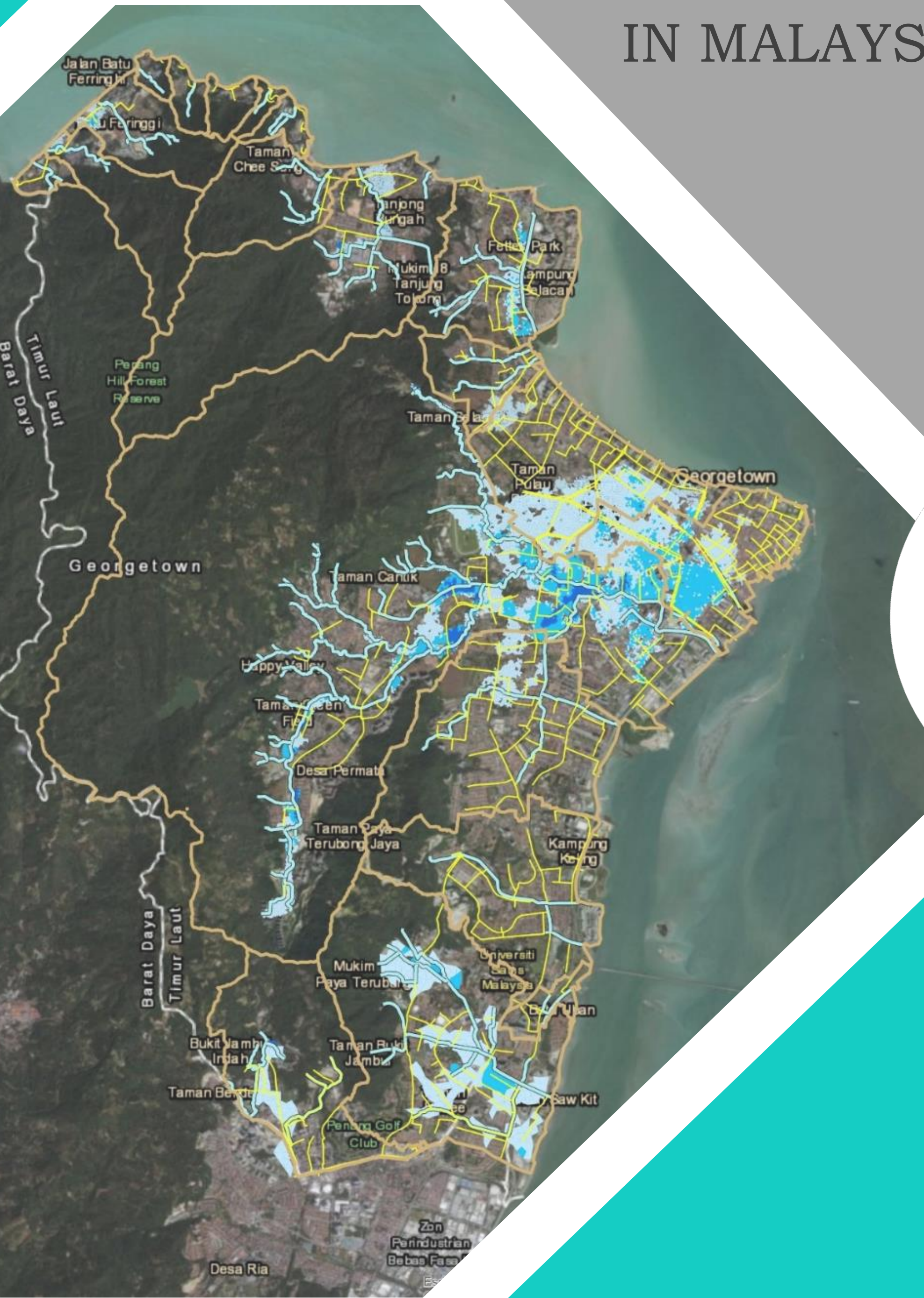
CREAM
CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA

DEVELOPMENT OF FLOOD RISK ASSESSMENT (FRA) AND FLOOD VULNERABILITY INDEX (FVI) FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA : A CASE STUDY IN SUNGAI PINANG PULAU PINANG



INCEPTION REPORT

NOVEMBER 2018

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DEVELOPMENT OF FLOOD RISK ASSESMENT AND FLOOD VULNERABILITY INDEX (FVI) FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA

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INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 STUDY ENGAGEMENT

The Construction Research Institute of Malaysia (CREAM) is desirous in obtaining the services of a professional consultancy services to carry out a study '***Development of Flood Risk Assessment and Flood Vulnerability Index (FVI) for Critical Infrastructure (CI) in Malaysia for Sungai Pinang River Basin***'.

Upon evaluating the submitted technical and financial proposals from RBM Engineering Consultant (RBMEC), CREAM has awarded the above consultancy services to RBMEC via letter[1] referral no.: CREAM/UPP-09/1/2 klt. 2 (40) dated 10th October 2018 which is to be completed in 9 months within the service period between 17th October 2018 and 17 July 2018.

RBMEC is very much grateful to be entrusted by CREAM to undertake the above consultancy services.

1.2 BACKGROUND

Latest catastrophic events that occurred in Malaysia have witnessed numbers of massive devastation, economic change and loss of human life. The country has experienced unprecedented events, including the worst flood event in 50 years and strong earthquake in 39 years since 1976. Even though Malaysia geographically considered less vulnerable, the exposure to a range of climate-related disasters has intensified in part, due to climatic and topographical conditions.

New risks and vulnerabilities have emerged as the features of climate change in term of the scale, frequency, severity and unpredictability of extreme weather. Human activities including immense population growth, sprawling development and megacities is another factor that cause threats to the environment thus lead to disasters. In time of uncertainties, the risk and

[1] Appendix of Chapter 1

vulnerabilities exposed by natural hazards and disasters rise at accelerating pace add sense of urgency to the challenge of being resilience.

Moving forward, resilience features need to be enhanced in multi-disciplinary actions. Enhanced resilience enables better anticipation of disaster and planning to minimise the impact and losses. The critical question is, how resilience is we, and are we ready to face various challenges and uncertainties in the future?

Conceptually, resilience needs to have the ability to maintain acceptable levels of functionality during and after disruptive events with recover full functionality within a specific period. The strategy in developing resilience involve short and long-term planning, investments of time and resources prior to an event. Resilience is a process that needs to take into account the economic, social, psychological, physical and environment factors that will ensure continuity to survive (Dodman, Ayers, & Huq, 2010).

The Sendai Framework for Disaster Risk Reduction 2015 to 2030 (SFDRR) adopted in 2015 echoes global commitment to address Disaster Risk Reduction (DRR) and the building of resilience to disasters with renewed sense of urgency (United Nations, 2015). Align with the global agenda, Malaysia government under the Eleventh Malaysia Plan (11th MP) aims to strengthening resilience against climate change and natural disaster. Building the culture and practice of disaster resilience will require focused action within and across multi sectors.

1.3 STUDY OBJECTIVES

The aim of this study is to develop flood risk assessment and vulnerability index for critical infrastructure in Sungai Pinang, Pulau Pinang. This is to be achieved through the following specific objectives as highlighted in the terms of reference[1]: -

- To identify indicators that will be selected to construct an index for critical infrastructure in respected area.
- To develop a multi-criteria assessment of the critical infrastructure.
- To identify the parameters for developing flood vulnerability index (FVI) of critical infrastructure and assigning score for each parameter.

1.4 SCOPE OF WORKS

The scope of work as stipulated in the terms of reference[1] are outlined as follows: -

- To identify indicators/ parameters for flood risk assessment and FVI for critical infrastructures.
- Review existing flood hazard/risk map of the study area.
- Prepare and verify methodology to develop FVI for critical infrastructures.
- Prepare and verify methodology to review existing flood hazard/risk map.
- Based on the reviewed, further identify the critical infrastructure.
- Collect, collate, and analyse data (primary and secondary) to support the development of FVI for critical infrastructures in the selected areas.
- Develop FVI for critical infrastructure.
- Propose flood and development zoning with respect to FVI

1.5 DELIVERABLES

The expected deliverables as stipulated in the terms of reference[1] are outlined as follows:

- New flood risk map.
- FVI for Critical Infrastructures.
- Flood and development zoning.
- Presentation materials must be handed to CREAM.
- Provide training for CREAM personnel and others.

1.6 OUTLINE OF THE INCEPTION REPORT

Chapter 1– Introduction

Chapter 2– Description of Study Area

Chapter 3 – Flood Risk Assessment, Flood Vulnerability Index and Critical Infrastructure

Chapter 4 – Approach and Methodology

Chapter 5 – Data Collect and Database Management

Chapter 6 – Work Programme and Study Team Organisation

APPENDIX TO CHAPTER 1

TERM OF REFERENCE

FOR CONSULTANCY SERVICES

DEVELOPMENT OF FLOOD RISK ASSESSMENT AND FLOOD VULNERABILITY INDEX (FVI) FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA

FOR

CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA (CREAM)
Subsidiary of the CIDB Malaysia

TERM OF REFERENCE: CONSULTANCY SERVICES

1.0 Project Title

Development of Flood Risk Assessment and Flood Vulnerability Index (FVI) for Critical Infrastructure (CI) in Malaysia.

2.0 Background

2.1 Latest catastrophic events that occurred in Malaysia have witnessed numbers of massive devastation, economic change and loss of human life. The country has experienced unprecedented events, including the worst flood event in 50 years and strong earthquake in 39 years since 1976. Even though Malaysia geographically considered less vulnerable, the exposure to a range of climate-related disasters has intensified in part, due to climatic and topographical conditions.

2.2 New risks and vulnerabilities have emerged as the features of climate change in term of the scale, frequency, severity and unpredictability of extreme weather. Human activities including immense population growth, sprawling development and megacities is another factor that cause threats to the environment thus lead to disasters. In time of uncertainties, the risk and vulnerabilities exposed by natural hazards and disasters rise at accelerating pace add sense of urgency to the challenge of being resilience.

2.3 Moving forward, resilience features need to be enhanced in multi-disciplinary actions. Enhanced resilience enables better anticipation of disaster and planning to minimise the impact and losses. The critical question is, how resilience is we, and are we ready to face various challenges and uncertainties in the future?

2.4 Conceptually, resilience needs to have the ability to maintain acceptable levels of functionality during and after disruptive events with recover full functionality within a specific period. The strategy in developing resilience involve short and long-term planning, investments of time and resources prior to an event. Resilience is a process that needs to take into account the economic, social, psychological, physical and environment factors that will ensure continuity to survive (Dodman, Ayers, & Huq, 2010).

2.5 The Sendai Framework for Disaster Risk Reduction 2015 to 2030 (SFDRR) adopted in 2015 echoes global commitment to address Disaster Risk Reduction (DRR) and the building of resilience to disasters with renewed sense of urgency (United Nations, 2015). Align with the global agenda, Malaysia government under the Eleventh Malaysia Plan (11^{th} MP) aims to strengthening resilience against climate change and natural disaster. Building the culture and practice of disaster resilience will require focused action within and across multi sectors.

3.0 Purposes

The purpose of this research is for the construction sectors to improve the resilience of the built environment through:

i. Understand risk of natural hazards to buildings and infrastructure,
ii. Understand issues and countermeasures against the buildings and infrastructure regarding to DRR,
iii. Mainstream DRR into planning, design, construction and maintenance of building and infrastructure, and
iv. Adopt good practice and lessons on building resilience for building and infrastructure from other countries.

4.0 Objectives

The aim of this study is to develop flood risk assessment and vulnerability index for critical infrastructure in Sungai Pinang, Pulau Pinang.

