson et al., 2017).

This study aims to develop a tool to increase understanding about the impact of flooding on Bangkok's MSWM systems with simulation and prediction of the situation during flooding. It helps to recommend an appropriate alternative for mitigating the impact of MSWM service during flood events. Bangkok has a high increased generation rate of MSW (Laohalidanond et al., 2015). Therefore, it was chosen as a case study of a city in a developing country with a high rate of urban expansion, which has resulted in an increased rate of MSW. The research applied the SD model approach as a tool to study the relationships and complexity of the MSWM system with MSW amount flow. The different flooding scenarios in various areas of the MSWM service system in Bangkok were investigated to indicate the vulnerable areas for future mitigation planning. The results are applied along with a decision support system, as an analytic hierarchy process (AHP), to provide an approach for the city's important public environmental service provision towards urban flood mitigation.

1.2 Objectives

1) To develop an SD model for Bangkok's MSWM system.

2) To evaluate the flood impacts on Bangkok's MSWM service system at each management stage for collection and transfer through the SD model.

3) To recommend approaches to mitigate impacts of urban flooding on the MSWM system.

1.3 Research Hypothesis

Flooding impacts MSWM system service areas inside as well as outside the floodplain, with different impact levels depending on the disturbed management stage and the responsible waste amount. Therefore, MSWM service areas in the floodplain are not the only vulnerable ones.

1.4 Scope of the Research

1) The SD analysis on MSWM under flooding in the Nongkhaem transfer station service responsibility area is divided into 22 districts.

2) The MSWM service system in this study consists of collection and transfer.

3) Vensim@PLE Plus 7.2 is a SD software program used to formulate and simulate the SD model of the MSWM system.

4) A flood-prone area is defined as any public roadway that runs the risk of being covered by enough water to hinder the transportation of an MSW truck.

1.5 Expected Results

1) The SD model of Bangkok's MSWM system.
2) An understanding of the flood impact on Bangkok's MSWM system in terms of the relationship level at the collection and transfer stages during floods.
3) The approaches to mitigate impacts of urban flooding on Bangkok's MSWM system.

1.6 Conceptual Framework

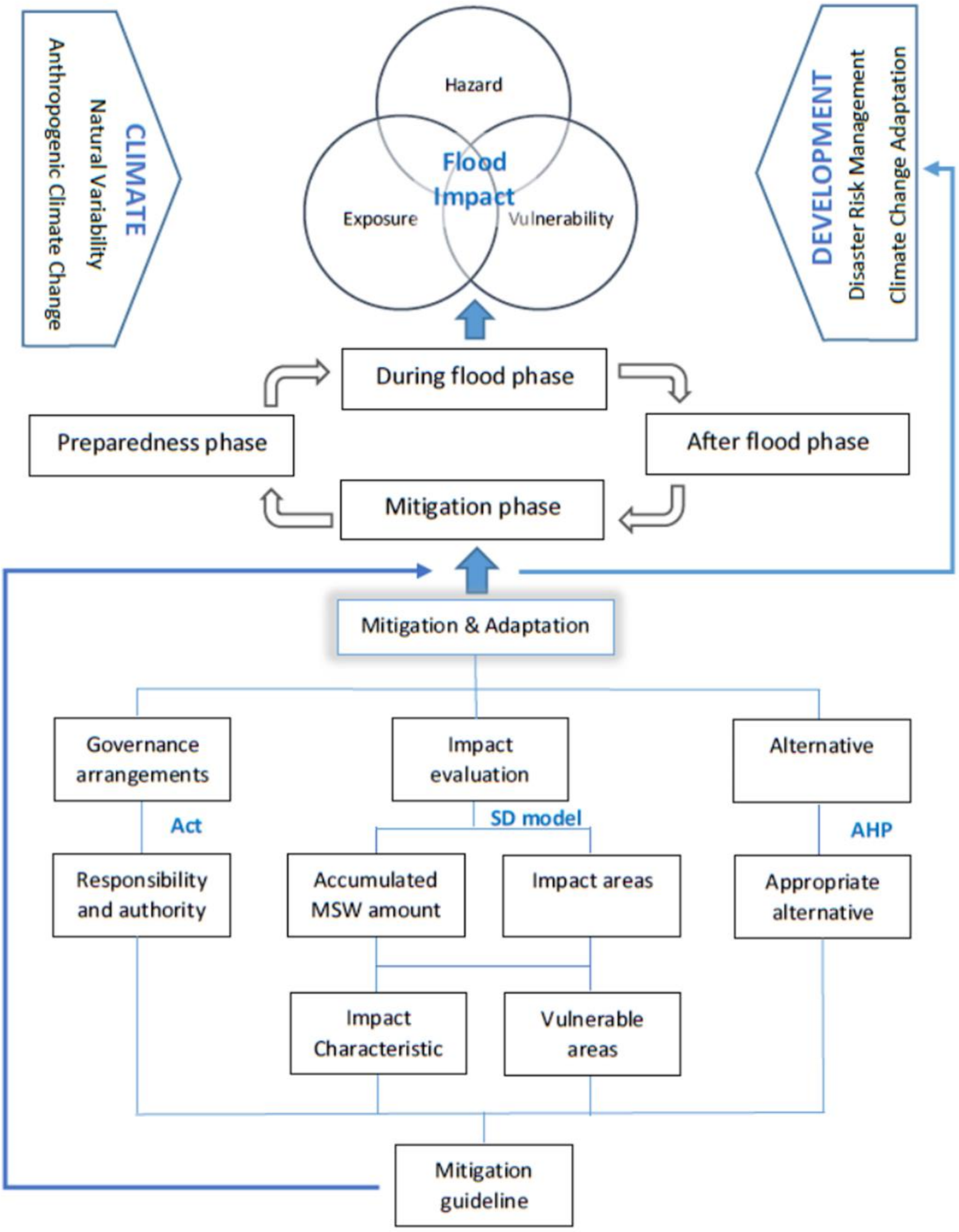

Figure 1. Research conceptual framework

Chapter 2
Literature Review

This chapter presents an integrative review of the theoretical and empirical literature, describing the concepts in the study model and their interrelationships. Reviews of related literature are listed as follows:

1. Municipal solid waste management (MSWM)
2. Urban flood impacts
3. System Dynamics (SD)
4. Analysis Hierarchy Process (AHP)
5. Relevant research

2.1 Municipal Solid Waste Management (MSWM)

2.2.1 MSWM situation

MSWM is a critical service for cities; in low- and middle-income countries especially, MSWM comprises the largest portion of the city budget and hires the most employees. It also occupies the main position in high-income countries' expenditure on disposal (World Bank, 2012) as shown in Figure 2. It is a major management challenge for many cities in developing and transitional countries (Habitat, 2010). Asia has the fastest-growing amounts of waste, mostly organic waste and paper, in the waste stream. The East Asia and Pacific regions have the highest percentage of organic waste (62%) compared to OECD countries, while developed countries have the least (27%) (World Bank, 2012).

MSWM is not only related to economics but also affects public health, the environment, and resource management. Therefore, integrated solid waste management should consist of an evaluation of the best-balanced assessments of all technical, environmental, social, and financial issues in specifying the amount, scale, and distribution of collection, transportation, treatment, and disposal systems.

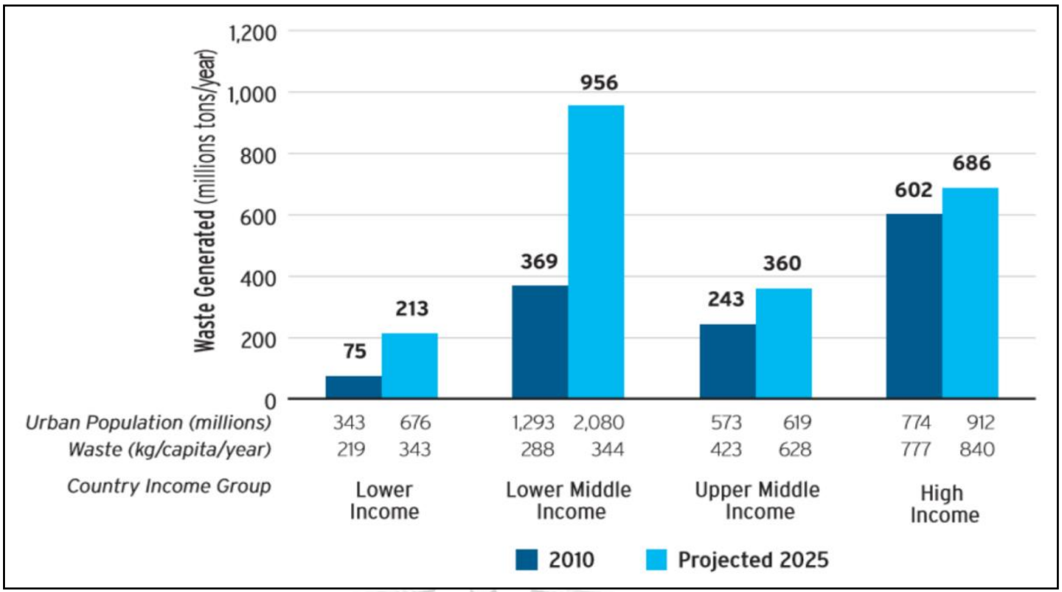

Figure 2 A global review of waste generation by income level and year (World Bank, 2012)

2.2.2 Bangkok's MSWM situation

Bangkok is the capital of Thailand. The city features as a financial and residential centre, with an administrative area of 1,568.74 km^2 and comprised of 50 districts. Bangkok has 2,753,972 households and 5,696,409 people, excluding the non-registered population (BMA, 2015d), generating waste of around 9,940 tons/day as of 2014 (BMA, 2015c). This amount of waste generation is in a similar range to other Asian megacities such as Hong Kong and Beijing (Laohalidanond, Chaiyawong, & Kerdsuwan, 2015), as shown in Table 1.

Table 1 Comparison of the MSW Generation Rates of Asian Megacities

Cities	Bangkok	Beijing	Hong Kong	Seoul	Singapore	Tokyo
MSW generation rate (kg/capita/day)	1.04–1.18	0.85–1.20	1.27–1.36	0.95–1.08	0.96–1.10	0.77–1.03

The Department of Environment (DOE) under the Bangkok Metropolitan Administration (BMA) is responsible for MSWM, together with the Environment and Sanitation Section in each local district. Bangkok's MSW generation rate has increased steadily; from 1991 to 2000, the average rate increased by 6–6.5% per year.

During the major flooding in 2011–2012, the amount of MSW generation increased to 9% (BMA, 2015c).

The BMA's MSWM service system is illustrated in Figure 3. MSW is collected by local municipalities from containers in front of houses, buildings, or designated locations on specific dates and times. Bangkok's waste collection service is operated separately by local districts and divided into sub-service areas. After collection, the MSW is transported to three main transfer stations in Bangkok, On-Nuch, Nongkhaem, and Sai-Mai. The On-Nuch transfer station handles MSW from 16 districts while the Nongkhaem and Sai-Mai transfer stations handle waste from 22 and 12 districts, respectively. As per the proportion of MSW shown in Figure 4, the On-Nuch transfer station has the capacity to handle 3,900 tons of waste per day, composting around 1,200 tons and transporting approximately 2,700 tons to the Phanom Sarakam landfill in Chachoengsao province. The Nongkhaem transfer station's capacity is 3,600 tons/day, where approximately 500 tons are treated by incinerator per day and 3,100 tons are transported to the Kampangsan landfill in Nakhorn Pathom province. The Sai-Mai transfer station's capacity is the lowest, at 2,400 tons/day, which is disposed of in the Kampangsan landfill.

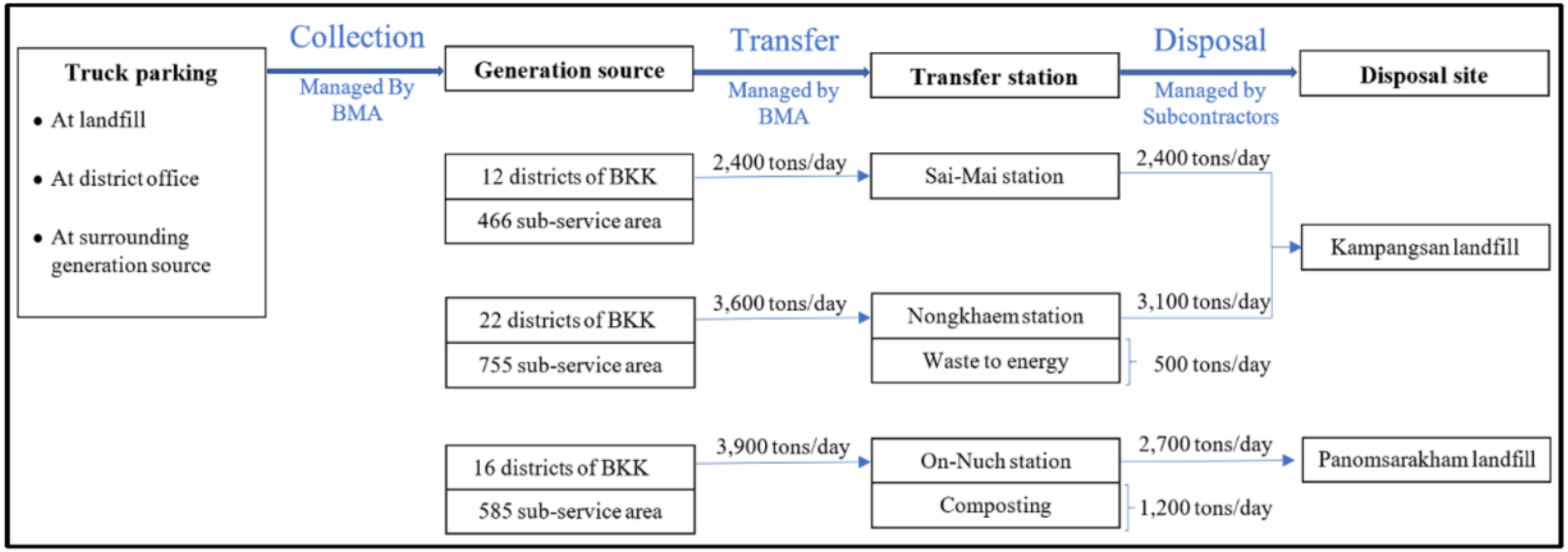

Figure 3. The service system of BMA's MSWM

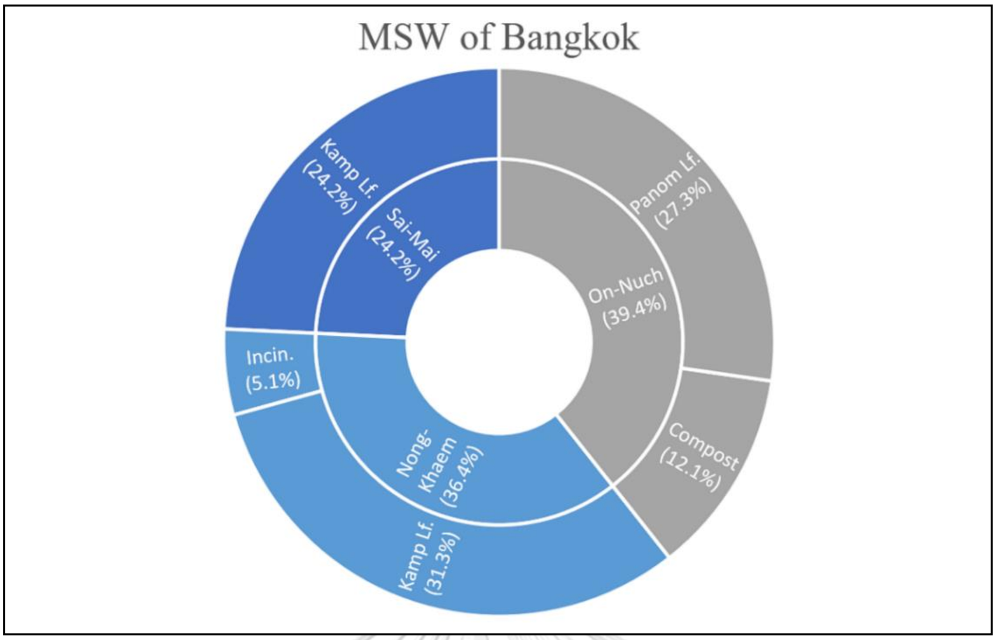

Figure 4. The proportion of BMA's MSWM

2.1.3 Bangkok's MSWM plan

The BMA devised its MSWM strategic plan for 2015 to 2019, aiming to become a metropolis with a sustainable waste management system to minimize waste and reduce its impact on climate change (BMA, 2015b). The strategic plan triumphs with the concept of waste as a resource, to promote reuse of materials in all sectors and minimize waste by changing it into electrical energy or fertilizer with environmentally friendly technology as the target for management, as follows:

- The amount of household waste collected in 2019 will be less than in 2015 by at least 7%.
- The amount of household hazardous waste collected in 2019 will be greater than in 2015 by at least 20%.
- The amount of MSW handled using waste technology will represent at least 30% of the total MSW collected in 2015.

Currently, there is still no strategy or plan to prepare for and mitigate the impact of an emergency during which the MWSM would be unable to function properly under regular routines and procedures.

2.1.4 Bangkok's MSWM during the flood period

The impact on Bangkok's MSWM during a flood can be determined using the actual experience of a major flood in 2011. From October to December 2011, many areas in Bangkok were flooded, causing municipal workers to collect MSW. MSW that accumulates in front of households or is left uncollected for a long period may increase health and safety risks. The collection trucks could not enter flooded areas, thus increasing the amounts of MSW needing to be collected. However, only temporary solutions, such as hiring volunteers to pull waste, procuring 681 trucks to enter some flood areas, and using boats to collect and store MSW, were available for handling waste in case of unexpected incidents (BMA, 2012).

However, the BMA prepared an MSWM management plan in 2015–2019 by analysing the potential of Bangkok's MSWM. Several significant weaknesses were caused by internal factors, which currently have no emergency preparation or protection strategies or measures in place in the event of disasters, such as flooding or a fire at an MSW storage facility (BMA, 2015b). This issue is critical to the management of MSW within a complex and dynamic system under emergency disturbance. There is a need to understand the potential scope of impacts and set up a comprehensive plan to minimize future impacts.

2.2 Urban Flood Impacts

2.2.1 Urban flooding

A flood is 'the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged, it includes river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods' (IPCC, 2012). Flooding directly affects businesses and infrastructure inside the flooded area and indirectly causes the disruption of public services outside the flooded area (Schumann, 2011). From 2001 to 2010, the average number of floods and other hydrological events represented over 50% of all disasters (Guha-Sapir, 2011). Flooding impacts are wide-ranging, affecting the well-being of humans in terms of economic, social, and environmental impacts; thus, addressing flood impact is important in terms of delivering sustainable development (Carter et al., 2009). A change in the climate physically changes many of the factors affecting floods (IPCC, 2012).

Urban areas are complex systems that pose potential management challenges in terms of the interplay between people, infrastructure, institutions, and environmental processes (Ruth & Coelho, 2007). The pressure for urban areas to expand onto floodplains and coastal strips has resulted in an increase in exposure of populations to riverine and coastal flood impacts (McGranahan, Balk, & Anderson, 2007). The urban expansion combines with heavy rainfall overwhelming drainage systems and waterways, making its way into basements and streets, and causing flooding (CNT, 2014). Thus, the impact of disasters significantly affects the development and management of cities.

2.2.2 Bangkok's flood.

In 2011, Thailand experienced exceptionally heavy rains, causing the worst flooding since 1942. Approximately 800 deaths and 9.5 million victims were reported, with widespread damage and losses to homes, factories, businesses, transport and energy infrastructure, social service facilities, and agricultural crops and livestock (ADB, 2012). With $40 billion of damages, it was the greatest economic loss from a natural disaster in Thailand's history, with damages amounting to 12.7% of the GDP (Guha-Sapir, 2012). The flooding especially affected Bangkok, which had experienced rapid urbanization as Thailand's major economic and cultural centre.

Bangkok is located on the Chao Phraya River wetlands and experiences the influence of sea levels (Figure 5). It has a tropical monsoon climate, which produces heavy precipitation, particularly between May and October (Gemenne, 2012). Major flooding in Bangkok was recorded in 1942, 1978, 1980, 1983, 1995, 1996, 2002, 2006, and 2011 (Gemenne, 2012). Cooper's (2014) representation of the areas of flood occurrence is displayed in flood extent/hazard maps based on historical data from 2005 to 2012, as shown in Figure 6.

Bangkok is prone to two types of flooding. The first is a river (fluvial) flood. Being located at the mouth of the Chao Phraya River (which has a catchment area of 159,000 km^2), a large volume of water passes through the middle of Bangkok. River floods occur when the surface water runoff exceeds the capacity of the river to accommodate the flow. The second type is a pluvial flood, sometimes referred to as an urban flood (Saito, 2014).

Bangkok's floods are caused by both natural and physical factors. The natural factors are seasonal precipitation with peak frequency from mid-August through October, run-off water from the north and east caused by a slope, upstream run-off from the Chao Phraya basin, high tides during October to December, changes in natural phenomena such as higher rainfall than usual from La Nina, and heavy rainfall in some areas despite low total rainfall from El Nino. The physical factors are urban planning problems due to rapid urbanization, consequent decreased space to absorb water as open land is replaced by buildings, drainage problems because canals are encroached upon, and land subsidence problems (BMA, 2015a).

Presently, Bangkok analyses its surrounding flood-prone areas by local rainfall and the area's drainage system, determining that there are a total of 19 points of data. These data are used as baseline information for determining the area of Bangkok flood management (BMA, 2016).

Moreover, Bangkok's Department of Drainage and Sewage produces an annual action plan for preventing and mitigating flooding, which determines measures and plans for flood management, including structural and non-structural measures (BMA, 2015a):

- Structural measures are used in densely populated areas. They include the Polder System, a method for areas below the water level outside, including external water inflow protection to manage an area, drainage from an area, and storage in natural ponds and lowlands.

- Non-structural measures are used for non-densely populated community and agricultural area management and floodplain management, including urban planning and land use control, public relations for flood preparation, and setting up a forecasting and warning system, as well as establishment of urgent operations to protect and resolve flooding and a flood management division.

However, some issues, such as a vulnerability assessment (Yuddhana, 2012) and the linking of flood impact management plans into strategic plans of other services, such as the MSWM (BMA, 2015c), are not covered in flood management strategies.

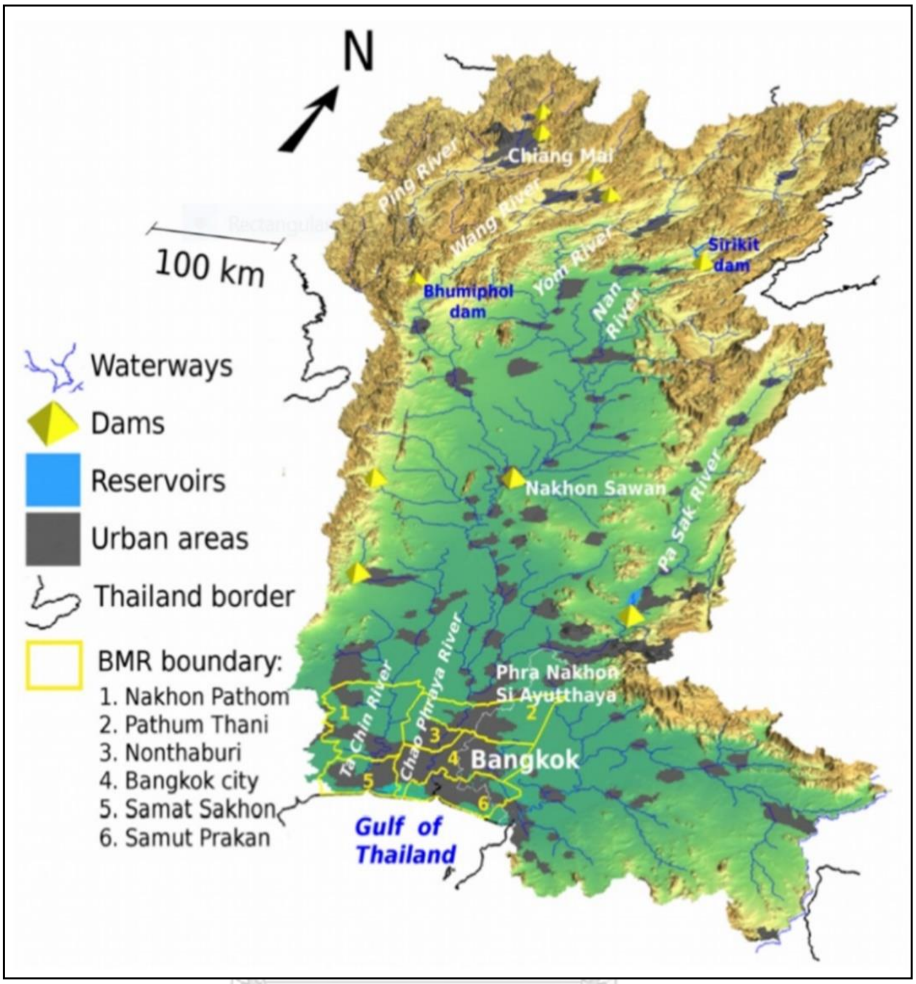

Figure 5. The three-dimensional view of the Bangkok Metropolitan Region (BMR) located in the Chao Phraya River basin and adjacent Sa Keo sub-basin (Cooper, 2014)

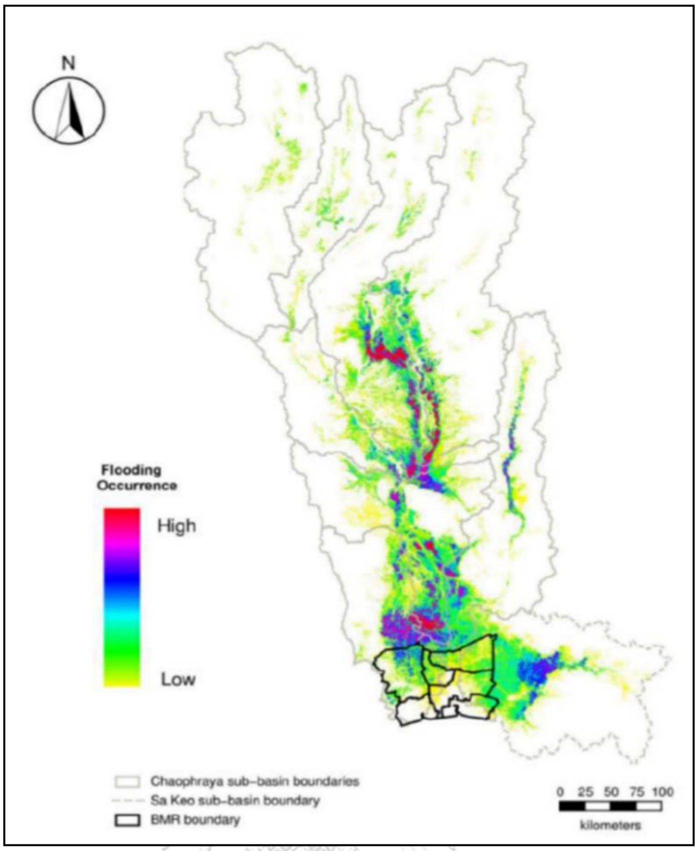

Figure 6. Flood extent/hazard map of BMR, Chao Phraya River basin, and adjacent Sa Keo sub-basin (Cooper, 2014)

2.2.3 Flood impact management

A flood's impact is defined as hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, and environmental effects (Figure 7). Typically, a framework for assessing a flood's and other disasters' impact consists of three factors, namely hazard, exposure, and vulnerability assessment. According to the IPCC, impact management is a process for designing, implementing, and evaluating strategies, policies, and measures to improve the understanding of disaster impact, foster disaster impact reduction and transfer, and promote continuous improvement in disaster preparedness, response, and recovery practices, with the explicit purpose of increasing human security, well-being, quality of life, resilience, and sustainable development (IPCC, 2012).

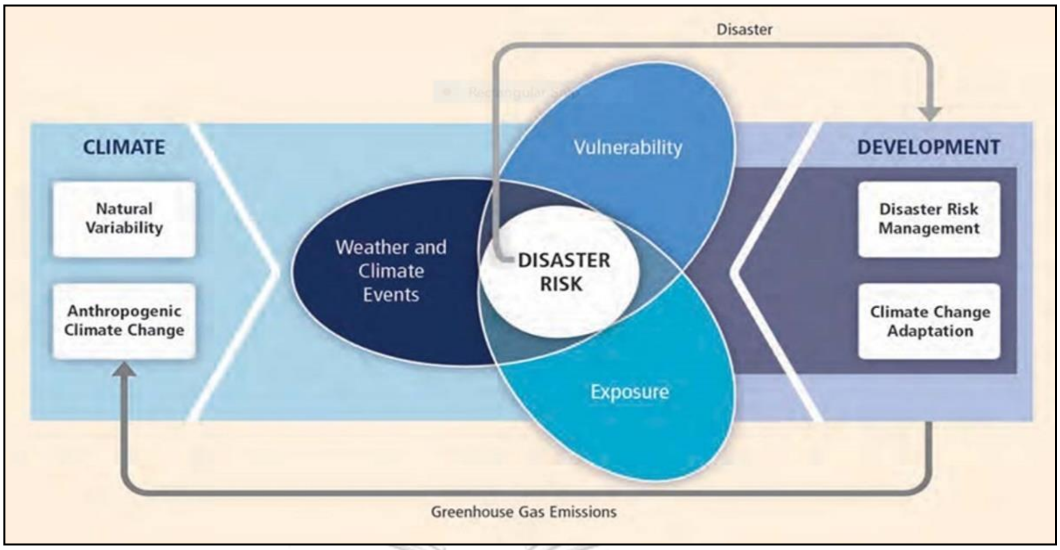

Figure 7. Core concept of disaster management (IPCC, 2012)

Indeed, the complete prevention of massive flooding is difficult. At the very least, it requires planning for managing and mitigating the impacts. Various methods have been used for flood management, such as flood risk mapping, flood hazard zoning, site selection of flood mitigation measures, prioritization of flood mitigation strategies, and integrated assessment of long-term flood management scenarios (Ahmadisharaf et al., 2016).

Therefore, flood impact evaluation is an important basis for mitigation plans, to develop guidelines for prioritization of areas in flood management. A flood impact evaluation is necessary to process for flood management, which possibly reflects the individual characteristics of all elements at the time of the flood (Scheuer et al., 2013). The evaluation should offer suggestions for adaptation and mitigation by the social sector and improvement of the government sector for justice and sustainability in the planning.

Flood impact is thus a function of the hazard and vulnerability (susceptibility) of the receptor exposed to the hazard (Foudi et al., 2015). The character and severity of impacts from climate extremes depend not only on the extremes themselves, but also on exposure and vulnerability. Hazard is defined as the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources. Exposure and vulnerability are dynamic, varying across temporal and spatial scales (IPCC, 2012). The keystone of flood management is mapping, which represents and communicates the spatial relationship between hazard and vulnerability (Chen et al., 2015) such as Geographic Information System (GIS).

Several studies have evaluated the impact of flooding around the world, including in Europe, America, Asia, and Africa. However, they have not been comprehensive in the case of a sustainable flood management system because most studies investigated the direct impact on parameters in flood areas, such as building density and structure (Foudi, Osés-Eraso, & Tamayo, 2015; Prawiranegara, 2014; Tingsanchali, 2012; Zhou et al., 2012), population density and characteristics (Camarasa & Soriano, 2012; Foudi, Osés-Eraso, & Tamayo, 2015; Prawiranegara, 2014; Suroso et al., 2013; Tingsanchali, 2012), and land usage (Camarasa & Soriano, 2012; Canters et al., 2014; Foudi, Osés-Eraso, & Tamayo, 2015; Suroso, Kombaitan, & Setiawan, 2013). There is less evaluation of flood impact on environmental services such as water supply, water treatment, and waste management services, which are directly and indirectly flood-affected, as a result of the connections of the complex system.

However, the above is neither comprehensive nor appropriate for flood management, according to the IPCC (2014), which identified adaptation issues and prospects of flood impact in case of a reduction in the vulnerability of lifeline infrastructure and service (water, energy, and waste management). There have been far fewer flood impact evaluations on environmental services that are dynamic systems, such as water supply, water treatment, and waste management services, in particular the MSWM service, the city’s most important service provision (World Bank, 2012) . The MSWM service system is an example of an exposed system which is both directly and indirectly affected by the flooding that interrupts service both inside and outside flooded areas.

2.2.4 Flood waste management phases and aspects

Disaster management is usually divided into four phases: mitigation, preparedness, relief, and recovery (He & Zhuang, 2016). Flood waste management follows a different set of interrelated phases during a disaster, namely mitigation, preparedness, during a flood, and after a flood (Kubota et al., 2015). During the mitigation and preparedness phases, municipal waste processes are carried on as in normal circumstances, while free time is used to prepare for flood management. The during and after flood phases are when damage from a flood occurs. Each of the phases has different characteristics of waste and circumstances, which present management challenges on different levels, as shown in the cycle of flood waste management in Figure 8.

The mitigation phase starts after complete recovery from a flood, when a resilient waste management system is developed that attempts to decrease societal impact from the next flood. The preparedness phase requires that measures be taken to prepare for and reduce the impact by developing a preparedness plan and strategy (He & Zhuang, 2016). The during-flood phase is an emergency phase that begins with floods while the daily generation of municipal waste continues, which causes immediate threats to public health and safety (Brown, Milke, & Seville, 2011). Finally, the after-flood phase is a period of demolition and management of construction waste generated by the flood.

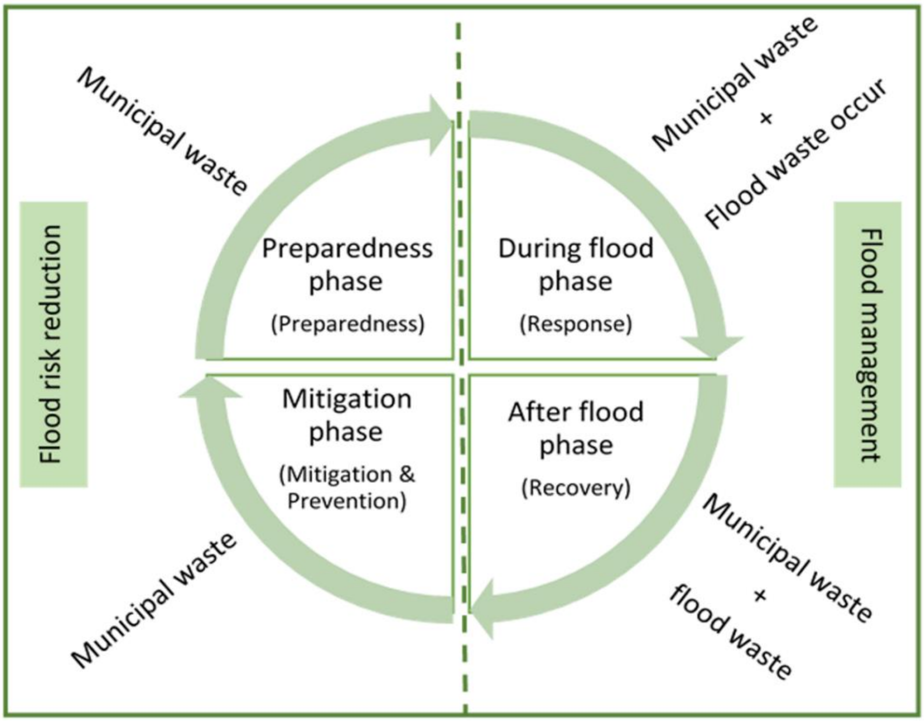

Figure 8. Waste management on flooding phase cycle

2.3 System Dynamics (SD)

2.3.1 SD attribute

The concept of SD was first theorized by Jay W. Forrester from the Massachusetts Institute of Technology in 1961 (Forrester, 1961) and a variety of definitions have been put forward since that year. SD is behaviour observation of managed systems by using feedback information features with a model for designed systems to improve system management and guide policy making (Forrester, 1961). Problem analysis in SD is a method which uses time as an important factor to study how the system can survive or lead forms that are useful in external conditions (Coyle, 1996). It is a tool to manage the complex system and constantly changes with time, grounded in the theory nonlinear dynamics and feedback control developed in mathematics, physics, and engineering (Sterman, 2000). Moreover, it is a strategy more than an operational tool, but can be used to integrate policies across organisations where analysis variation and behavioural feedback are important (Wolstenholme, 2005).

Therefore, it is used to study patterns of behaviour in organisations and ground these in the organisational structure, their operational processes, and policies by using feedback information features to improve the complex system management. It constantly changes and guides policy making to ensure system survival under external conditions.

2.3.2 SD structure

The structure of SD modelling can successfully show various objectives, has a clear relationship with rationality, makes it easy to understand a mathematical pattern, presents the relationship between industrial, economic, and social factors, and can increase the number of variables without computer restrictions. The model is composed of four key characteristics (Forrester, 1961) as shown in Figure 9 and listed below:

- Level: This demonstrates the accumulation of resources flowing into the system at a particular time.
- Flow Rate: This is the rate of change, which indicates the speed of change in the system.

- Decision Function or Rate Equation: These statements of policy consist of four parts: target or desired status, status of the study, difference of both statuses, and reactions that depend on the difference in status. This decision causes the action and flow again as shown in Figure 10.
- Information as a Basic Criterion for Decision: This information leads to new decisions as a feedback loop as shown in Figure 11.