This is to be achieved through the following specific objectives:

4.1 To identify indicators that will be selected to construct an index for critical infrastructure in respected area.

4.2 To develop a multi-criteria assessment of the critical infrastructure.

4.3 To identify the parameters for developing flood vulnerability index (FVI) of critical infrastructure and assigning score for each parameter.

4.4 To assist construction industry and local authority in making decision to manage and strengthen the security and resilient of the critical infrastructure.

5.0 Work Scope

The proposed scope of work are as follows:

5.1 To identify indicators/ parameters for flood risk assessment and FVI for critical infrastructures.

5.2 Review existing flood hazard/risk map of the study area.

5.3 Prepare and verify methodology to develop FVI for critical infrastructures.

5.4 Prepare and verify methodology to review existing flood hazard/risk map.

5.5 Based on the reviewed, further identify the critical infrastructure.

5.6 Collect, collate, and analyse data (primary and secondary) to support the development of FVI for critical infrastructures in the selected areas.

5.7 Develop FVI for critical infrastructure.

5.8 Propose flood and development zoning with respect to FVI.

6.0 Deliverables

6.1 New flood risk map.

6.2 FVI for Critical Infrastructures.

6.3 Flood and development zoning.

6.4 Presentation materials must be handed to CREAM.

6.5 Provide training for CREAM personnel and others.

7.0 Duration

The duration of the consultancy services is 9 months effective upon official date letter of appointment from CREAM.

8.0 Referral Document for Appointed Consultant

The appointed consultants may obtain relevant documents for reference from CREAM and other sources that relate to the scope of the above-'scope of work'.

9.0 Deliverables Submission Format

All reports must be in English. The schedule of submission and number of copies are specified in **Section 10**.

10.0 Schedule of Payment

The Consultant is required to submit a Progress Payment for the completed services for each work submission.

10.1 Any expenses (other than consulting costs) can not be claimed by the consultant.

10.2 CREAM reserves the right to change the payment scheme and payment schedule as follows:

Deliverable	Date of Submission	No of Copies	% Payment
Deliverable 1: Inception Report	1 month after appointment	5 Hard Copy with PDF	20
Deliverable 2: Interim Report	4 month after appointment	5 Hard Copy with PDF	20
Deliverable 3: Draft Final	7 month after appointment	5 Hard Copy with PDF	20
Final Report	9 month after appointment	15 Hard Copy with PDF	40

11.0 Intellectual Property Rights

11.1 Deliverables and sub-deliverables prepared and submitted by the consultants under the terms of reference (TOR) are the intellectual property of CREAM. No part or parts need to be reproduced in any form without prior permissions by CREAM. CREAM reserves the right to alter, modify, or change any information if it deems so.

11.2 The consultant and CREAM is responsible to take all reasonable steps to protect confidential information (if any) specified by one of the parties.

12.0 Agreement of Consulting Services

12.1 A consultant will be given a copy of the agreement stating the terms and conditions of the consultant's services shortly after the consultant agrees to the appointment to the reception of the consultant's appointment.

12.2 The consultant is required to provide the minutes of the meeting and distribute it to the relevant parties.

13.0 Termination of Consulting Services

CREAM has the right to terminate the consulting services if:

a) The consultants fails to produce results with the agreed time without a valid reason

b) The consultant fails to perform task for the identified scope with a high level of commitment

c) The consultant fails to attend meeting or workshop that were agreed upon in advance

14.0 Estimated cost

A total of **RM 200,000.00** is allocated for this consultancy service using the provision of MAMPAN- CREAM-CIDB.

Note: Kindly prepare proposal according to template given.

TEMPLATE FOR PROPOSAL

1.0 Title of project

2.0 Introduction

3.0 Background of project

4.0 Propose Methodology

5.0 Deliverable

6.0 Milestone

7.0 Consultancy cost

8.0 Research team (should include)

- 8.1 Project Manager
- 8.2 Hydrologist
- 8.3 Socio-economic
- 8.4 River/Hydraulics Modeler
- 8.5 GIS Expert/ Database Developer

9.0 CV for each individual involve

10.0 Consultancy project experience and expertise related to landslide

CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA
A Subsidiary of CIDB MALAYSIA
CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA (CREAM) (646889 - V)
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Bil. Rujukan : CREAM/UPP-09/1/2 klt. 2 (40)
Tarikh : 10 Oktober 2018

RBM ENGINEERING CONSULTANT
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(up: Ir. Ahmad Sharmy bin Mohammed Jaffar) Email: sharmyjaffar@googlemail.com

Tuan,

SURAT TAWARAN KERJA
- **PERKHIDMATAN PERUNDINGAN "DEVELOPMENT OF FLOOD RISK ASSESSMENT (FRA) AND FLOOD VULNERABILITY INDEX (FVI) FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA (SUNGAI PINANG)**

Dengan segala hormatnya perkara di atas adalah dirujuk.

2. Sukacita dimaklumkan bahawa CREAM telah bersetuju untuk menerima tawaran cadangan sebutharga tuan bernilai **Ringgit Malaysia Satu Ratus Sembilan Puluh Sembilan Ribu Sembilan Ratus Enam Puluh Enam dan Empat Puluh Sen Sahaja (RM199,966.40)** untuk perkhidmatan di atas.

3. Tawaran ini tertakluk kepada tawaran sebutharga tuan, terma dan syarat yang telah dilampirkan bersama surat sebutharga tuan bertarikh 03 Mei 2018.

4. Surat ini dihantar kepada tuan dalam dua (2) salinan. Sekiranya tuan menerima tawaran ini, sila tandatangani surat persetujuan seperti yang dilampirkan dan kembalikan kepada CREAM dalam tempoh tujuh (7) hari daripada tarikh surat ini.

Sekian, terima kasih.

MOHD AIZUDDIN BIN AYOB
Pengurus
Korporat dan Pembangunan Bisnes

SURAT SETUJU TERIMA TAWARAN

SKOP BEKALAN / KERJA / PERKHIDMATAN:
PERKHIDMATAN PERUNDINGAN "DEVELOPMENT OF FLOOD RISK ASSESSMENT (FRA) AND FLOOD VULNERABILITY INDEX (FVI) FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA (SUNGAI PINANG)

HARGA KONTRAK :
RINGGIT MALAYSIA SATU RATUS SEMBILAN PULUH SEMBILAN RIBU SEMBILAN RATUS ENAM PULUH ENAM DAN EMPAT PULUH SEN SAHAJA (RM199,966.40)

TEMPOH PERKHIDMATAN:
17 OKTOBER 2018 SEHINGGA 17 JULAI 2019 (9 BULAN)

Dengan ini, saya yang bertandatangan seperti dibawah mengakui penerima Surat Tawaran untuk perkhidmatan Perundingan "Development of Flood Risk Assessment (FRA) and Flood Vulnerability Index (FVI) for Critical Infrastructure (CI) In Malaysia (Sungai Pinang) dan bersetuju dengan tawaran Bil. Rujukan : CREAM/UPP-09/1/2 Klt 2 (40) serta bersetuju untuk memberi perkhidmatan tersebut dengan menepati segala penentuan dan syarat-syarat dokumen sebutharga. Saya selanjutnya bersetuju untuk memberi perkhidmatan tersebut.

.... (Tandatangan Pembekal)		.... (Saksi)	
Nama Penuh	....	Nama Penuh	....
Kad Pengenalan	....	Kad Pengenalan	....
Alamat	....	Alamat	....
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Cop Syarikat	....	Cop Syarikat	....
Tarikh	....	Tarikh	....

CHAPTER 2

DESCRIPTION OF STUDY AREA

CHAPTER 2

DESCRIPTION OF STUDY AREA

2.1 THE SUNGAI PINANG RIVER BASIN

The Sungai Pinang river basin lies within the Latitude of *5° 21′ 32″ N* to *6° 26′ 48″ N* and Longitude of *100° 14′ 26″ E* to *100° 10′ 42″ E*. It is located on the north-eastern coast of Penang Island, which mainly comprises the urban areas of Georgetown, Air Itam and Paya Terubong towns and their vicinity as shown in **Figure 2.1**.

Sungai Pinang river basin area is approximately 46km square and it is the largest, most built-up river system on the island. Sungai Pinang flows originate from the central hilly to undulating part of the catchment. Others than the tributaries, Sungai Pinang itself is only about 3.6km. These tributaries are Sungai Jelutong (5.94km), Sungai Air Itam (12.88km), Sungai Air Terjun (9.30km), Sungai Dondang (6.97km), Sungai Air Putih (3.89km), Sungai Kecil (Parit Lumba Kuda) (2.64km) and Sungai Mati (0.6km).

Among these tributaries, Sungai Air Itam is the largest tributary and Sungai Mati is the shortest tributary. Sungai Air Itam is regulated by a water supply dam located at the upstream part. Most of Sungai Pinang and its tributaries have been channelized and lined during the development of the surrounding area.

The topography of the project area as shown in **Figure 2.2** can mainly be divided into two geomorphic zones namely the **Lowland Coastal Flood Plains** and the **Interior Hills**. The hill terrains, which are mainly located in the central and northern part of the island, are generally rugged and steep terrain with and average slope of more than 30 percent. In general, the elevation ranges from 300 m to 800 m, while the highest peak is Bukit Western (830 m) located at Penang Hill. On the other hand, the low or flat alluvial lands basically occupy the coastal side of the island. The elevations of these floodplains merely exceed the elevation of more than few meters while many areas near the estuary of Sungai Pinang are just 1 meter above the sea level.