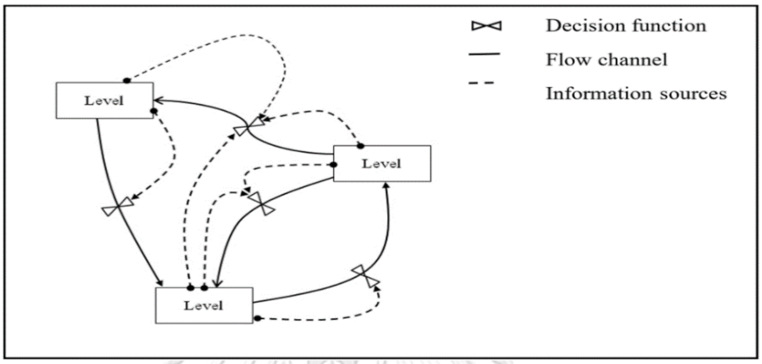

Figure 9. Basic model structure of SD (Forrester, 1961)

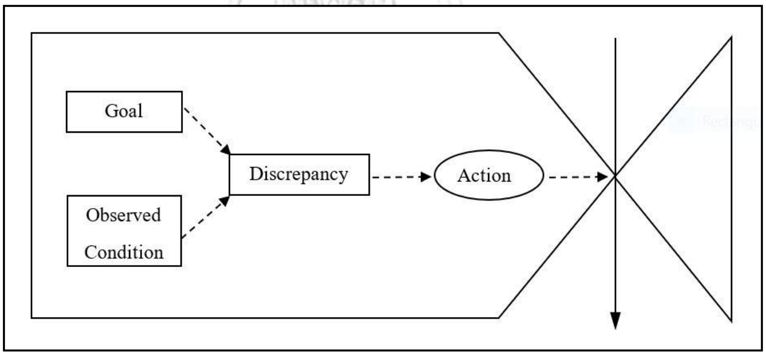

Figure 10. The structure of the Decision Function (Forrester, 1961)

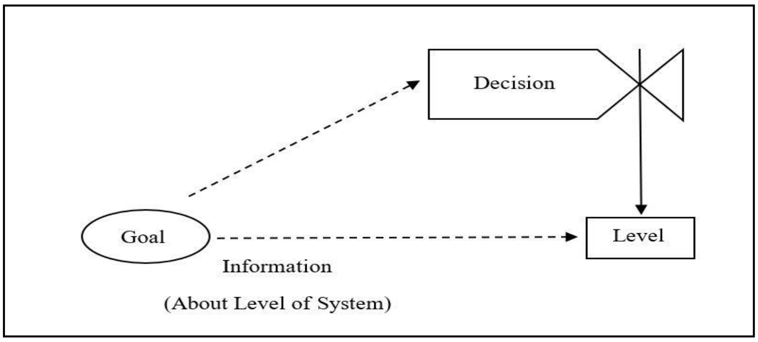

Figure 11. Feedback loop (Forrester, 1961)

The diagrams used in the dynamic systems modelling include two types, namely casual-loop diagrams, also known as influence diagrams, and flow diagrams. A casual-loop diagram is used as the feedback structure. This diagram represents the relationship between factors that are difficult to explain and the illustration of the circular relationship chain of cause and effect. It consists of four elements: variables, causal link (the relationship between the variables connected by arrows), negative or positive polarity relationship, and the loop marks showing positive (reinforcing feedback) or negative (balancing feedback) relationships (Figure 12). The flow diagram or level/rate diagram presents two kinds of variables in the form of level or stock and variable rate in the form of rate of flow. Level or stock is represented by a rectangle, inflow is represented by a pipe with an arrowhead towards the stock, and outflow is represented by a pipe with an arrowhead shot from a stock and value to control the flow (Kirkwood, 1998; Sterman, 2000) as shown in Figure 13.

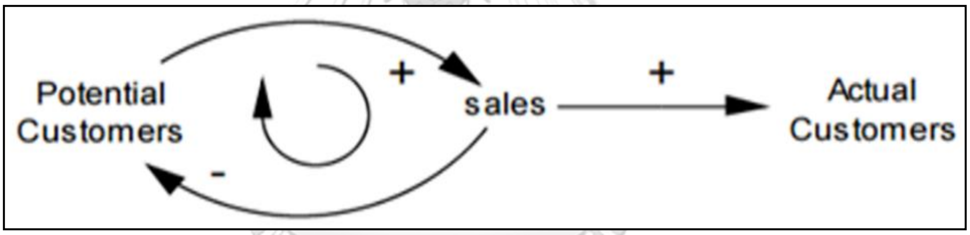

Figure 12. The causal loop diagram (Kirkwood, 1998)

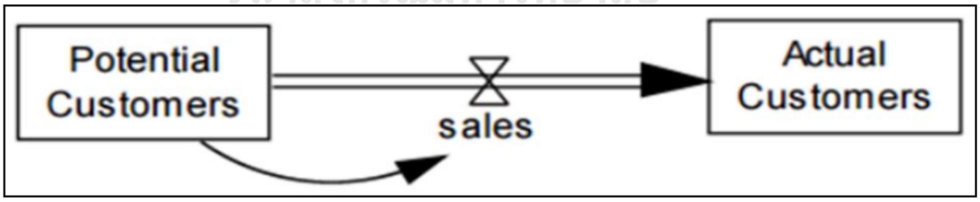

Figure 13. Stock and flow diagram (Kirkwood, 1998)

2.3.3 SD processing

SD processing helps to conceptualize and rationally analyse the structure of a complex system. Processes in SD are viewed in terms of ‘stock’ and ‘flow’. Stock is the measurable accumulation of physical (and non-physical) resources while flow is the rate of change, which indicates the speed of change in the system. The process of SD modelling is presented by focusing on the problem-solving process with simulations, as shown in Table 2. The processes begin with problem identification and definition. While the final process is different in some conceptions, the real system is adjusted to be based on the model, which leads to improvement (Forrester, 1961), new policy design to find the optimal policy (Coyle, 1996; Starr, 1980), and policy implementation (Richardson & Pugh, 1981).

Table 2 SD Processing Conception

Processing	**Source of data**			
	Forrester (1961)	**Coyle (1996)**	**Starr (1980)**	**Richardson (1983)**
- Problem identification and definition.	✓	✓	✓	✓
- System conceptualisation.				✓
- Determine the factors.	✓	✓	✓	
- Follow feedback loop.	✓	✓		
- Set the policy-based decisions in a system.	✓	✓	✓	
- Set a mathematical model.	✓	✓	✓	✓
- Set scenario into a computer program.	✓	✓	✓	✓
- Model evaluation by comparing the results from the model with the real system.	✓	✓	✓	✓
- Editing the model to be used instead of real systems.	✓	✓	✓	✓
- Improve the model and change the relationship of structure and policy.	✓		✓	✓
- Adjust the real system to be based on the model which leads to an improvement.	✓			
- Set a new policy to find the optimal policy.		✓	✓	
- Policy implementation.				✓

2.3.4 SD software

The SD model is constructed by using computer software where variables act as system elements. The variables are linked with mathematical mapping by relative equations. The first software of SD operation, DYNAMO, which was developed steadily was used in 1960. The SD software can be divided into the following three groups:

- DYNAMO/DYSMAP/COSMIC: The evolution of the equation concept with a text editor.

- STELLA/Powersim: Using small symbols to form a schematic drawing for a level/rate diagram, which automatically writes an equation.

- Vensim: A text editor which uses symbol forms.

Most computer simulation applications of SD modelling rely on either Vensim or Stella, while Powersim has been developed for business applications (Kollikkathara, Feng, & Yu, 2010). However, the choice of software should take into consideration the use of theoretical dynamics, user comprehension, and simplicity of use, whether it has a system to set a model, and whether the system facilitates debugging of the simulation, is simple to experiment on, and can be amplified (Coyle, 1996).

2.3.5 SD application

The SD has supporting tools offering a useful modelling approach to simulate scenarios in a wide array of disciplines. The SD models are used to analyse the structure and behaviour of a system as well as design efficient policies to manage the system (Mirjana, 2007). For example, SD models were used to find appropriate decisions for agricultural development (Saysel, Barlas, & Yenigün, 2002); sustainable coral reef management with determined socio-economic, environmental, biological, and management area subsystems to join with the SD model configuration with a user-friendly interface based on a decision support system (DSS) (Chang, Hong, & Lee, 2008); a business system (Sterman, 2000); a spatial system dynamic model of desertification expansion of the Ordos in China with the integration of climate, soil, water, population, economy, pasturage, and land use factors (Xu et al., 2016); determining the technical system of energy performance of buildings with the description of a mathematical model for accurately predicting indoor temperature, and heat losses of the space heating and domestic hot water system components (Horvat & Dović, 2016).

Most SD models are used to study the most susceptible variables of a system to be set as the initial variables for the optimization scenarios, while the challenging features of SD are rarely applied to study the recovery of the system from external interference.

2.4 Analysis Hierarchy Process (AHP)

The analytic hierarchy process (AHP) is a mathematical method for multi-criteria decision-making (Saaty, 1980). The AHP allows one to make decisions involving various concerns, including planning, setting priorities, selecting the best among a number of alternatives, and allocating resources (Garfi et al., 2009). It is an outstanding technique to break down a decision-making problem into several levels in a hierarchy with directional hierarchical relationships between levels (Aragones-Beltran et al., 2010), like a family tree.

The AHP uses pairwise comparison judgements to distribute weights of the homogeneous elements in each level, measuring their relative importance on a 1 to 9 scale, and finally calculates overall weights for evaluation at the bottom level. The scale of values to represent the intensities of judgements is shown in Table 3. This scale has been derived through stimulus response theory and validated for effectiveness, not only in many applications by a number of people, but also through theoretical justification of what scale one must use in the comparison of homogeneous elements (Saaty & Vargas, 2013).

The AHP is especially concerned with departure from consistency. It also calculates a consistency ratio (CR) to verify the coherence of the judgements and dependence within and between its structure's groups of elements, which must be about 0.10 or less to be acceptable (Saaty & Vargas, 2013).

The AHP has been widely applied in different fields in complex decision and evaluation problems involving the trade-off among several objectives (Contreras et al., 2008). It is an outstanding way to study the decision-making process in waste management as it appears to be utilized in this field 65% of the time (Soltani et al., 2015). It is an important tool in studying determination of waste disposal sites and public administration, sustainable development and recycling of solid residues, and management of electronic waste (Vitorino de Souza Melare et al., 2017). The AHP has been widely used in MSWM planning to incorporate the preferences of different actors in the field of decision-making for an MSWM plan (Contreras et al., 2008), to manage the solid waste problems of a city, present opportunities involved in approaching (Coban et al., 2018) community groups for waste paper management decision-making (Hanan et al., 2013) and to compare different waste management solutions in Sahrawi refugee camps (Garfi, Tondelli, & Bonoli, 2009). It is also used to determine the most appropriate location for an MSW site in a waste management system so as to rank suitable MSW facility sites with stakeholders' involvement (De Feo & De Gisi, 2010) and to evaluate the suitability of the study region as an optimal site for a landfill for MSW Karaj using AHP and GIS techniques (Moeinaddini et al., 2010). In those applications, AHP techniques have been applied to minimize conflicts, reducing the number of alternatives to facilitate convergence and achieve an optimal alternative.

Table 3 The Fundamental Scale of Absolute Numbers

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

2.5 Relevant Research

There are numerous works of research which relate to the introduction of the SD applied to waste management as well as the system behaviour analysis and forecasting to adopt the optimized policy to manage and improve a system. Thus, MSWM and forecasting, contributions using SD, have been extensively applied across a wide range because they can be facilitated by SD (Vassilios Karavezyris, 2002). The SD is applied to evaluate the amount of MSW generation with different simulation models, based on the contributing factors of population growth, household income, people per household, and economic activity to address the impact on sustainable development, for example, in San Antonio (Dyson & Chang, 2005). Moreover, the SD is used to analyse optimized management of the amount of MSW with related factors such as landfill capacity and related cost management based on a predictive decision support tool for waste prognosis, which utilizes demographic and socio-economic parameter values from studies carried out under the life cycle analysis-integrated waste-management project (Kollikkathara, Feng, & Yu , 2010). The study incorporates the complexity of the waste generation and management process to some extent, through a combination of simpler sub-processes linked together to form a whole.

In Thailand, SD is a tool in the application of the waste management problem to represent the relationship of cause and effect of MSWM. SD helps to prioritize problems and recommends an approach to a management system as a prototype diagram of an MSWM model with Vensim software for a site in Songkhla province. This is to find urgent issues and important variables in the system to guide the implementation of MSWM with analysis of management variables, namely identifying that a new MSWM landfill is urgently required in Songkhla (Sontamino, 2004). SD used to find important variables in the MSWM system is also used to study MSW source separation at the Sai-Mai transfer station service area in Bangkok (Sukholthaman & Sharp, 2016). The developed SD model is a high-ranking benefit for policy makers, strategic planners, or MSWM staff to assess the importance of source separation in waste management systems.

Many studies of sustainable MSWM focus on the recycling of solid residues and management of electronic waste, forecasting, planning and management of collection, and transport routes (Vitorino de Souza Melare et al., 2017). Some studies have focused on future projection in the MSWM system’s normal state. However, only a few have paid attention to the investigation of waste management during a critical event such as flooding. This issue should be a major concern to acquire better understanding and preparedness for a waste management system service.

Therefore, an analysis of Bangkok’s MSWM in the framework of the dynamic systems concept can improve the understanding of the MSWM mechanism. In addition, modelling dynamic systems concepts with computer software allows an analysis of the sensitivity of elements, which can simulate situations and predict changes that will occur in the conditions and situation of each relationship. This will lead to breakthroughs in the application of the SD model to a framework of mitigation and adaptation in the MSWM system under urban flooding. Moreover, it is also useful as a guide to study disaster impacts of other environmental services that are typically affected both directly and indirectly by disaster and/or that are interrupted inside and outside the disaster areas.

Chapter 3

Research Methodology

This chapter presents a description of the research methodology used in this study, including:

1. Study area
2. Research design
3. Data analysis

3.1 Study Area

Bangkok, the capital of Thailand, is experiencing rapid urbanization as a major economic and cultural centre. The city is a financial and residential centre, with an administrative area of 1,568.74 km^2, comprising 50 districts (BMA, 2015d) and generating 9,940 tons/day of waste in 2014 (BMA, 2015c). Bangkok's waste collection service is operated separately by local districts and divided into sub-service areas. After collection, MSW is transported to three main transfer stations in Bangkok, namely On-Nuch, Nongkhaem, and Sai-Mai. The On-Nuch transfer station handles MSW from 16 districts while the Nongkhaem and Sai-Mai transfer stations handle waste from 22 and 12 districts, respectively.

Bangkok is situated in the Chao Phraya River delta in Thailand's central plains. The river meanders through the city in a southward direction, emptying into the Gulf of Thailand. The area is flat and low-lying, with an average elevation of +0.0 m to +1.50 m above mean sea level by the bank of the Chao Phraya River. The north is elevated +1.50 m above mean sea level (BMA, 2012). Most of the area was originally swampland, as part of the central plains of Thailand (The Lower General Plain of Thailand) (BMA, 2013). The course of the river as it flows through Bangkok has been modified by the construction of several shortcut canals. The 19 flood-prone areas around Bangkok are indicated with local rainfall and drainage system capacity information by the Bangkok Metropolitan Administration (BMA). These data were used as baseline information for determining the areas requiring flood management, with an annual action plan to prevent and mitigate flooding (BMA, 2015a).

The Nongkhaem transfer station has been selected as a case study representative of the impact of flooding on MSWM service. This transfer station is responsible for the largest area, overseen by 22 local governments (districts), and comprises up to 11 flood-prone areas out of Bangkok’s total of 19, as shown in Figure 14. Therefore, the area is interesting for studying the complexity of flood impact on the MSWM system in order to recommend mitigating approaches.

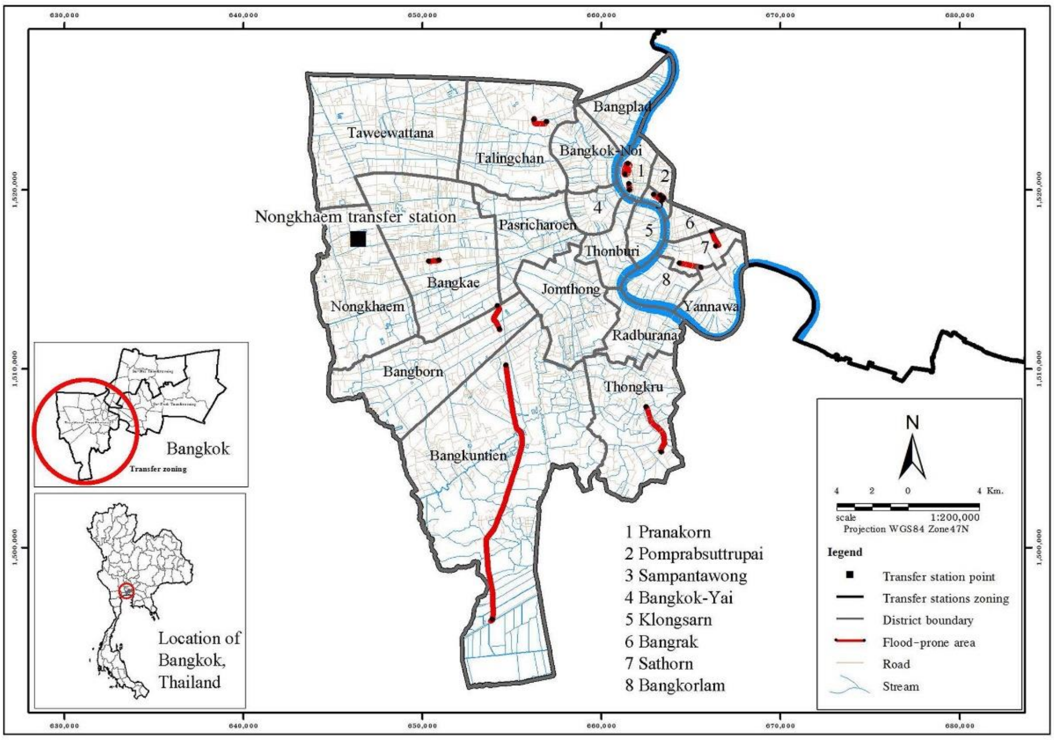

Figure 14. The Nongkhaem transfer station area with 11 flood-prone areas

3.2 Research Design

The comprehensive analysis in this study is proposed for analysing flood impacts on Bangkok’s MSWM system. The SD model of Bangkok’s MSWM has been developed to better understand the system’s behaviour and evaluate flood impacts. The results will be applied to recommend appropriate approaches to flood mitigation of MSWM. The Bangkok waste collection service is provided separately by local districts. Each district is divided into sub-service areas, which share transportation routes and trucks. The MSW of Bangkok is transported to three transfer stations located in the city, namely On-Nuch, Nongkhaem, and Sai-Mai. This study used secondary and primary data to analyse the results as follows:

The secondary data acquired from the BMA included the amount of MSW, population size, and data of flood-prone areas. The amount of waste collection of each district and the population size of each sub-district were collected from actual records from January 2013 to December 2016.

The primary data were collected during site visits and interviews with key personnel. Site visits assessed the waste collection and transfer process, including a weighing procedure to record the amount of waste in each truck. Twenty-two interviews of district officials from each study area were conducted. Interviews generated current situation data about the waste management service, including about truck parking location, collection routes, and transfer routes. It also included information about spatial impact in sub-service areas of each flood-prone area. The truck parking location, service routes, and sub-service area data were considered for waste management service analysis at the sub-district level for SD modelling. The flood impact identification of each flood-prone area was used to simulate impact in different scenarios, while analysis of importance factors and alternatives for flood mitigation were obtained through interviews of the participating experts and responsible providers. The methods utilized in an individual section are presented in Figure 15 and the following sections.

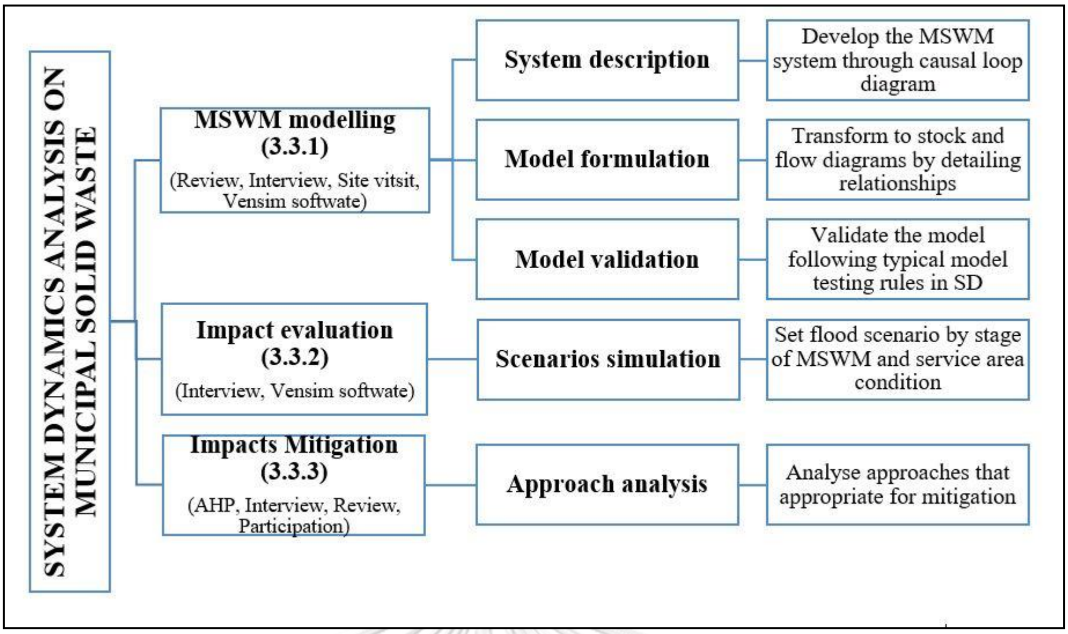

Figure 15. The comprehensive analysis method of this research

3.3 Data Analysis

3.3.1 MSWM modelling. The concept of SD with computer software was used as a tool for developing the system dynamics model of Bangkok's municipal solid waste management system. The process of determining the SD modelling approach in this study was developed from Coyle's (1996) SD concept which has concise, obvious, and comprehensive steps to manage the problem, namely (1) defining the problem, (2) describing the system by determining the factors affecting the relationship between factors affecting the relationship between cause and effect, (3) setting the scenario modelling into a computer program to process the behaviour of the system and test accuracy, and (4) using an approach designed to find the optimal method for mitigation and adaptation of urban floods on MSWM.

The MSWM model is an abstract and conceptual model focused on selected factors and hypotheses of their interactions (Vassilios Karavezyris, 2002). In this study, the process of SD modelling is required to use the amounts of MSW generation per capita of each district as a base for linking the system's input to output. This was derived from the amount of MSW and the population size. The district-level MSW amount was converted to sub-district level data in combination with population data.

The population size was recorded in the annual data of each sub-district converted into monthly data with a constant rate of change.

A system dynamics software program, Vensim$^{@}$ PLE Plus 7.2 version, was chosen to formulate the SD model and simulate the MSWM in different scenarios through a combination of simpler sub-processes involved to form a whole. This program is a text editor which uses symbol forms, making the user interface easy to use, whether the system facilitates debugging of the simulation. In order to clarify and identify the distinct performance of the collection and transfer stage, the conditions of each of the 22 districts was simulated separately before integrating them to find the Nongkhaem transfer station's MSWM system's performance. The complement system variable and the relationship between the variables for use in system analysis and modelling were performed by site visits and interviews in each of the system's districts.

The MSW collection and transfer rates of sub-service areas in each district variable are considered in the normal existing situation, which is the same data set. The data of 2013–2016 are used for the model formation, while data for 2017 are used to verify the model.

3.3.2 Impacts evaluation

This process evaluates the impacts of a system with the SD model when disturbed by external conditions. The impacts of the flood on the MSWM system result in accumulated waste in each district of the system in different scenarios.

The analysis of past events through flood hazard characteristics helps to estimate the probability of flood occurrence. Typically, water from large floods in major rivers continues to spread along the surrounding waterways and land before flowing into an estuary. The Chao Phraya River feature process was similar, except during the Bangkok flooding. The passage and degree of Bangkok's inundation are modified by the presence of many flood walls, dikes, local polders, and canals (Liew et al., 2016). The determination of Bangkok's flood hazard level not only depends on topography and natural factors but also management factors.

Therefore, all 22 districts with MSWM service were simulated in the model, which ran under 11 different scenarios in flood-prone areas, as identified by the BMA

(BMA, 2016). The flood-prone areas of Bangkok were analysed by local rainfall and drainage system capacity in the area. They represent a critical situation as detailed in Table 5. They were applied to evaluate impacts in case of crisis or non-function in each flood-prone area with the MSW collection and transfer status of sub-service areas in each district.

The spatial impacts data of each district from each flood-prone area were compiled from site visits and interviews with evaluation documents as shown in Appendix B. These primary data from 22 district officials were integrated into the scenarios. The accumulated waste amount of each district was shown as the amount of uncollected waste in the collection stage and remaining waste in the transfer stage. The amount of MSW was expressed in terms of weight per day.

Table 4 The 11 Flood-Prone Areas of All Scenarios Identified by BMA

Scenarios	Flood-prone area	Location (District)	Starting point	Ending point
Scenario 1	FP1	Pranakorn	13.744743, 100.494540	13.747648, 100.494201
Scenario 2	FP2	Pranakorn	13.757819, 100.493917	13.752451, 100.492483
Scenario 3	FP3	Sampantawong	13.741837, 100.510488	13.740439, 100.512256
Scenario 4	FP4	Sampantawong	13.739452, 100.511494	13.742384, 100.507002
Scenario 5	FP5	Sathon	13.707596, 100.520216	13.705445, 100.531389
Scenario 6	FP6	Sathon	13.723578, 100.536596	13.716056, 100.538906
Scenario 7	FP7	Talingchan	13.780434, 100.445299	13.779330, 100.451977
Scenario 8	FP8	Bangkae	13.709655, 100.395982	13.709218, 100.390596
Scenario 9	FP9	Bangborn	13.674774, 100.427060	13.686575, 100.426123
Scenario10	FP10	Bangkhuntien	13.656534, 100.430189	13.528270, 100.422461
Scenario11	FP11	Thongkru	13.635130, 100.502440	13.612139, 100.510090

3.3.3 Impact mitigation. The impact results from scenarios are used to analyse sensitive or vulnerable exposures in each sub-system and stage of the MSWM system. The vulnerable exposure of each part in the different scenarios is used as a key for recommendation as an approach to mitigation. They are applied to development of flood mitigation approaches in the MSWM system.

This process uses impact results from the SD model and decision-making methods by experts and responsible providers to recommend approaches to mitigate the possible impacts of urban flooding on the MSWM system. The results indicate mitigation approaches that will allow the MSWM system to survive during flooding. The approach of flood mitigation for MSWM applies the concept of mitigation strategy development guidelines of the Federal Emergency Management Agency (FEMA, 2013) and disaster waste management guidelines of the Joint UNEP/OCHA environment unit (UNEP/OCHA, 2013). The feasibility and appropriateness analysis of the approach was conducted as per the participation of vulnerable local government bodies, authorities' analysis, and responsibilities of various government agencies identified in the Public Disaster Prevention and Mitigation Act, B.E. 2550.

In this study, the AHP was used to indicate the criteria priorities and provide a clear rationale for a mitigation alternative. The secondary data were collected using a form to extract data about the factors of the MSWM from the literature review. The primary data about the importance of factors was obtained through interviews with the participating experts and responsible providers.

The AHP is based on the judgments and opinions of a selected group of experts and responsible providers with different relevant backgrounds and experience, who have served at different operational and strategic levels of responsibility. The AHP approaches decision-making by arranging the important components of a problem into a hierarchical structure, such as a family tree. Hierarchical structure is divided into three levels. The first level is the objective, the second is criteria to determine the appropriate alternative, and the third represents alternative options to applied approaches to mitigate impacts from urban flooding on the MSWM system. Figure 16 shows the hierarchy structure. The considered methodology involves five main steps:

1. Setting objectives: The main objective is to mitigate flood impact on the MSWM system. The specific objective of the process is finalized by the flood impact result from the MSWM's SD model to ensure its reality and feasibility.

2. Criteria identification: The criteria that impact the MSWM under flood conditions are identified through the literature review. They represent main factors in sustainable urban development, including the environment, economy, and society.

3. Alternative identification: The mitigation alternatives are analysed and based on the international literature review and actual operations during the 2011 Bangkok flood.

4. Decision alternatives comparison: This step involves experts and responsible providers who used pairwise matrices to evaluate the relative importance of each variable (criteria/alternative) at levels two and three against other variables at the same level. The obtained weights of variables of different levels were then presented in the hierarchy. The significance of the root causes to the objective was calculated by multiplying the scores of the direct variables in the second level by those of their indirect variables in the third level. A score vector can be determined for each single alternative. The final score of each alternative is derived by the total of the final vector elements. The higher score alternative is the more appropriate one.

5. Calculating relative weights: A weight can be defined as a value assigned to a criterion which indicates its relative importance with respect to other criteria under consideration (Garfi, Tondelli, & Bonoli, 2009). Calculating relative weights involves pairwise comparisons, consistency of pairwise judgement assessment, and relative weights calculation. These averages provide an estimate of the relative weights of the criteria being compared. The consistency vector can be calculated by dividing the weighted sum vector by the criterion weights determined previously. The formula for calculating the consistency ratio is (CR) = CI / RI; where RI is the random index and depends on the number of elements. If CR < 0.10, it indicates the level of reasonableness of consistency in the pairwise comparison; if CR > 0.10, it indicates inconsistent judgements.

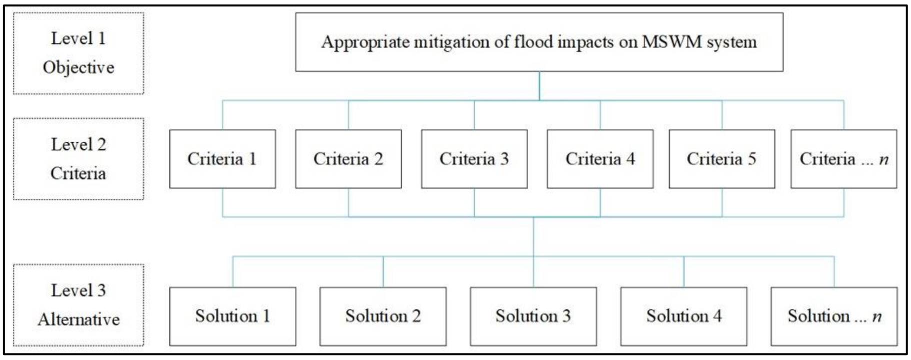

Figure 16. Priority setting of Analytic Hierarchy Process (AHP) process

Chapter 4

System Dynamics Model of MSWM

4.1 System Description

The MSWM system service of the Nongkhaem transfer station covers 22 districts. The MSW amounts of all districts are reported automatically through the online weighing system by the transfer station to a central office at the Department of Environment under the BMA. Each district separately manages their own MSW, subdivided into sub-service areas. The layout of the sub-service area is based on convenience to the MSW collection access route at the generation site, but trucks are still shared by many sub-service area routes. Consequently, the amount of waste is insufficient to divide the area into sub-service areas. Therefore, GPS is used by groups of nearby sub-service areas in the district and sub-district. Figure 17 shows an example of MSWM service in the Bangrak District that consists of 32 sub-service areas in five sub-districts.

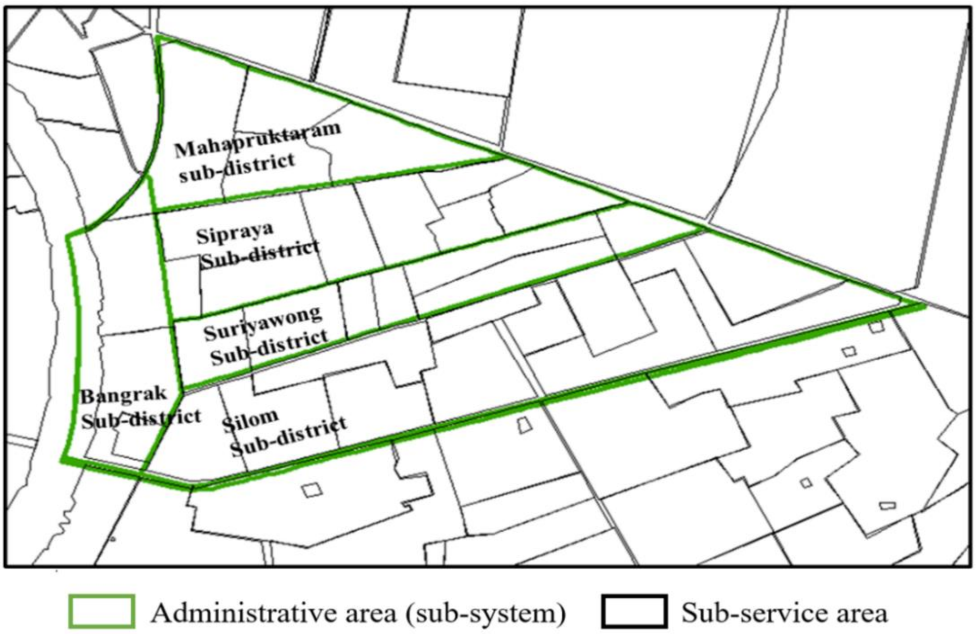

Figure 17. MSWM sub-service area and sub-district of Bangrak District

The waste amount at district level was used with the population size data as the basis for conversion to the sub-district level. While the population size was recorded in each sub-district's annual data of, they were used by conversion into monthly data with a constant rate of change as a proportion. These data were used for calculating each district's amount of waste generation per capita, based on the 48-month average.

Bangkok's MSWM service boundaries consist of collection and transfer stages. The scope of the MSWM service system was used to illustrate the relationship using a casual loop diagram. Then, the quantitative relationship between the variables was represented as the system's level and rate with the stock-flow diagram of 22 districts in the Nongkhaem transfer station area considered as sub-systems. For each district, the variables were separated to simulate each sub-district's data over the same period, as shown in Figure 18.

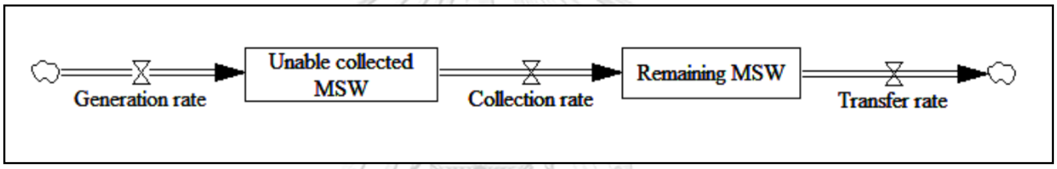

Figure 18. Bangkok's MSWM service boundaries

The casual loop diagram represents the relationship between the factors, while showing the circular cause and effect relationship between the four main parts as follows: 1. variables, 2. causal link (the relationship between the variables connected by arrows), 3. negative or positive polarity relationship, and 4. loop marks that show positive (reinforcing feedback) or negative (balancing feedback) relationships. The stock-flow diagram or level/rate diagram presents two kinds of variables in the form of level or stock and the variable rate in the form of flow rate. Level of stock is represented by a rectangle; inflow is represented by a pipe with its arrowhead towards the stock; outflow is represented by a pipe with the arrowhead shot from a stock (Kirkwood, 1998; Sterman, 2000).

Therefore, modelling was developed from a basic boundary description by creating a casual diagram to represent the system. The historical statistical data series between 2013 to 2016 was used to drive the SD model development. In preliminary processing, the related variables of Bangkok's MSWM were used as shown in Table 5, to set the preliminary diagram. For each district, the variables were separated to simulate each sub-district’s data over the same period, as illustrated by the causal loop diagram in Figure 19.

Table 5 Variables Used in the Preliminary Diagram

Cause - variables	**Effect - variables**
- The population size at base year of sub-district	- The population size of sub-district
- Dynamic rate of population	
- The population size of the recent year	- Dynamic rate of population
- The population size of sub-district	- The population size of district
- The amount of waste generation of district	- The amount of waste generation per capita of district
- The population size of district	
- The population size of district	- The amount of waste generation of sub-district.
- The population size of sub-district	
- The amount of waste generation of district	
- The amount of waste generation of sub-district.	- The amount of waste collection of districts.
- The collection status	
- The amount of waste generation rate of sub-district	- The amount of waste generation rate of district
- The amount of waste collection rate of sub-district	- The amount of waste collection rate of district
- The amount of waste generation rate of district	- The amount of uncollected waste of district
- The amount of waste collection rate of district.	
- The amount of waste collection rate of district	- The amount of remaining waste of district
- The amount of waste transfer rate of district	

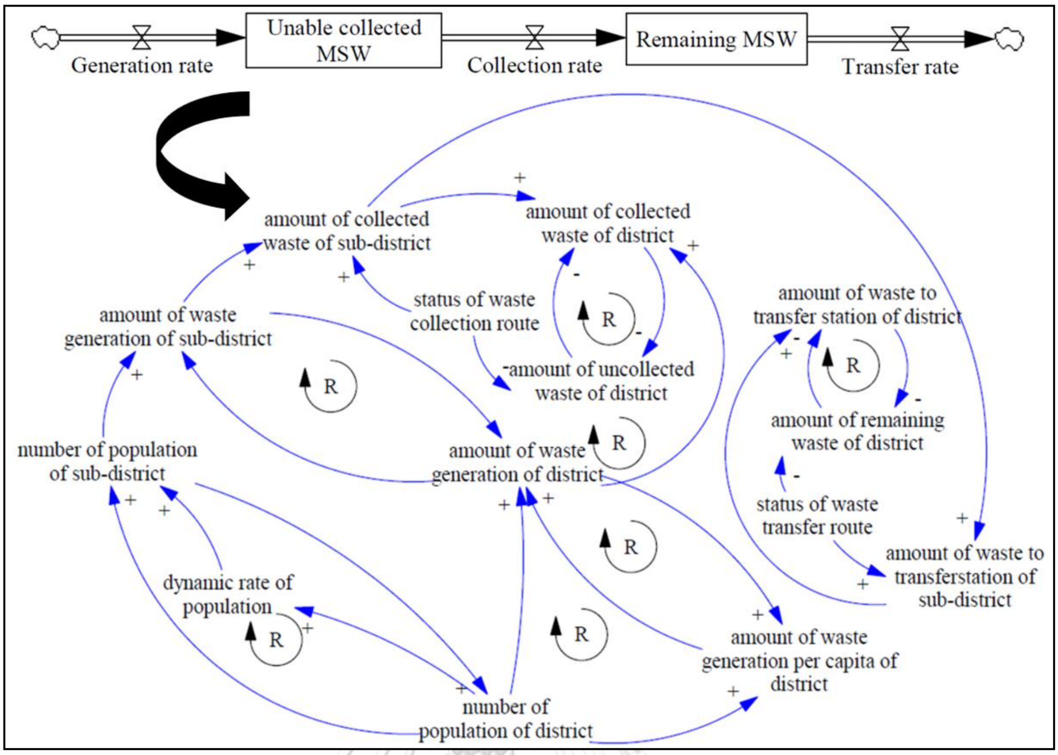

Figure 19. The causal loop diagram for each district

4.2 Model Formulation

The model was run under historical information driven by the statistical data series between 2013 and 2016. The variables in the causal loop diagram were used to form a correlation equation in the stock-flow diagram for each district. The equations determine i = 1, 2, 3, …, where i represents the number of sub-districts in each district. The description and unit of variables are shown in Table 6, where each district is considered as a sub-system of the Nongkhaem MSW transfer station.

Table 6 The Description and Unit of Variables

Variables/Levels	**Descriptions**	**Units**
Prediction year	Number of years from base year (2016)	-
Population base year ddss	Population size of sub-district A (2016)	person
Pn	Population size of the recent year	person
A0	Population size at base year of sub-district	person
Population dynamic rate (r)	Dynamic rate of population (2013-2016)	-
Population ddss	Population size of sub-district A at prediction year	person
Population dd	Total population size of district	person
Waste per capita dd	Amount of waste generation per capita of district (Jan 2013- Dec 2016)	kg/day
Waste generation dd	Amount of total waste generation of district	kg/day
Waste generation ddss	Amount of waste generation of sub-district	kg/day
Generation rate dd	Rate of waste generation rate of district	kg/day
Collection status ddss	Situation of waste collection route (normal or crisis)	-
Waste collection ddss	Amount of waste collection of sub-districts	kg/day
Collection rate dd	Amount of waste collection rate of district from generation source	kg/day
Uncollected waste dd	Amount of uncollected waste from generation source	kg/day
Transfer status ddss	Situation of waste transfer route (normal or crisis)	-
Transfer rate dd	Rate of waste transfer of district to transfer station	kg/day
Remaining waste dd	Amount of remaining waste from collection stage	kg/day

Subsequently, each district's amount of MSW is the result of the amount of MSW collected and transferred. The amount of MSW was expressed in terms of weight per day. The amount of waste generation of a district was calculated in terms of population size and waste generation/capita (4.1).

$$\textit{waste generation dd} = \textit{population dd} * \textit{waste per capita dd} \qquad (4.1)$$

The population size of a district is based on the sum of all sub-districts (4.2), which is calculated by the population size at base year (for instance, 2016) and the population dynamic rate (4.3).

$$\textit{population dd} = \sum_{i=1}^{I}(\textit{population ddss}) \qquad (4.2)$$

$$\textit{population dd ss} = A0\ (1+r)\ n \qquad (4.3)$$

The population dynamic rate is calculated from the population size of the recent year and the number of years (4.4) for which the waste amount data will be predicted (prediction year), which is calculated by the difference between the prediction years and base year (4.5).

population dynamic rate = (Pn-(Pn-1)) / (Pn-1) / n (4.4)

prediction year (n) = prediction year - base year (2016) (4.5)

The amount of waste collection of the sub-districts was calculated from the waste generation and collection status of the sub-district (4.6).

*waste collection dd ss = collection status dd ss * waste generation dd ss* (4.6)

A sub-district's waste generation was calculated from the waste generation of the district and the ratio of the population size of the sub-district to that of the district. The generation and collection rates of districts were based on the sum of all sub-districts' waste generation (4.7) and collection amounts (4.8) respectively, while the transfer rate of districts was based on the sum of all sub-districts' waste collection amount and transfer status (4.9).

$$generation\ rate\ dd = \sum_{i=1}^{I}(waste\ generation\ ddss) \quad (4.7)$$

$$collection\ rate\ dd = \sum_{i=1}^{I}(waste\ collection\ \ ddss) \quad (4.8)$$

$$\text{transfer rate dd} = \sum_{i=1}^{I}(waste\ collection\ ddss * transferstatus\ ddss) \quad (4.9)$$

The variables in the system linked by the equation are represented by each district's stock and flow diagrams. The complexity of each district depends on the number of sub-districts. If there are more sub-districts, the complexity of the system is greater, as shown in Appendix A. Figure 20 shows the diagram of Radburana with its two sub-districts, while Figure 21 shows the diagram of Pasicharoen district with its respective seven sub-districts. Each district is a subsystem of the main system. The main system page in the MSWM system's SD model is used to execute crisis conditions via the command page, as shown in Figure 22.

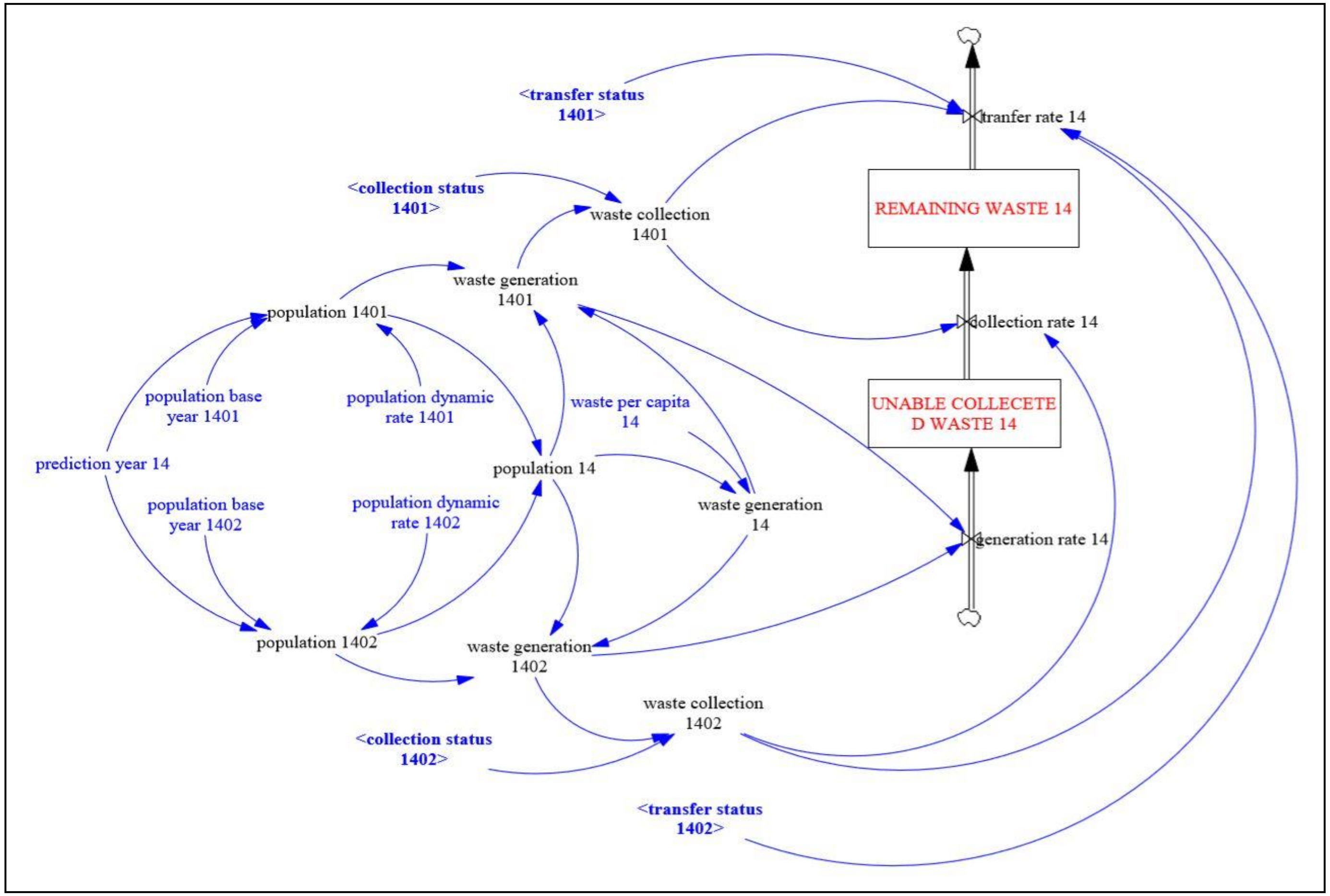

Figure 20. The stock-flow diagram of Radburana District

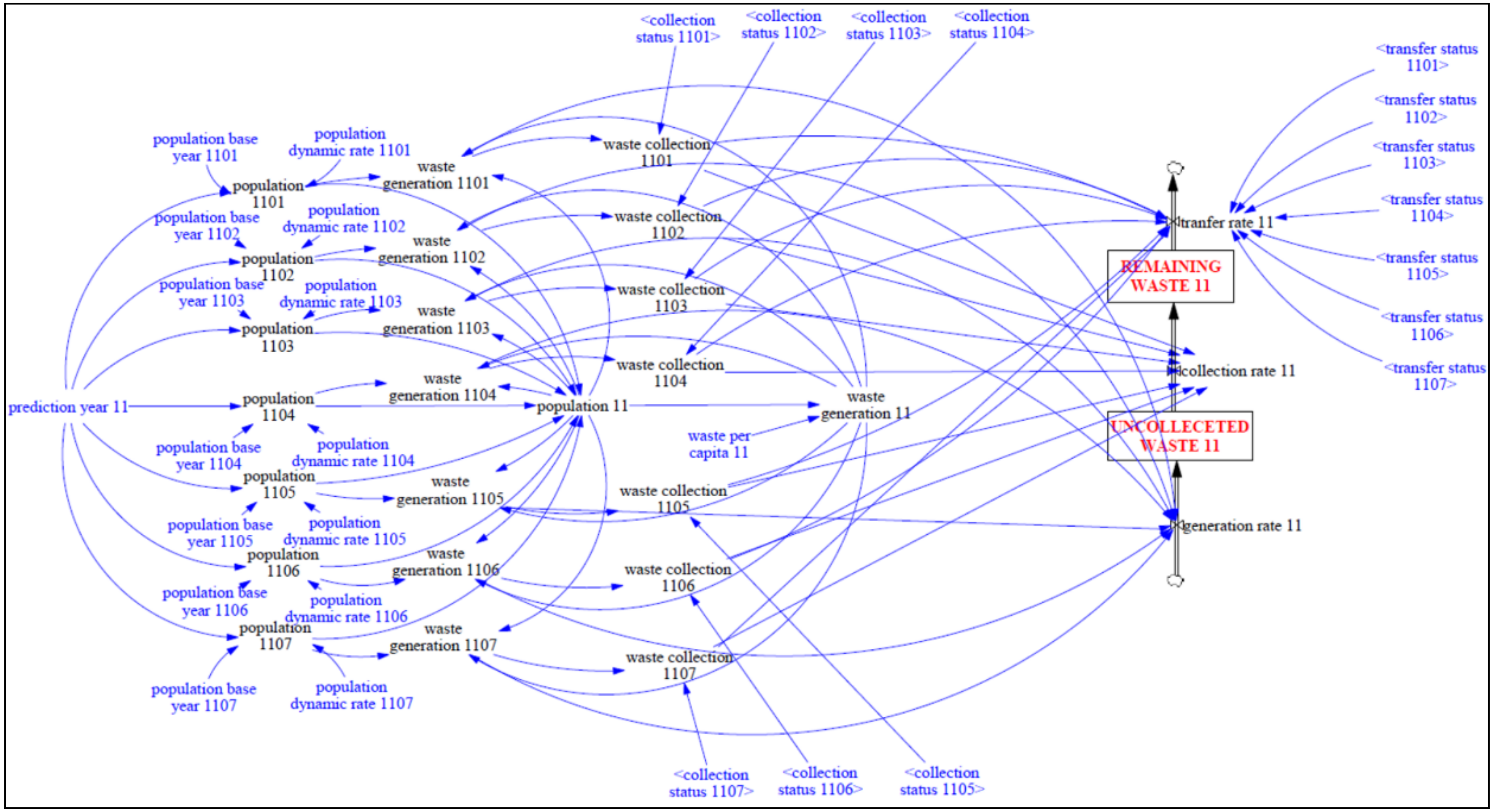

Figure 21. The stock-flow diagram of Pasicharoen District

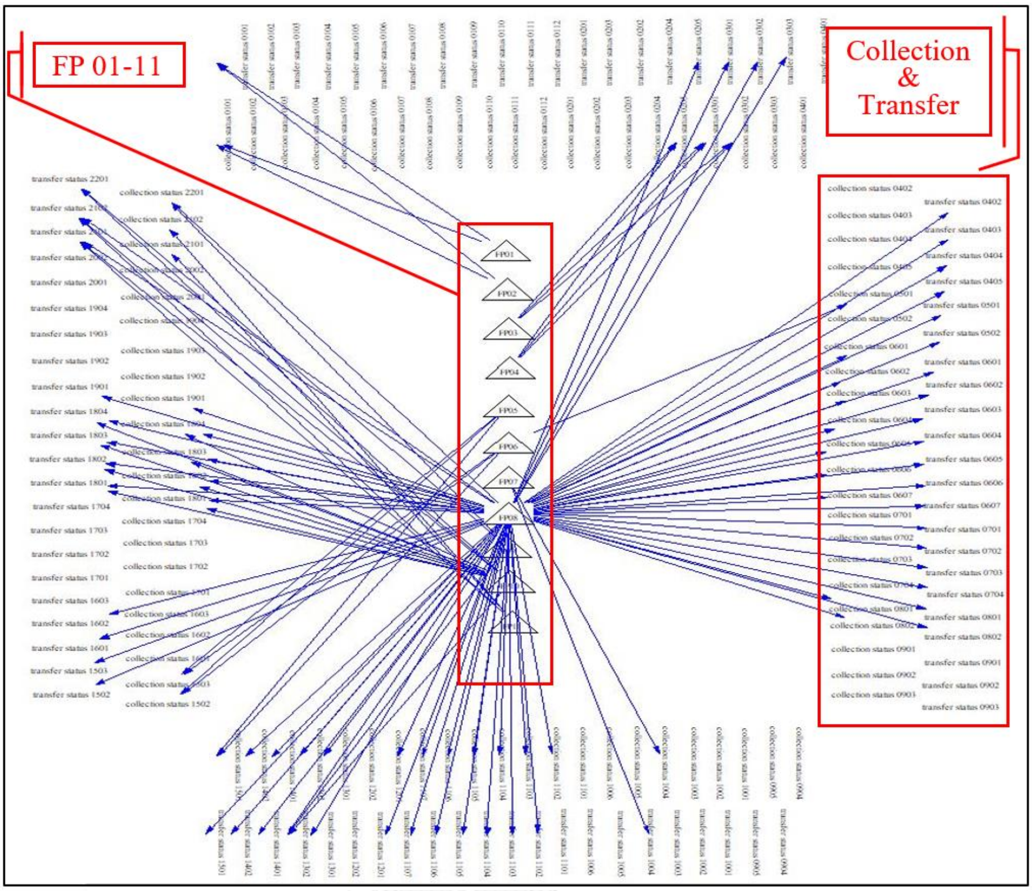

Figure 22. The command page of MSWM SD model to execute crisis conditions

4.3 Model Validation

The generated SD model of the MSWM system was validated through a series of tests because this is a critical process before running the simulation.

First, the dimensional consistency was tested through parameters by automatically verifying the dimension function in the Vensim$^{@}$ software after defining the measurement units of the variables.

Second, an extreme condition test was conducted using the ‘reality checks’ function in the Vensim$^{@}$ software by assigning extreme values to the model variables.

Third, the historical behaviour test was run in conjunction with the empirical data of the amount of collected waste and population size from 2013 to 2016. The model results, as predicted for the year 2017, were shown to be consistent with the actual amounts of waste and population size.

As the SD model develops, it can be used to describe the relationship of the behaviour of an MSWM service system, which covers the collection and transfer service stage of the 22 districts that transfer MSW to the Nongkhaem transfer station. It has the appropriate characteristics of a tool to understand the complex systems within the MSWM system and can also be used to develop predictive scenarios when systems are disturbed by a crisis, such as major flooding.

The MSWM service system of Bangkok is a complicated network. Interference with each part can affect the other parts as well as the whole network. The distinction between impacts in terms of crisis preparedness needs to be comprehended, whereby both the spatial and accumulated amounts of MSW in the collection and transfer processes serve as the main imperative in the MSWM. Therefore, the SD model is an appropriate tool for studying behaviour and impact assessment of flooding on the MSWM system. It is a method to analyse problems and study how the system can survive under the disturbance caused by external conditions (Coyle, 1996).

However, the official data of Bangkok's collected MSW have been used as input data to calculate the amount of waste generation per capita with the monthly waste amount and annual population size. Furthermore, the amount of waste collected from the model has not been included in the amount of recyclable waste discharged from the system by the informal sector. Accordingly, the amounts of accumulated waste from the flood impact evaluation with an SD model of MSWM are a significant minimum amount to use as a guideline for flood mitigation in Bangkok's MSWM system.

Chapter 5
Impact Evaluation Results

The developed model can be used as a tool to understand the system of waste management. Moreover, it is used to evaluate the impact that occurs when the system is disturbed by a crisis. The model was implemented by inputting flood situation variables to disturb the system, including collection and transfer status. The status of these variables depends on the location of flood-prone areas.

In this study, a flood-prone area is defined as any public roadway that runs the risk of being covered by enough water to hinder the transportation of an MSW truck. This is analysed by BMA with local rainfall and drainage system capacity information.

The simulation of the 22 districts' MSWM models runs on 11 different scenarios with possible conditions in flood-prone areas (BMA, 2016). The result shows the amount of waste forecasted for the future (in 2020) to illustrate the flood impact on the collection and transfer stages in each district in terms of accumulated waste amount. The scenarios are built based on the assumptions that if a flood occurs in any flood-prone area, waste trucks will not be able to provide normal service in or through that area.

The findings of this study lead to detecting the vulnerability in the MSWM system as a hot-spot of both spatial and quantitative impact. The MSW collection-transport status of sub-service areas in each district variable (5.1) and the MSW transfer-transport status of sub-service areas in each district variable (5.2) is defined as a system variable condition in IF/THEN/ELSE order. In a normal situation, these variables are determined by a value equal to one, and a value equal to zero in case of emergency or ‘cannot function’.

$$\textit{collection status ddss} = \textit{IF "normal" THEN}=1,\ \textit{ELSE}=0 \tag{5.1}$$

$$\textit{transfer status ddss} = \textit{IF "normal" THEN}=1,\ \textit{ELSE}=0 \tag{5.2}$$

5.1 Spatial Impact

Results obtained from 11 flood-prone area scenarios are discussed in this section to present the impacts of various flooding area options on the MSWM system. They include the collection and transfer service stages of the 22 districts. The impacts not only have effects within the flooded area, but also out of it. It is explicitly stated that every district the flood-prone area is located in is affected in every scenario, as shown in Table 7 and Figure 23.

Table 7 Spatial Impact of Each District in Each Flood-Prone Area (FP)

District Name	FLOOD-PRONE AREA (FP) No.																					
	01		02		03		04		05		06		07		08		09		10		11	
	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T
Pranakorn	✓	✓	✓	✓																		
Pomprab																						
Sampantawong					✓		✓									✓						
Bangrak																✓						
Yannawa											✓					✓						
Thonburi															✓	✓						
Klongsarn																✓						
Bangkok-Yai															✓	✓						
Bangkok-Noi																						
Talingchan													✓	✓								
Pasricharoen															✓	✓						
Nongkhaem																						
Bangkuntien															✓	✓		✓		✓		
Radburana															✓	✓						
Sathorn									✓		✓					✓						
Bangkorlam																✓						
Bangplad																						
Jomthong															✓	✓			✓	✓		
Bangkae															✓	✓						
Taweewattana																						
Thongkru																✓				✓	✓	✓
Bangborn															✓		✓	✓		✓		

Remark: C, collection stage; T, transfer stage

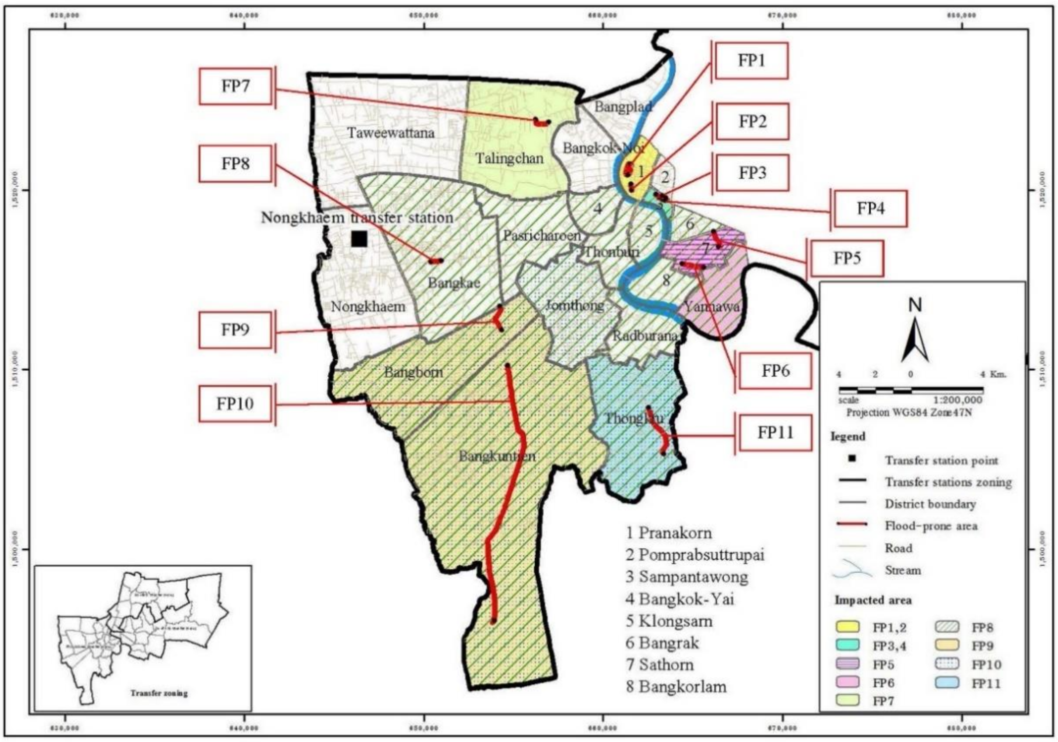

Figure 23. The spatial flood impact on MSWM system of all flood-prone areas

‘Scenario 1’ and ‘Scenario 2’ represent the flood impact of flood-prone areas 1and 2 (FP1 and FP2) in Pranakorn District on the MSWM system of flooded areas in the district (Figure 24 and Figure 25). Similarly, FP3 and FP4 are located in Samphanthawong District (Figure 26 and Figure 27), FP5 in Sathon District (Figure 28), FP7 in Talingchan District (Figure 30) and FP11 in Thongkru District (Figure 34). They only affect the MSWM in the area where they are located. Meanwhile, FP6 and FP8–FP10 affect the MSWM system both inside and outside the flooded areas.

‘Scenario 6’ represents the flood impact of flood-prone area 6 (FP6) in Sathorn District, which affects the MSWM system in Sathorn and Yannawa District (Figure 29).

‘Scenario 8’represents the flood impact of flood-prone area 8 (FP8) in Bangkae District, which affects the MSWM system in Bangkae, Sampantawong, Bangrak, Yannawa, Thonburi, Klongsarn, Bangkokyai, Pasicharoen, Bangkuntien, Radburana, Sathorn, Bangkorlam, Jomthong, Thongkru, and Bangborn District (Figure 31).

‘Scenario 9’ represents the flood impact of flood-prone area 9 (FP9) in Bangborn District, which affects the MSWM system in Bangborn and Bangkuntien Districts (Figure 32).

‘Scenario 10’ represents the flood impact of flood-prone area 10 (FP10) in Bangkuntien District, which affects the MSWM system in Bangkuntien, Jomthong, Thongkru, and Bangborn Districts (Figure 33).