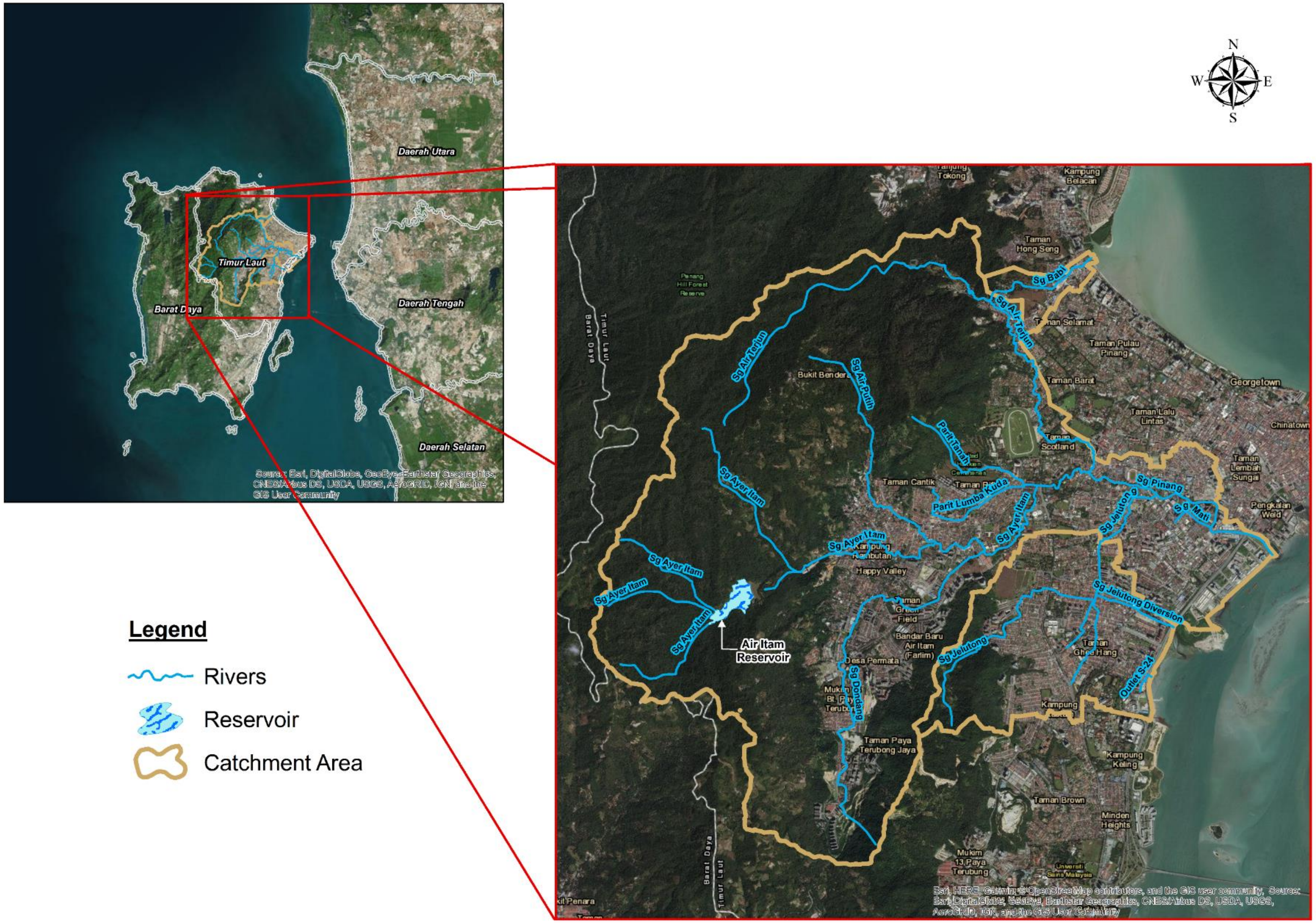


Figure 2.1: Location of Project Area. The Sungai Pinang River Basin

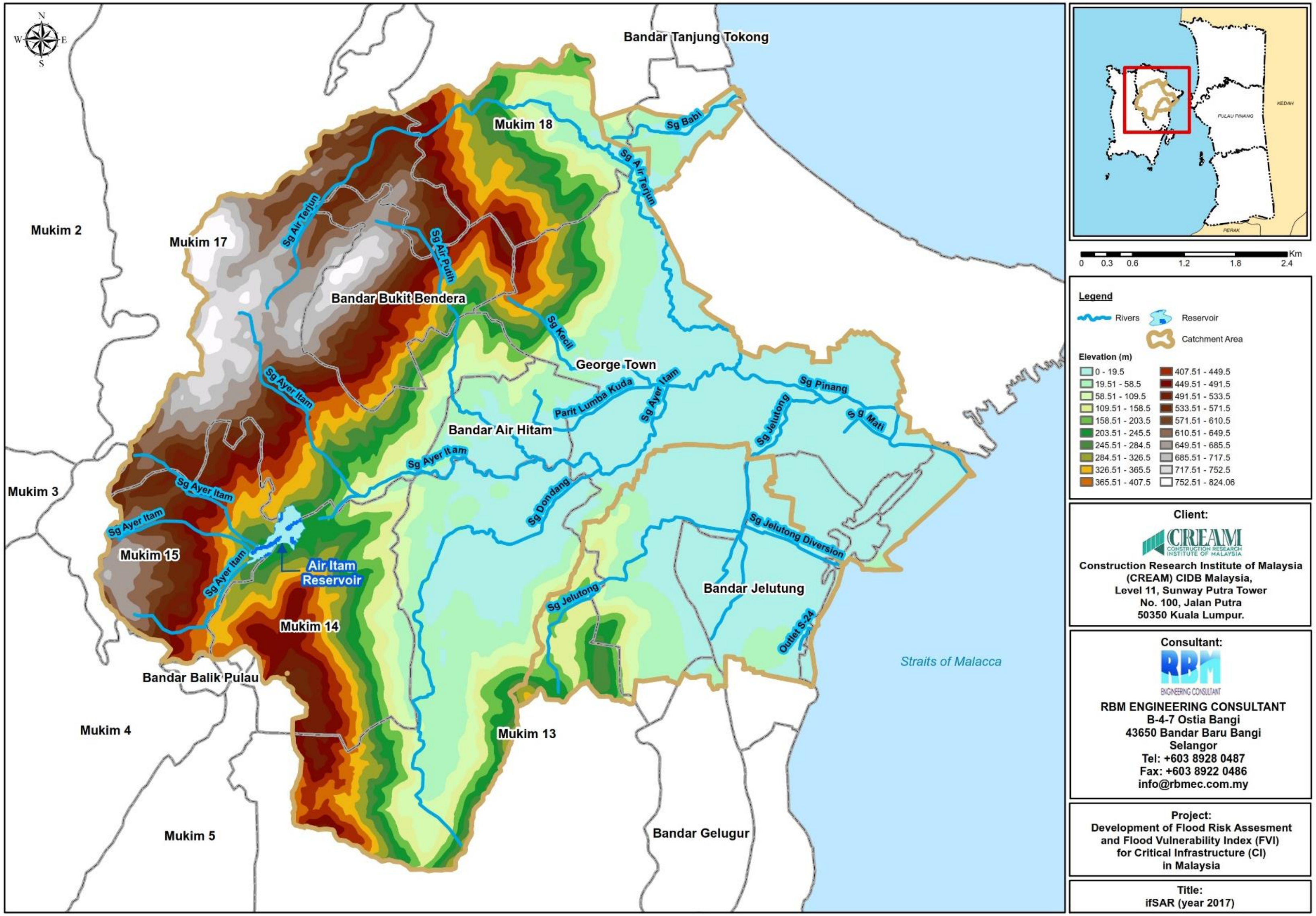


Figure 2.2: Topography of the Sungai Pinang River Basin

2.2 ADMINISTRATIVE JURISDICTION

The project area is wholly located in the District of Timur Laut and comprise 8 mukims or sub-district, 12 Dewan Undangan Negeri and 5 Parliament as shown in **Figure 2.3**, **Figure 2.4** and **Figure 2.5**. The respective areas of those administrative boundaries within the project area are shown in **Table 2.1** to **Table 2.3**.