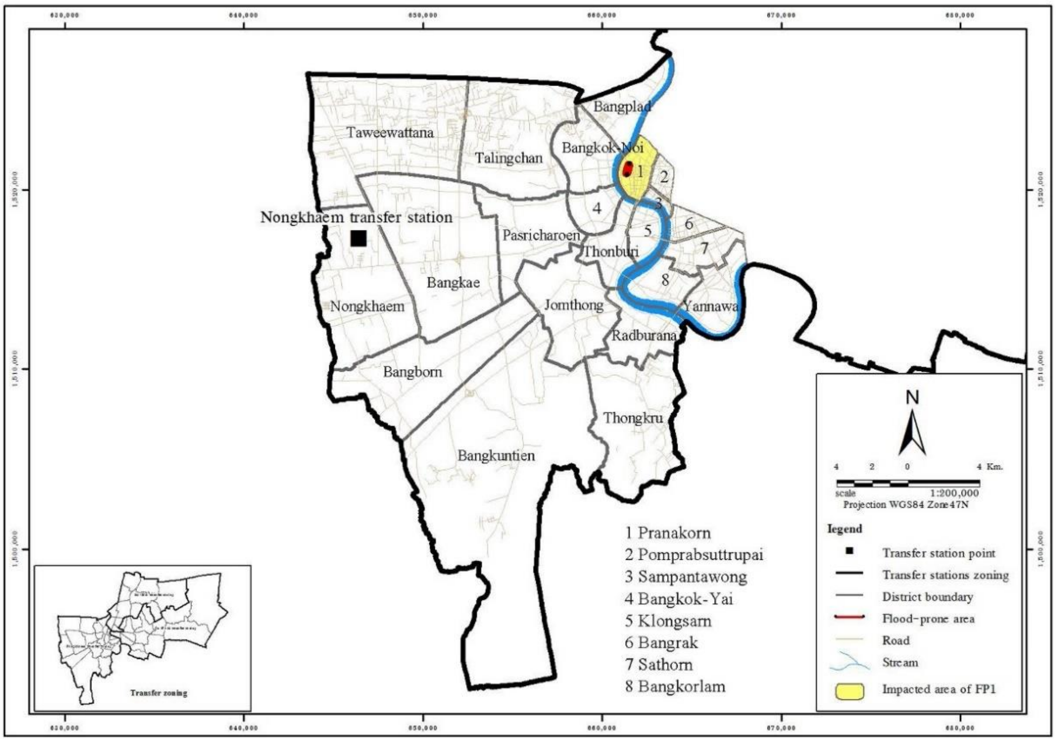

Figure 24 The spatial flood impact on the MSWM system in flood-prone area1

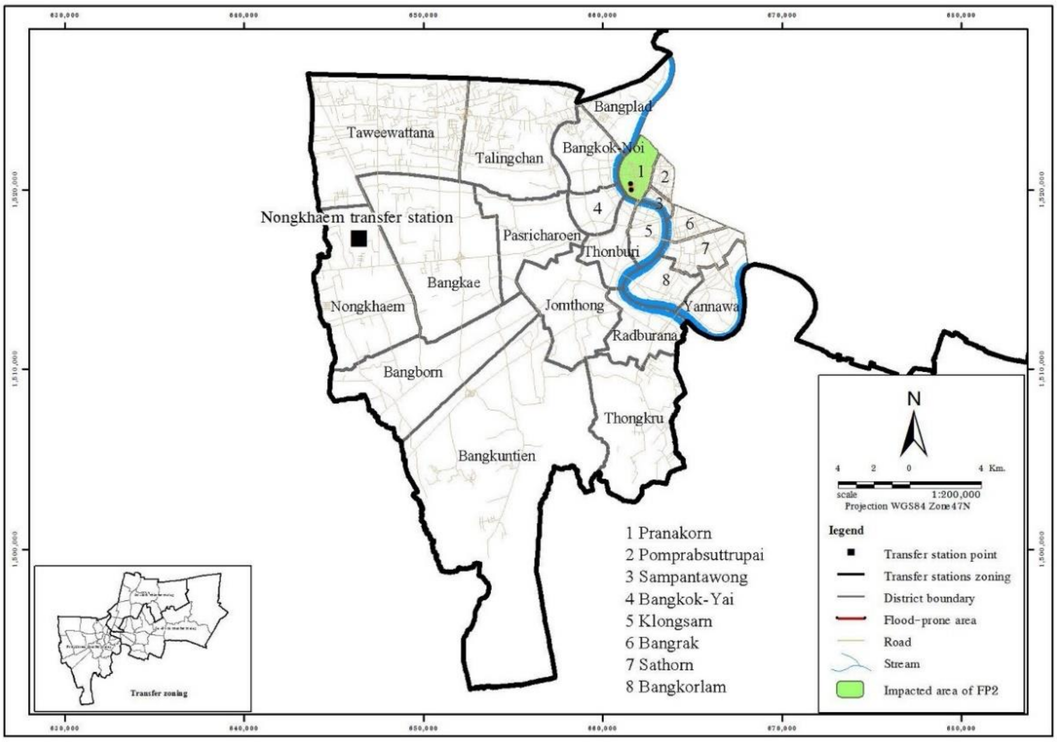

Figure 25 The spatial flood impact on the MSWM system in flood-prone area2

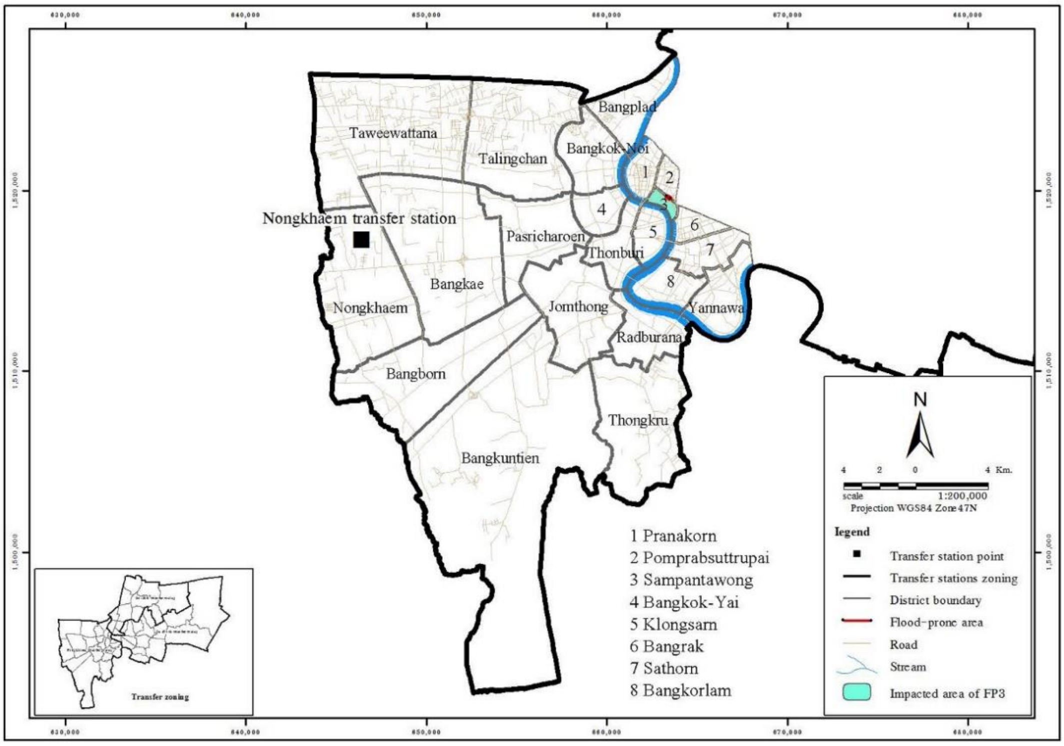

Figure 26 The spatial flood impact on the MSWM system in flood-prone area3

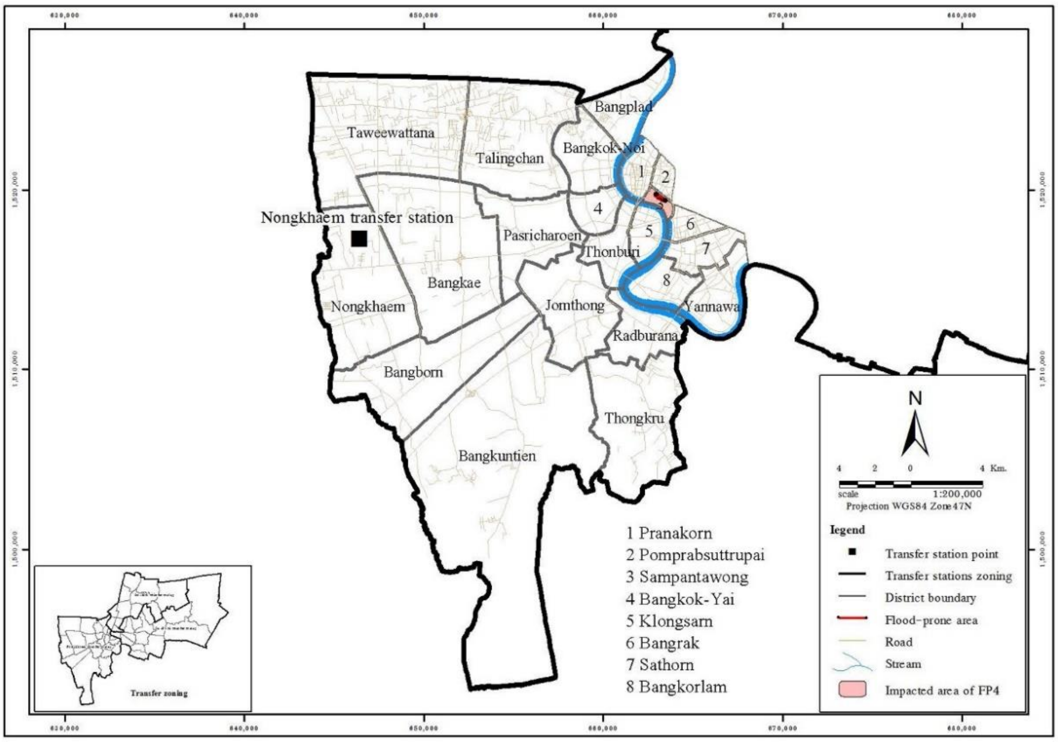

Figure 27 The spatial flood impact on the MSWM system in flood-prone area4

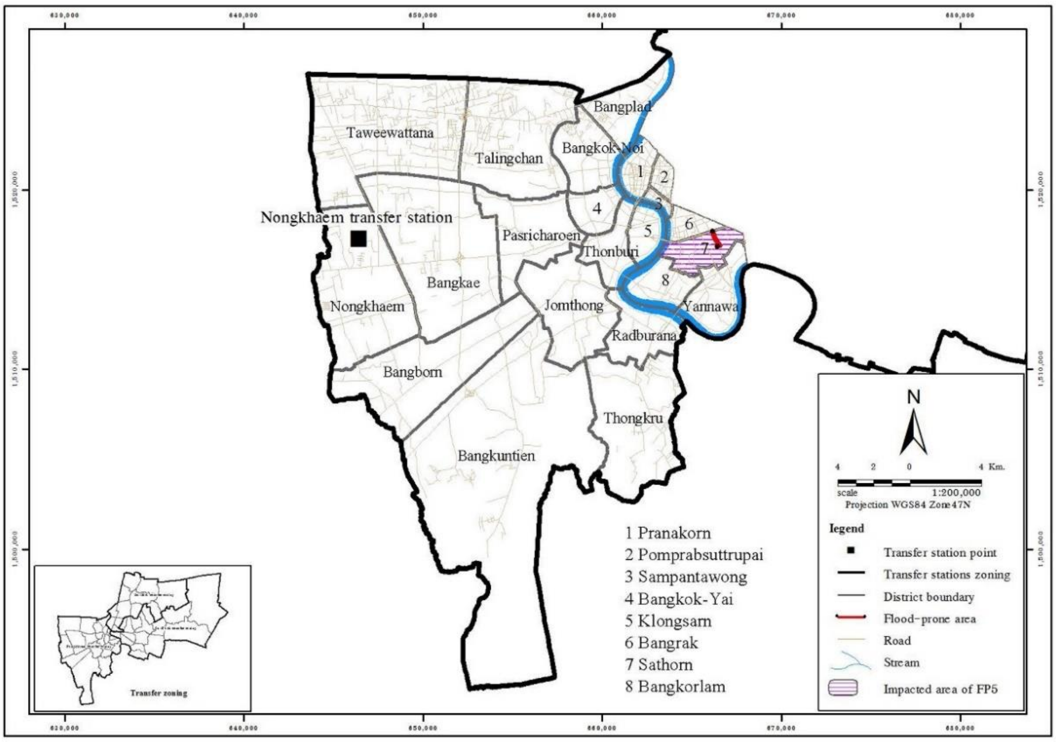

Figure 28 The spatial flood impact on the MSWM system in flood-prone area5

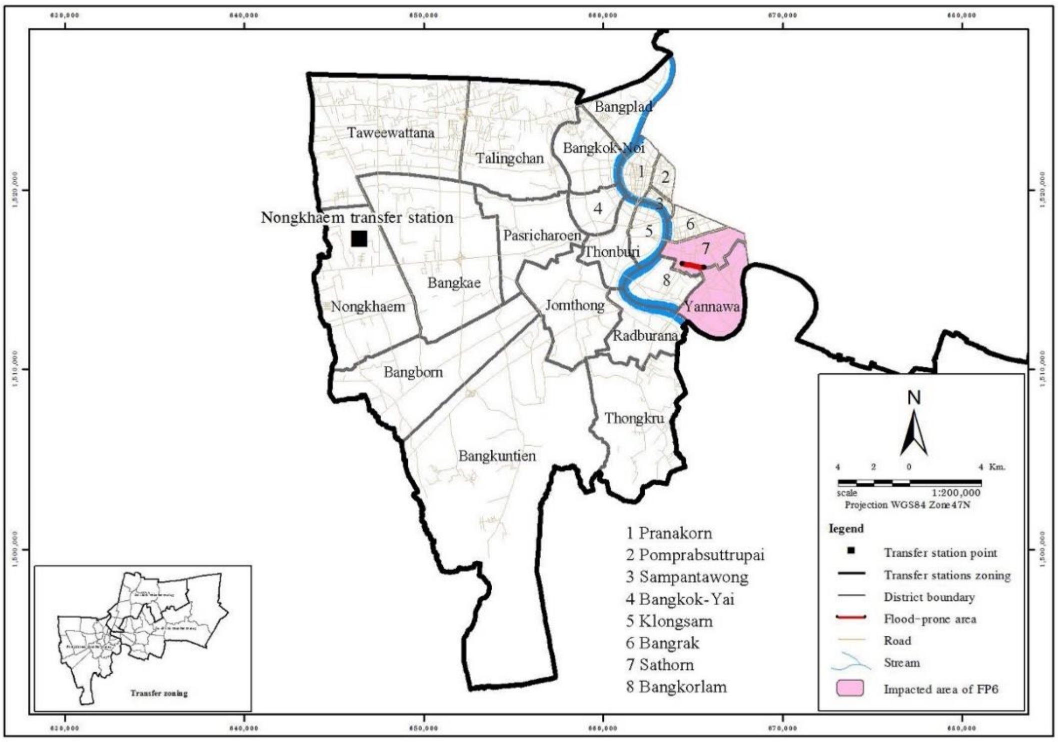

Figure 29 The spatial flood impact on the MSWM system in flood-prone area6

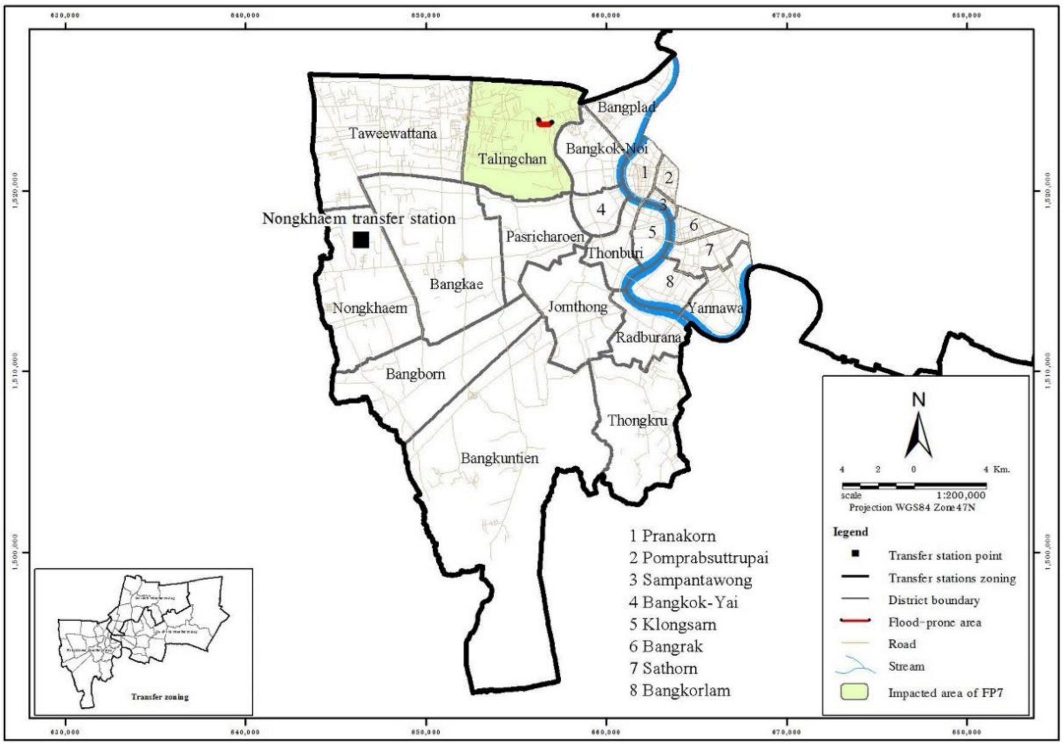

Figure 30 The spatial flood impact on the MSWM system in flood-prone area7

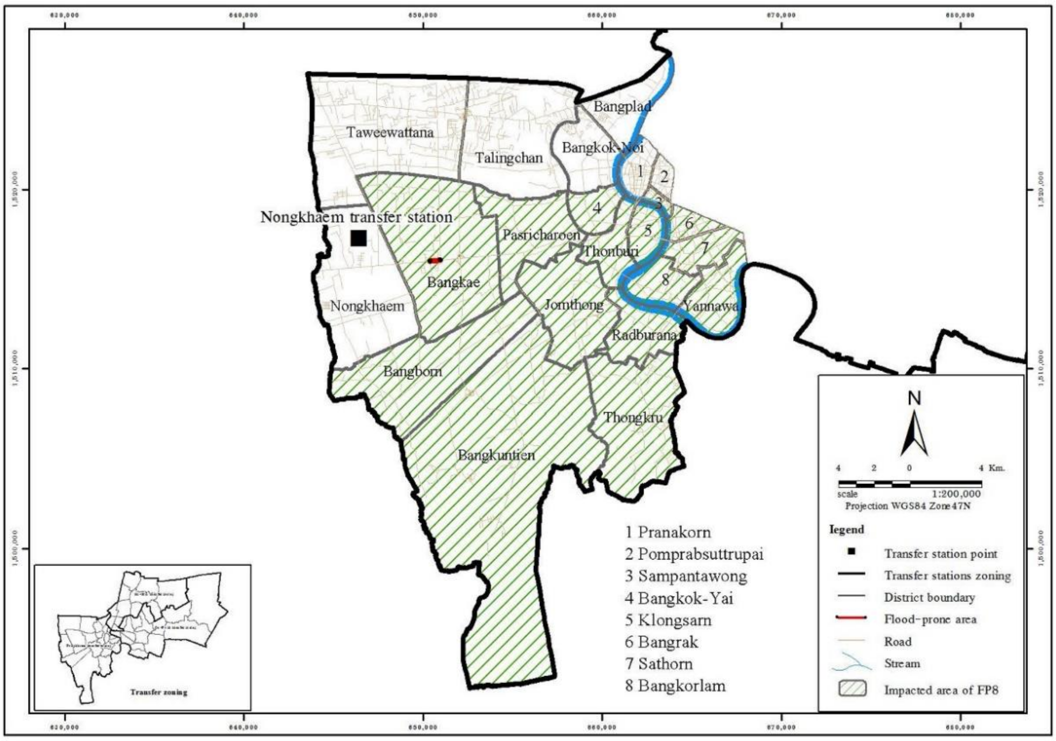

Figure 31 The spatial flood impact on the MSWM system in flood-prone area8

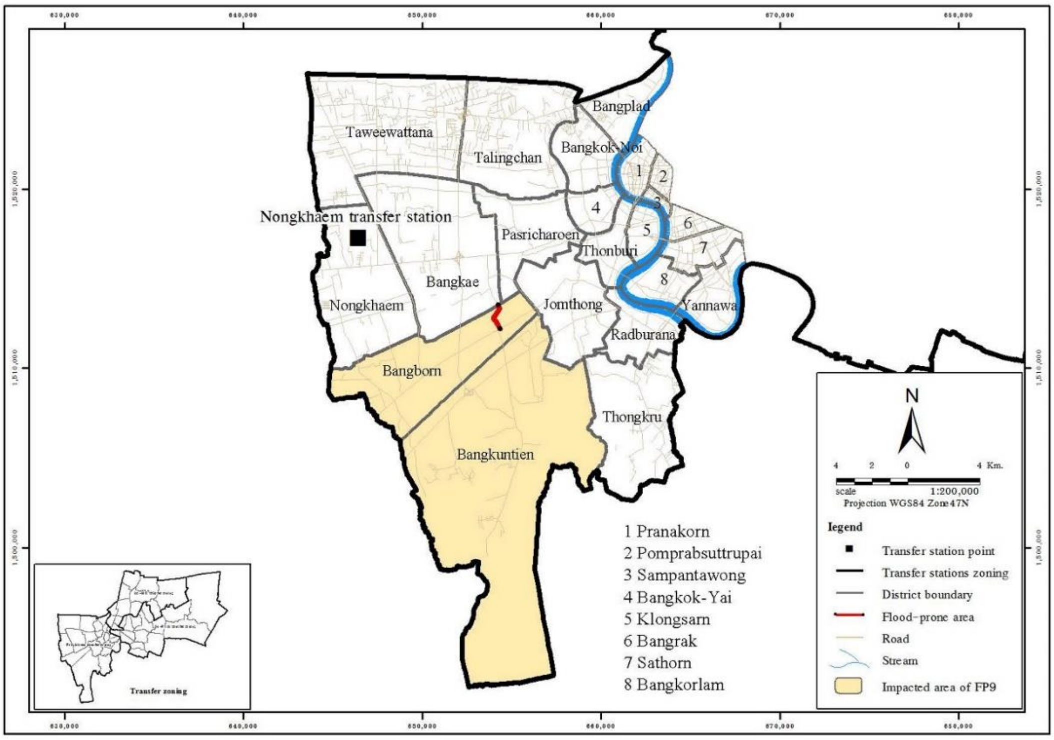

Figure 32 The spatial flood impact on the MSWM system in flood-prone area9

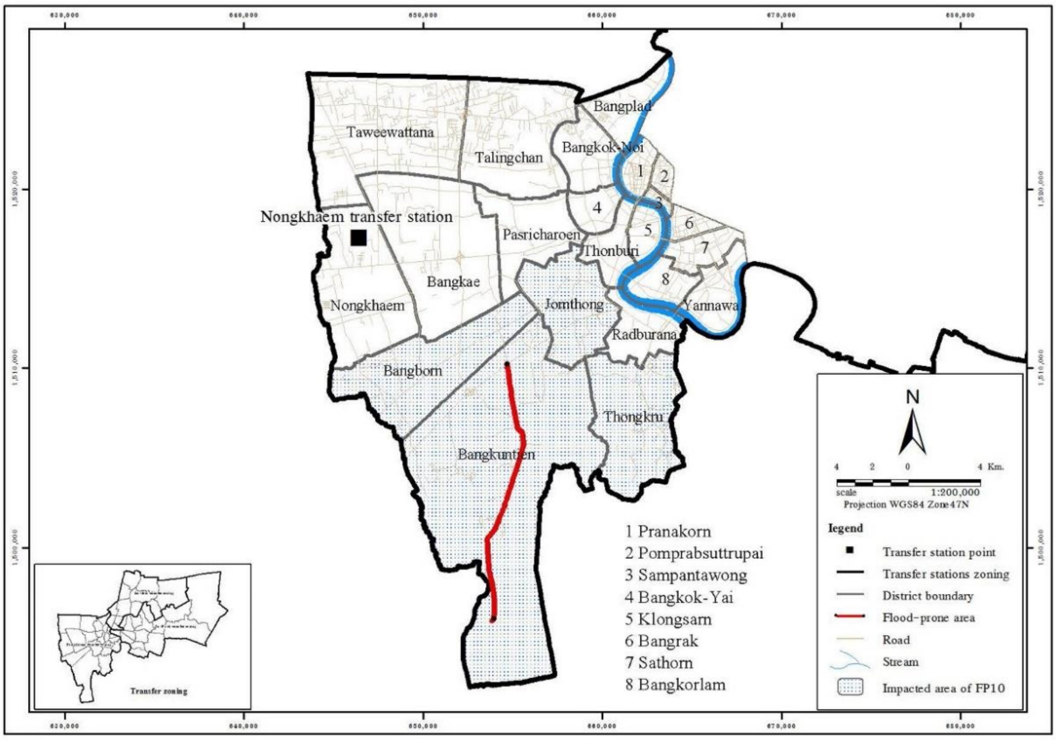

Figure 33 The spatial flood impact on the MSWM system in flood-prone area10

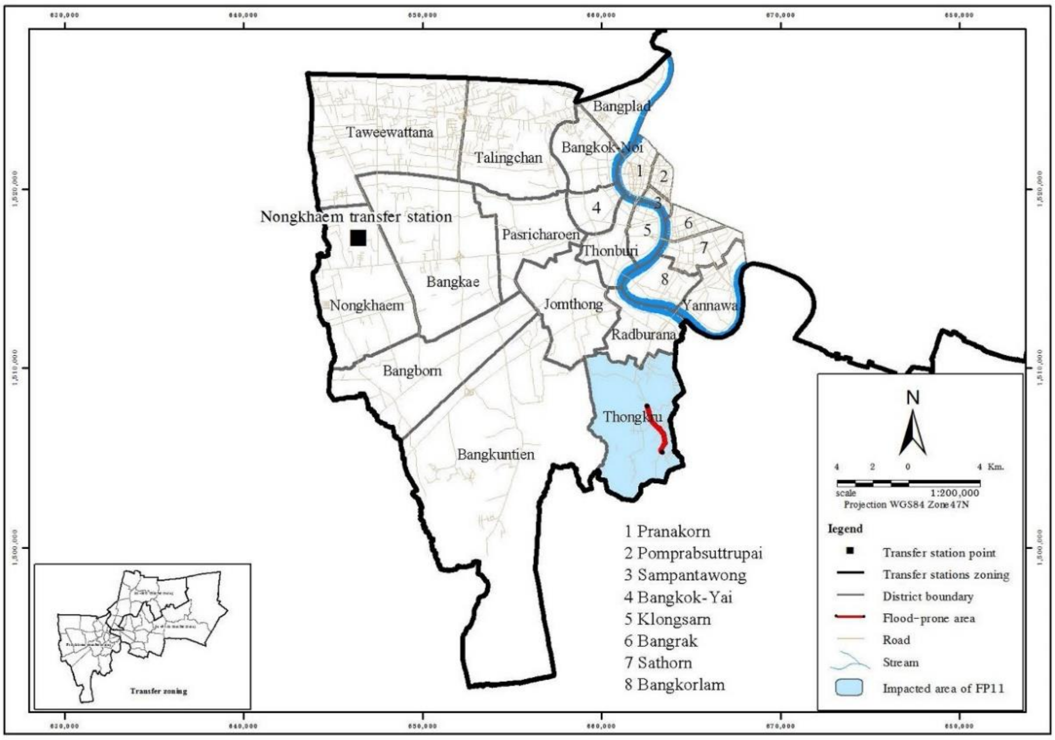

Figure 34 The spatial flood impact on the MSWM system in flood-prone area11

The model can illustrate the impacts not only within but also outside the flooded area. The flood impacts on the MSWM service of seven FP scenarios are affected only in the district of the flooded areas themselves, while the impact of four FPs on the MSWM service can expand outside the flooded areas.

From all the above scenarios, the impact from FP8 in ‘Scenario 8,’ which took place in the Bangkae District, indicates the greatest number of affected areas in the MSWM service. This affected 15 districts; eight in the collection stage and seven in the transfer stage only. The second was FP10, located in Bangkhuntien District, which affected one district in the collection stage and three in the transfer stage only, as shown in Table 8 and Figure 35.

In terms of the administrative area, the districts most vulnerable to flooding are Sampantawong, Bangkhuntien, Sathorn, Thongkru, and Bangborn. They are vulnerable to the effects of the three flood-prone areas, as shown in Figure 36.

Table 8 Spatial Impact of Each District and Sub-District in Collection and Transfer Stage

Flood-prone area	**Location (district)**	**District**			**Sub-district**		
		Total	**C**	**T**	**Total**	**C**	**T**
FP1	Pranakorn	1	1	1	1	1	1
FP2	Pranakorn	1	1	1	1	1	1
FP3	Sampantawong	1	1	0	3	3	0
FP4	Sampantawong	1	1	0	3	3	0
FP5	Sathon	1	1	0	3	3	0
FP6	Sathon	2	2	0	4	4	0
FP7	Talingchan	1	1	0	1	1	1
FP8	Bangkae	15	8	15	47	26	46
FP9	Bangborn	2	1	1	2	1	2
FP10	Bangkhuntien	4	1	3	8	4	8
FP11	Thongkru	1	1	1	2	2	2

Remark: C, collection stage; T, transfer stage

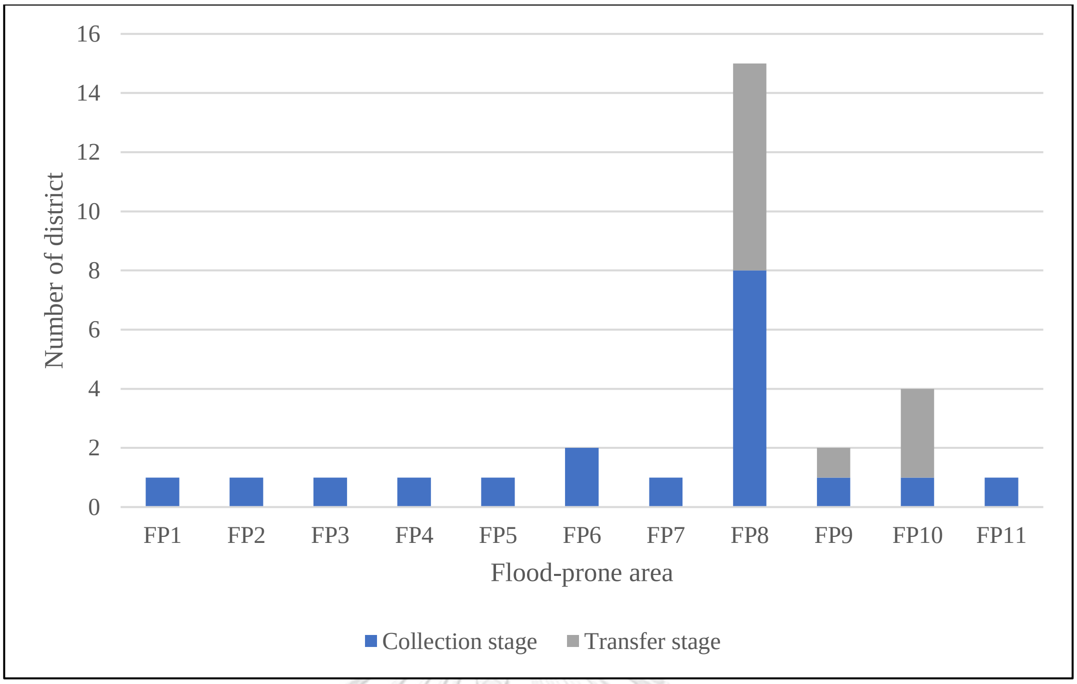

Figure 35. Number of affected districts by flood-prone area (FP)

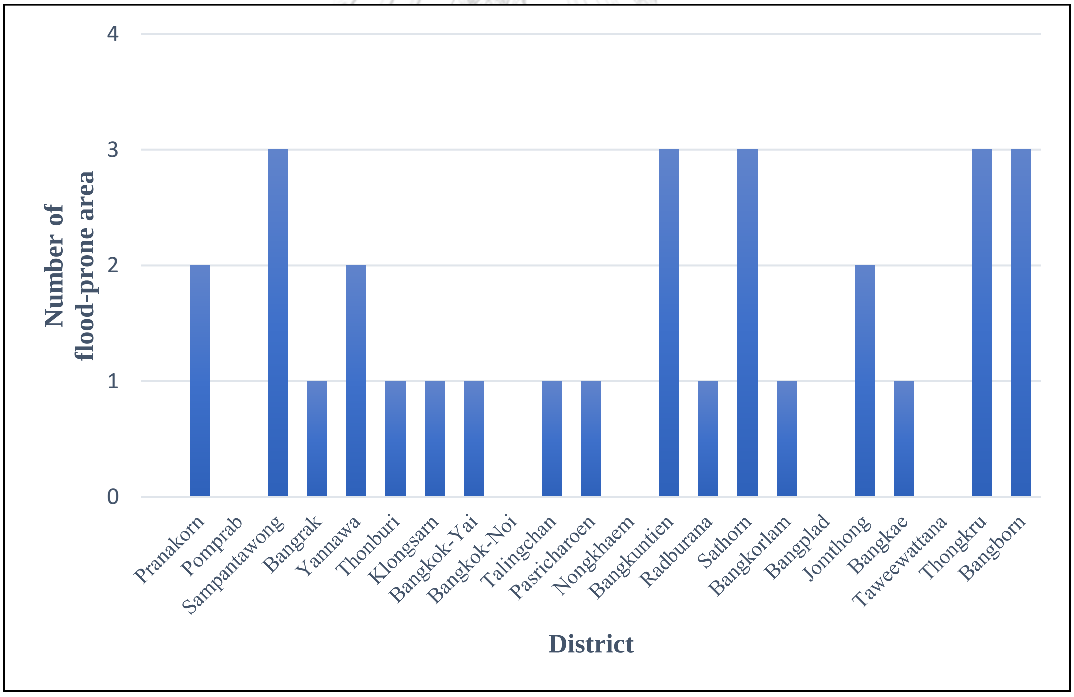

Figure 36. Number of flood-prone areas affecting each district

5.2 Quantitative Impact

The 11 scenarios represent the susceptible situation of a flood-prone area (FP) in different locations. The impact on the accumulated MSW amount in each area has been divided into two stages: collection and transfer. The projected impact of each flood-prone area in 2020 varies in quantitative terms, as shown in Table 9. The impact on the collection stage affects the amount of uncollected waste from the generation source, while impact on the transfer stage affects the amount of remaining waste. Impact rankings have shown the distribution amount of accumulated MSW from the lowest to highest result as follows: FP1, FP2, FP7, FP3, FP4, FP11, FP5, FP9, FP6, FP10, and FP8, respectively. FP1–FP7 and FP11 only involve the collection stage as they only affect the amount of uncollected waste. FP8–FP10 involve both collection and transfer stages, causing amounts of uncollected and remaining waste as follows:

- Flood-prone areas 1 (FP1) and 2 (FP2) result in 13 tons/day of congested waste, including only 13 tons of uncollected waste.
- Flood-prone areas 3 (FP3) 4 (FP4) result in 49 tons/day of congested waste, including only 49 tons of uncollected waste.
- Flood-prone area 5 (FP5) results in 174 tons/day of congested waste, including only 174 tons of uncollected waste.
- Flood-prone area 6 (FP6) results in 347 tons/day of congested waste, including only 347 tons of uncollected waste.
- Flood-prone area 7 (FP7) results in 45 tons/day of congested waste, including only 45 tons of uncollected waste.
- Flood-prone area 11 (FP11) results in 104 tons/day of congested waste, including only 104 tons of uncollected waste.
- Flood-prone area 8 (FP8) results in 2,074 tons/day of congested waste, including 1,127 tons of uncollected waste and 947 tons of remaining waste.
- Flood-prone area 9 (FP9) results in 253 tons/day of congested waste, including 122 tons of uncollected waste and 131 tons of remaining waste.
- Flood-prone area 10 (FP10) results in 499 tons/day of congested waste, including 142 tons of uncollected waste and 357 tons of remaining waste.

Table 9 The Amount of Uncollected and Remaining Waste per Day of Each District in Each Flood-Prone Area

District	FP1		FP2		FP3		FP4		FP5		FP6		FP7		FP8		FP9		FP10		FP11	
	U	R	U	R	U	R	U	R	U	R	U	R	U	R	U	R	U	R	U	R	U	R
Pranakorn	13	-	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pomprab	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sampantawong	-	-	-	-	49		49	-	-	-	-	-	-	-	-	49	-	-	-	-	-	-
Bangrak	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	176	-	-	-	-	-	-
Yannawa	-	-	-	-	-	-	-	-	-	-	173	-	-	-		276	-	-	-	-	-	-
Thonburi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	104	-	-	-	-	-	-	-
Klongsarn	-	-	-	-	-	-	-	-	-	-	-	-	-	-		58	-	-	-	-	-	-
Bangkok-Yai	-	-	-	-	-	-	-	-	-	-	-	-	-	-	110		-	-	-	-	-	-
Bangkok-Noi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Talingchan	-	-	-	-	-	-	-	-	-	-	-	-	45	-	-	-	-	-	-	-	-	-
Pasricharoen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	126	-	-	-	-	-	-	-
Nongkhaem	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-
Bangkuntien	-	-	-	-	-	-	-	-	-	-	-	-	-	-	193	-	-	131		131	-	-
Radburana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	272	-	-	-	-	-	-	-
Sathorn	-	-	-	-	-	-	-	-	174	-	174	-	-	-	-	174	-	-	-	-	-	-
Bangkorlam	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	110	-	-	-	-	-	-
Bangplad	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jomthong	-	-	-	-	-	-	-	-	-	-	-	-	-	-	142	-	-		142	-	-	-
Bangkae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	58	-	-	-	-	-	-	-
Taweewattana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thongkru	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	104	-	-	-	104	104	-
Bangborn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	122		122			122	-	-
Total	13		13		49		49		174		347		45		1127	947	122	131	142	357	104	-

Remark: Unit = Tons; U, uncollected waste; R, remaining waste

5.3 Vulnerable Flood-Prone Area and Service Area of MSWM System

Each scenario represents a susceptible situation of a flood-prone area. They have different impacts on the distribution of affected areas both inside and outside the floodplain area and on the accumulated amount of MSW.

The flood impacts on the MSWM service of seven FP scenarios are affected only in the district of the flooded areas themselves, which affects only the collection process of the MSWM service. The impact on FP1 and FP2 in the Pranakorn District location would result in 12.5 tons/day of uncollected waste. Similarly, FP3 and FP4 in the Sampantawong District location would face 49.1 tons/day of uncollected waste. In FP5, FP7, and FP11, 173.8, 44.6, and 104.3 tons/day of uncollected waste, respectively, show up as a result of flooding impact.

However, the impact on the MSWM service of four FPs indicates that flood impacts can expand outside the flooded areas. The impact of FP6 in the Sathon District location shows the flood affecting the Sathon and Yannawa Districts, which lie outside the floodplain area. This impact resulted in a total of 347.1 tons/day of uncollected waste, including 173.8 tons/day in the Sathon District and 173.3 tons/day in the Yannawa District. Although the impact of FP9 in Bangborn and FP10 in Bangkhuntien show the impact of flooding inside and outside the floodplain area, like the impact of FP6, they also illustrate the impact on the collection and transfer processes. The uncollected waste amount of FP9 was 122.0 tons/day, and the remaining waste amount was 130.1 tons/day. The impact on FP10 led to 142.1 tons/day of uncollected waste and 357.2 tons/day of remaining waste.

Therefore, the impact from FP8 in ‘Scenario 8,’ in the Bangkae District, indicates the greatest number of spatial flood impacts on the MSWM system. This illustrates that some scenarios are very sensitive because they have a very wide and complex impact, like ‘Scenario 8’. This affected 15 districts, with the impact on eight districts being 1,127.0 tons/day of uncollected waste and that on seven districts being 946.9 tons/day of the remaining waste. Figure 37 represents the results of the impact of FP8 ‘Scenario 8’ as accumulated MSW amount in the collection and transfer processes in 15 districts.

The collection process in eight local districts was affected because of the amount of uncollected waste in the MSWM system, with Radburana being the highest affected, as shown by the simulated results over time in Figure 38a. On the contrary, the transfer process of seven local districts was affected because of the amount of remaining waste in the MSWM system, with Yannawa being the highest affected, as shown by the simulated results over time in Figure 38b.

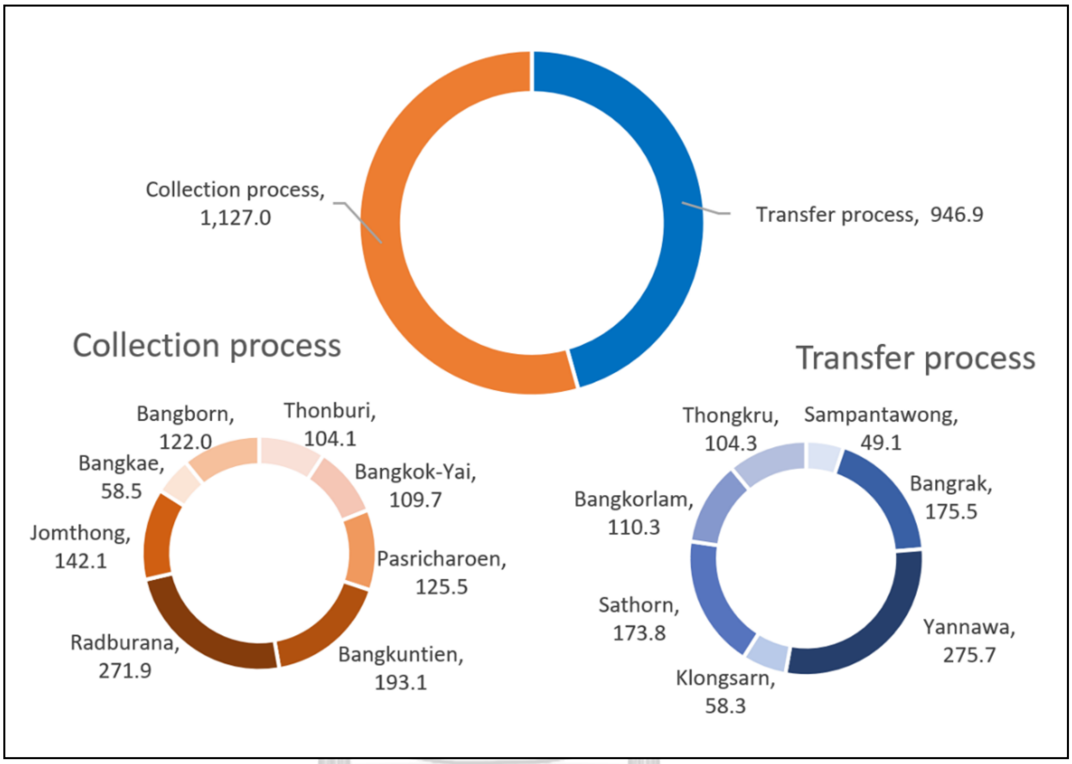

Figure 37. Accumulated MSW amount of FP8 in 15 districts of collection and transfer stages (tons/day)

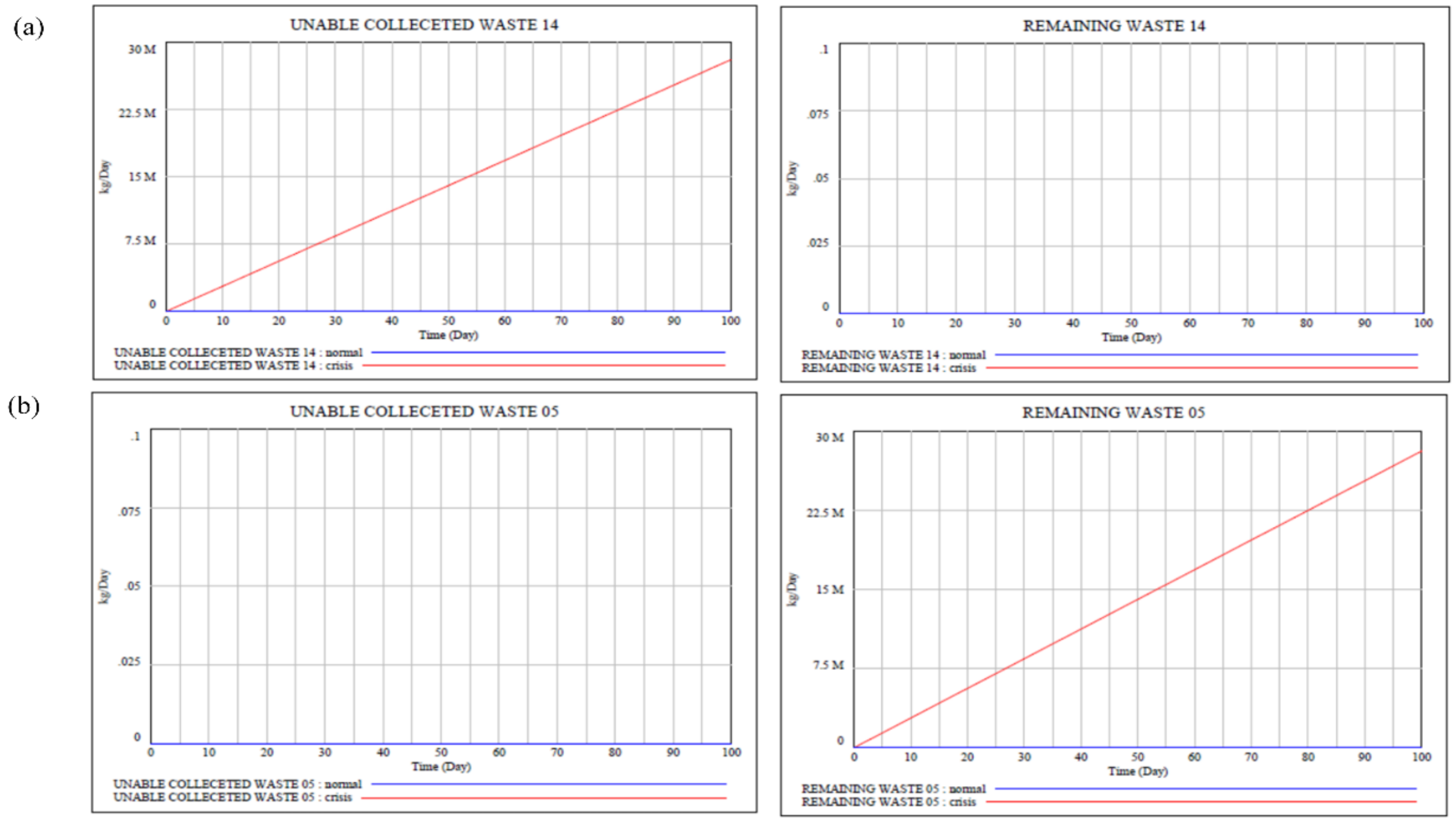

Figure 38. Simulated result of uncollected and remaining waste of flood-prone area 8 over time.

(a) Radburana Districts: No.14, (b) Yannawa District: No.05

According to the impact, evaluation results can be classified as impacts occurring in three situations: 1) Cannot collect waste from sources (CNC), 2) Cannot transfer waste for final disposal (CNT), and 3) Cannot collect and transfer waste for final disposal (CNC and CNT). Each flood-prone area and district is classified by impact characteristic into the following groups as shown in Tables 10 and 11.

Table 10 Grouping of Districts According to Impact Situations

District	**Impact situation**		
	CNC	**CNT**	**CNC and CNT**
Pranakorn	✓	✓	✓
Pomprab	-	-	-
Sampantawong	✓	✓	✓
Bangrak	-	✓	-
Yannawa	✓	✓	✓
Thonburi	✓	✓	✓
Klongsarn	-	✓	✓
Bangkok-Yai	✓	✓	✓
Bangkok-Noi	-	-	-
Talingchan	✓	✓	✓
Pasricharoen	✓	✓	✓
Nongkhaem	-	-	-
Bangkuntien	✓	-	✓
Radburana	✓	✓	✓
Sathorn	✓	✓	✓
Bangkorlam	-	✓	-
Bangplad	-	-	-
Jomthong	✓	✓	✓
Bangkae	✓	✓	✓
Taweewattana	-	-	-
Thongkru	✓	✓	✓
Bangborn	✓	✓	✓

Table 11 Grouping of Flood-Prone Areas According to Impact Situations

Flood-prone area	**Impact situation**		
	CNC	**CNT**	**CNC and CNT**
FP1	✓	✓	✓
FP2	✓	✓	✓
FP3	✓	-	-
FP4	✓	-	-
FP5	✓	-	-
FP6	✓	-	-
FP7	✓	✓	✓
FP8	✓	✓	✓
FP9	✓	✓	✓
FP10	✓	✓	✓
FP11	✓	✓	✓

SD principles can be applied to evaluate the impact that occurs both spatially and quantitatively when the system is disturbed by external conditions, such as flooding. Thus, it is appropriate to study the mechanism for MSWM during the flood as a guide to prioritize the preparedness plans for flood impact mitigation in MSWM with systematic and effective evaluation of impact levels in terms of waste amount accumulated during floods. This is an important element that is lacking in Bangkok's MSWM strategy plan (BMA, 2015c), because the flood impact does not occur only in flooded areas but affects areas inside and outside the network. It indicates the vulnerability of the MSWM service system during flooding in different areas in terms of spatial and quantitative impact on the flood management of urban cities (Yuddhana, 2012).

Therefore, this study has adopted the results of impact in terms of vulnerable areas and impact characteristics as an instruction for application to flood mitigation in three impact characteristics. Results obtained from 11 FP area scenarios are discussed in this section to present the impact of various flooding area options on the MSWM system, which helps to understand the problem and its impact, as well as to prioritize the preparedness plans and recommend an appropriate mitigation approach.

Chapter 6

Impact Mitigation

This step includes the recommended approachs to flood mitigation on MSWM methods: The AHP-based hierarchical model used to indicate the criteria and mitigation alternative priority. It is used as a basis for alternative actions to recommend mitigation guidelines for the MSWM system during flooding. Moreover, there have been experiments using guidelines to develop action plans for vulnerable areas from impact evaluation results with the participation of local government organisations (district) under the relevant authority and responsibility. The mitigation guidance processes are discussed in this chapter to recommend approaches to mitigation impacts from urban flooding on Bangkok's MSWM system, including:

1. Impact mitigation approaches
2. Impact mitigation guidelines
3. Impact mitigation action plan

6.1 Impact Mitigation Approaches

The AHP process formulated in this study consists of three levels. At the first level is the goal, followed by the criteria at level two. Flood mitigation on MSWM alternatives is at level three. At the second and third level, a pairwise comparison matrix is developed. It is carried out by 13 selected experts and responsible providers through pairwise matrices to evaluate the relative importance of each variable (criteria/alternative) as shown in the overall process of AHP in Figure 39.

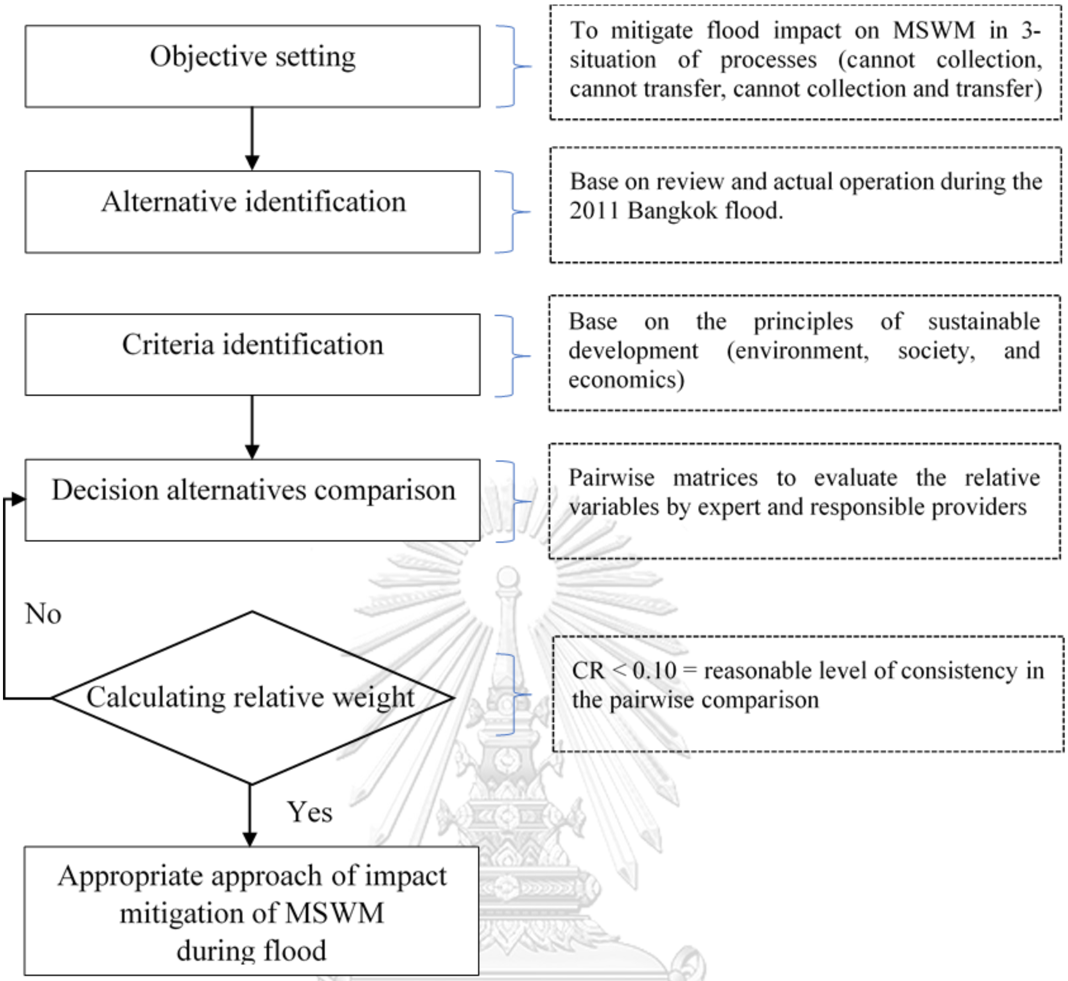

Figure 39. Overall step of Analytic Hierarchy Process (AHP)

6.1.1 Setting objective

The flood impact results, as discussed in the previous section, can be divided into three categories of flood situation cause and effect as shown in Figure 40. The results of each categories are different characteristics of MSW congestion in the system as follows:

- Cannot collect waste from sources (CNC): leads to increased amount of uncollected waste due to the inability to collect waste at generation sources
- Cannot transfer waste for final disposal (CNT): leads to increased amount of remaining waste due to an inability to transport collected waste from sources to transfer station
- Cannot collect and transfer waste for final disposal (CNC and CNT): leads to uncollected waste due to the inability to manage waste.