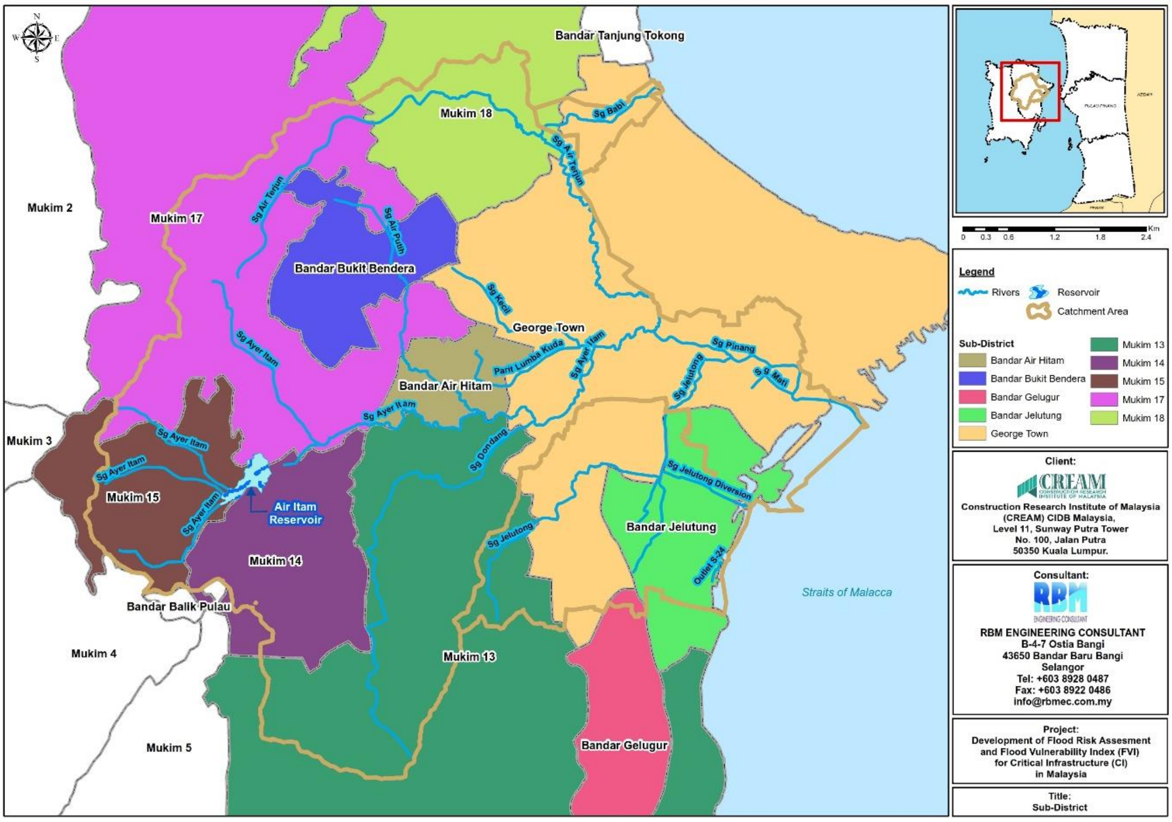


Figure 2.3: Mukim within the Project Area

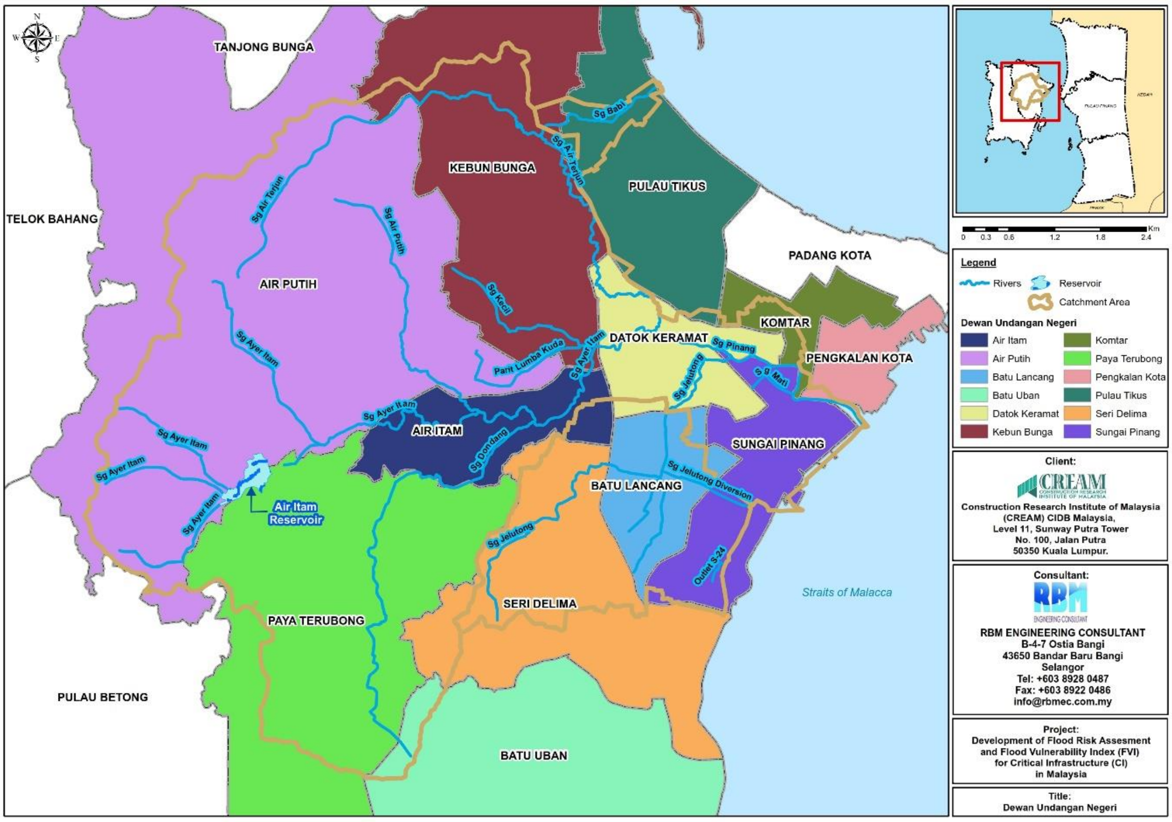


Figure 2.4: DUN within the Project Area

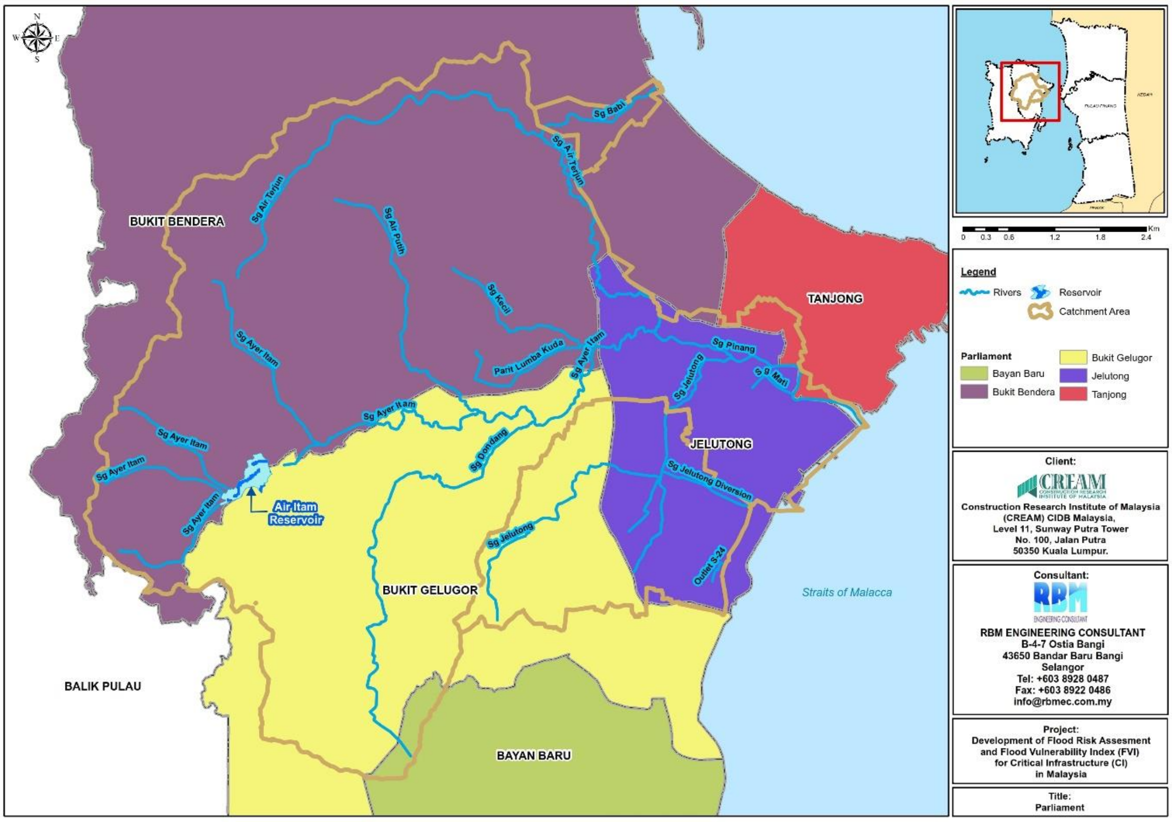


Figure 2.5: Parliament within the Project Area

Table 2.1: Mukim of the Sungai Pinang River Basin

Mukim	Area (m^2)
Bandar Air Hitam	1,750,822.60
Bandar Bukit Bendera	3,475,368.77
Bandar Gelugur	99,895.73
Bandar Jelutung	3,594,321.76
George Town	13,270,014.15
Mukim 13	9,569,681.96
Mukim 14	4,590,980.11
Mukim 15	3,535,538.43
Mukim 17	9,499,702.17
Mukim 18	3,882,340.99

Table 2.2: DUN of the Sungai Pinang River Basin

DUN	Area (m^2)
Air Itam	3,127,027.36
Air Putih	18,472,677.82
Batu Lancang	2,514,122.65
Batu Uban	461,520.53
Datok Keramat	2,893,298.95
Kebun Bunga	7,284,370.47
Komtar	437,401.33
Paya Terubong	10,230,606.04
Pengkalan Kota	57,241.72
Pulau Tikus	842,949.97
Seri Delima	4,434,591.86
Sungai Pinang	3,264,721.15

Table 2.3: Parliament of the Sungai Pinang River Basin

Parliament	Area (m^2)
Bayan Baru	461,520.53
Bukit Bendera	26,599,998.27
Bukit Gelugor	17,792,225.26
Jelutong	8,672,142.75
Tanjong	494,643.05

2.3 CLIMATE

Like other part in the west coast of Peninsular Malaysia, the study area experience uniform temperature, high humidity and heavy rainfall with two major monsoon seasons i.e., southeast and northeast monsoon. However, there are some uniform periodic changes in climates and based on these changes two inter-monsoon seasons can be observed between these major monsoons. These can be defined as follows in **Table 2.4**.

Table 2.4: Seasons in the Study Area

Seasons	Month
Northeast Monsoon	November – March
Inter-monsoon	March – May
Southwest Monsoon	May – September
Inter-monsoon	September - November

However, relatively less rain is received during the southwest monsoon season from May to August, due to the sheltering effect of Sumatra. The average rainfall in the area is around 2000 mm per year, with the lowest monthly average around 60 mm for February and the highest monthly averages around 210 mm for August and October.

2.4 GEOLOGICAL CHARACTERISTICS

The site is generally located on the granite and recent alluvium area as shown in Geological Map for the Project Area in **Figure 2.6**. This river traverses through granitic rock in the upstream area and cross recent alluvium area near the downstream. The granite occupies the major part of the main island and can be divided into two bodies: The North Pinang pluton and the South Pinang pluton. The granite in the northern part is believed to be of epizonal zone and was emplace during early Jurassic age of about 180 million years ago. The Sungai Pinang area is located in North Pinang pluton area and can be classified into Tanjung Bunga Granite.

The Tanjung Bunga granites are fine to coarse-grained and categorized as biotic granite due to the mica content in the rock. The granites can be divided into two phases which cut by quartz dykes, veins, numerous fault and shear zones. Some parts of the faults and shear zones are occupied by quartz veins. Medium to coarse grained biotite granite represents the first stage of magmatic activity. Some quartz veins existed around the island and may form as aplite dykes and vein. The residual soils derived from the granite varies from 6 to 15 meters thick are generally sandy in nature.

The alluvium covers the downstream area at eastern part of Sungai Pinang along valleys. This alluvium was deposited around 7 million years ago and only a few meters thick. The topsoil is usually consisting of yellowish brown clay and underlain by a thicker layer of brownish grey soft clay with abundant plant remains of fine to medium-grained sand. The base of the alluvium layer consists of coarse sand layer with some greyish clay or layer of peat.

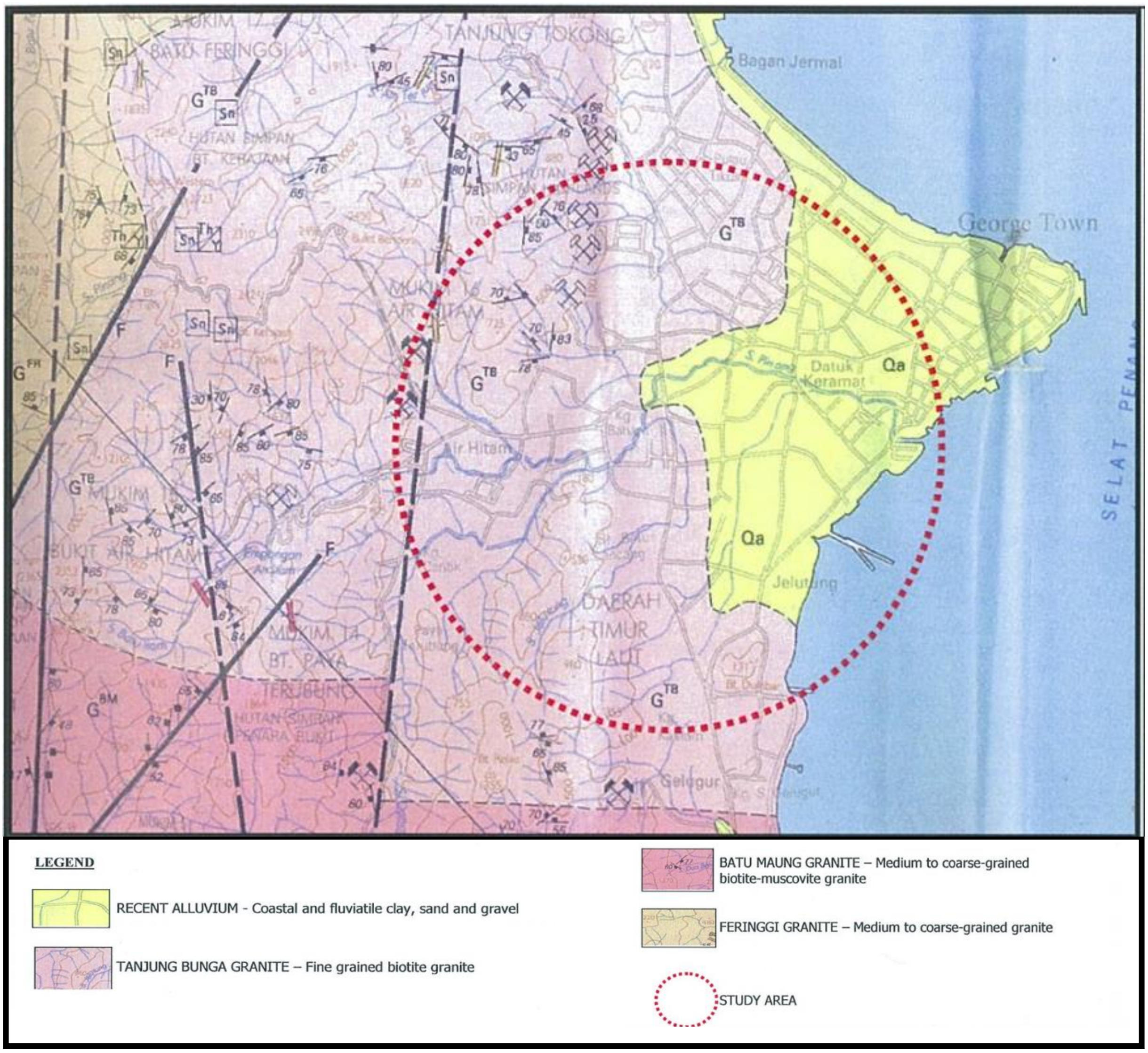


Figure 2.6: Geological Map of the Project Area

2.5 LANDUSE AND VALUE

2.5.1 The Current Landuse

The study area is highly developed area comprising more than 40% or urban areas in Penang Island. The majority of the built-up areas lies within the Georgetown Conurbation, Air Itam and Paya Terubong area. Georgetown is the state capital of Penang. The land uses under the category of 'built-up areas' include residential, commercial, industrial, administrative and institution, recreation/open spaces and cemeteries. The non-built up land uses include agriculture, forest/scrubs and forest reserve. The Land use map of the study area is as shown in **Figure 2.7**.