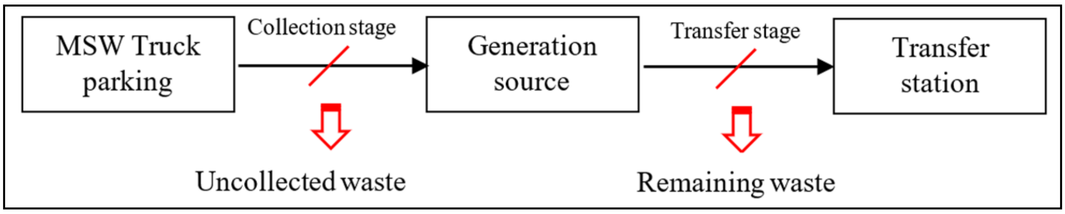

Figure 40. The different impact characteristics of flood impact on MSWM

The main objective is to mitigate flood impact on the MSWM system in three flood impact situations. The impacts of different flood scenarios on MSW processes are then used to develop flood mitigation approaches for the MSWM system. The results indicate mitigation approaches to allow the MSWM system to survive during a flood. The decision-making process followed in the study was divided into three situations: 1) CNC, 2) CNT, and 3) CNC and CNT. The main objective is to mitigate a flood's impact on the MSWM system in three levels of flood impact.

6.1.2 Criteria identification.

The criteria impacting the MSWM system in flood conditions are identified through literature reviews relating to waste management factors in various areas used to extract data as shown in Table 12. Various specific criteria from 12 studies have been grouped into four general groups for consideration in terms of waste management factors in critical situations. These factors are selected and integrated by 22 district officials, involved in the relationship with Bangkok's waste management context.

Therefore, the six selected factors in this study are related to waste management in critical situations in Bangkok. They represent factors in sustainable urban development, including the environment, economy, and society. The sub-criteria of environmental factors are environmental risk (EN1), energy and resource consumption (EN2), and separated management of waste (EN3). The sub-criteria of societal factors are health risk of community (SO1) and visual impact (SO2), while cost (EC1) is presented as an economic factor, as detailed in Table 13.

Table 12 Criteria of MSWM System Approach

General group	Specific criteria	Justification from literature
Technical characteristics	- Small-scale technology	(1)
	- Municipalities and waste volume	(2)
	- Land demand	(6)
	- Landscape impact, Visual impact	(1) (2) (9) (10) (11)
Environmental impacts	- Environmental risk	(3)
	- Ecological impact	(6) (7) (9) (11)
	- Emissions to environment, air emission	(3) (5) (9)
	- Compatibility with environment	(1)
	- Topography	(2)
	- Soil pollution	(9)
	- Flood	(4) (1)
	- Fuel or non-renewable energy consumption	(1)
	- Non-renewable raw materials use	(1)
	- Power	(2)
	- Resource consumption	(6) (7)
	- Acceptable time collection	(1)
	- Separated management	(1)
	- Temporary storage not dangerous to ecosystem	(1)
	- Runoff and sewage systems	(2)
	- Protected areas	(2)
Social aspects	- Living conditions of local community	(1)
	- Health of the community	(1) (2) (5) (6) (7) (9)
	- Flexibility with population growth	(1)
	- Social acceptability	(6) (7)
	- Landscape impact, Visual impact	(1) (2) (9) (10) (11)
Economical aspects	- Availability and access with low cost	(1)
	- Employment of local staff	(1)
	- Initial investment costs	(3)
	- Operation Cost	(3) (5)
	- System cost	(6)
	- Transportation Cost	(3)
	- Cost of the area	(8)
	- Cost	(9)

(1) (Garfi, Tondelli, & Bonoli, 2009), (2) (Aragones-Beltran, 2010), (3) (Coban, Ertis, & Cavdaroglu, 2018), (4) (Kemal Korucu & Erdagi, 2012), (5) (Contreras, 2008), (6) (Hung et al., 2007), (7) (Hanan, Burnley, & Cooke, 2013), (8) (De Feo & De Gisi, 2010), (9) (Josimovic et al., 2015), (10) (De Feo & De Gisi, 2014), (11) (Moeinaddini, 2010)

Table 13 Criteria Adopted to Evaluate the Mitigation of a Flood Impact on the MSWM System

Main criteria	**Sub criteria**	**Description**
Environment	• Environmental risk (EN1)	Waste water, Air pollution and Noise
	• Energy and resource consumption (EN2)	Fuel, non-renewable energy consumption and raw materials use.
	• Separated management of waste (EN3)	Separated management of organic, hazardous or recyclable waste.
Society	• Health risk of community (SO1)	Health of the community (e.g. food safety, disease reduction, hygiene)
	• Visual impact (SO2)	Visual impact to public
Economics	• Cost (EC1)	Investment and operational

6.1.3 Alternative identification

The mitigation alternatives are analysed and based on an international literature review and local government interviews regarding actual operations during the 2011 Bangkok floods. The alternatives in this study are:

- Alternative 1 Sub-transfer area (temporary storage site): including a temporary storage site in the waste generation area for waste storage before moving to the disposal site.

- Alternative 2 Truck parking area: including a temporary waste truck parking area in the MSW generation area for parking before and after transportation.

- Alternative 3 Modified truck: making modifications to waste hauling trucks, such as adjustment of truck height and extension of the snorkel to air intake chamber and air exhaust systems to protect the engine's combustion system, to transport through flooded areas.

- Alternative 4 Boats to collect and store waste: using boats to collect MSW in flooded areas and store before moving to the disposal site

- Alternative 5 Changing transfer station: changing the MSW transfer to another transfer station in Bangkok, including On-nuch and Sai-mai.

6.1.4 Decision alternatives comparison

This study has been carried out by a group of 13 experts and responsible providers through pairwise matrices to evaluate the relative importance of each variable (criteria/alternative) at level two and three against other variables at the same level. The experts who have served at different operational and strategic levels of responsibility, had different relevant backgrounds and experiences. They were selected from various departments and organizations such as the BMA's Department of Drainage and Sewerage and Department of Environment, the public park and cleaning divisions of different districts, waste management specialists, and town planning specialists as detailed in Appendix C. These experts were requested to give their personal opinions, based on their knowledge and experience, on the importance of each alternative and criterion in the context of flood mitigation in the MSWM system as shown in the comparative document in Appendix D.

The hierarchy for selection of the most appropriate flood mitigation approach in MSWM is presented below (Figure 41).

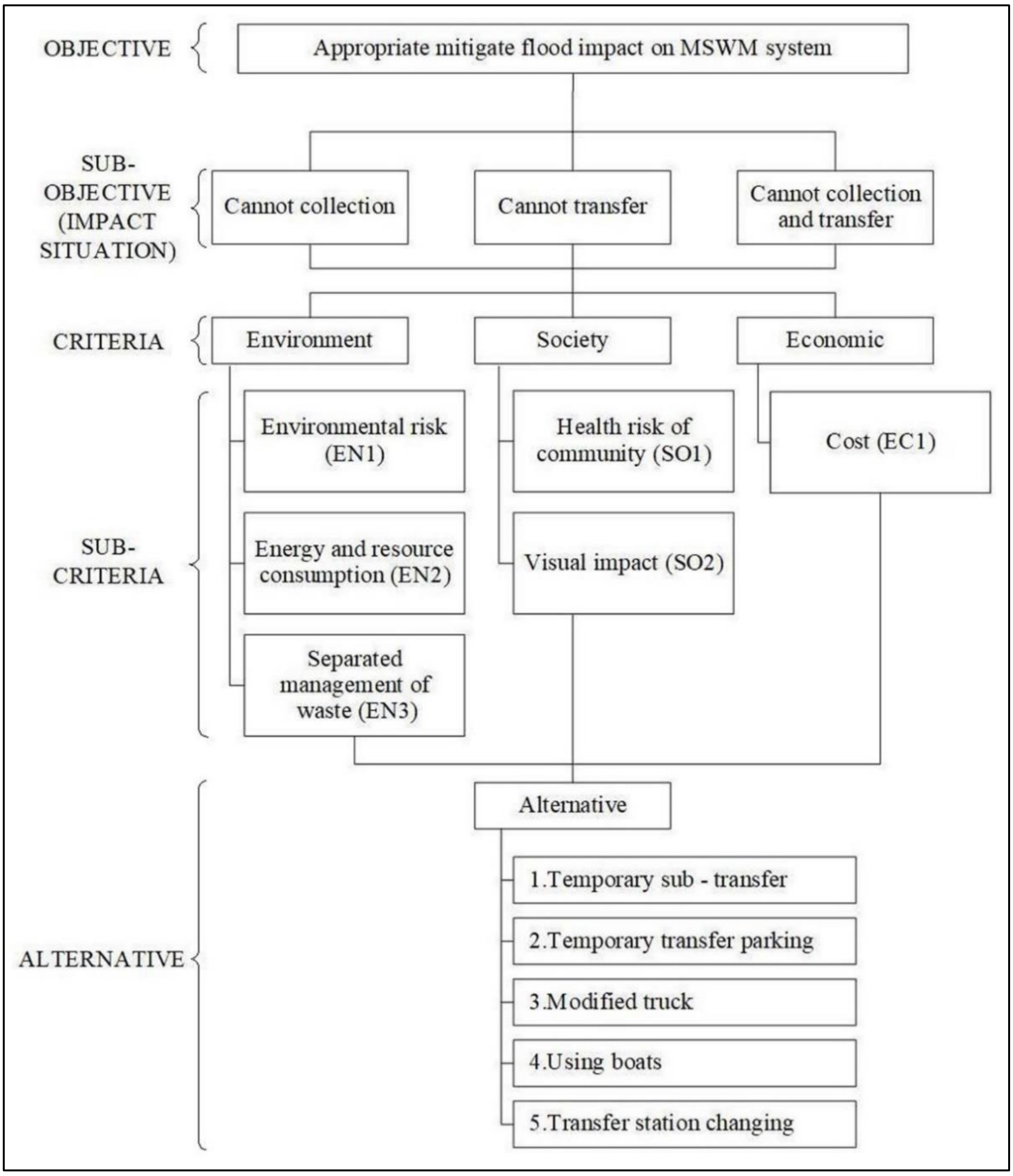

Figure 41. Analytic Hierarchy Process (AHP) formulation for alternative options to mitigate flood impacts on MSWM system

A pairwise comparison matrix is developed in each level. The matrix entries signify the numerical importance of each element in comparison with other elements. The obtained weights of criteria at different levels in three situations are presented in Table 14 and Figure 42.

Table 14 Criteria scores of three flood impact situations

Criteria	CNC	CNT	CNC and CNT
Environmental risk	0.18	0.23	0.26
Energy and resource consumption	0.16	0.16	0.08
Separated management of waste	0.23	0.27	0.10
Health risk of community	0.28	0.23	0.41
Visual impact	0.06	0.05	0.10
Cost	0.08	0.06	0.05

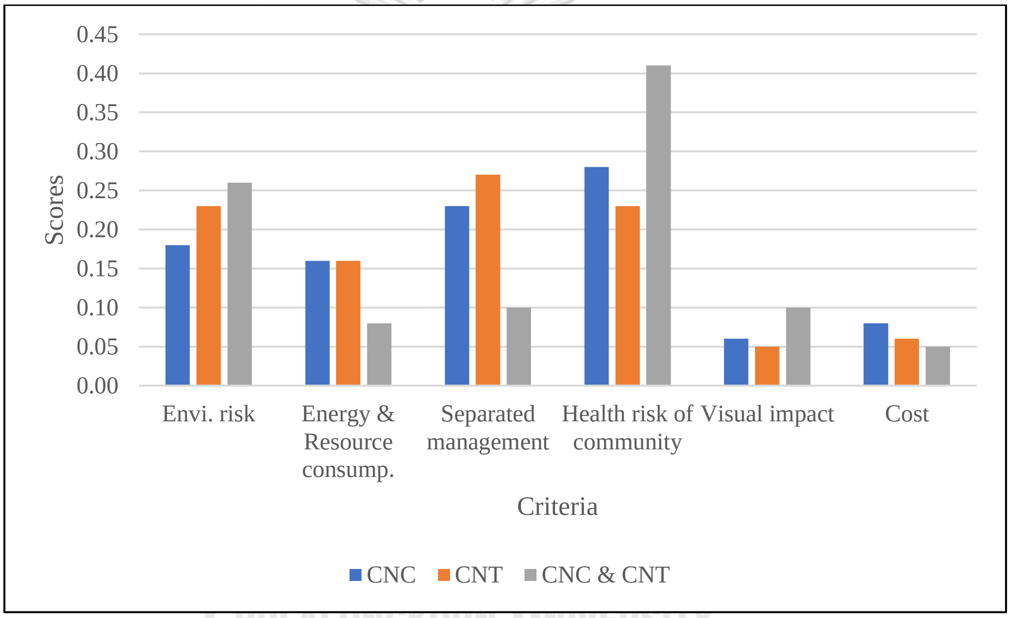

Figure 42 Criteria score of three flood impact situations

A situation where collection is not possible: The weighting score of health risk of community is 0.28, which is the highest score. The scores of separated management of waste, environmental risk, energy and resource consumption, cost, and visual impact are 0.23, 0.18, 0.16, 0.08, and 0.06, respectively.

A situation where transfer is not possible: The weighting score of health risk of community is 0.27, which is the highest score. The scores of environmental risk, separated management of waste, energy and resource consumption, cost, and visual impact are 0.23, 0.23, 0.16, 0.06, and 0.05 respectively.

A situation where neither collection nor transfer are possible: The weighting score of health risk of community is 0.41, which is the highest score. The scores of environmental risk, separated management of waste, visual impact, energy and resource consumption, and cost are 0.26, 0.10, 0.10, 0.08, and 0.05, respectively.

The criteria in the second level of each situation were calculated by multiplying the weights of the alternatives in the third level. These scores in each criterion are illustrated in Table 15.

Table 15 The weighting scores of the alternatives in the third level in each criterion

Criteria/Alternative	**Sub-transfer**	**Sub-park**	**Modified truck**	**Using boats**	**Transfer changing**
- Environmental risk	0.06	0.22	0.29	0.27	0.17
- Energy & resource consumption	0.25	0.22	0.18	0.20	0.15
- Separated management of waste	0.39	0.17	0.20	0.13	0.12
- Health risk of community	0.05	0.12	0.25	0.25	0.34
- Visual impact	0.04	0.11	0.25	0.24	0.36
- Cost	0.18	0.26	0.18	0.21	0.17

- For the highest weighting score of the alternatives with criteria of environmental risk is modified truck at 0.29. While the score of take boat, sub-truck parking area, transfer station changing, and sub-transfer area (temporary storage site) are 0.27, 0.22, 0.17, and 0.06 respectively.

- The highest weighting score of the alternatives with criteria of energy and resource consumption is sub-transfer area (temporary storage site) at 0.25. While the score of sub-truck parking area, using boats, modified truck, and transfer station changing are 0.22, 0.20, 0.18, and 0.15, respectively.

- The highest weighting score of the alternatives with criteria of separated management of waste is sub-transfer area (temporary storage site) at 0.39. While the score of modified truck, sub-truck parking area, using boats, and transfer station changing are 0.20, 0.17, 0.13, and 0.12, respectively.

- The highest weighting score of the alternatives with criteria of health risk of community is transfer station changing at 0.34. While the score of modified truck, using boats, sub-truck parking area, and sub-transfer area (temporary storage site) are 0.25, 0.25, 0.12, and 0.05, respectively.
- The highest weighting score of the alternatives with criteria of visual impact is transfer station changing at 0.36. While the score of modified truck, using boats, sub-truck parking area, and sub-transfer area (temporary storage site) are 0.25, 0.24, 0.11, and 0.04, respectively.
- The highest weighting score of the alternatives with criteria of cost is sub-truck parking area at 0.26. While the score of using boats, modified truck, sub-transfer area (temporary storage site), and transfer station changing are 0.21, 0.18, 0.18, and 0.17, respectively.

The priority score results of the alternative in each situation are obtained by multiplying criteria weighting scores in the second level with priority alternative weighting scores of criteria in the third level, as shown in Table 16 and Figure 43.

Table 16 The weighting scores of the alternatives in three flood impact situations

Alternative	CNC	CNT	CNC and CNT
Temporary sub-transfer	0.17	0.18	0.10
Temporary sub-park	0.17	0.18	0.16
Modified truck	0.23	0.23	0.25
Using boats	0.21	0.21	0.24
Transfer changing	0.21	0.20	0.25

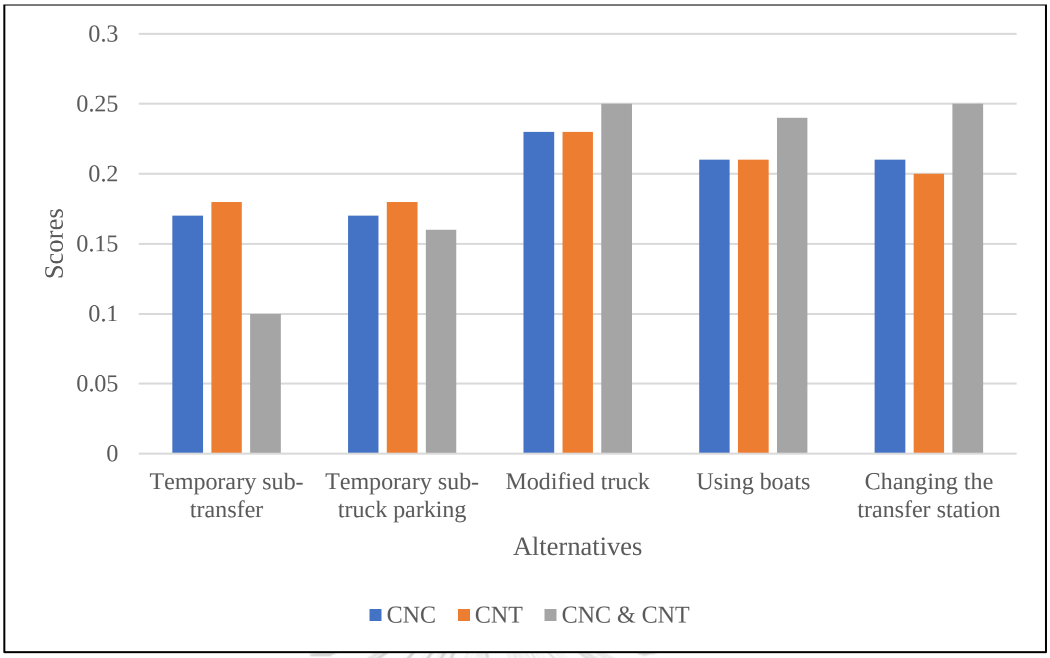

Figure 43 Alternative scores of three flood impact situations

The results show that the modified truck is the most significant alternative for all three situations. The first and third priority scores of alternatives are cluster scores. The second-lowest score alternatives for all situations are temporary sub-truck parking area and temporary sub-transfer area (temporary storage site). They also have cluster scores but are different from the first cluster.

In the CNC situation where waste cannot be collected, the highest priority is the modified truck alternative at 0.23. The scores of using boats, transfer station changing, sub-truck parking area, and sub-transfer area (temporary storage site) are 0.21, 0.21, 0.17, and 0.17, respectively.

In the CNT situation where waste cannot be transferred, the highest priority is the modified truck alternative at 0.23. The scores of using boats, transfer station changing, sub-truck parking area, and sub-transfer area (temporary storage site) are 0.21, 0.20, 0.18, and 0.18, respectively.

In the CNC and CNT situation where waste can neither be collected nor transferred, the highest priority is the modified truck alternative and transfer station changing at 0.25. The scores of using boats, sub-truck parking area, and sub-transfer area (temporary storage site) are 0.24, 0.16, and 0.10, respectively.

6.1.5 Consistency. The AHP results are concerned with consistency ratio, which indicates a reasonable relative level of consistency in the pairwise comparison. It is undertaken by CR rate not more than 0.10. The consistency index (CI) is defined by Saaty (1980) as follows:

$$CI = \lambda_{max} - N / n - 1$$

Where CI = Consistency Index
λ_{max} = Maximum eigenvalue
N = Dimension of Matrix

The value of random consistency (RI) for different values of n as provides in Table 17. The ratio of CI with RI metrics is the consistency ratio (CR) as expressed:

$$CR = CI / RI$$

Where CR = Consistency Ratio
CI = Consistency Index
RI = Random Consistency Index

Table 17 The value of random consistency index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49	1.51	1.48	1.56	1.57	1.59

In this study, the comparative documents for providing expert opinion were developed by prioritizing the variables at each level before proceeding with a step-by-step comparison process to help reduce confusion in the case of many variables as shown in Appendix D.

The consistency ratios of criteria priority scores in the situations of cannot collect, cannot transfer, and cannot collect and transfer are 0.08, 0.08, and 0.07, respectively. The calculation results of alternative consistency ratios of each criteria priority are between 0.06–0.08, as shown in Figure 44. The ratio indicates a reasonable relative level of consistency in the pairwise comparison. Thus, this judgement matrix is reasonably consistent and can continue the process of decision-making using AHP (Saaty & Vargas, 2013).

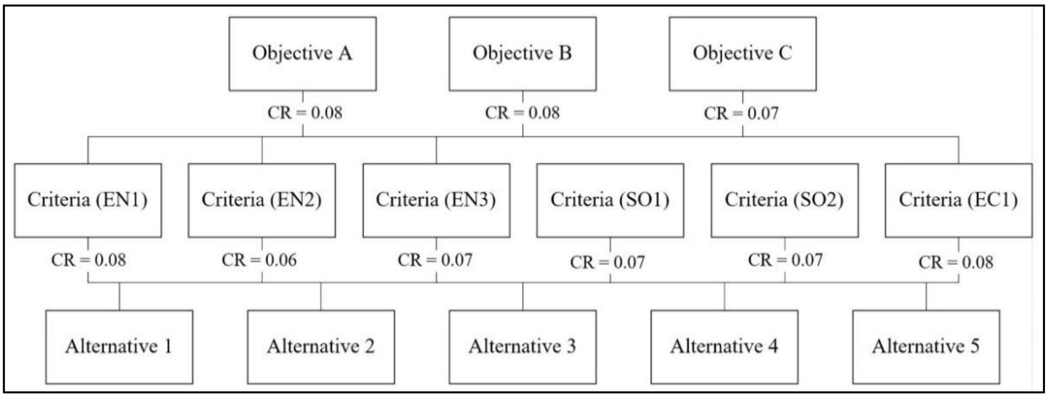

Figure 44. Consistency ratio of criteria and alternative priorities

The MSWM flood mitigation approach has been classified into three situations in accordance with the problematic characteristics of flood impact. The AHP method is used to study appropriate flood mitigation measures. According to the AHP results, health risk of community is the main criterion for ‘cannot collect’ and ‘cannot collect and transfer’, while the separated management of waste is the main criterion for ‘cannot transfer’ situation, due to the different problems affecting different impacts. In case of ‘cannot transfer’, a flood only affects the transfer route, while the collection area is not flooded. Thus, the health risk to the community is secondary to the separated management of waste criterion to prepare for storage and pending transfer. The impact of environmental risk is not the main criterion in all three situations, different from normal conditions such as the study of MSW facility sites ranking, which found that absence of areas of highest value for natural habitats is the most considered criterion (De Feo & De Gisi, 2010). In addition, the criteria of cost shows that the important MSWM criteria in a crisis differ from normal conditions (Hanan, Burnley, & Cooke, 2013). It is the lowest priority score for ‘cannot collect and transfer’ and the second lowest score for ‘cannot collect’ and ‘cannot transfer’.

The high priority score of alternatives for flood mitigation in all three situations is the modified truck, which is consistent with information gained from interviews about operations during the 2011 flooding. Transfer station changing, using boats to collect, and storing waste are alternatives that score close to the high priority. It was found that in the 2011 flooding all three of these alternatives often had to be used together.

In the provision of a temporary sub-transfer area (temporary storage site) alternative, the priority score is low. Although temporary storage sites are often recommended as a common tool for use in disaster waste management (Brown, Milke, & Seville, 2011), they are a risk to the environment. They require consideration of their impact on the environment, health of the community, pre-disaster site identification, land-use planning issues, and cost for urbanization of Bangkok.

6.2 Impact Mitigation Guidelines

The framework and goal of guidelines are developed to reduce the flood impact on the MSWM system of the districts in the service of the Nongkhaem transfer station. The results from the MSWM SD model can be divided into the collection and transfer stages with different impacts of affected areas and the accumulated MSW amount. The AHP results are indicated in the criteria and alternatives for flood mitigation in the MSWM system during flooding. The AHP helps to determine mitigation measures of impact in the collection and transfer stages. There is different weighing of environment, society, and economy criteria. The weight of each criterion influences the mitigating alternative approach in different problems and causes. It is used as a basis to recommend mitigation guidelines which have passed a feasibility and appropriateness analysis with the participation of 15 local governments (districts) affected by flood-weak point 8. It was found that some alternatives are suitable for use, while others, such as using boats, are suitable for areas such as transfer station changing.

Based on interviews with local government authorities, a flood impacts the collection process if either the service area or route between the truck parking and service area is flooded. The impact on the transfer process occurs when the route between the service area and transfer station is flooded.

Therefore, appropriate mitigation measures should be differentiated according to the cause of the impact. A method consistent with the characteristic of the problem and its causes is shown in Figure 45.

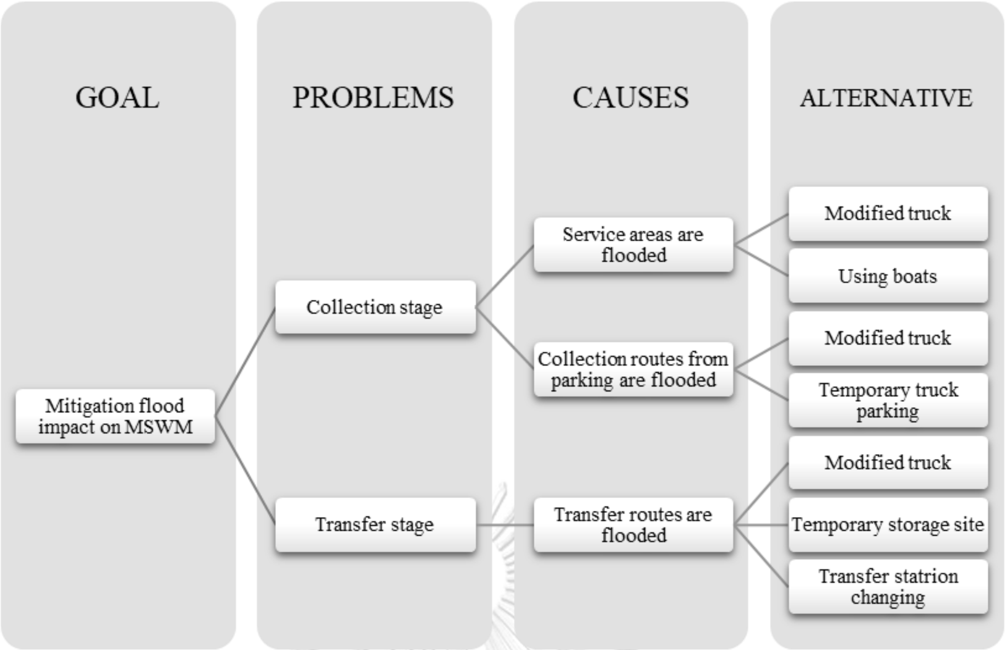

Figure 45. Mitigation approach analysis

Moreover, the action of mitigation with various alternatives depends on the authorities and responsibilities; it is an important mechanism in mitigation actions. Therefore, the mitigation guideline is a combined analysis of the authorities and responsibilities of various government agencies identified in the Public Disaster Prevention and Mitigation Act, B.E. 2550.

6.2.1 Authority and responsibility structure management

The authority and responsibility structure of flood mitigation in Bangkok's MSWM system is outlined under the Public Disaster Prevention and Mitigation Act, B.E. 2550. The Act identifies the governor of Bangkok as the director of prevention and mitigation, with the director of each district as the assistant director responsible for their respective districts.

The BMA headquarters is responsible for carrying out tasks assigned by the central government director and preparing a prevention and mitigation plan with the Department of Defence and higher educational institutions as advisors. They must coordinate with various government agencies to report and receive support. They are responsible for the provision of vehicles, supplies, equipment, and MSWM facilities in the form of transfer stations and disposal sites during floods. Meanwhile, the district officer is responsible for prevention and mitigation operations such as collection, transportation, and temporary storage sites. The district government can use the facilities, equipment, and vehicles of both the public and private sectors in the district area as necessary for prevention and mitigation, as shown in Figure 46.

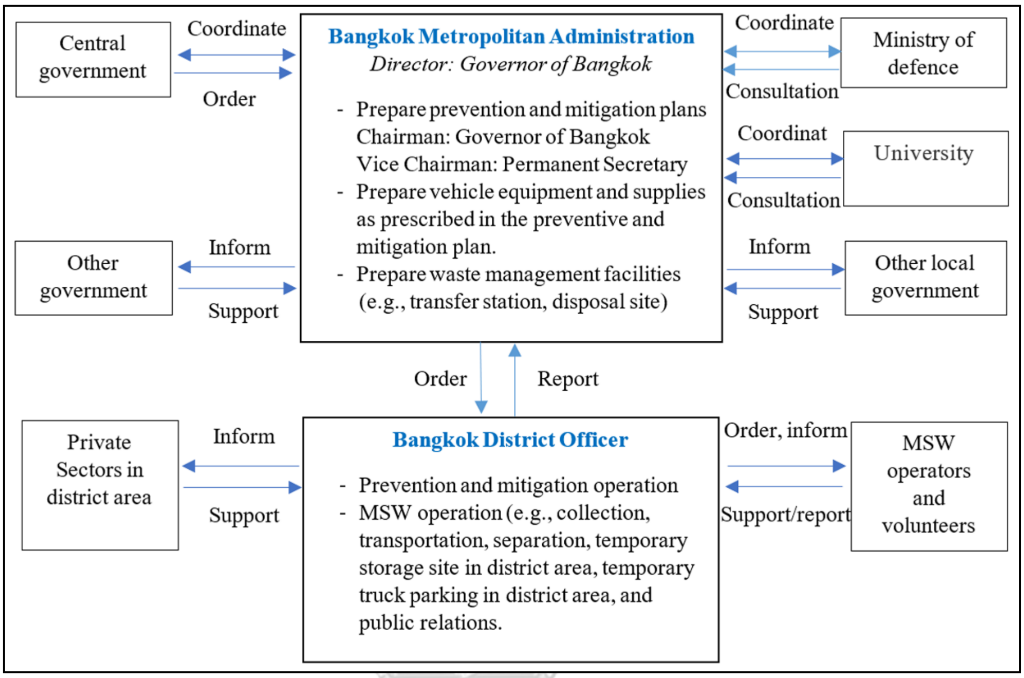

Figure 46. Authority and responsibility structure for MSWM under flooding of Bangkok

6.2.2 Mitigation procedure. The information obtained from the integration of alternatives and the authority and responsibility structure has been applied to flood mitigation in the MSWM guideline. This guideline has been tested and developed to be consistent with flood-preparedness mitigation through participatory processes with the15 districts, which is impacted by flood-prone area 8 as shown in Appendix E.

The flood mitigation in MSWM guidelines includes objectives, scope, definitions, responsibilities, and operating procedures. The operation starts at the time of the flood; the districts report the flood situation to the BMA for impact evaluation. This step will be concise with the application of the MSWM SD model presented in this research. Impact evaluation is performed by evaluating highly vulnerable areas to prioritize rapid relief assistance to minimize impact. The vulnerability evaluation includes the accumulated amount of MSW in the area and the number of impacted areas. The impact mitigation approach must be precise in the impact characteristic, whether in the collection or transfer process, to link problems, causes, and alternatives. Therefore, the mitigation guideline is based on applying the mitigation approach to the authority and responsibility structure as shown in Figure 47.

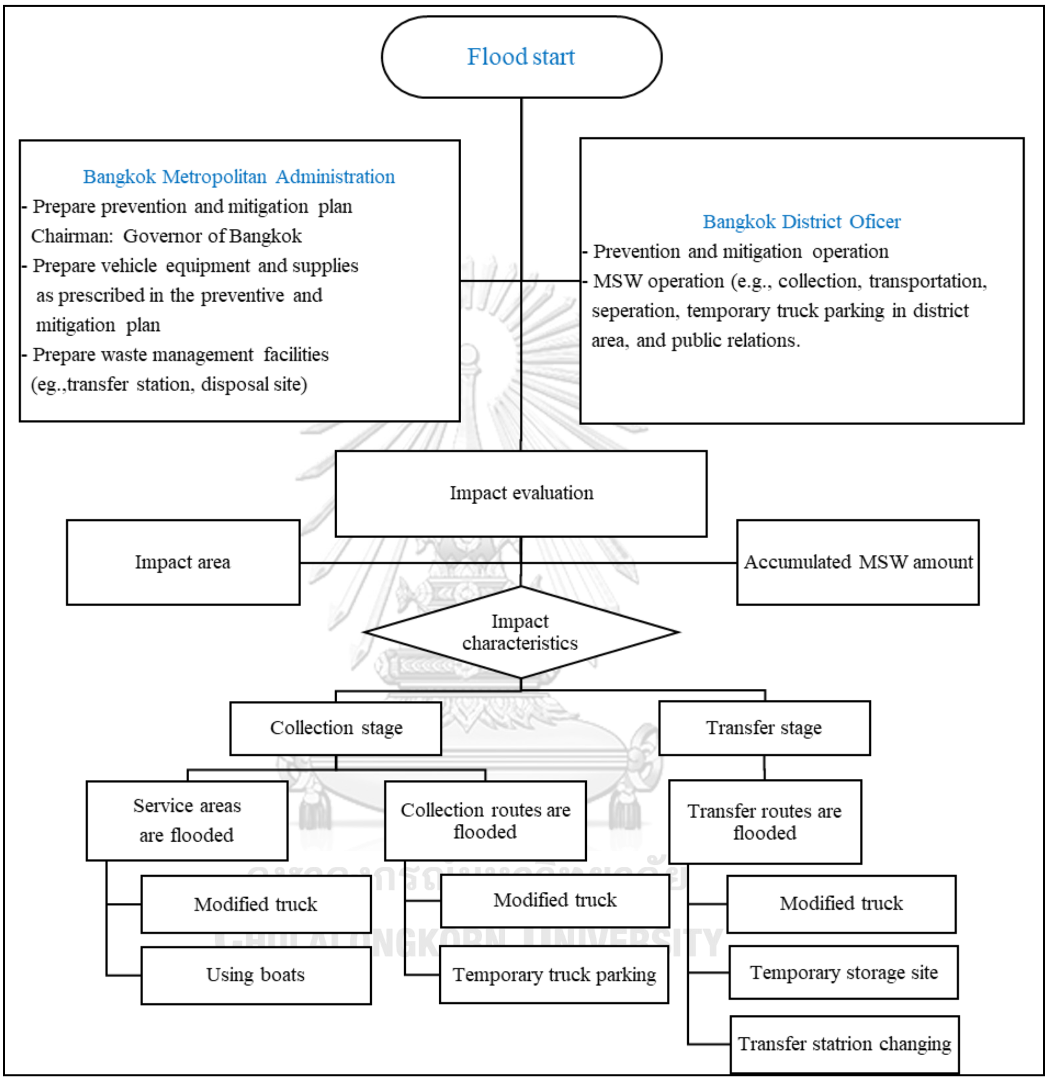

Figure 47. Flow of flood mitigation in the MSWM of Bangkok

6.2.3 Mitigation approach technique. The results from the SD model supported that flood-prone area 8, located in Bangkae District, is the most vulnerable. Flooding in this area impacts 15 districts, including 47 sub-districts, which represent more than half of the total 22 districts. It will generate 2,074 tons/day of accumulated waste in 2020, including 1,127 tons/day of uncollected waste and 947 tons/day of remaining waste. This amount of accumulated waste is up to 50% of the total MSW of the Nongkhaem transfer station service. Therefore, this area was chosen as a prototype to study flood mitigation measures. The detailed technique of each alternative can be analysed as follows:

1) Sub-transfer area (temporary storage site)

Provision of temporary storage is directly related to flooding in case of 'cannot transfer' MSW to Nongkhaem transfer station. The size of temporary storage sites is calculated using the method published by Kubota (2015), based on the following formula: Necessary land area for temporary storage site(m^2) = [Estimated volume of flood waste (t)] / [waste bulk density (t/m^3)] / [height of pile of waste (m)] * [auxiliary land area factor (0.3)]. Tabata et al. (2017) introduced the values for combustibles. Waste bulk density is 0.4 t/m^3 with limitation of height for stacking the combustibles. Disaster waste is 3.0 m or less. However, the size of the area depends on whether it is prepared as a single area or divided into several smaller ones. Kubota (2015) recommends temporary areas of 8 rais or division into 5 rais between two sites for flood waste over 2,500 tons.

2) Temporary truck parking area

The provision of temporary truck parking areas is directly related to flood-affected areas in the collection stage. Many areas are indirectly affected by floods, even if they are not in flooded areas because, in normal circumstances, the truck parking area is far from the service area, routes that are typically blocked by flooded areas. Thus, preparing the sub-parking area (temporary truck parking area) for parking before and after transportation will facilitate the collection stage. It should be enough for all trucks that have problems in the collection stage.

3) Modified truck

To prepare, modifications must be made to waste hauling trucks, such as adjustment of truck height and extension of the snorkel to air intake chamber and air exhaust systems to protect the engine's combustion system, for transport through flooded areas. The number of vehicles to accommodate the amount of accumulated waste must be considered together with the number of rounds per day and the amount of waste collected that can be loaded per cycle. The number of trucks depends on distance to be travelled and traffic conditions. At present, five-ton trucks have the potential size and height suitable for transporting MSW in flood conditions. The number of recommended trucks is shown in Table 18.

Table 18 The number of trucks and temporary storage areas corresponding to the amount of accumulated MSW

District	Collection	Transfer	Accumulated waste/day (tons)	Storage area for 30 days (m2)	Number of five-ton trucks
Sampantawong		✓	49	4124	10
Bangrak		✓	176	14742	35
Yannawa		✓	276	23159	55
Thonburi	✓		104	8744	21
Klongsarn		✓	58	4897	12
Bangkok-Yai	✓		110	9215	22
Pasricharoen	✓		126	10542	25
Bangkuntien	✓		193	16220	39
Radburana	✓		272	22840	54
Sathorn		✓	174	14599	35
Bangkorlam		✓	110	9265	22
Jomthong	✓		142	11936	28
Bangkae	✓		59	4914	12
Thongkru		✓	104	8761	21
Bangborn	✓		122	10248	24

Remark: number of five-ton trucks is based on one round per day and five tons loading.

4) Using boats to collect and store MSW

The use of boats is a good alternative with others, such as using boats to collect solid waste in small alleys where large trucks cannot reach. Moreover, boats can store MSW waiting for collection by trucks. Although the use of boats for MSW collection has a low impact on environment, society, and the economy, many officers are required to load them because of their low loading capacity. Therefore, the use of boats to transport MSW during floods is a complementary approach to other alternatives in the context of urban floods.

5) Transfer station changing

Changing transfer stations is the only alternative available in some service areas that are not far from other transfer stations. However, most are rarely considered due to transportation distances, which affect the time and cost of transportation. Therefore, while changing transfer stations the terms of distance and traffic conditions from flooding should be considered.

However, these solution guidelines should be used together under preparation in every approach to integrate plans to mitigate the impacts of flooding during the event. It is a challenging key practice for development in sustainable cities and communities.

6.3 Impact Mitigation Action Plan

The mitigation guidelines have been applied to the action plans of local government organisations in vulnerable service areas, based on participatory testing in the Radburana and Yannawa District, which has the most impact on collection and transfer processes in flood-prone area 8. The guidelines are used to develop the local administrative mitigation action plan according to the current management situation.

Presently, Bangkok provides MSW collection services by private truck charter companies with five-ton MSW trucks and dump trucks for use in transportation through flooded areas, operated by Bangkok's drivers and waste collectors. Therefore, modifying trucks or using them for transport through flooded areas at risk of damage to the vehicle requires permission from the company. The action plan identifies vehicle preparations, alternative routes, temporary areas for truck parking, and storage sites in the district areas, as shown in Appendix F and below:

6.3.1 Radburana District action plan. This local government is most vulnerable to accumulated MSW that cannot be collected when flooding occurs in flood-prone area 8. Most of the MSW trucks, which must pass through the flood-prone area before reaching the service area, are parked near Nongkhaem transfer station. However, even if collection is possible, it also affects the transfer process to the transfer station. Therefore, the mitigation approaches should be divided into the two processes of collection and transfer.

Collection process:

Step 1) The MSW trucks park near Nongkhaem transfer station, when the transportation is completed in each round, to be maintained until the next transportation cycle follows the designated route. In case of risky transportation, nearby routes should be used, i.e., Kanchanapisek Road and Taweewattana–Kanchanapisek Road. The total distance is 30 kilometres, increasing from the original distance of 5 kilometres.

Step 2) In case the overall route cannot be reached by MSW truck, Bangkok should coordinate with truck charter companies to temporarily permit replacement truck parking. The district director should coordinate with private owners of land near the district office, located next to the Wilaiwan Mansion, Bangpakok, with an area of 26 rai, for a temporary parking request during the flood,.

Transfer process:

Step 1) Bangkok should make an agreement with truck charter companies to modify trucks for use in transportation through flooded areas. MSW in various areas should be collected by all types of trucks to full load to reduce the number of cycles per day in transit.

Step 2) Transportation between 21.00 and 06.00 to deliver MSW to the On-Nuch transfer station will reduce traffic problems. The Rama IV Road through Sukhumvit 77 Road is the appropriate route and its total distance is 20 kilometres. It is the shortest route but has heavy traffic and goes through community areas; it must be avoided during rush hour.

Step 3) Use temporary storage sites when the route to Nongkhaem and On-Nuch transfer station is not transported by MSW truck. The district director should coordinate with the owner of the land under Rama 9 Bridge at Thonburi, beside Kasikorn Bank Head Office, Radburana, with an area of 5 rai (supported by approximately 2,500 tons of MSW)

6.3.2 Yannawa District action plan. These local governments are most vulnerable to accumulated MSW that cannot be transferred when flooding occurs in flood-prone area 8. This is because all MSW trucks transport through the flood-prone area to Nongkhaem transfer station. However, this area is not affected by MSW collection because the truck parking area is in the district itself. Therefore, the mitigation approach is only for the transfer process.

Step 1) Bangkok should make an agreement with truck charter companies to modify trucks for use in transportation through flooded areas. MSW in various areas should be collected in all types of trucks to full load to reduce the number of cycles per day in transit.

Step 2) Transportation should occur between 21.00 and 06.00 to deliver MSW to the On-Nuch transfer station to reduce traffic problems. Rama IV Road through Sukhumvit 77 Road is used with a total distance of 31 kilometres, increased from the original distance of 4 km. This route has heavy traffic and goes through community areas, so it must be avoided during rush hour.

Step 3) Temporary storage sites can be used when the total route to Nongkhaem and On-Nuch transfer station is not traversed by MSW trucks. The district director must coordinate with the owner of the Thailand state railway land at Chong Nonsi sub-district, and the area on New Yannawa Road (Under Bhumibol Bridge) each of 5 rai (supported by approximately 2,500 tons of MSW).

Chapter 7
Conclusion and Recommendations

7.1 Conclusion

The SD model was developed to understand the MSWM system, project future scenarios for 2020, and study external effects that disturb system stability. The SD model of MSWM was applied to the scope of MSWM performance in the collection and transfer stages in term of spatial impact and MSW amount. The aggregate system is linked by the Nongkhaem transfer station, which is divided into sub-systems as 22 districts. Sub-systems overlap and interrelate within the system with the transportation route for waste collection and transfer to the transfer station. The developed model envisages the understanding of the MSWM system's relational structure with the causal loop and stock-flow diagrams.

The model has been used to simulate impacts when difficult-to-control conditions, such as flooding, interfere with the system. The 11 flood-prone areas in the vicinity of the Nongkhaem transfer station analysed for responsibility and identified by the BMA were used to represent the flood scenarios in the model.

Simulation results present the impacts of critical external conditions such as major floods on the MSWM system assuming that waste trucks would not be able to travel through that area if any flood-prone area floods. It can evaluate and identify susceptible service and flood-prone areas that disturb the system at various levels. In terms of service areas, five districts are vulnerable to impacts by three flood-prone areas, both inside and outside the district itself, including Sampantwong, Bangkuntien, Sathorn, Thongkru, and Bangborn. Flood-prone area 8, in Bangkae District, is a vulnerable flood-prone area. It indicates the greatest number of affected areas in 15 districts up to 2,074 tons/day, with an impact on eight districts at the collection stage and seven districts at the transfer stage.

The SD modelling approach is an appropriate tool for understanding sophisticated public utility services like MSWM. The MSWM SD model can indicate the impact of floods on MSWM systems both inside and outside the floodplain with different formats in term of spatial and quantitative impact. It helps to identify vulnerable flood-prone areas, which impact vulnerable service areas as ‘hot-spots’, and accumulated MSW amount to recommend appropriate mitigation approaches.

The result of flood impact can be divided into three categories of flood impact situations. All three were considered to determine appropriate mitigation alternatives by the AHP method. The results showed that the modified truck has the highest score in all situations, with the highest score of factor support for separated management of waste in a ‘cannot transfer’ situation. The highest score of factor support for ‘cannot collect’ and ‘cannot collect and transfer’ is the health risk of the community. The impact situation characteristics used in the problem cause mitigation alternative analysis to develop a guideline for flood mitigation in the MSWM service system that is consistent with the authority and responsibility structure. However, the mitigation guidelines will be most useful and ready for use in crisis when they have been tested for use and details identified as local action plans.

Hence, the MSWM is inadequate without a spatial and quantitative impact evaluation, which is a prerequisite outcome for consideration in the appropriate approach to flood mitigation. As a result, the flood mitigation in MSWM guidelines should be considered compliant with the characteristics of the impact and vulnerable area findings to achieve an optimised possible response.

7.2 Recommendations

1. Data entry in this MSWM SD model uses different levels of variable data, such as the monthly amount of waste and annual population size. Due to limitations of data recording from relevant departments, the problems are solved by converting annual data into monthly data with a constant rate of change as a proportion. Thus, the importing of data at the same level may make the model’s numerical results more accurate.

2. In some districts, MSW truck parking areas are separated for collection convenience of MSW generation areas and the driver. Thus, the survey of access collection routes requires a special resolution.

3. Based on a Geographic Information System (GIS), some sub-service areas overlap in many sub-district areas. Thus, a survey from the local responsible

authorities would be required to identify sub-district areas with the highest proportion of MSW.

4. The results of the flood impact evaluation from the SD model can also be used as a preventive measure because the results point out areas vulnerable to major flooding as hotspots.

5. The mitigation guidelines should be used and applied specifically by local governments to ensure compliance with the regulatory authority structure.

6. This model can also be applied to the study of other environmental management areas with a complex network, especially public utility services.

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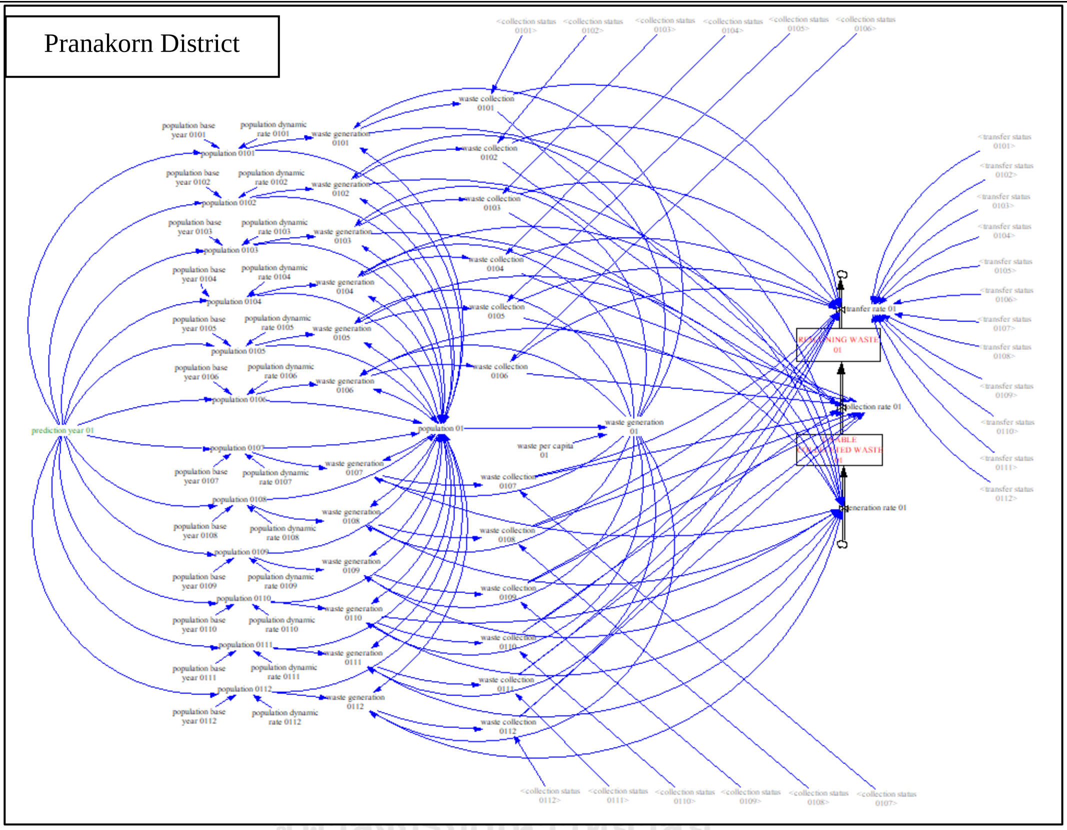
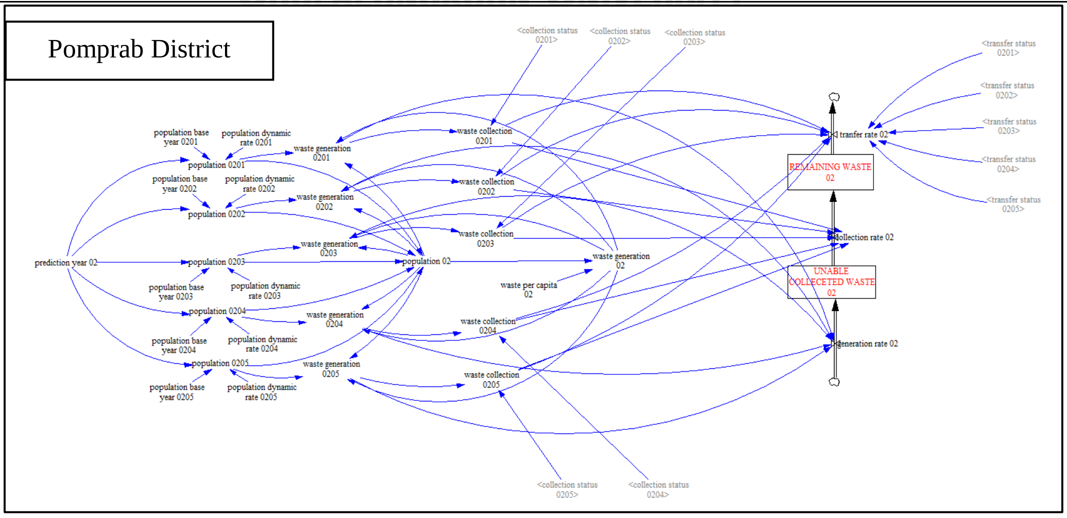
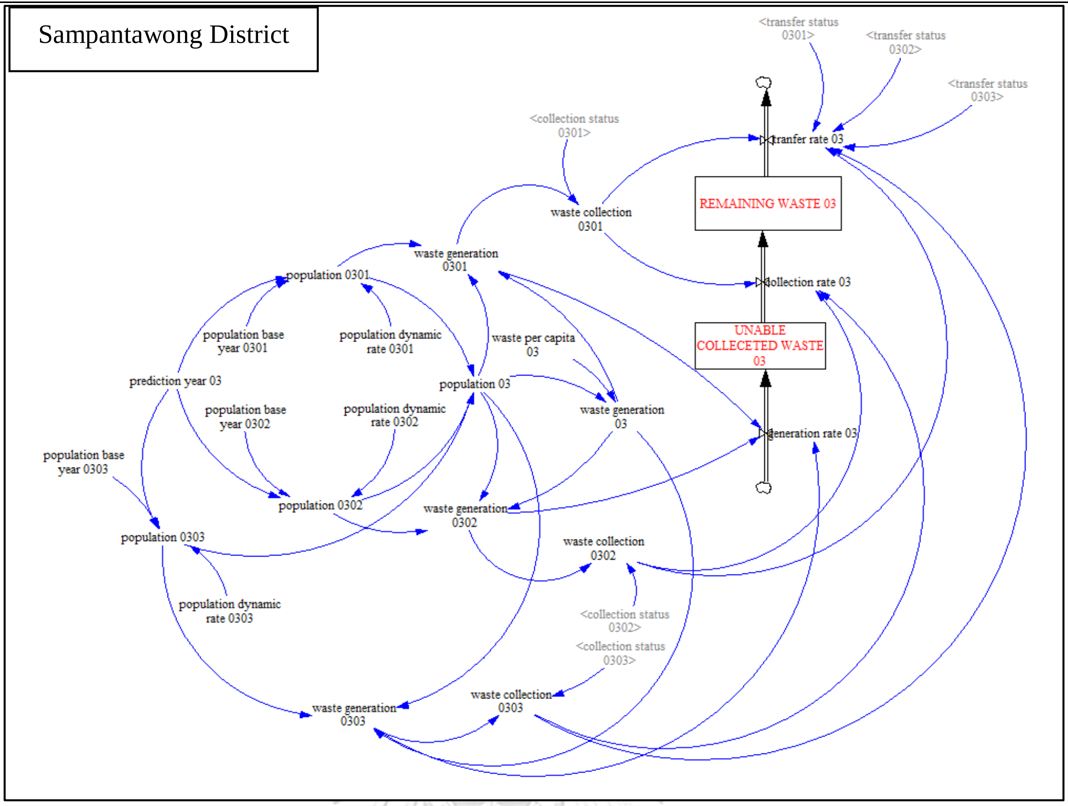
APPENDIX

Appendix A The stock-flow diagram of 22 districts (sub-system)



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prediction year 03
population 03
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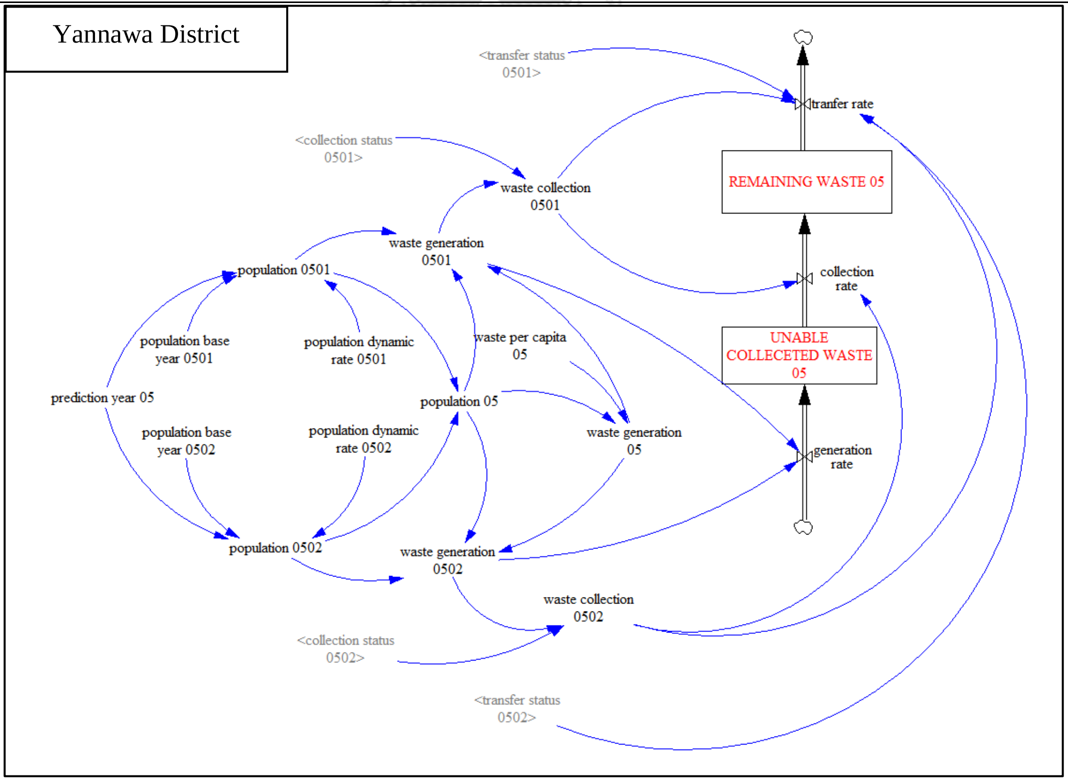
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population dynamic rate 0501
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prediction year 05
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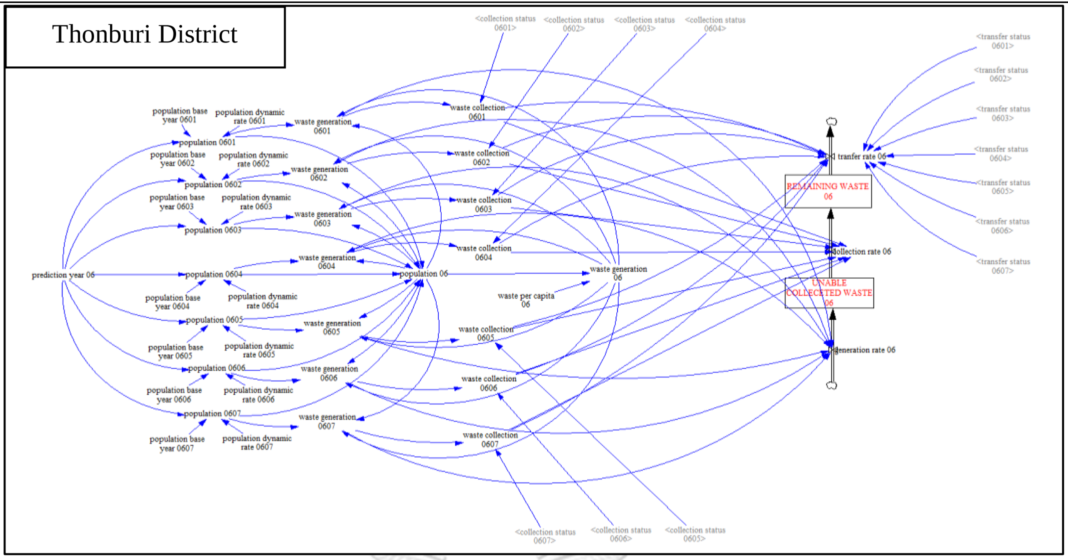
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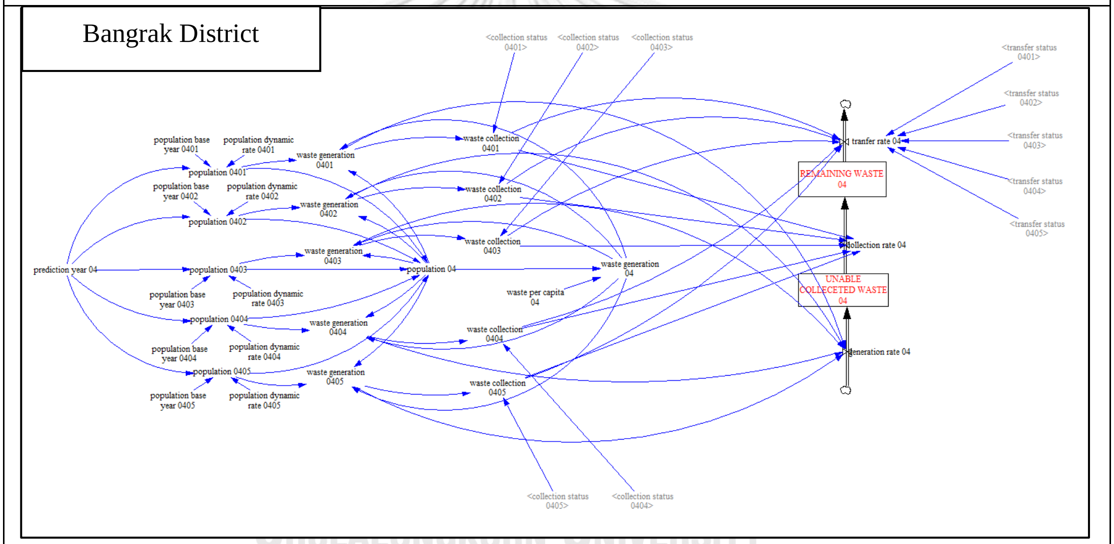
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prediction year 04
population 0403
population 04
waste generation 04
population base year 0403
population dynamic rate 0403
waste per capita 04
population 0404
waste generation 0404
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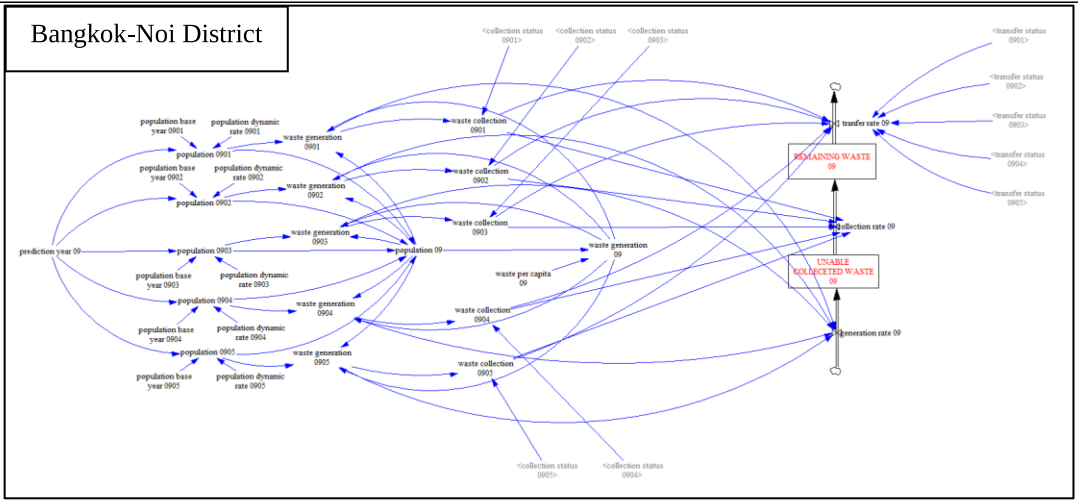
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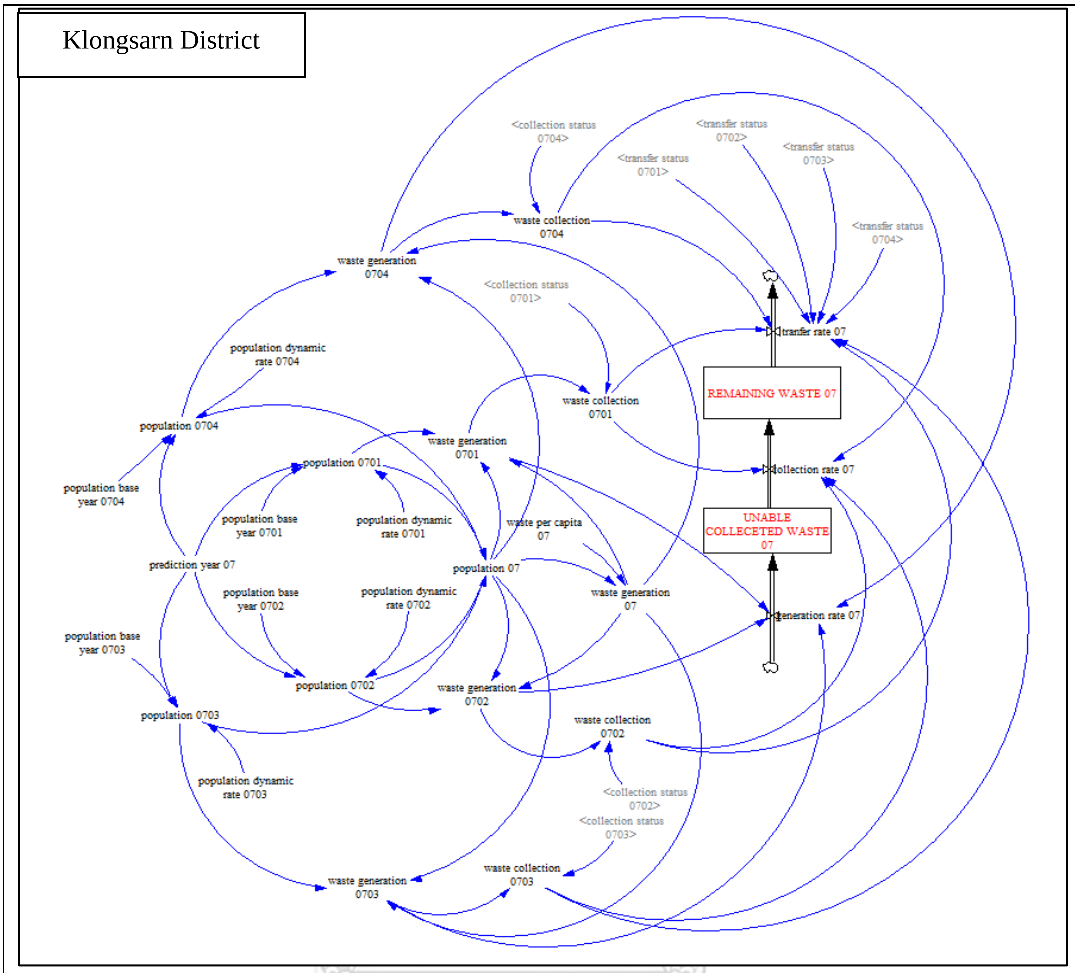
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population base year 0701
population dynamic rate 0701
waste per capita 07
UNABLE COLLECETED WASTE 07
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population 07
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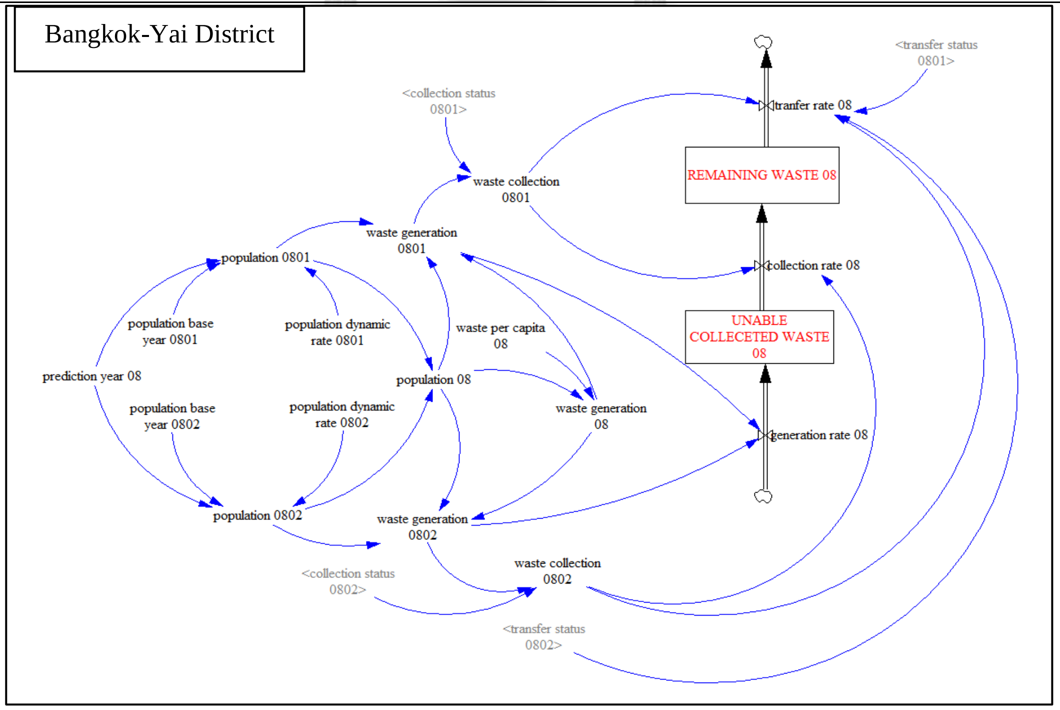
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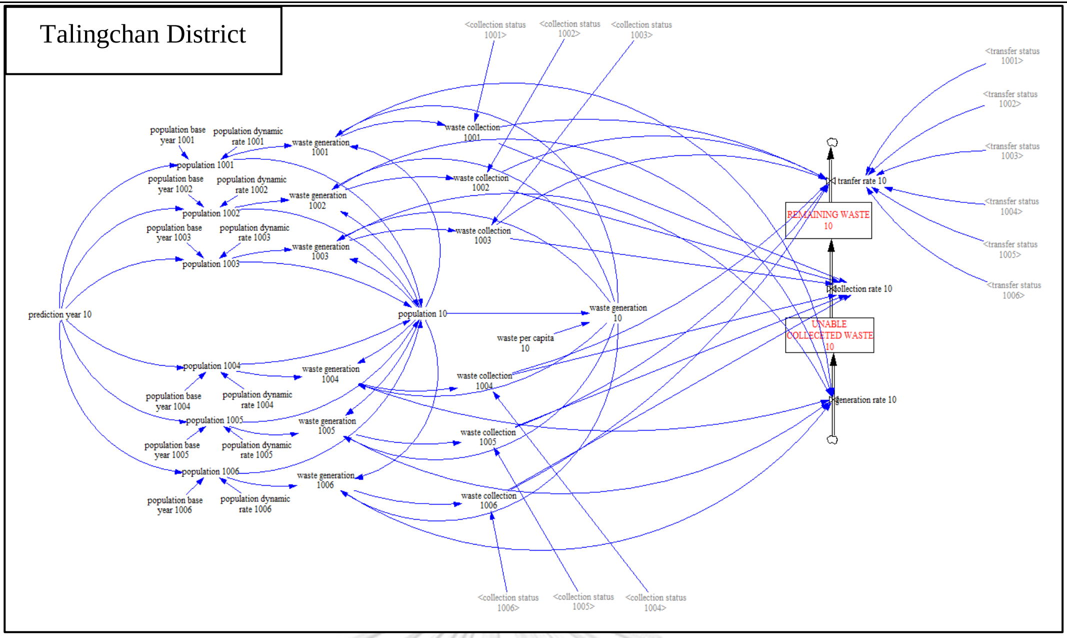
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generation rate 10
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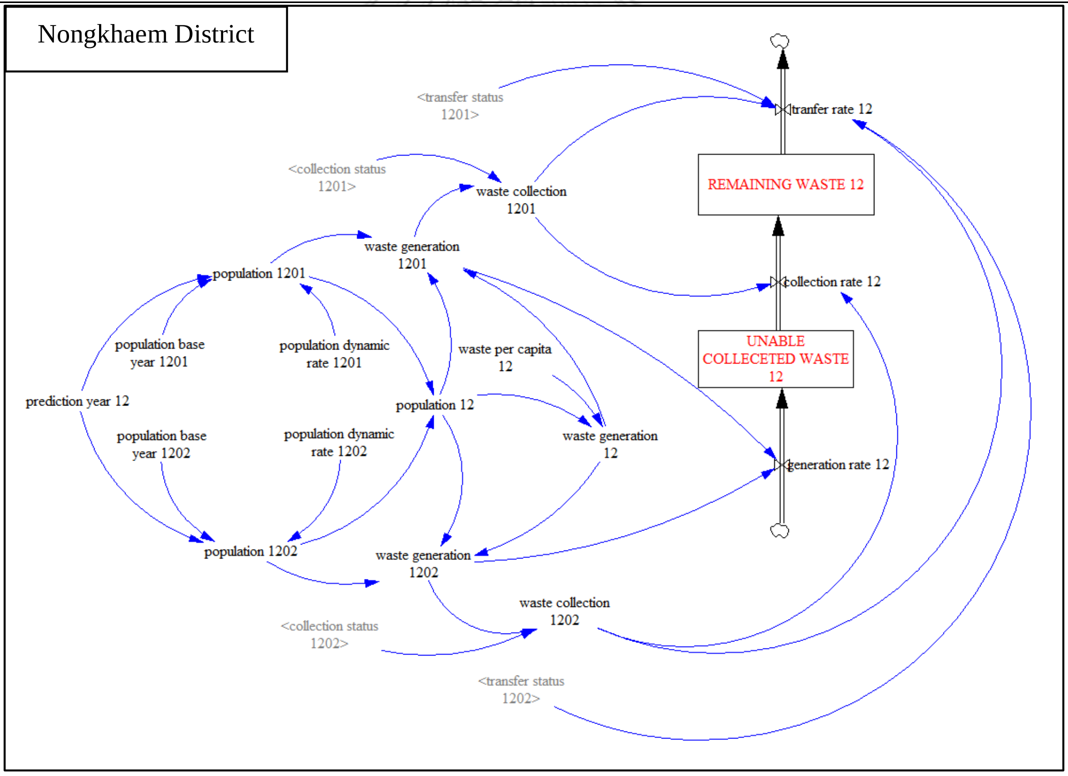
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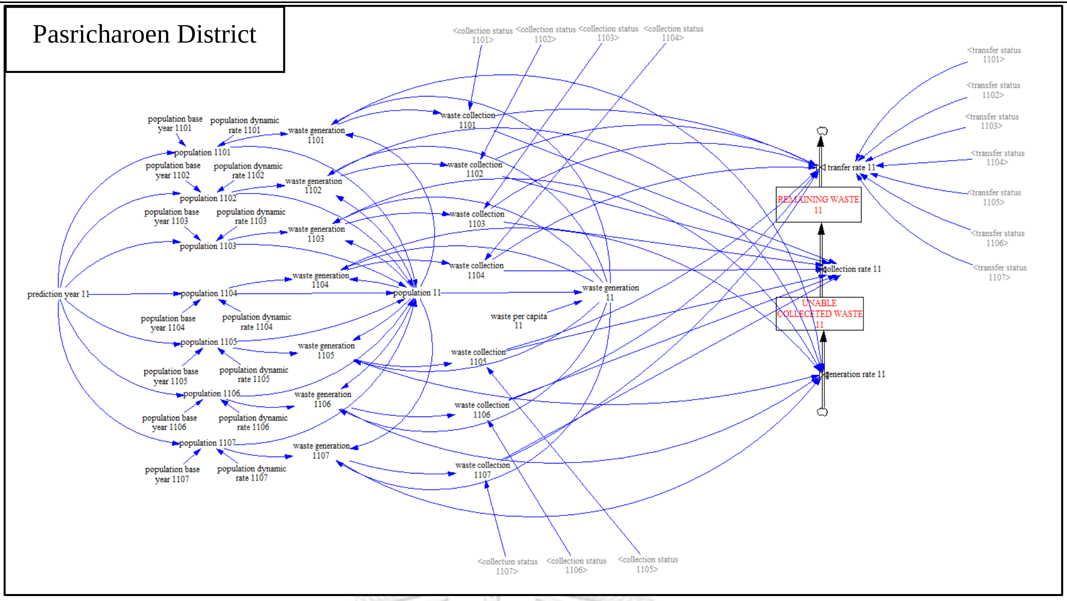
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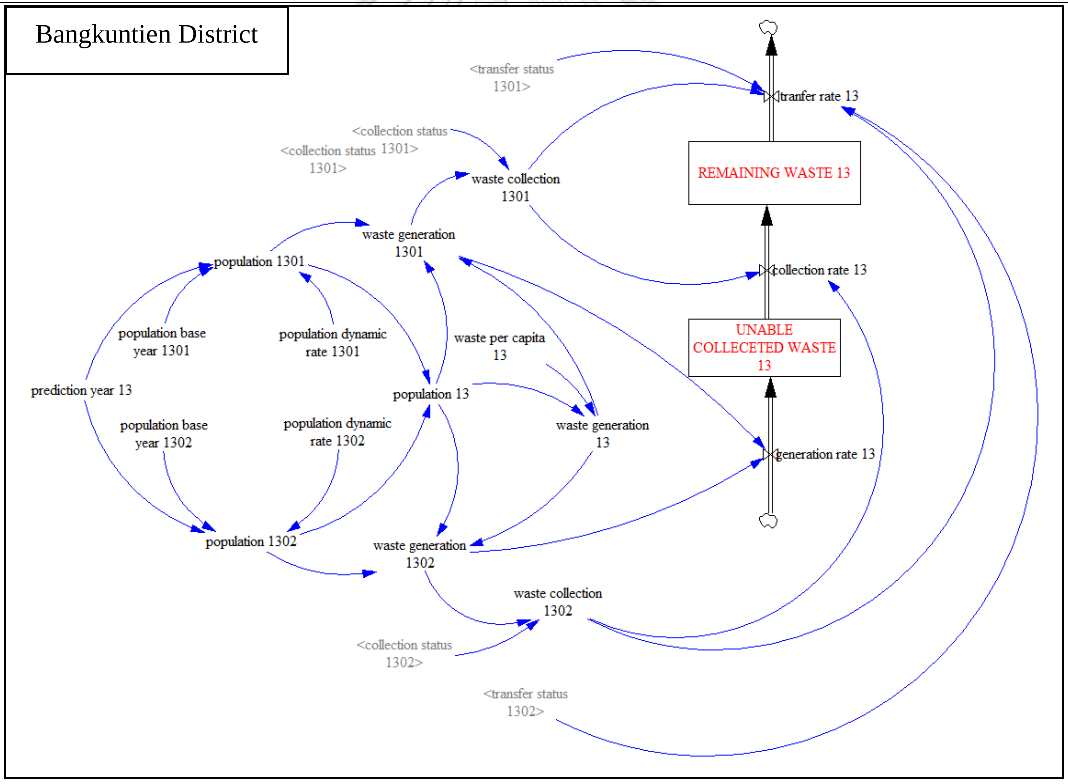
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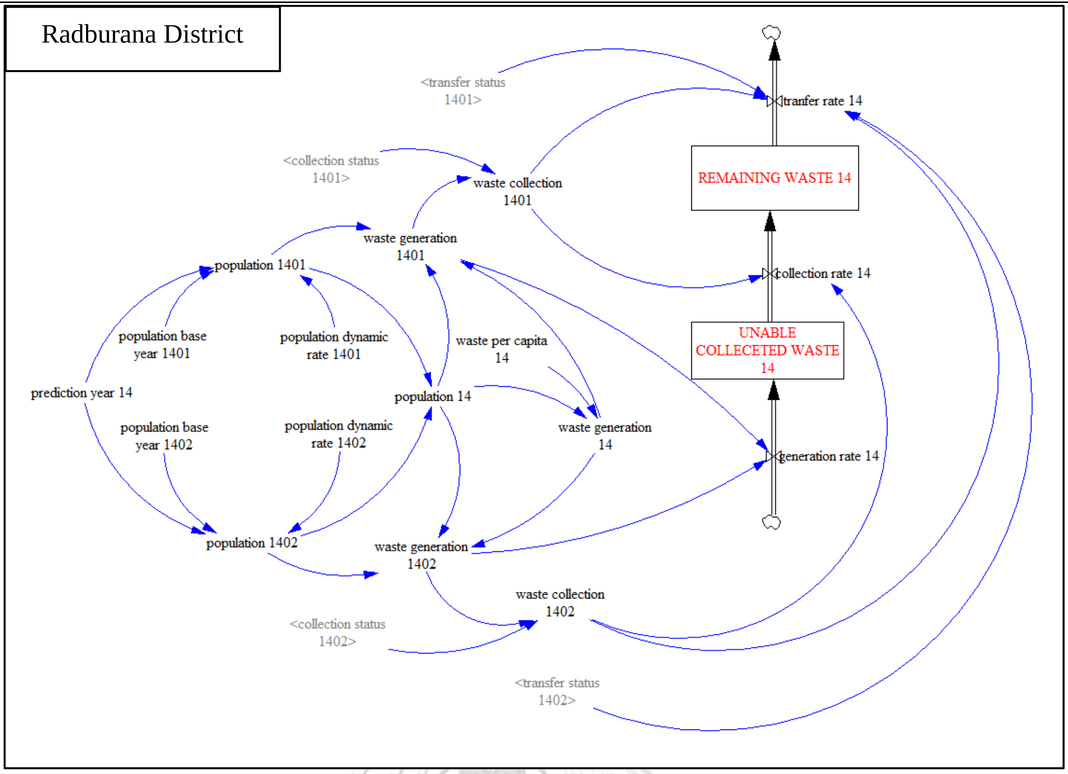
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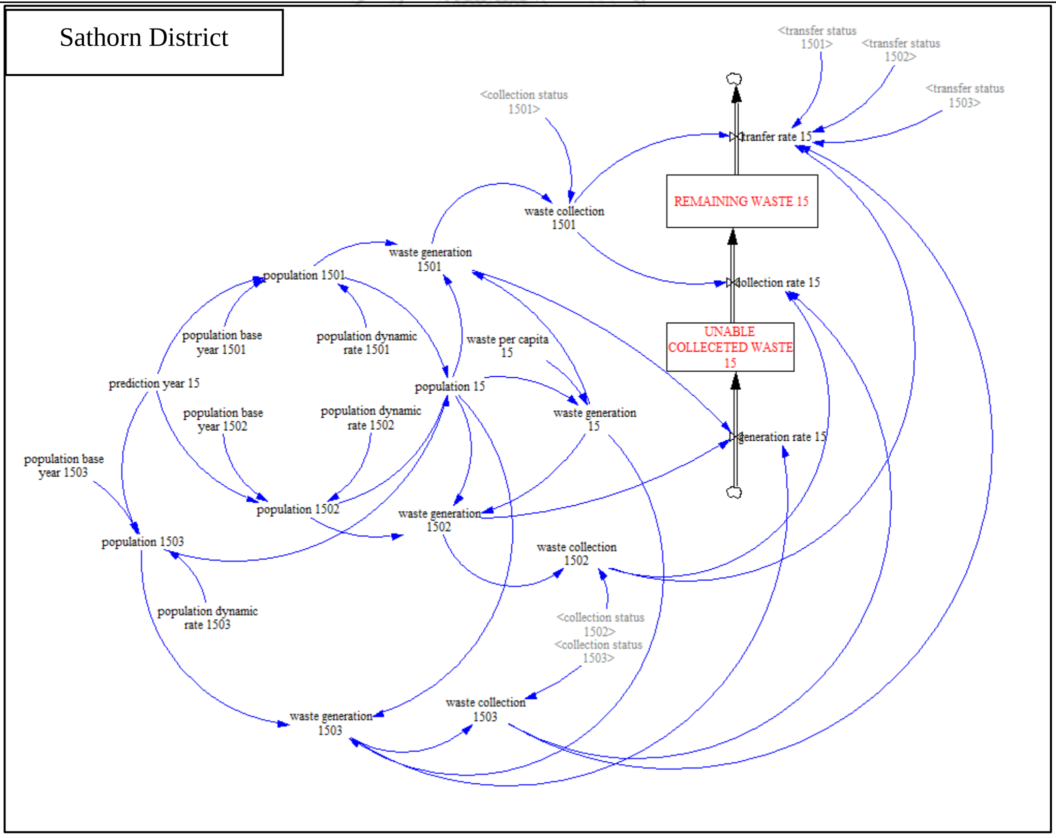
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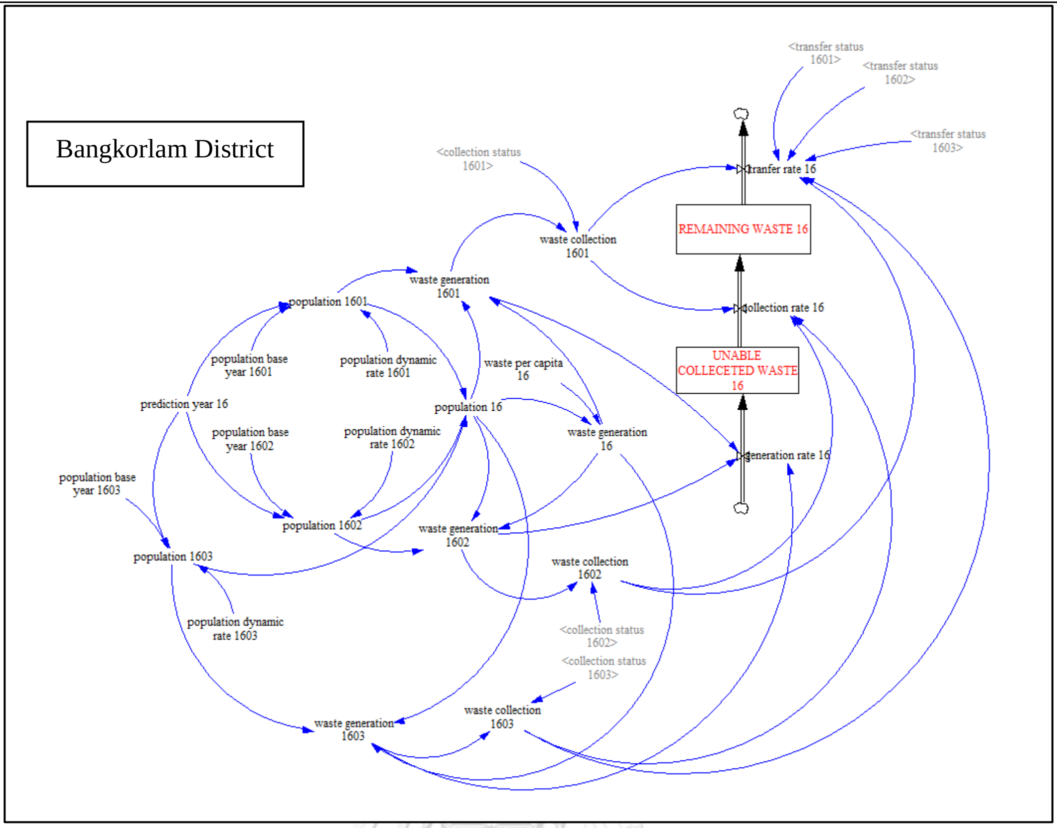
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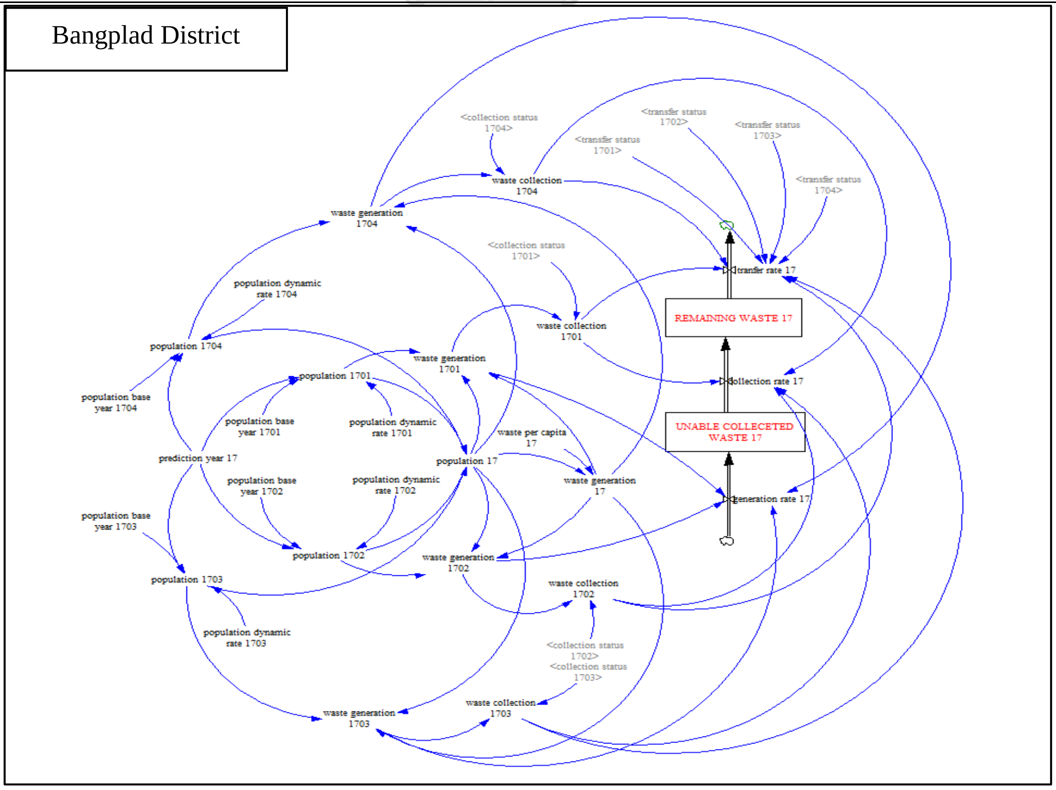
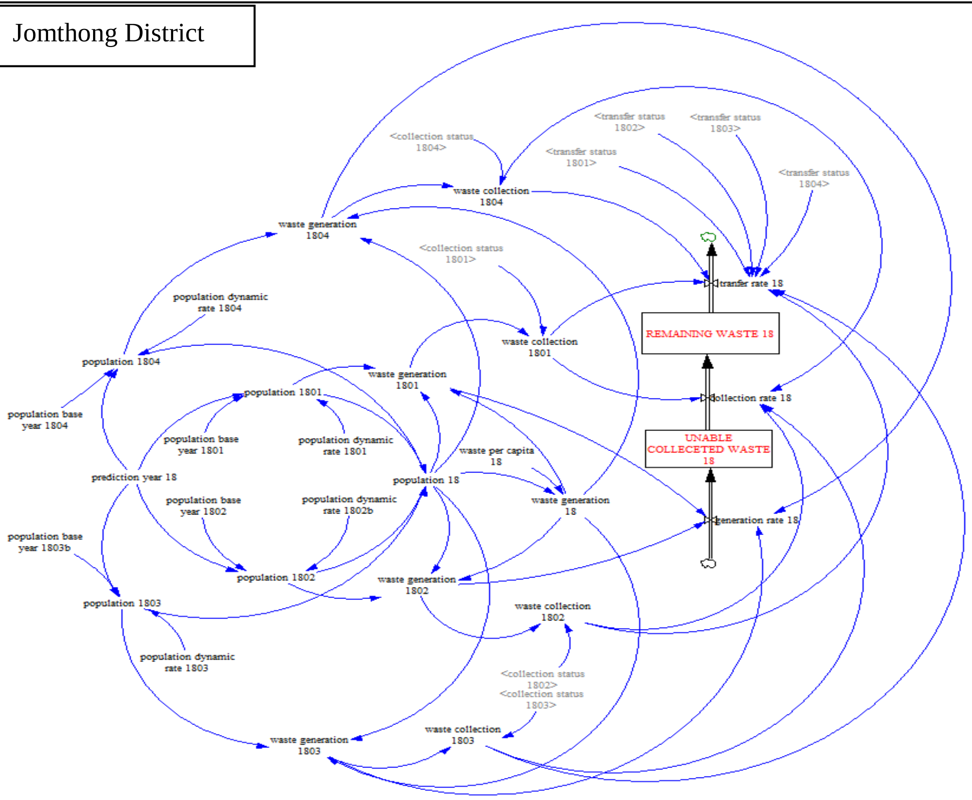
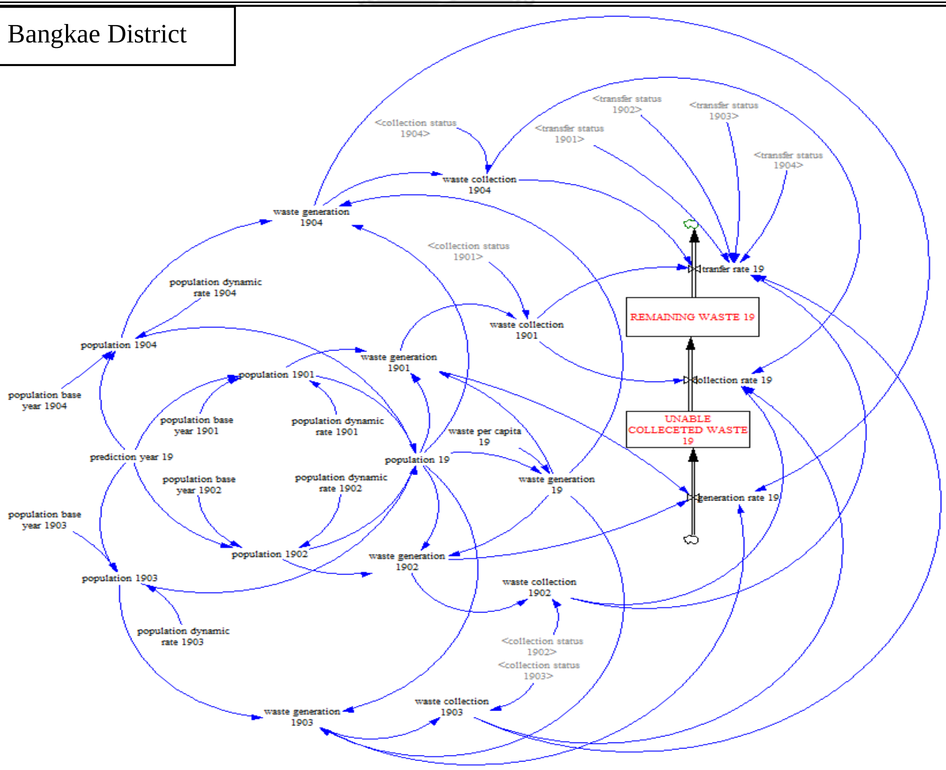
waste collection 1603
waste generation 1603