The map indicates urban land uses as residential, which cover approximately 1,475 ha (28.9%) followed by institutional, 457 ha (8.9%), commercial, 83 ha (1.6%) and industrial, 51 ha (1%). The large percentage if the built-up areas is expected to generate high amount of surface runoff and thus non-point source pollution. Agriculture activities cover a minor part of the study area, which constitute 565 ha or 11% of the total area. These agricultural lands are mostly located near the upper reaches of the river, providing buffer between the urban areas and the natural forest vegetation. Forest is the single largest land use type in the whole basin. The total area covered by forest is approximately 1,885 ha (36.9%) of the total basin area. Most of the forest areas are gazette forest reserves located at the upper reaches of the river and constitute part of the Air Itam dam water catchment.

2.5.2 Projected Landuse

As Georgetown has been well established over several hundred years, the study area therefore is well matured in terms of development with most of the available land having potential have already been developed. Areas left undeveloped mostly comprise of hilly and forested areas which are not suitable for development. Despite the land constraints, some land use changes have been observed in the project area. These changes are mostly re-development consisting of conversions of residential to commercial uses and the development of high-density apartments/flat replacing the traditional/low density settlements. There are also several vacant lands being developed for commercial and residential purposes. **Figure 2.8** shows the projected Land use for the project area.

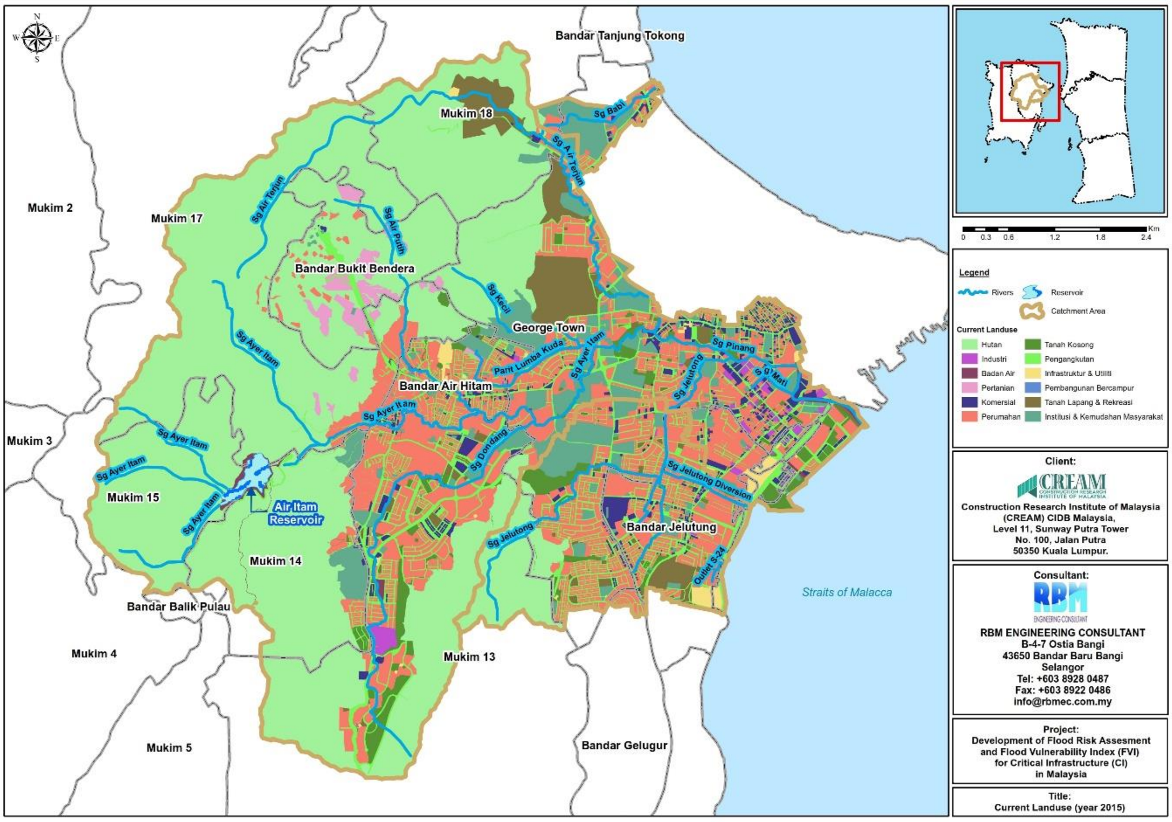


Figure 2.7: Current Land use Map of the Project Area

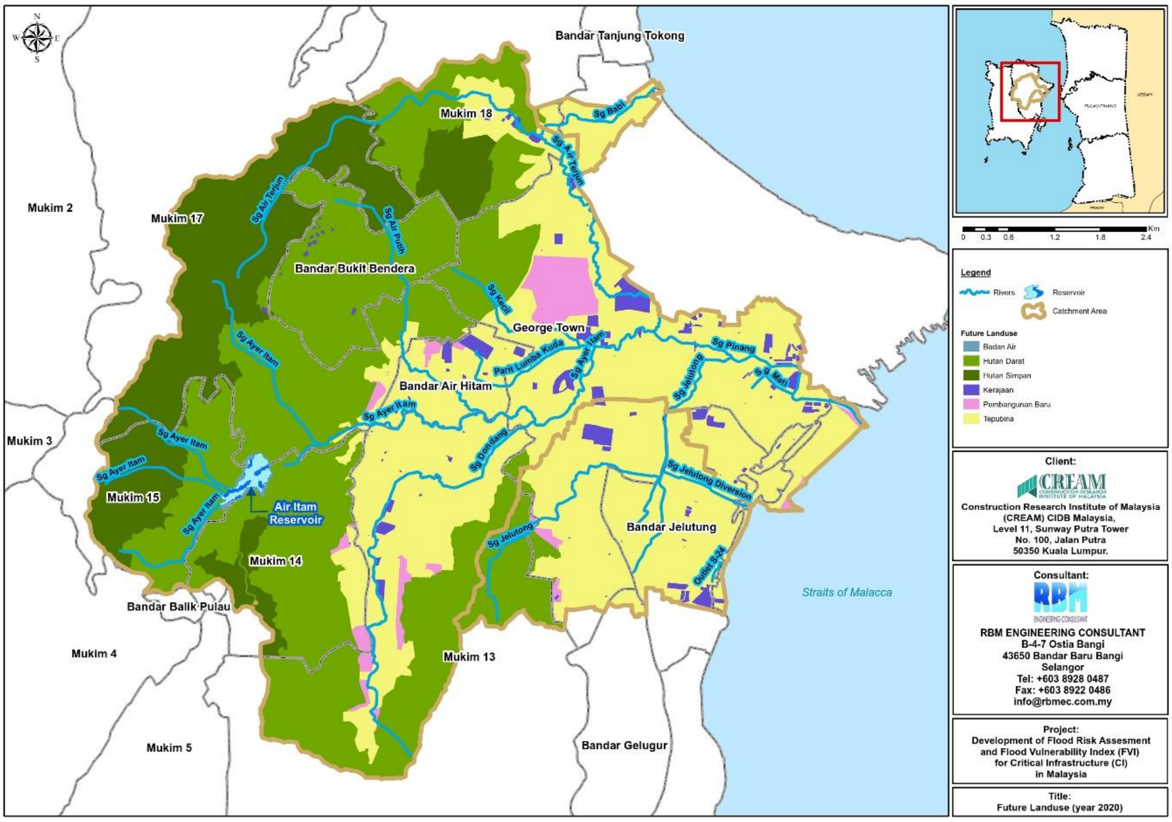


Figure 2.8: Projected Land use for the project area.

2.5.3 Land Values

The project area has among the highest urban land values in the country. Despite the small lots available, a typical commercial land at Chulia Street has an average value of RM20.9 million per hectare (*source: Rancangan Struktur Negeri Pulau Pinang, 2005. The figure will be updated during the inception report*). **Table 2.5** list the typical land values in the project area.

Table 2.5: Typical Land Values on the Project Area
(source: Rancangan Struktur Negeri Pulau Pinang, 2005)

Land use	Location	Average Area (ha)	Land Value (RM/ha)
Agricultural	Jln Sungai Pinang	0.92	437,000
	Jln Balik Pulau	5.21	1,902,000
	Off Jalan Balik Pulau	0.31	578,000
Residential	Green Road	0.09	6,400,000
	Jalan Lahat	0.95	8,440,000
	Jln P Ramlee	0.05	9,180,000
	Jln Boundry	0.17	5,050,000
	Jalan Tanjung Bunga	0.04	10,490,000
	Jalan Macalister	0.26	10,210,000
Commercial	Chulia Street	0.06	20,900,000
Industrial	Jln Sungai Pinang	0.16	8,380,000
	Jln Terusan	0.12	7,410,000

2.6 POPULATION AND HOUSING

2.6.1 Existing Scenario

According to the Population and Housing Census of Malaysia 2000, the population of the Project Area is 169,978 (this figure will be updated during inception report). This figure forms 38% of the population of the District of Timur Laut or 13% of the whole population of the State of Penang. The population is ethnically split between malays, Chinese and Indians, the largest of the three groups being the Chinese followed by the malays. The ratios of ethnic background among the races are 59.6% Chinese; 33% Malays and 11.4% Indian population.

The most populated area is the city of Georgetown followed by the Mukim of Paya Terubong and Mukim Ayer Itam, which form the immediate areas of the Sungai Pinang river basin. **Table 2.6** and **Table 2.7** shows the population at the mukim level (sub-district) and racial distribution within the Sungai Pinang river basin respectively.

Table 2.6: Distribution of Population by Mukim

Mukim	No. of Populations
Bandaraya Georgetown	72,541
Mukim 13 Paya Terubong	74,191
Mukim 14 Bukit Paya Terubong	1,817
Mukim 15 Bukit Air Itam	39
Mukim 16 Ayer Itam	18,532
Mukim 17 Batu Feringhi	167
Mukim 18 Tg Tokong	2,691

Table 2.7: Racial Distribution of Populations

Mukim	Malays	Chinese	Indian	Others	Total
Bandaraya Georgetown	36,578	120,765	14,612	907	172,862
Mukim 13 Paya Terubong	45,261	103,563	18,107	748	167,679
Mukim 14 Bukit Paya Terubong	4	1,761	23	1	1,789
Mukim 15 Bukit Air Itam	0	52	0	0	52
Mukim 16 Ayer Itam	1,873	14,464	1,809	68	18,214

Table 2.8 shows the distribution of households and the distribution of households and living qurters in the affected mukims. The number of households is highest in Georgetown City and Mukim 13 (Paya Terubong) with 43,889 and 42,590 respectively. Consequently, the number of living quarters is also highest in these two mukims with 52,537 and 57,899 respectively. However, all these figures will be updated during the inception report later.

Table 2.8: Households and Living Quarters according to Mukim

Mukim	Household	Living Quarters
Bandaraya Georgetown	42,889	52,537
Mukim 13 Paya Terubong	42,590	57,899
Mukim 14 Bukit Paya Terubong	429	539
Mukim 15 Bukit Air Itam	10	10
Mukim 16 Ayer Itam	5,105	6,439
Total	**91,023**	**117,424**

2.6.2 Future Population and housing trends

The population of the study area has been observed to increase every year. The increase is contributed among others by rural-urban migration and increase in accommodations as more traditional settlements are redeveloped into high-density residential areas. The rate of population increases for Daerah Timur Laut between 1990 to 2000, averages at 1.3% annually.

2.7 SUNGAI PINANG RIVER SYSTEM

The Sungai Pinang is the continuation of its tributaries that originates from the central hilly and undulating part of the catchment. The river generally flows eastwards and eventually drains into the Penang Straits through 3 outlets namely the main river mouth of Sungai Pinang, Sungai Jelutong Diversion river mouth and Sungai Air Terjun Diversion Tunnel through the Sungai Babi.

Other than the tributaries, Sungai Air Pinang itself is only approximately 3.6 km long. These tributaries are Sungai Jelutong (5.94km), Sungai Air Itam (12.88km), Sungai Air Terjun (9.30km), Sungai Dondang (6.97km), Sungai Air Putih (3.89km), Sungai Kecil (Parit Lumba Kuda) (2.64km) and Sungai Mati (0.6km). The river system along with its catchment boundaries are as shown in **Figure 2.9**. The river longitudinal section and a few typical cross-sections of Sungai Pinang and others are as shown in **Figure 2.10** and **Figure 2.11** respectively.

Among these tributaries, Sungai Air Itam is the largest and it has a length of 11 km. Sungai Kecil is the smallest tributary with its length of 4 km. The lengths, corresponding sub-catchment areas as well as average flows are shown in **Table 2.9**. Sungai Air Itam is regulated by a water supply dan located at the upstream part. Most of the Sungai Pinang and its tributaries have been channelized and lined during the development of the surrounding areas. Photos of the existing river condition along the river system of Sungai Pinang are illustrated in **Figure 2.12** to **Figure 2.18**.

Table 2.9: Physical Parameters of Sungai Pinang and its Tributaries

Rivers	Catchment Area (km2)	Length (km)	Slope (%)
Sungai Pinang	45.9	3.6	0.07
Sungai Jelutong	7.4	6.2	2.2
Sungai Air Itam	30.8	10.9	3.7
Sungai Air Terjun	10.3	10.3	6.9
Sungai Dondang	11.6	6.9	1.9
Sungai Air Putih	4.8	4.1	8.6
Sungai Kecil	1.6	2.3	8.8

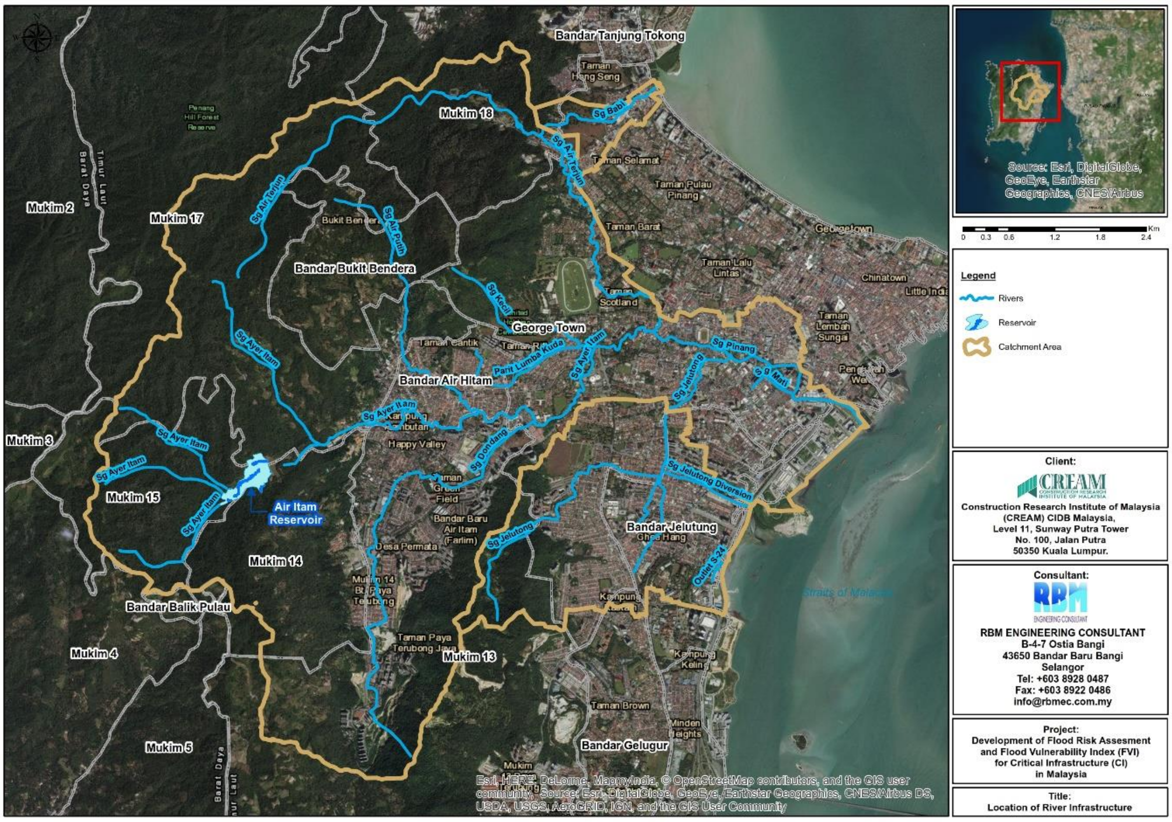
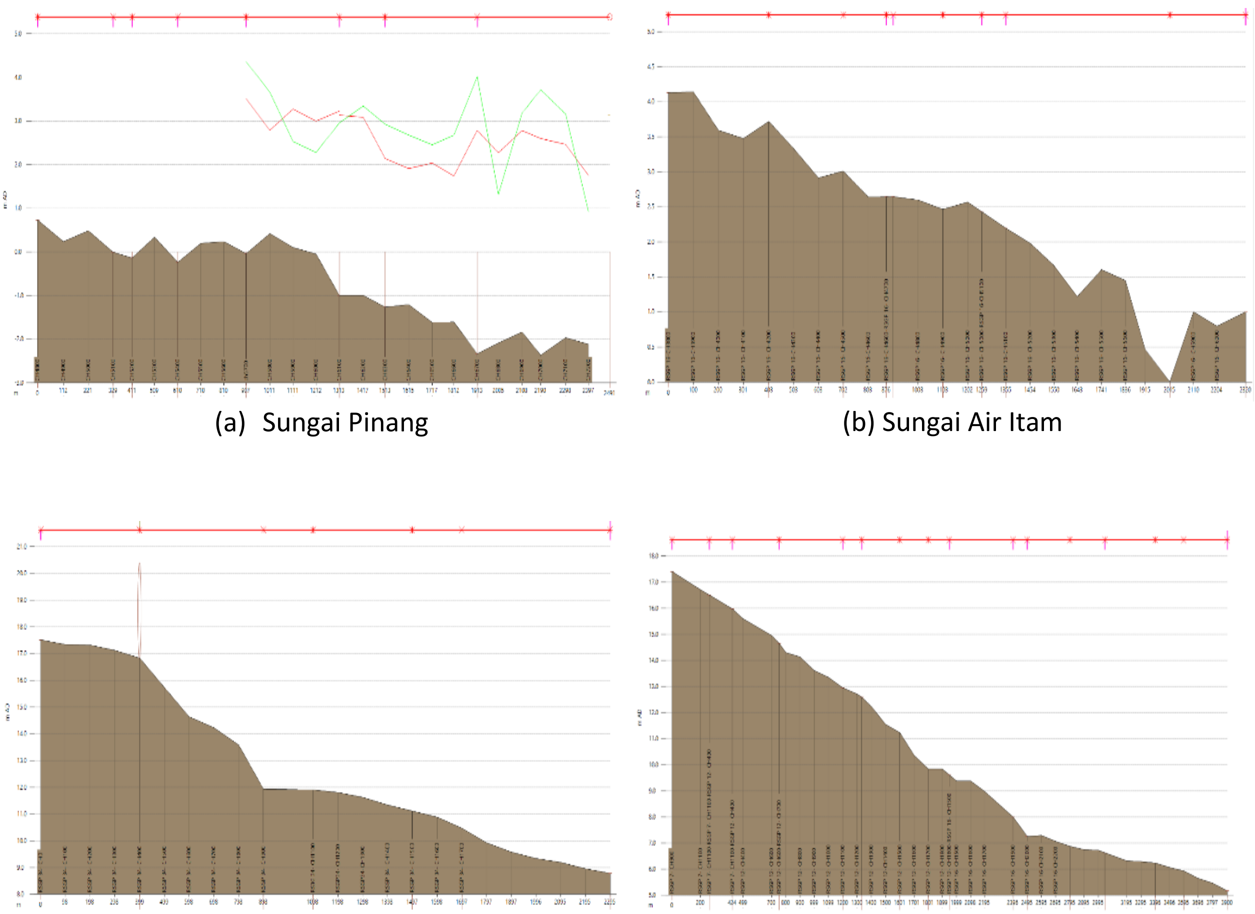