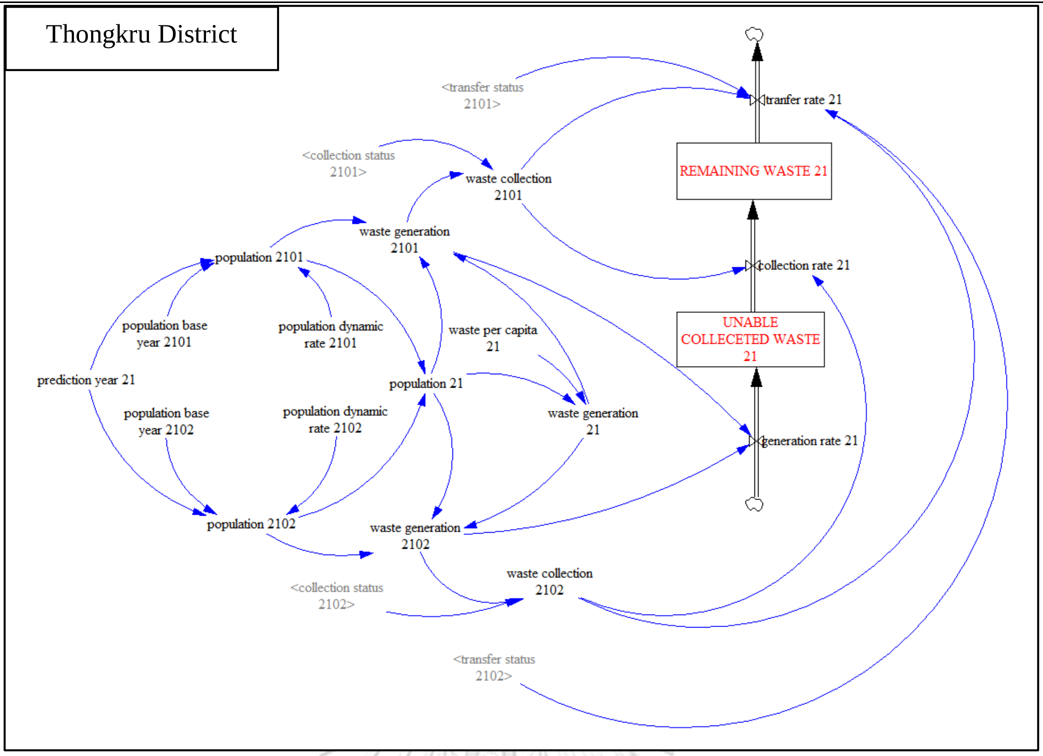

Bangplad District
<collection status 1704>
<transfer status 1702>
<transfer status 1701>
<transfer status 1703>
<transfer status 1704>
waste collection 1704
waste generation 1704
<collection status 1701>
tranfer rate 17
population dynamic rate 1704
REMAINING WASTE 17
waste collection 1701
population 1704
waste generation 1701
population 1701
collection rate 17
population base year 1704
population base year 1701
population dynamic rate 1701
UNABLE COLLECETED WASTE 17
waste per capita 17
prediction year 17
population 17
population base year 1702
population dynamic rate 1702
waste generation 17
generation rate 17
population base year 1703
population 1702
waste generation 1702
population 1703
waste collection 1702
population dynamic rate 1703
<collection status 1702>
<collection status 1703>
waste collection 1703
waste generation 1703

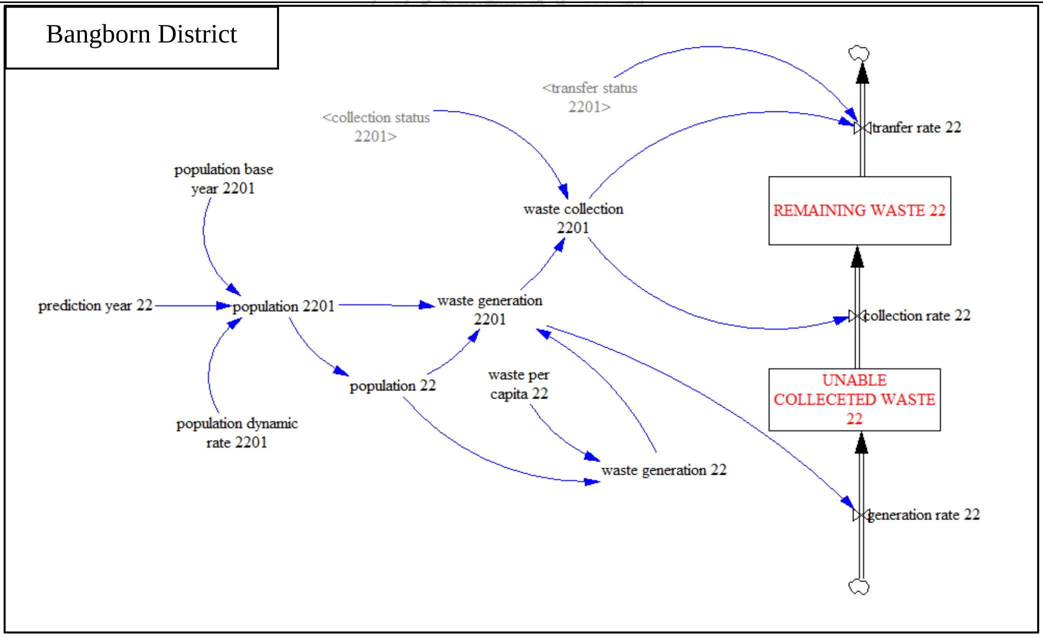
Jomthong District

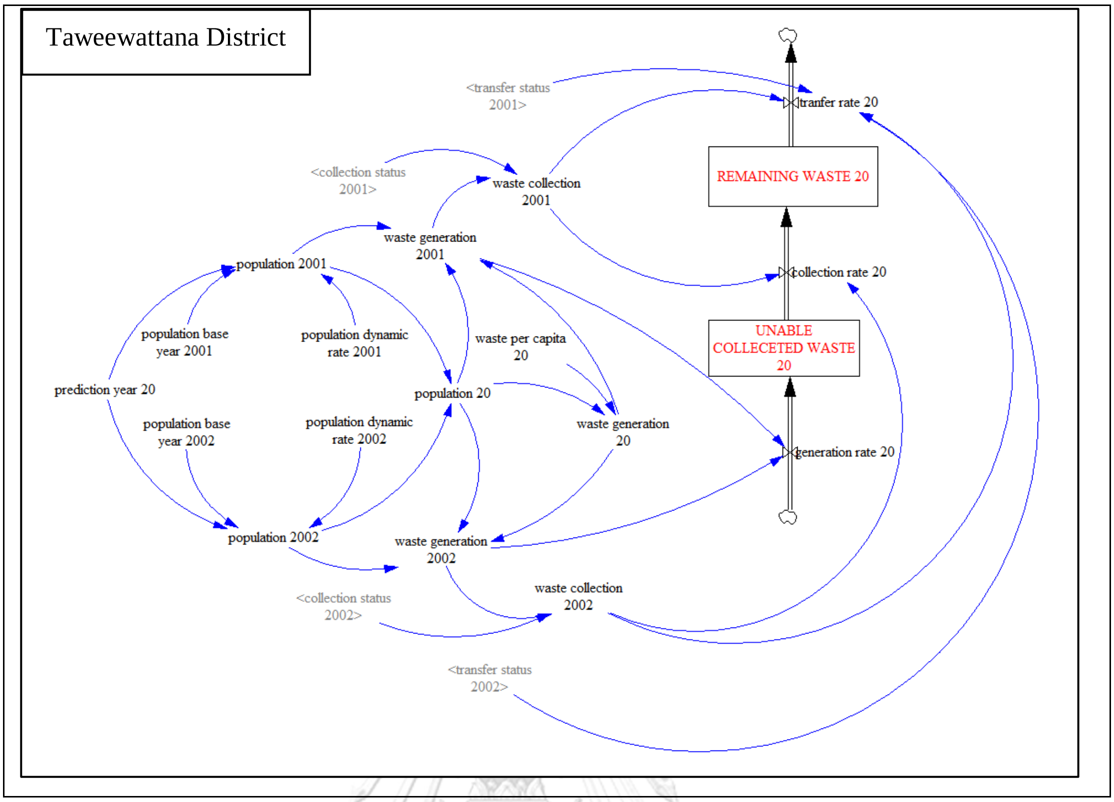


Bangkae District




Thongkru District
<transfer status 2101>
tranfer rate 21
<collection status 2101>
waste collection 2101
REMAINING WASTE 21
waste generation 2101
population 2101
collection rate 21
population base year 2101
population dynamic rate 2101
waste per capita 21
UNABLE COLLECETED WASTE 21
prediction year 21
population 21
population base year 2102
population dynamic rate 2102
waste generation 21
generation rate 21
population 2102
waste generation 2102
waste collection 2102
<collection status 2102>
<transfer status 2102>


Bangborn District
<transfer status 2201>
<collection status 2201>
tranfer rate 22
population base year 2201
waste collection 2201
REMAINING WASTE 22
prediction year 22
population 2201
waste generation 2201
collection rate 22
population 22
waste per capita 22
UNABLE COLLECETED WASTE 22
population dynamic rate 2201
waste generation 22
generation rate 22


Taweewattana District
<transfer status 2001>
tranfer rate 20
REMAINING WASTE 20
<collection status 2001>
waste collection 2001
waste generation 2001
population 2001
collection rate 20
population base year 2001
population dynamic rate 2001
waste per capita 20
UNABLE COLLECETED WASTE 20
prediction year 20
population 20
population base year 2002
population dynamic rate 2002
waste generation 20
generation rate 20
population 2002
waste generation 2002
waste collection 2002
<collection status 2002>
<transfer status 2002>

Appendix B The flood impact evaluation document

เอกสารประกอบการพิจารณาผลกระทบของน้ำท่วมต่อการจัดการมูลฝอย

เรื่อง การวิเคราะห์พลวัติระบบการจัดการขยะชุมชนภายใต้ภาวะน้ำท่วม

ของกรุงเทพมหานคร

เอกสารนี้เป็นส่วนหนึ่งของวิทยานิพนธ์ระดับดุษฎีบัณฑิต

หลักสูตรสหสาขาวิชาวิทยาศาสตร์สิ่งแวดล้อม บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย

1.กรุณาตรวจสอบความถูกต้องของรหัสพื้นที่ เลขข้าง และเลขทะเบียนรถบรรทุกที่รับผิดชอบ

2. กรุณาประเมินผลกระทบต่อการขนส่งขยะทั้ง เส้นทางไปรับมูลฝอยจากชุมชน และ เส้นทางไปส่งมูลฝอยที่สถานีขนถ่ายฯหนองแขม

ว่ามีการผ่านพื้นที่อ่อนไหวต่อการเกิดน้ำท่วม (Flood-prone area) จำนวน 11 พื้นที่ตามเอกสารแนบหรือไม่ โดยการกรอกเครื่องหมาย (/) ในกรณีที่มีการผ่านพื้นที่ที่ระบุ และ(-) กรณีที่ไม่ผ่านพื้นที่ที่ระบุ

เอกสารแนบประกอบการพิจารณา

รายละเอียดพื้นที่อ่อนไหวต่อน้ำท่วม (Flood-prone area)

ลำดับเส้นทาง	**เขต**	**รายละเอียดเส้นทาง**
1	พระนคร	ถนนสนามไชย จากซอยเศรษฐการถึงถนนท้ายวัง
2	พระนคร	รอบสนามหลวง
3	สัมพันธวงศ์	ถนนเจริญกรุง(แยกหมอมี) จากถนนแปลงนามถึงแยกหมอมี
4	สัมพันธวงศ์	ถนนเยาวราชฝั่งเหนือ จากถนนทรงสวัสดิ์ถึงถนนราชวงศ์
5	สาธร	ถนนจันทร์ จากซอยบำเพ็ญกุศลถึงไปรษณีย์ยานนาวา
6	สาธร	ถนนสวนพลู จากถนนสาธรใต้ถึงถนนนางลิ้นจี่
7	ตลิ่งชัน	ถนนฉิมพลี จากถนนบรมราชชนนีถึงทางรถไฟสายใต้
8	บางแค	ถนนเพชรเกษม บริเวณแยกพุทธมณฑลสาย2 ถึงปากซอยเพชรเกษม 63
9	บางบอน	ถนนบางบอน1 จากถนนเอกชัยถึงคลองบางโคลัด
10	บางขุนเทียน	ถนนบางขุนเทียน จากถนนพระรามที่2 ถึงถนนบางขุนเทียนชายทะเล
11	ทุ่งครุ	ถนนประชาอุทิศ จากคลองรางจากถึงหน้าสำนักงานเขตทุ่งครุ

ชื่อ-นามสกุล ………………………………………………………………………………………

ตำแหน่งงาน……………………………………………………………………………………….

เขต …………………………………………………………………………………………

วัน / เดือน / ปี ที่ทำแบบประเมิน …………………………………………………………….

รหัสพื้นที่	เลขข้างรถ	ทะเบียน	ประเภทรถ	เส้นทางผ่านไปเก็บขยะมูลฝอยจากชุมชน											เส้นทางผ่านไปส่งขยะมูลฝอยที่สถานีขนถ่ายฯ										
				Flood-prone area No.											Flood-prone area No.										
				1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11

นางสาวนัชชา ผลพอตน นิสิตระดับดุษฎีบัณฑิต หลักสูตรสหสาขาวิชาวิทยาศาสตร์สิ่งแวดล้อม
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
Email: Nuchcha.ph@gmail.com Tel. 087-8089209 Fax.0-2464-5319

Appendix C Experts and responsible providers' opinions on the AHP

1. Waste management specialist
    - Qualified Director in Environmental Pollution, National Environment Board
    - Academic teacher, Faculty of Environment and Resource Studies, Mahidol University
2. Town planning specialist
    - Architect Specialist, Department of Public Works and Town Planning (Expertise: Town and Disaster Planning)
    - Town Analyst, Department of Public Works and Town Planning (Expertise: Urban flood vulnerability analysis)
3. Department of environment (BMA)
    - Head of Hazardous Waste Work Group, Hazardous Waste and Waste Management Division, Department of Environment
    - Head of Cleanliness and Public Parks, Bangkhen District (Former head of solid waste management group, Environment Office (Year 2011)
4. Department of Drainage and Sewerage (BMA)
    - Head of Flood Protection System Control Group, Department of Drainage and Sewerage
    - Senior Civil Engineer, Department of Drainage and Sewerage
5. The Public Park and Clean Section of District
    - Yannawa District
    - Thongkru District
    - Bangborn District
    - Sathon District
    - Bangkhuntien District

Appendix D The interview documentation for the Analytic Hierarchy Process (AHP)

เอกสารประกอบการสำรวจค่าคะแนนน้ำหนักด้วยกระบวนการลำดับขั้นเชิงวิเคราะห์

เรื่อง การวิเคราะห์พลวัติระบบการจัดการขยะชุมชนภายใต้ภาวะน้ำท่วมของกรุงเทพมหานคร

เอกสารนี้เป็นส่วนหนึ่งของวิทยานิพนธ์ระดับดุษฎีบัณฑิต
หลักสูตรสหสาขาวิชาวิทยาศาสตร์สิ่งแวดล้อม บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย

วัตถุประสงค์การศึกษา : เพื่อศึกษาแนวทางการบรรเทาผลกระทบจากน้ำท่วม ที่มีต่อระบบการจัดการขยะมูลฝอย ของกรุงเทพมหานคร

รายละเอียดเอกสาร : เอกสารแบ่งออกเป็น 7 ส่วน ดังนี้

1. รายละเอียดผู้เชี่ยวชาญ
2. การประเมินลำดับความสำคัญของทางเลือกและปัจจัยที่เหมาะสมเบื้องต้น
3. คำชี้แจงวิธีการตอบแบบสอบถาม
4. การเปรียบเทียบความสำคัญของปัจจัยในการเลือกแนวทางการบรรเทาผลกระทบจากน้ำท่วมที่มีต่อระบบการจัดการขยะมูลฝอย กรณีสามารถเข้าเก็บขนมูลฝอยได้แต่ ไม่สามารถนำออกจากพื้นที่ไปสู่สถานีขนถ่ายมูลฝอยได้
5. การเปรียบเทียบความสำคัญของปัจจัยในการเลือกแนวทางการบรรเทาผลกระทบจากน้ำท่วมที่มีต่อระบบการจัดการขยะมูลฝอย กรณีไม่สามารถเข้าเก็บขนมูลฝอยได้ แต่ สามารถนำออกจากพื้นที่ไปสู่สถานีขนถ่ายได้
6. การเปรียบเทียบความสำคัญของปัจจัยในการเลือกแนวทางการบรรเทาผลกระทบจากน้ำท่วมที่มีต่อระบบการจัดการขยะมูลฝอย กรณีไม่สามารถเข้าเก็บขนมูลฝอยได้ และ ไม่สามารถนำออกจากพื้นที่ไปสู่สถานีขนถ่ายได้
7. การเปรียบเทียบทางเลือกจำนวน 5 แนวทาง ต่อปัจจัยต่าง ๆ

ส่วนที่ 1 รายละเอียดผู้เชี่ยวชาญ

ชื่อ-นามสกุล ผู้เชี่ยวชาญ ……………………………………………………………………………

ความเชี่ยวชาญ……………………………………………………………………………………

สังกัด ………………………………………………………………………………………………

วัน / เดือน / ปี ที่ทำแบบสอบถาม ……………………………………………………………

ส่วนที่ 2 การประเมินลำดับความสำคัญของทางเลือกและปัจจัยที่เหมาะสมเบื้องต้น

การจัดลำดับความสำคัญของปัจจัยในการพิจารณาแนวทางบรรเทาผลกระทบน้ำท่วมต่อการจัดการขยะ (ลำดับ 1 ถึง 6 : โดย 1 มีความสำคัญสูงสุด)

ปัจจัย	**กรณีเก็บได้ แต่ส่งสถานีขนถ่ายขยะไม่ได้**	**กรณีเก็บไม่ได้ แต่ส่งสถานีขนถ่ายขยะได้**	**กรณีเก็บไม่ได้ และส่งสถานีขนถ่ายขยะไม่ได้**
ผลกระทบสิ่งแวดล้อม			
การใช้พลังงานและทรัพยากร			
การแยกประเภทขยะ			
ผลกระทบต่อสุขภาวะชุมชน			
ผลกระทบต่อทัศนียภาพ			
ค่าใช้จ่าย			

การจัดลำดับความสำคัญของทางเลือกการบรรเทาผลกระทบน้ำท่วมต่อการจัดการขยะ ในด้านปัจจัยต่างๆ (ลำดับ 1-5 : โดย 1 มีความสำคัญสูงสุด)

ทางเลือก	ผลกระทบสิ่งแวดล้อมน้อย	การใช้พลังงานและทรัพยากรน้อย	การแยกประเภทขยะได้ดี	ผลกระทบต่อสุขภาวะชุมชนน้อย	ผลกระทบต่อทัศนียภาพน้อย	ค่าใช้จ่ายน้อย
พื้นที่กองพักขยะในพื้นที่						
พื้นที่จอดรถบรรทุกขยะในพื้นที่						
การปรับแต่งรถบรรทุก						
การใช้เรือ						
การเปลี่ยนสถานีขนถ่ายมูลฝอย						

ส่วนที่ 3 คำชี้แจงวิธีการตอบแบบสอบถาม

คำถามในแบบสอบถามนี้ใช้การเปรียบเทียบเป็นคู่ ให้ผู้ตอบแบบสอบถามเปรียบเทียบความสำคัญของทางเลือก โดยระดับของการให้ความสำคัญจะถูกวัดโดยการแสดงค่าตัวเลข 1 ถึง 9 ดังตารางเกณฑ์มาตรฐาน ดังนี้

เกณฑ์เชิงปริมาณ	เกณฑ์เชิงคุณภาพ
1	เท่ากัน
2	เท่ากันถึงปานกลาง
3	ปานกลาง
4	ปานกลางถึงค่อนข้างมาก
5	ค่อนข้างมาก
6	ค่อนข้างมากถึงมากกว่า
7	มากกว่า
8	มากกว่าถึงมากที่สุด
9	มากที่สุด

วิธีการ

- เปรียบเทียบความสำคัญระหว่างคู่ปัจจัยด้านซ้ายและขวาในตาราง โดยเลือกฝั่งที่ท่านมีความเห็นว่าสำคัญมากกว่า โดยเลือกคะแนนตามเกณฑ์ระดับความสำคัญ
- กรณีที่ท่านมีความเห็นว่าปัจจัยทั้ง2ฝั่ง มีความสำคัญเท่ากัน ให้เลือกคะแนน “1” เท่านั้น
- การให้คะแนน จะต้องเลือกให้คะแนนเพียงคำตอบเดียวเท่านั้น

ตัวอย่าง

กรณีที่คำตอบ คือ ปัจจัย ด้านผลกระทบสิ่งแวดล้อมมีความสำคัญ มากกว่า ด้านการใช้พลังงานและทรัพยากร โดยมีระดับความสำคัญ "ค่อนข้างมาก” ให้เลือกคะแนนดังนี้

ข้อ	ปัจจัย	ระดับความสำคัญเปรียบเทียบระหว่างคู่ปัจจัย																	ปัจจัย
1	ผลกระทบ สิ่งแวดล้อม	9	8	7	6	[✓ 5]	4	3	2	1	2	3	4	5	6	7	8	9	การใช้พลังงาน และทรัพยากร

รายละเอียดของปัจจัย

ปัจจัย	**รายละเอียด**
ผลกระทบสิ่งแวดล้อม	ผลกระทบต่อสิ่งแวดล้อม ได้แก่ มลพิษทางดิน น้ำ และอากาศ รวมถึงระบบนิเวศโดยรอบพื้นที่
การใช้พลังงานและทรัพยากร	การใช้พลังงานทั้ง renewable และ non-renewable รวมทั้งการใช้ทรัพยากรธรรมชาติ
การแยกประเภทขยะ	การแยกประเภทขยะเพื่อการจัดการที่เหมาะสม
ผลกระทบต่อสุขภาวะชุมชน	ผลกระทบต่อสุขภาพของประชาชนโดยรอบพื้นที่
ผลกระทบต่อทัศนียภาพ	ผลกระทบต่อทัศนียภาพโดยรอบพื้นที่
ค่าใช้จ่าย	ค่าใช้จ่ายในการลงทุนและการดำเนินการ

รายละเอียดของทางเลือก

ทางเลือก	**รายละเอียด**
พื้นที่กองพักขยะในพื้นที่	พื้นที่กองพักขยะรวมแบบชั่วคราวในพื้นที่ เพื่อรวบรวมและพักรอการขนส่งสู่สถานีขนถ่ายมูลฝอย
พื้นที่จอดรถบรรทุกขยะในพื้นที่	พื้นที่จอดรถบรรทุกขยะในพื้นที่ เพื่อความสะดวกในการเข้าเก็บขนขยะ และลดความเสี่ยงต่อการผ่านจุดเสี่ยงน้ำท่วม
การปรับแต่งรถบรรทุก	การปรับแต่งรถบรรทุกให้สามารถขนส่งผ่านพื้นที่น้ำท่วมได้
การใช้เรือ	การใช้เรือเพื่อการเก็บขนขยะ และการเพื่อการเก็บรวมรวมหรือพักขยะในพื้นที่
การเปลี่ยนสถานีขนถ่ายมูลฝอย	การเปลี่ยนการขนถ่ายมูลฝอยในพื้นที่จากสถานีขนถ่ายมูลฝอยหนองแขม สู่สถานีขนถ่ายมูลฝอยอื่น ๆ