Figure 2.9: Sungai Pinang River System



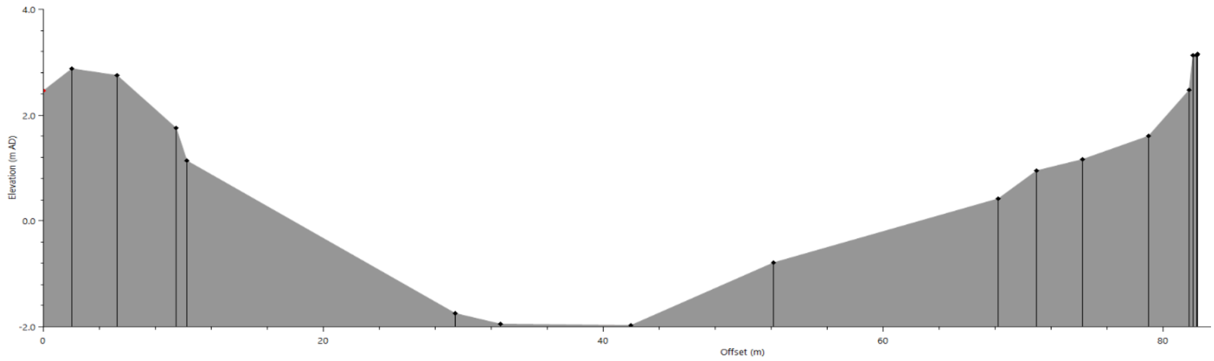
(a) Sungai Pinang

(b) Sungai Air Itam

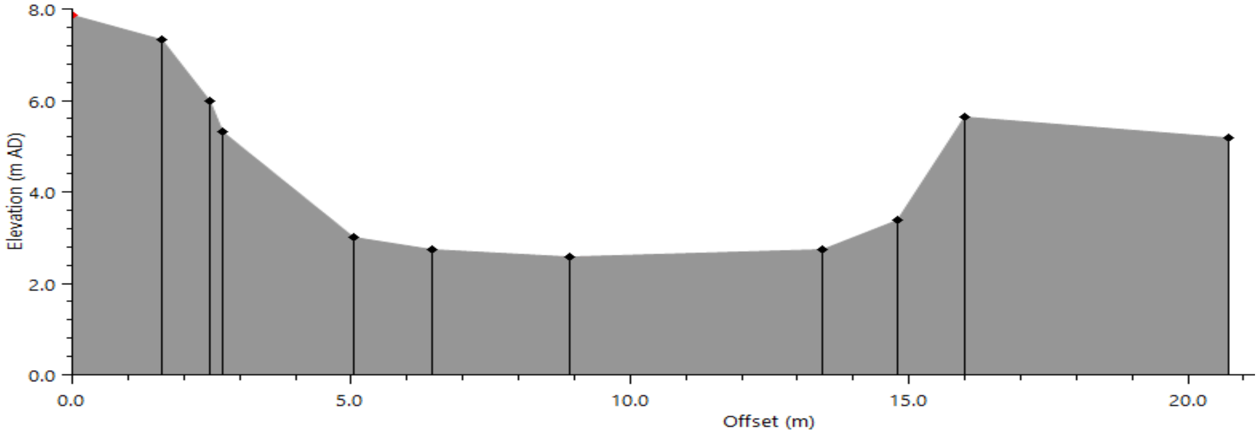
(c) Sungai Air Terjun

(d) Sungai Dondang

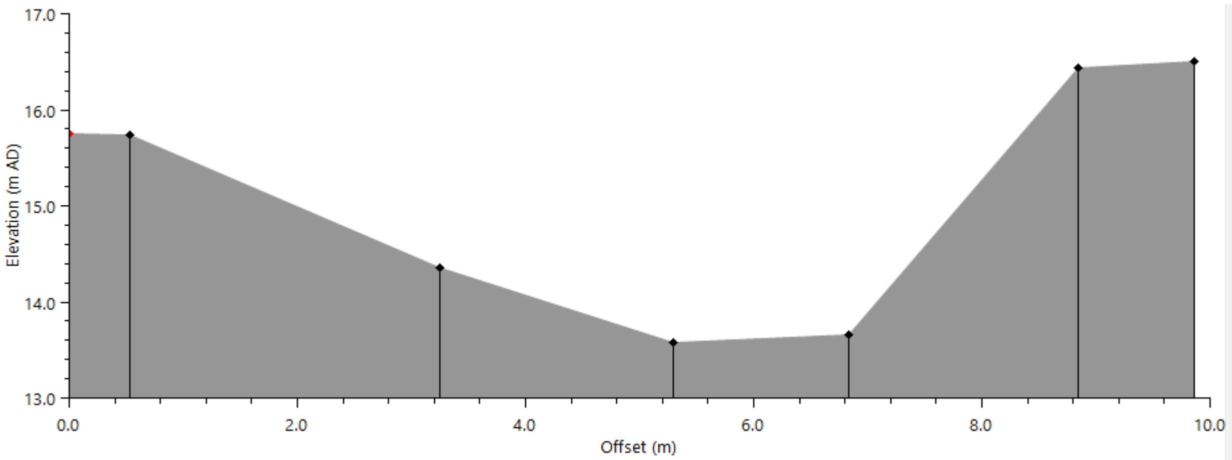
Figure 2.10: Longitudinal Sections



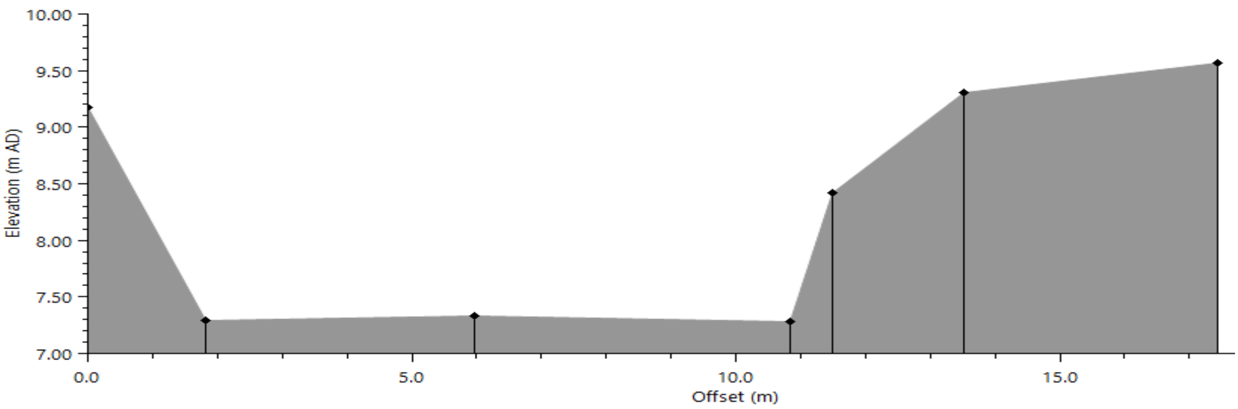
(a) Sungai Pinang



(b) Sungai Air Itam



(c) Sungai Air Terjun



(d) Sungai Dondang

Figure 2.11: Typical Cross Sections of Rivers

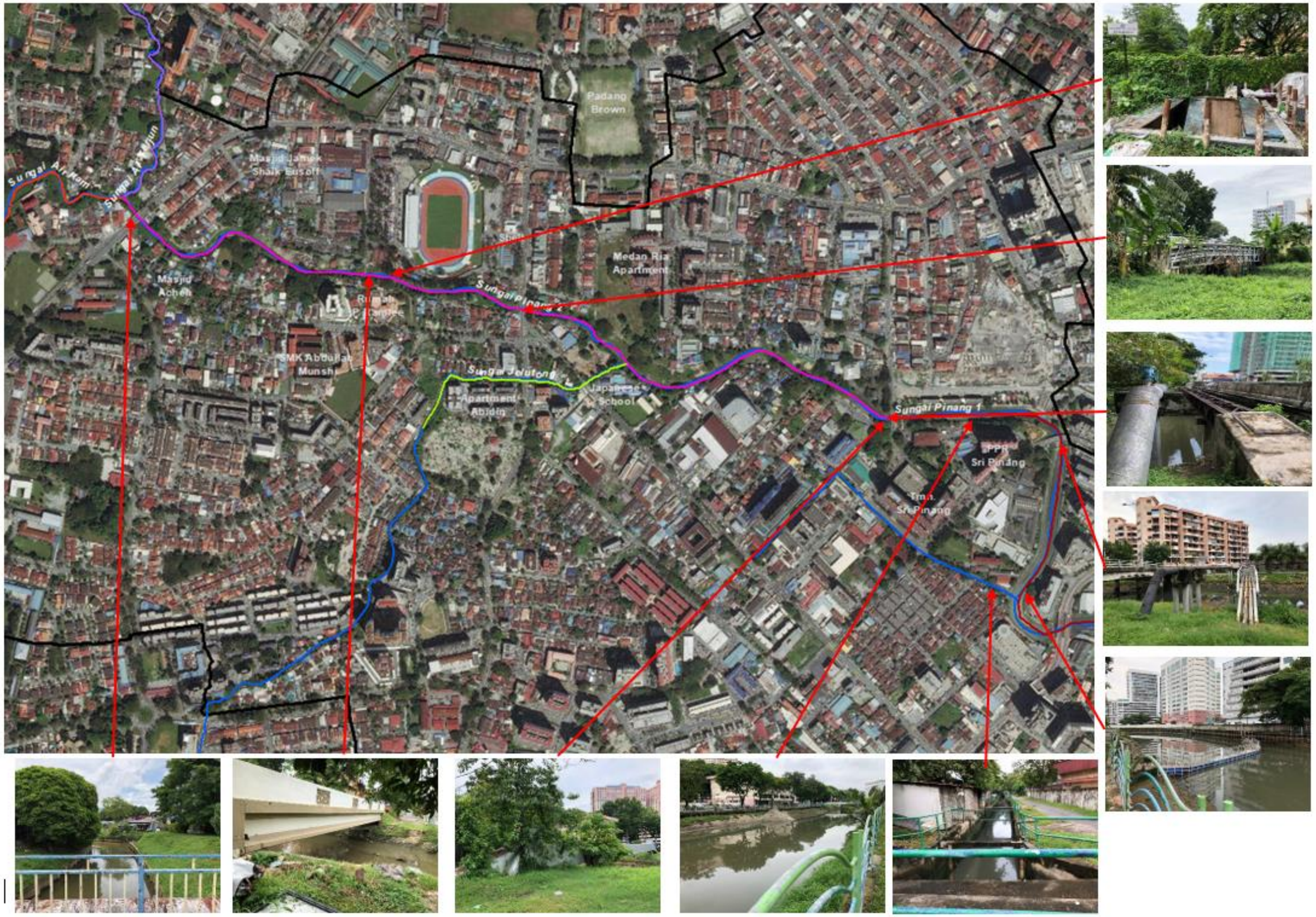


Figure 2.12: Sungai Pinang

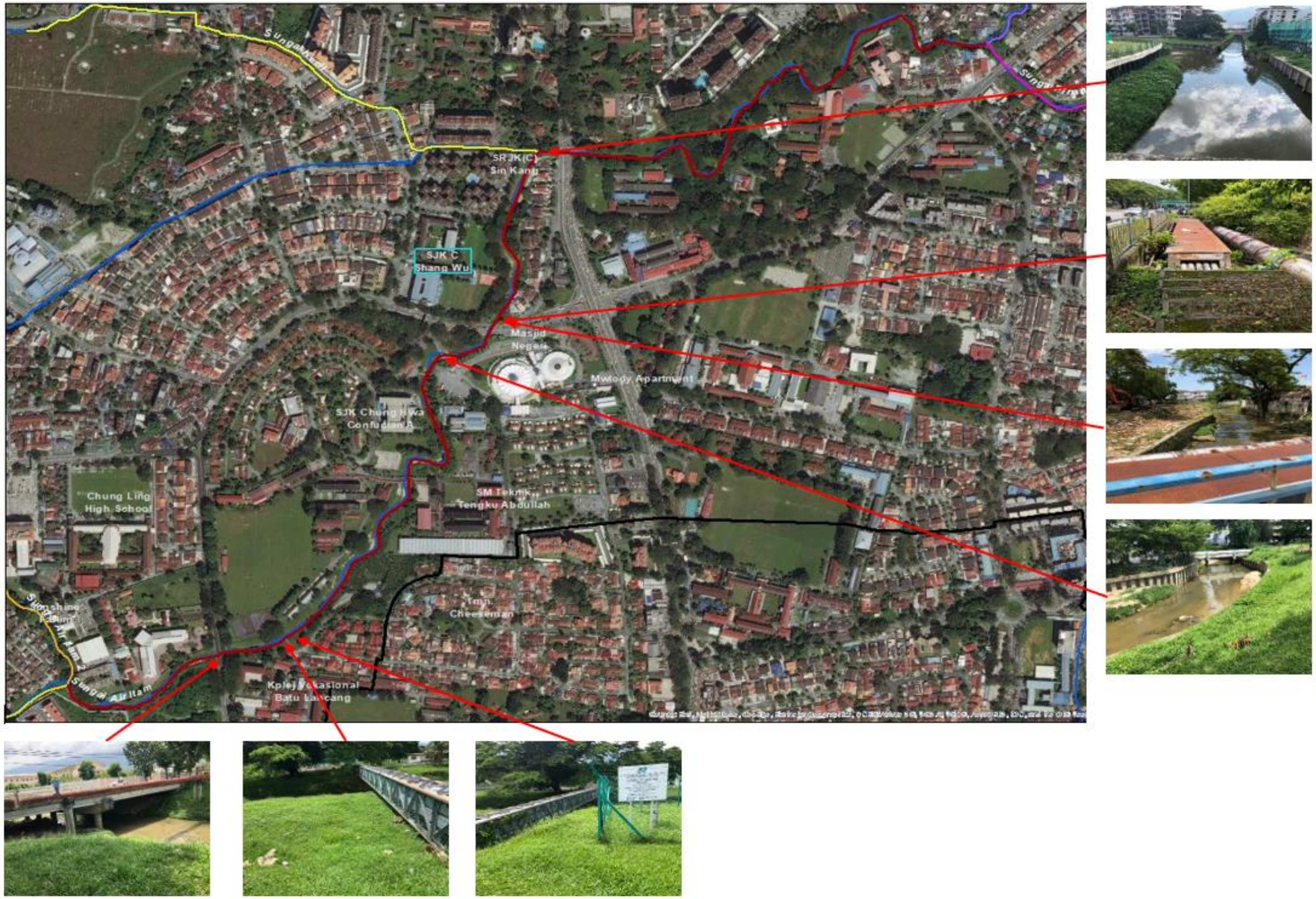


Figure 2.13: Sungai Air Itam 1

Figure 2.14: Sungai Air Itam 2