ส่วนที่ 4 การเปรียบเทียบความสำคัญของปัจจัยในการเลือกแนวทางการบรรเทาผลกระทบจากน้ำท่วมที่มีต่อระบบการจัดการขยะมูลฝอย กรณีสามารถเข้าเก็บขนมูลฝอยได้แต่ ไม่สามารถนำมูลฝอยออกจากพื้นที่ไปสู่สถานีขนถ่ายมูลฝอยได้

ข้อ	ปัจจัย	ลำดับความสำคัญเปรียบเทียบระหว่างคู่ปัจจัย																	ปัจจัย
1	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	พลังงานและทรัพยากร
2	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การแยกประเภทขยะ
3	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อสุขภาวะชุมชน
4	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
5	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
6	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การแยกประเภทขยะ
7	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อสุขภาวะชุมชน
8	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
9	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
10	การแยกประเภทขยะ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อสุขภาวะชุมชน
11	การแยกประเภทขยะ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
12	การแยกประเภทขยะ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
13	ผลกระทบต่อสุขภาวะชุมชน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
14	ผลกระทบต่อสุขภาวะชุมชน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
15	ผลกระทบต่อทัศนียภาพ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย

ส่วนที่ 5 การเปรียบเทียบความสำคัญของปัจจัยในการเลือกแนวทางการบรรเทาผลกระทบจากน้ำท่วมที่มีต่อระบบการจัดการขยะมูลฝอย กรณีไม่สามารถเข้าเก็บขนมูลฝอยได้ แต่ สามารถนำมูลฝอยออกจากพื้นที่ไปสู่สถานีขนถ่ายได้

ข้อ	ปัจจัย	ลำดับความสำคัญเปรียบเทียบระหว่างคู่ปัจจัย																	ปัจจัย
1	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	พลังงานและทรัพยากร
2	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การแยกประเภทขยะ
3	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อสุขภาวะชุมชน
4	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
5	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
6	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การแยกประเภทขยะ
7	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อสุขภาวะชุมชน
8	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
9	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
10	การแยกประเภทขยะ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อสุขภาวะชุมชน
11	การแยกประเภทขยะ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
12	การแยกประเภทขยะ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
13	ผลกระทบต่อสุขภาวะชุมชน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
14	ผลกระทบต่อสุขภาวะชุมชน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
15	ผลกระทบต่อทัศนียภาพ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย

ส่วนที่ 6 การเปรียบเทียบความสำคัญของปัจจัยในการเลือกแนวทางการบรรเทาผลกระทบจากน้ำท่วมที่มีต่อระบบการจัดการขยะมูลฝอย กรณีไม่สามารถเข้าเก็บขนมูลฝอยได้ และ ไม่สามารถนำมูลฝอยออกจากพื้นที่ไปสู่สถานีขนถ่ายได้

ข้อ	ปัจจัย	ลำดับความสำคัญเปรียบเทียบระหว่างคู่ปัจจัย																	ปัจจัย
1	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	พลังงานและทรัพยากร
2	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การแยกประเภทขยะ
3	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อสุขภาวะชุมชน
4	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
5	ผลกระทบสิ่งแวดล้อม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
6	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การแยกประเภทขยะ
7	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อสุขภาวะชุมชน
8	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
9	การใช้พลังงานและทรัพยากร	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
10	การแยกประเภทขยะ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อสุขภาวะชุมชน
11	การแยกประเภทขยะ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
12	การแยกประเภทขยะ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
13	ผลกระทบต่อสุขภาวะชุมชน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ผลกระทบต่อทัศนียภาพ
14	ผลกระทบต่อสุขภาวะชุมชน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย
15	ผลกระทบต่อทัศนียภาพ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ค่าใช้จ่าย

ส่วนที่ 7 การเปรียบเทียบทางเลือกวิธีบรรเทาผลกระทบของการจัดการขยะเมื่อน้ำท่วม

ข้อ	ทางเลือก	ระดับความสำคัญเปรียบเทียบระหว่างคู่ทางเลือก																	ทางเลือก
ปัจจัยที่ 1 ผลกระทบสิ่งแวดล้อม																			
1	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	พื้นที่จอดรถในพื้นที่
2	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การปรับแต่งรถบรรทุก
3	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
4	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
5	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การปรับแต่งรถบรรทุก
6	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
7	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
8	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
9	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
10	การใช้เรือ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
ปัจจัยที่ 2 การใช้พลังงานและทรัพยากร																			
1	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	พื้นที่จอดรถในพื้นที่
2	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การปรับแต่งรถบรรทุก
3	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
4	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
5	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การดัดแปลงรถบรรทุก
6	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
7	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
8	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
9	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
10	การใช้เรือ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย

ข้อ	ทางเลือก	ระดับความสำคัญเปรียบเทียบระหว่างคู่ทางเลือก																	ทางเลือก
ปัจจัยที่ 3 การแยกประเภทขยะ																			
1	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	พื้นที่จอดรถในพื้นที่
2	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การปรับแต่งรถบรรทุก
3	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
4	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
5	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การปรับแต่งรถบรรทุก
6	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
7	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
8	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
9	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
10	การใช้เรือ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
ปัจจัยที่ 4 ผลกระทบต่อสุขภาวะชุมชน																			
1	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	พื้นที่จอดรถในพื้นที่
2	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การปรับแต่งรถบรรทุก
3	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
4	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
5	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การดัดแปลงรถบรรทุก
6	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
7	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
8	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
9	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
10	การใช้เรือ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย

ข้อ	ทางเลือก	ระดับความสำคัญเปรียบเทียบระหว่างคู่ทางเลือก																	ทางเลือก
ปัจจัยที่ 5 ผลกระทบต่อทัศนียภาพ																			
1	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	พื้นที่จอดรถในพื้นที่
2	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การปรับแต่งรถบรรทุก
3	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
4	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
5	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การปรับแต่งรถบรรทุก
6	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
7	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
8	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
9	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
10	การใช้เรือ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
ปัจจัยที่ 6 ค่าใช้จ่าย																			
1	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	พื้นที่จอดรถในพื้นที่
2	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การปรับแต่งรถบรรทุก
3	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
4	พื้นที่กองพักขยะในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
5	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การดัดแปลงรถบรรทุก
6	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
7	พื้นที่จอดรถในพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
8	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	การใช้เรือ
9	การปรับแต่งรถบรรทุก	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย
10	การใช้เรือ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เปลี่ยนสถานีขนถ่าย

Appendix E Flood mitigation on MSWM service guideline

คู่มือการบรรเทาผลกระทบจากน้ำท่วมต่อการให้บริการกำจัดขยะมูลฝอย

วัตถุประสงค์

เพื่อใช้เป็นแนวทางในการบรรเทาผลกระทบที่มีต่อการให้บริการจัดเก็บขยะมูลฝอยระหว่างน้ำท่วม

ขอบข่ายการใช้งาน

ใช้สำหรับเขตพื้นที่ในกรุงเทพมหานคร

นิยาม

น้ำท่วม หมายถึง ภาวะระดับน้ำในพื้นที่ให้บริการมีระดับสูงกระทั่งส่งผลกระทบไม่สามารถดำเนินการให้บริการเก็บขนมูลฝอยและ/หรือการขนถ่ายมูลฝอย

ขั้นตอนการจัดเก็บขยะมูลฝอย หมายถึง ขั้นตอนการเดินทางของรถบรรทุกจากที่จอดรถสู่พื้นที่แหล่งกำเนิดเพื่อรวบรวมขยะมูลฝอย

ขั้นตอนการขนถ่ายขยะมูลฝอย หมายถึง การนำขยะมูลฝอยที่รวบรวมจากแหล่งกำเนิดขนส่งสู่สถานีขนถ่ายมูลฝอย

ความรับผิดชอบ

1. ผู้ว่าราชการกรุงเทพมหานคร :
   - มีหน้าที่เป็นผู้อำนวยการกรุงเทพมหานครรับผิดชอบและปฏิบัติหน้าที่ในการป้องกันและบรรเทาสาธารณภัย
   - จัดให้มีวัสดุ อุปกรณ์ เครื่องมือเครื่องใช้ ยานพาหนะ และสิ่งอื่น เพื่อใช้ในการป้องกันและบรรเทาสาธารณภัย
   - สั่งการและประสานงานกับหน่วยงานของรัฐและสำนักงานเขตที่เกี่ยวข้องในการป้องกันและบรรเทาสาธารณภัย
2. ผู้อำนวยการเขตที่ได้รับผลกระทบ :

   - เป็นผู้ช่วยผู้อำนวยการกรุงเทพมหานคร รับผิดชอบและปฏิบัติหน้าที่ในการป้องกันและบรรเทาสาธารณภัยในเขตรับผิดชอบของตน และมีหน้าที่ช่วยเหลือผู้อำนวยการกรุงเทพมหานคร ตามที่ได้รับมอบหมาย
   - ดำเนินการป้องกันและบรรเทาสาธารณภัยโดยเร็ว และแจ้งให้ผู้อำนวยการกรุงเทพมหานครทราบทันที
   - สั่งการส่วนราชการและหน่วยงานของกรุงเทพมหานครที่อยู่ในเขตพื้นที่ ให้ช่วยเหลือหรือร่วมมือในการป้องกันและบรรเทาสาธารณภัย
   - ประสานงานใช้อาคาร สถานที่ วัสดุ อุปกรณ์ เครื่องมือเครื่องใช้ และยานพาหนะของหน่วยงานของรัฐและเอกชนที่อยู่ในพื้นที่ปกครอง

3. หัวหน้าฝ่ายรักษาความสะอาดและสวนสาธารณะ :
   - รายงานสถานการณ์ผลกระทบต่อผู้อำนวยการเขต
   - ร่วมประเมินปัญหา สาเหตุ และแนวทางการป้องกันและบรรเทาสาธารณภัยในเขตพื้นที่รับผิดชอบ

วิธีการ

1. เมื่อพื้นที่เขตใดได้รับผลกระทบต่อภาวะน้ำท่วมให้หัวหน้าฝ่ายรักษาความสะอาดและสวนสาธารณะรายงานต่อผู้อำนวยการเขตนั้น ๆ
2. ผู้อำนวยการเขตมีหน้าที่รายงานต่อผู้ว่าราชการกรุงเทพมหานคร เพื่อร่วมประเมินสถานการณ์
3. หากเป็นภาวะที่ทำให้เกิดผลกระทบต่อสาธารณชน หรือความเสียหายต่อประชาชน ผู้ว่าราชการกรุงเทพมหานครมีหน้าที่เป็นผู้อำนวยกรุงเทพมหานครการรับผิดชอบและปฏิบัติหน้าที่ในการป้องกันและบรรเทาสาธารณภัย โดยมีผู้อำนวยการเขตที่ได้รับผลกระทบนั้นเป็นผู้ช่วยผู้อำนวยการกรุงเทพมหานครรับผิดชอบและปฏิบัติหน้าที่ในการป้องกันและบรรเทาสาธารณภัยในเขตของตน
4. ผู้อำนวยการกรุงเทพมหานครและผู้ช่วยผู้อำนวยการจากพื้นที่ที่ได้รับผลกระทบ ร่วมกันประเมินพื้นที่ให้บริการที่อ่อนไหว (Vulnerable areas) ที่ได้รับผลกระทบสูง (Hot spot) เพื่อจัดลำดับการให้ความช่วยเหลือบรรเทาผลกระทบอย่างรวดเร็วเพื่อลดความเสียหายต่อประชาชน
5. การประเมินผลกระทบให้พิจารณาปริมาณขยะมูลฝอยสะสมในเขตพื้นที่

6. ผู้ช่วยผู้อำนวยการกรุงเทพมหานครและหัวหน้าฝ่ายรักษาความสะอาดและสวนสาธารณะ ร่วมกันประเมินพื้นที่แขวงที่ได้รับผลกระทบ โดยพิจารณาจากพื้นที่บริการย่อยในเขตรับผิดชอบ
7. การประเมินผลกระทบในพื้นที่บริการย่อยในเขตรับผิดชอบให้แยกลักษณะผลกระทบออกเป็น 2 ประเภท คือ ผลกระทบที่มีต่อ *ขั้นตอนการจัดเก็บขยะมูลฝอย* และขั้นตอนการ*ขนถ่ายขยะมูลฝอย*
8. นำข้อมูลที่ได้จัดกลุ่มในลักษณะของแขวง เพื่อประเมินปริมาณขยะสะสมที่อาจเกิดขึ้นจากผลกระทบทั้ง 2 ประเภท
9. วิเคราะห์สาเหตุจากการเกิดผลกระทบทั้ง 2 ประเภท ดังนี้
    - 9.1 กรณีเป็นผลกระทบต่อขั้นตอนการเก็บขนมูลฝอย ให้ดำเนินการพิจารณาสาเหตุว่าเป็นกรณีพื้นที่ให้บริการอยู่ในพื้นที่น้ำท่วม หรือเป็นกรณีเส้นทางระหว่างจุดจอดรถบรรทุกมูลและพื้นที่ให้บริการอยู่ในพื้นที่น้ำท่วม
        - 9.1.1 กรณีสาเหตุจากการที่พื้นที่ให้บริการอยู่ในพื้นที่น้ำท่วม ให้พิจารณาแนวทางการจัดเตรียมและปรับเพิ่มสมรรถนะรถบรรทุกขนส่งขยะให้สามารถขนส่งผ่านบริเวณน้ำท่วมได้ และการจัดเตรียมพาหนะอื่น ๆรองรับเช่น เรือชักลากขยะมูลฝอย
        - 9.1.2 กรณีสาเหตุจากการที่ระหว่างจุดจอดรถบรรทุกกับพื้นที่ให้บริการถูกน้ำท่วม ให้พิจารณาแนวทางทางการจัดเตรียมพื้นที่จอดรถสำรองใกล้เขตพื้นที่ให้บริการ และการจัดเตรียมและปรับเพิ่มสมรรถนะรถบรรทุกขนส่งขยะให้สามารถขนส่งผ่านบริเวณน้ำท่วมได้
    - 9.2 กรณีเป็นผลกระทบต่อขั้นตอนการขนถ่ายมูลฝอย ให้ดำเนินการพิจารณาแนวทางการจัดเตรียมพื้นที่กองขยะมูลฝอยสำรองใกล้พื้นที่ให้บริการ, การจัดเตรียมและปรับเพิ่มสมรรถนะรถบรรทุกขนส่งขยะให้สามารถขนส่งผ่านบริเวณน้ำท่วมได้ และการเปลี่ยนการขนส่งสู่สถานีขนถ่ายมูลฝอยอื่นในเขตกรุงเทพมหานคร
10. การดำเนินการตามแนวทางต่าง ๆ ให้ดำเนินการตามอำนาจหน้าที่และความรับผิดชอบดังนี้

10.1 การจัดเตรียมและปรับเพิ่มสมรรถนะรถบรรทุกขนส่งขยะให้สามารถขนส่งผ่านบริเวณน้ำท่วม ให้สำนักสิ่งแวดล้อม โดยกรุงเทพมหานครเป็นผู้ดำเนินการร่วมกับหน่วยงานเอกชนที่ให้บริการรถเช่า

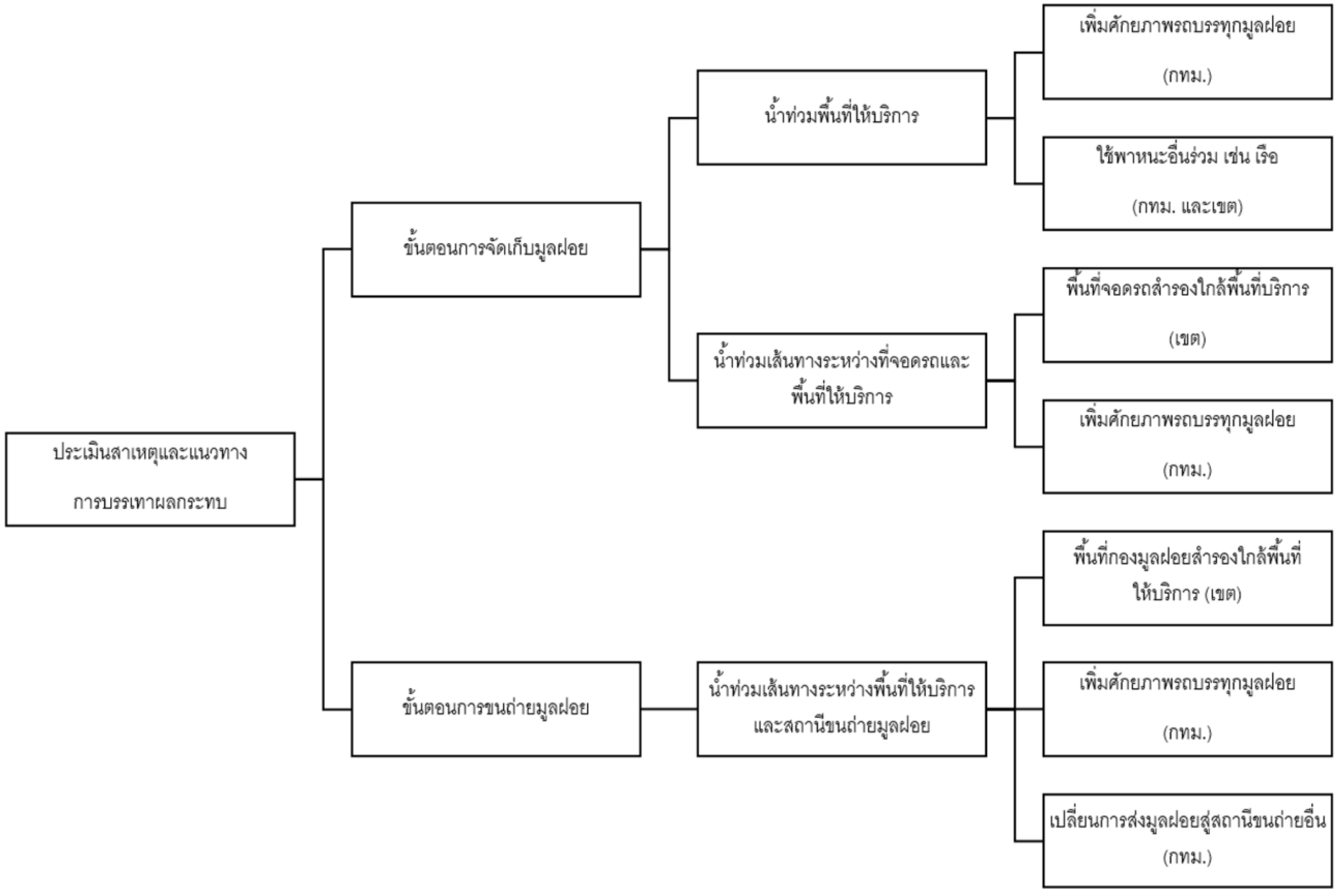
10.2 การจัดเตรียมพาหนะอื่น ๆรองรับเช่น เรือชักลากขยะมูลฝอย โดยให้กรุงเทพมหานครเป็นผู้มีอำนาจในการดำเนินการจัดเตรียมและขอสนับสนุนจากหน่วยงานภาครัฐอื่น ๆ และดำเนินการร่วมกับสำนักงานเขตพื้นที่ในการขอความร่วมมือจากหน่วยเอกชนในพื้นที่เพื่อการขอสนับสนุนใช้อุปกรณ์

10.3 การจัดเตรียมพื้นที่จอดรถสำรองใกล้เขตพื้นที่ให้บริการ โดยสำนักงานเขตพื้นที่ดำเนินการจัดเตรียมพื้นที่จอดรถสำรอง อาจดำเนินการร่วมมือกับหน่วยงานเอกชนและหน่วยงานรัฐในพื้นที่เพื่อการขอสนับสนุนใช้สถานที่

10.4 การจัดเตรียมพื้นที่กองขยะมูลฝอยสำรองใกล้พื้นที่ให้บริการ โดยสำนักงานเขตพื้นที่ดำเนินการจัดเตรียมพื้นที่กองขยะมูลฝอยสำรอง อาจดำเนินการร่วมมือกับหน่วยงานเอกชนในพื้นที่เพื่อการขอสนับสนุนใช้สถานที่ โดยให้มีขนาดอย่างน้อย 8 ไร่ ต่อปริมาณขยะมูลฝอย 2,500 ตัน

10.5 การเปลี่ยนการขนส่งสู่สถานีขนถ่ายมูลฝอยอื่นในเขตกรุงเทพมหานคร โดยสำนักงานกรุงเทพมหานครเป็นผู้ประสานงานการรับมูลฝอยเพิ่มเติมโดยสถานีขนถ่ายมูลฝอยแห่งอื่นในพื้นที่กรุงเทพมหานคร

ผังการประเมินลักษณะและแนวทางในการป้องกันและบรรเทาผลกระทบจากน้ำท่วมที่มีต่อการให้บริการกำจัดขยะมูลฝอย



เอกสารแนบ 1 แบบบันทึกรายการพื้นที่สำรองเพื่อการจอดรถบรรทุกขนส่งมูลฝอยและพื้นที่สำรองการกองเก็บขยะมูลฝอยชั่วคราวในพื้นที่เขต

ลำดับที่	พื้นที่สำรอง		ขนาดพื้นที่ (ตร.ม)	บริเวณที่ตั้ง (แขวงหรือสถานที่สำคัญ)	พิกัด	ผู้ถือกรรมสิทธิ์
	จอดรถบรรทุก	กองเก็บมูลฝอย				

Appendix F Local administrative action plan

แผนบรรเทาผลกระทบจากน้ำท่วมต่อการให้บริการกำจัดขยะมูลฝอย เขตราษฎร์บูรณะ กรณีน้ำท่วมเส้นทางขนส่งสู่สถานีขนถ่ายหนองแขม บริเวณถนนเพชรเกษม เขตบางแค

กรณีผลกระทบในขั้นตอนการจัดเก็บมูลฝอย

ขั้นตอนที่ 1 ให้ใช้วิธีเพิ่มสมรรถนะของรถบรรทุกมูลฝอย

- ให้หัวหน้าฝ่ายรักษาความสะอาดฯ ระบุจำนวนรถบรรทุกขนาด 5 ตัน และรถดั้ม ทุกคันที่ใช้ในปัจจุบัน แจ้งต่อผู้อำนวยการเขต และรายงานต่อกรุงเทพมหานครให้ประสานบริษัทเอกชนผู้ทำสัญญาให้เช่ารถบรรทุกเพื่อเตรียมพร้อมสมรรถนะรถให้พร้อมต่อการใช้งานในการขนส่งผ่านพื้นที่น้ำท่วม (เส้นทาง route-1)
- กรณีที่ระดับน้ำสูงขึ้นจนอยู่ในภาวะเสี่ยงต่อการขนส่ง ให้เลี่ยงใช้เส้นทางใกล้เคียง ได้แก่ ถนนกาญจนาภิเษก และถนนทวีวัฒนา-กาญจนาภิเษก ระยะทางรวมประมาณ 30 กิโลเมตร เพิ่มขึ้นจากระยะทางเดิม 5 กิโลเมตร (เส้นทาง route-1A)

ขั้นตอนที่ 2 กรณีเส้นทางโดยรวมไม่สามารถผ่านโดยรถบรรทุกได้ให้ใช้วิธีการจัดเตรียมที่จอดรถเก็บขยะมูลฝอยชั่วคราว

- ให้หัวหน้าฝ่ายรักษาความสะอาดฯ ระบุจำนวนรถบรรทุกทุกคันที่มีที่จอดปัจจุบันที่บริเวณศูนย์ขนถ่ายขยะมูลฝอยหนองแขม แจ้งต่อผู้อำนวยการเขต และรายงานต่อกรุงเทพมหานครให้ประสานบริษัทเอกชนผู้ทำสัญญาให้เช่ารถบรรทุกเพื่อการอนุญาตการเปลี่ยนที่จอดรถบรรทุกชั่วคราว
- ให้ผู้อำนวยการเขตเป็นผู้ดำเนินการประสานกับหน่วยงานเจ้าของกรรมสิทธิ์ที่ดินในการใช้พื้นที่ ดังนี้
  - พื้นที่ว่างของเอกชน ใกล้สำนักงานเขตฯ บริเวณข้างอาคารวิลาวรรณแมนชั่น แขวงบางปะกอก ขนาดพื้นที่ประมาณ 2.6 ไร่ (พื้นที่ T-1)

กรณีผลกระทบในขั้นตอนการขนถ่ายมูลฝอย

ขั้นตอนที่ 1 การขนส่งช่วงเวลา 06.00 – 21.00 ให้ใช้วิธีเพิ่มศักยภาพรถบรรทุกมูลฝอย

- ให้หัวหน้าฝ่ายรักษาความสะอาดฯ ระบุจำนวนรถบรรทุกขนาด 5 ตัน และรถดั้ม ทุกคันที่ใช้ในปัจจุบัน แจ้งต่อผู้อำนวยการเขต และใช้รายงานต่อกรุงเทพมหานครให้ประสาน

บริษัทเอกชนผู้ทำสัญญาให้เช่ารถบรรทุกเพื่อเตรียมพร้อมสมรรถนะรถให้พร้อมต่อการใช้งานในในการขนส่งผ่านพื้นที่น้ำท่วม (เส้นทาง route-1)

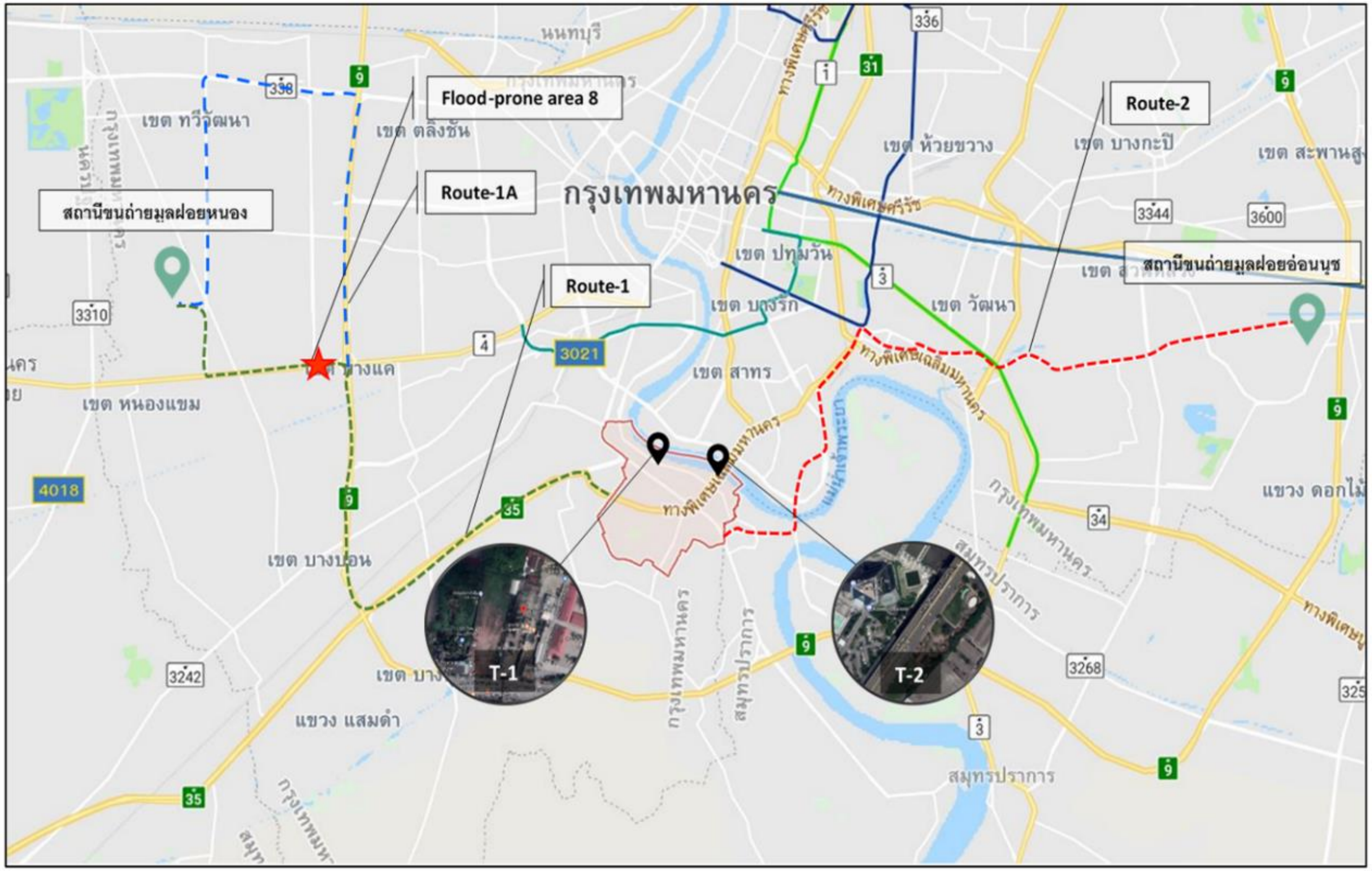
- ทำการรวบรวมขยะที่จัดเก็บได้ในพื้นที่ต่าง ๆ จากรถบรรทุกทุกประเภท ให้เต็มขนาดบรรทุก เพื่อลดจำนวนรอบต่อวันในการขนส่ง
- กรณีที่ระดับน้ำสูงขึ้น ให้เลี่ยงใช้เส้นทางใกล้เคียง ได้แก่ ถนนราชพฤกษ์ ถนนกาญจนาภิเษก และถนนทวีวัฒนา-กาญจนาภิเษก ระยะทางรวมประมาณ 30 กิโลเมตร เพิ่มขึ้นจากระยะทางเดิม 5 กิโลเมตร (เส้นทาง route-1A)

ขั้นตอนที่ 2 การขนส่งช่วงเวลา 21.00 – 06.00 ให้ใช้วิธีการส่งมูลฝอยไปสถานีขนถ่ายมูลฝอยอ่อนนุช

- ให้หัวหน้าฝ่ายรักษาความสะอาดฯ แจ้งต่อผู้อำนวยการเขต และใช้รายงานต่อกรุงเทพมหานครให้ประสานบริษัทเอกชนผู้ทำสัญญาให้เช่ารถบรรทุก ในการเปลี่ยนเส้นทางการขนส่ง
- ให้ใช้ถนนพระราม 3 และถนนสุขุมวิท 77 ระยะทางรวมประมาณ 31 กิโลเมตร เพิ่มขึ้นจากระยะทางเดิม 4 กิโลเมตร ซึ่งเส้นทางนี้มีปัญหาจราจรหนาแน่นและผ่านพื้นที่ชุมชนจึงหลีกเลี่ยงในช่วงเวลาเร่งด่วน (เส้นทาง route-2)

ขั้นตอนที่3 กรณีเส้นทางโดยรวมไม่สามารถขนส่งโดยรถบรรทุกได้ทั้งสถานีขนถ่ายมูลฝอยหนองแขมและอ่อนนุชให้ใช้วิธีการกองเก็บขยะมูลฝอยชั่วคราว

- ให้ผู้อำนวยการเขตเป็นผู้ดำเนินการประสานกับหน่วยงานเจ้าของกรรมสิทธิ์ที่ดินในการใช้พื้นที่ ดังนี้
    - พื้นที่ว่างบริเวณใต้สะพานพระราม9 ฝั่งธนบุรี ข้างธนาคารกสิกรไทย สำนักงานใหญ่ แขวงราษฎร์บูรณะ ของการทางพิเศษแห่งประเทศไทย ขนาดพื้นที่ 5 ไร่ (รองรับปริมาณขยะได้ประมาณ 2,500 ตัน) (พื้นที่ T-2)

ภาพเส้นทางและพื้นที่สำรองเขตราษฎร์บูรณะ กรณีน้ำท่วมเส้นทางขนส่งสู่สถานีขนถ่ายหนองแขม บริเวณถนนเพชรเกษม


แผนบรรเทาผลกระทบจากน้ำท่วมต่อการให้บริการกำจัดขยะมูลฝอย เขตยานนาวา กรณีน้ำท่วมเส้นทางขนส่งสู่สถานีขนถ่ายหนองแขม บริเวณถนนเพชรเกษม เขตบางแค

ขั้นตอนที่ 1 การขนส่งช่วงเวลา 06.00 – 21.00 ให้ใช้วิธีเพิ่มศักยภาพรถบรรทุกมูลฝอย

- ให้หัวหน้าฝ่ายรักษาความสะอาดฯ ระบุจำนวนรถบรรทุกขนาด 5 ตัน และรถดั้ม ทุกคันที่ใช้ในปัจจุบัน แจ้งต่อผู้อำนวยการเขต และรายงานต่อกรุงเทพมหานครให้ประสานบริษัทเอกชนผู้ทำสัญญาให้เช่ารถบรรทุกเพื่อเตรียมพร้อมสมรรถนะรถให้พร้อมต่อการใช้งานในการขนส่งผ่านพื้นที่น้ำท่วม (เส้นทาง route-1)
- ทำการรวบรวมขยะที่จัดเก็บได้ในพื้นที่ต่าง ๆ จากรถบรรทุกทุกประเภท ให้เต็มขนาดบรรทุกเพื่อลดจำนวนรอบต่อวันในการขนส่ง

ขั้นตอนที่ 2 การขนส่งช่วงเวลา 21.00– 06.00 ใช้วิธีการส่งมูลฝอยไปสถานีขนถ่ายมูลฝอยอ่อนนุช

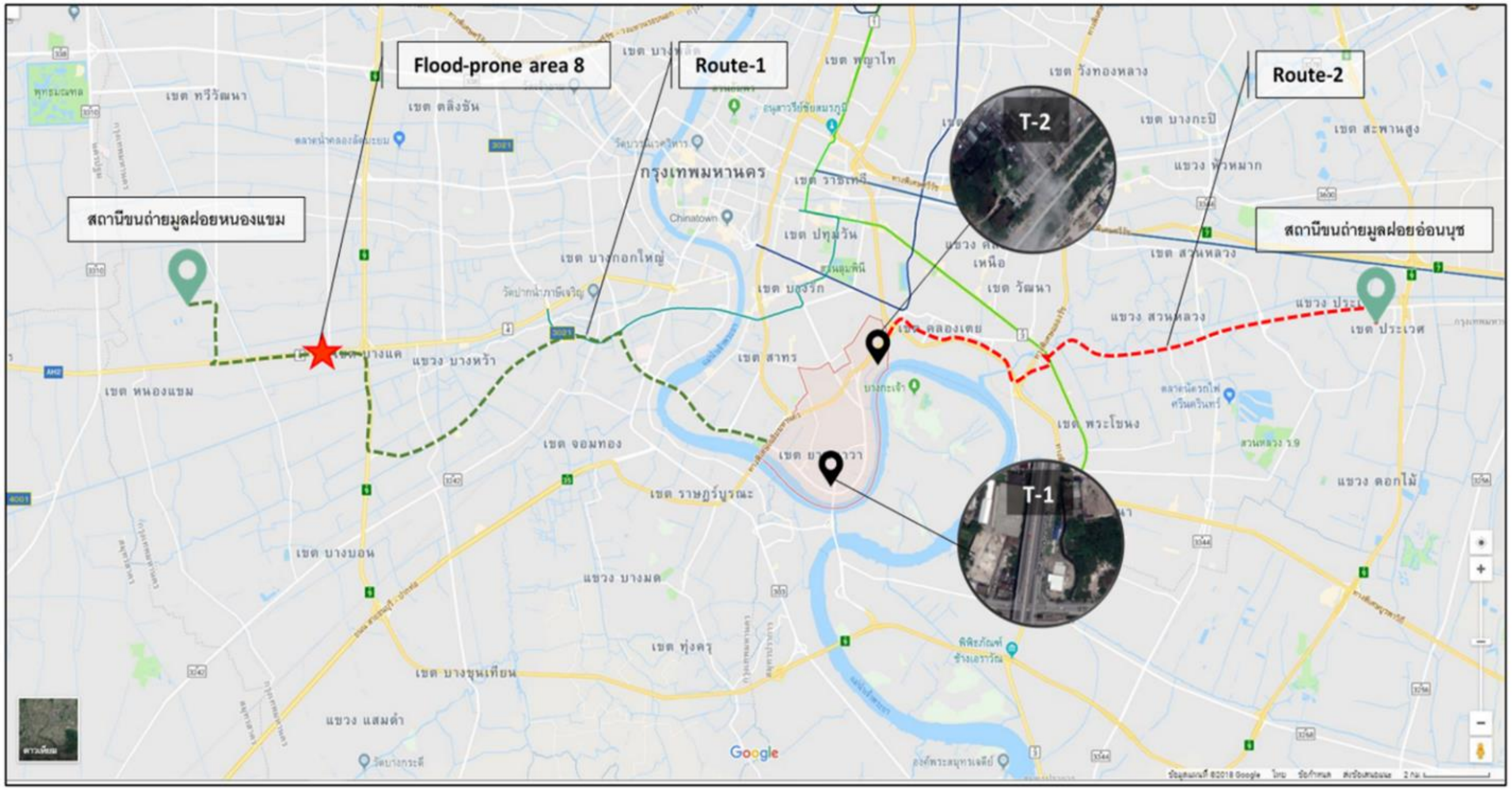
- ให้หัวหน้าฝ่ายรักษาความสะอาดฯ แจ้งต่อผู้อำนวยการเขต และใช้รายงานต่อกรุงเทพมหานครให้ประสานบริษัทเอกชนผู้ทำสัญญาให้เช่ารถบรรทุก ในการเปลี่ยนเส้นทางการขนส่ง
- ให้ใช้ถนนพระราม 4 และถนนสุขุมวิท 77 ระยะทางรวมประมาณ 20 กิโลเมตร ซึ่งเป็นเส้นทางที่มีระยะทางสั้นที่สุดแต่อาจมีปัญหาจราจรและการผ่านพื้นที่ชุมชน จึงหลีกเลี่ยงในช่วงเวลาเร่งด่วน (เส้นทาง route-2)

ขั้นตอนที่3 กรณีเส้นทางโดยรวมไม่สามารถขนส่งโดยรถบรรทุกได้ทั้งสถานีขนถ่ายมูลฝอยหนองแขมและอ่อนนุชให้ใช้วิธีการกองเก็บขยะมูลฝอยชั่วคราว

- ให้ผู้อำนวยการเขตเป็นผู้ดำเนินการประสานกับหน่วยงานเจ้าของกรรมสิทธิ์ที่ดินในการใช้พื้นที่ ดังนี้
    - พื้นที่ว่างการทางรถไฟ ขนาดพื้นที่ประมาณ 5 ไร่ (รองรับปริมาณขยะมูลฝอยประมาณ 2,500 ตัน) (พื้นที่ T-1)
    - พื้นที่บนถนนยานนาวาตัดใหม่ (ใต้สะพานภูมิพล) ขนาดพื้นที่ 5 ไร่ (รองรับปริมาณขยะมูลฝอยประมาณ 2,500 ตัน) (พื้นที่ T-2)

ภาพเส้นทางและพื้นที่สำรองเขตยานนาวา

กรณีน้ำท่วมเส้นทางขนส่งสู่สถานีขนถ่ายหนองแขม บริเวณถนนเพชรเกษม



VITA

NAME	Nuchcha Phonphoton
DATE OF BIRTH	15 June 1980
PLACE OF BIRTH	Chachoengsao
INSTITUTIONS ATTENDED	Mahidol University
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