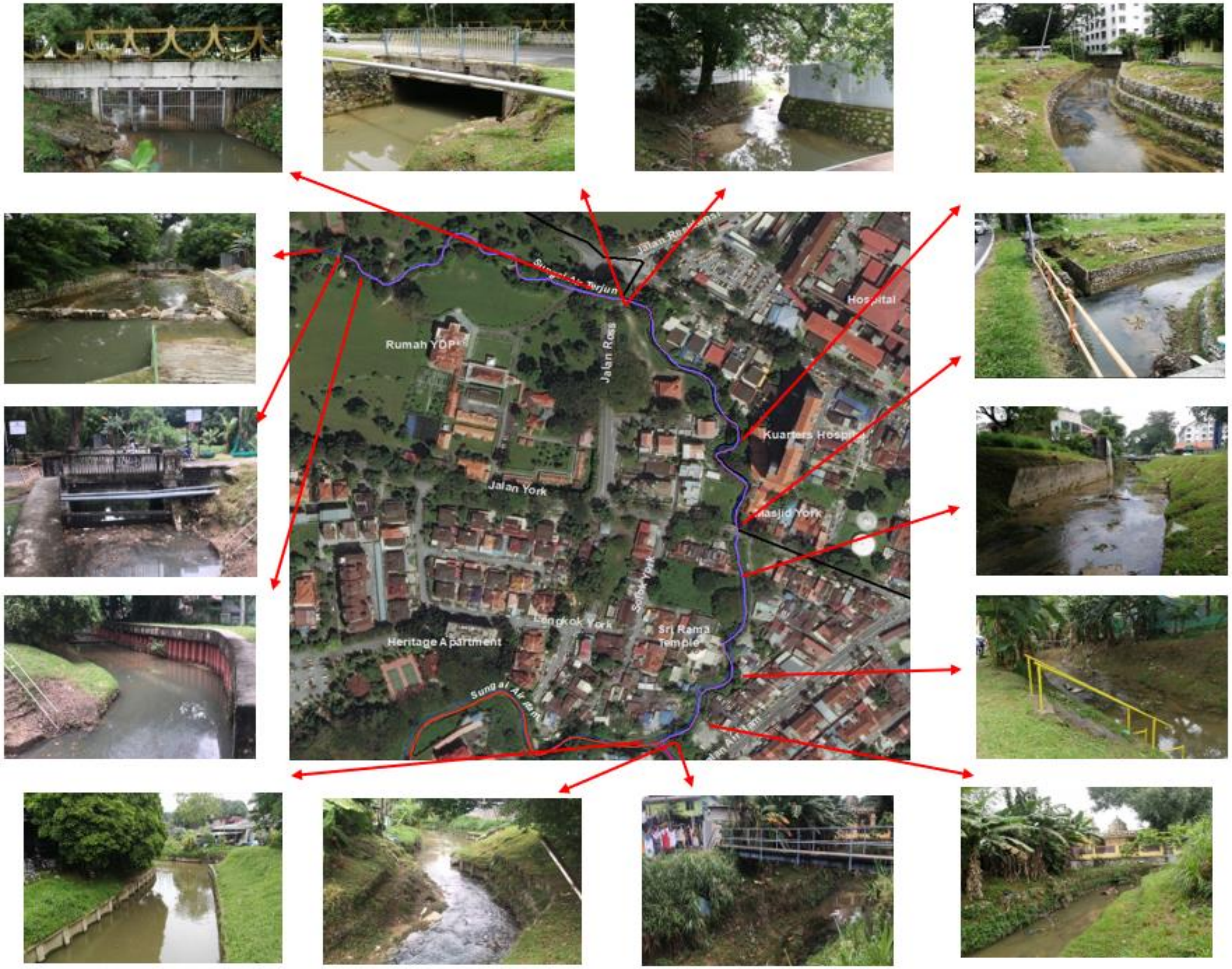


Figure 2.15: Sungai Air Terjun

Figure 2.16: Sungai Dondang

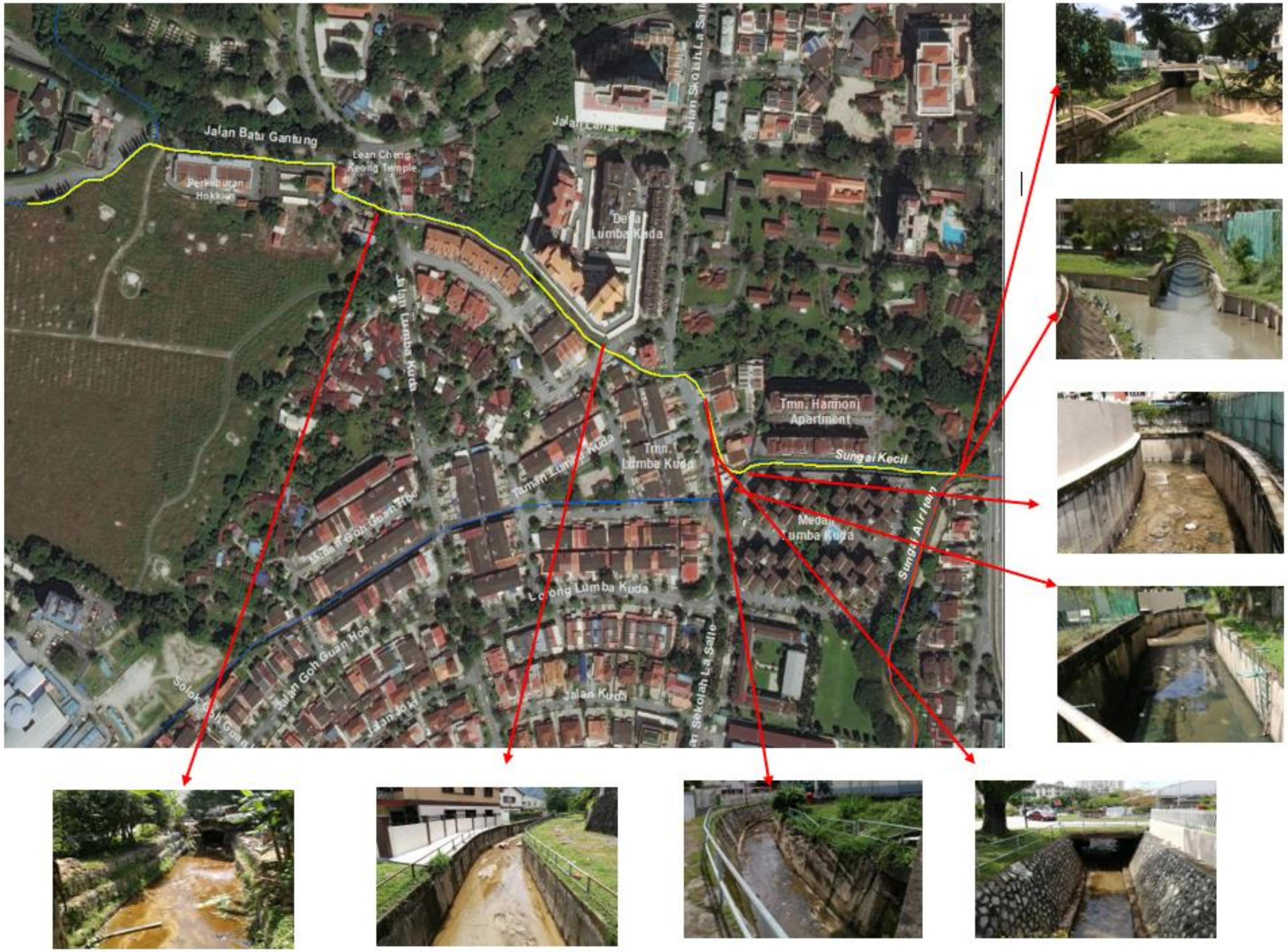


Figure 2.17: Sungai Kecil

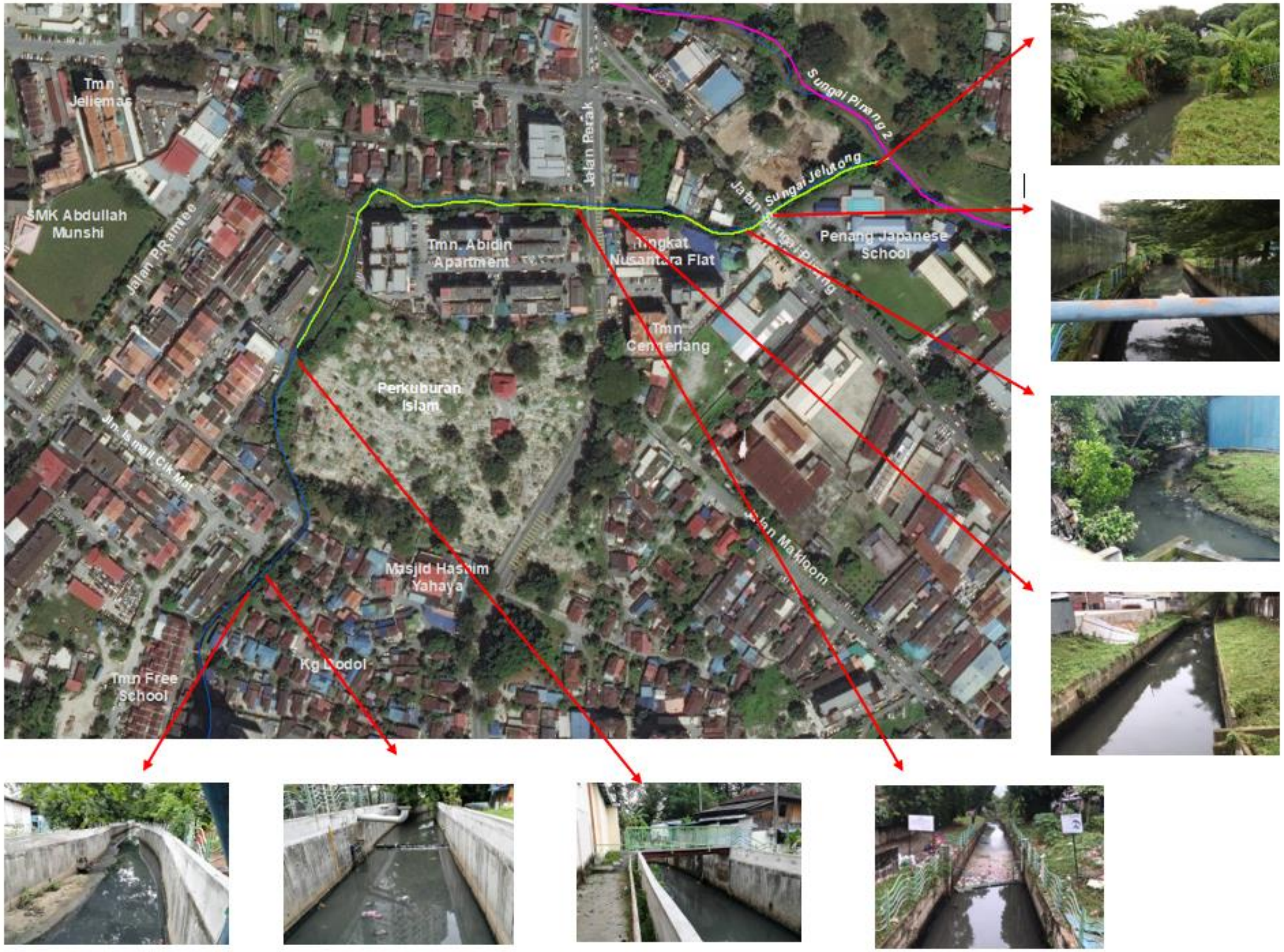


Figure 2.18: Sungai Jelutong

2.8 RIVER INFRASTRUCTURES

Based on the previous study on water quality for Sungai Pinang[2], the river infrastructure was built over the years for flood mitigation, water resources development, riverbank protection, garbage collection and to facilitate navigation. Brief description of few of these infrastructures are described below. **Figure 2.19** shows the location of the related infrastructures that were discussed herein.

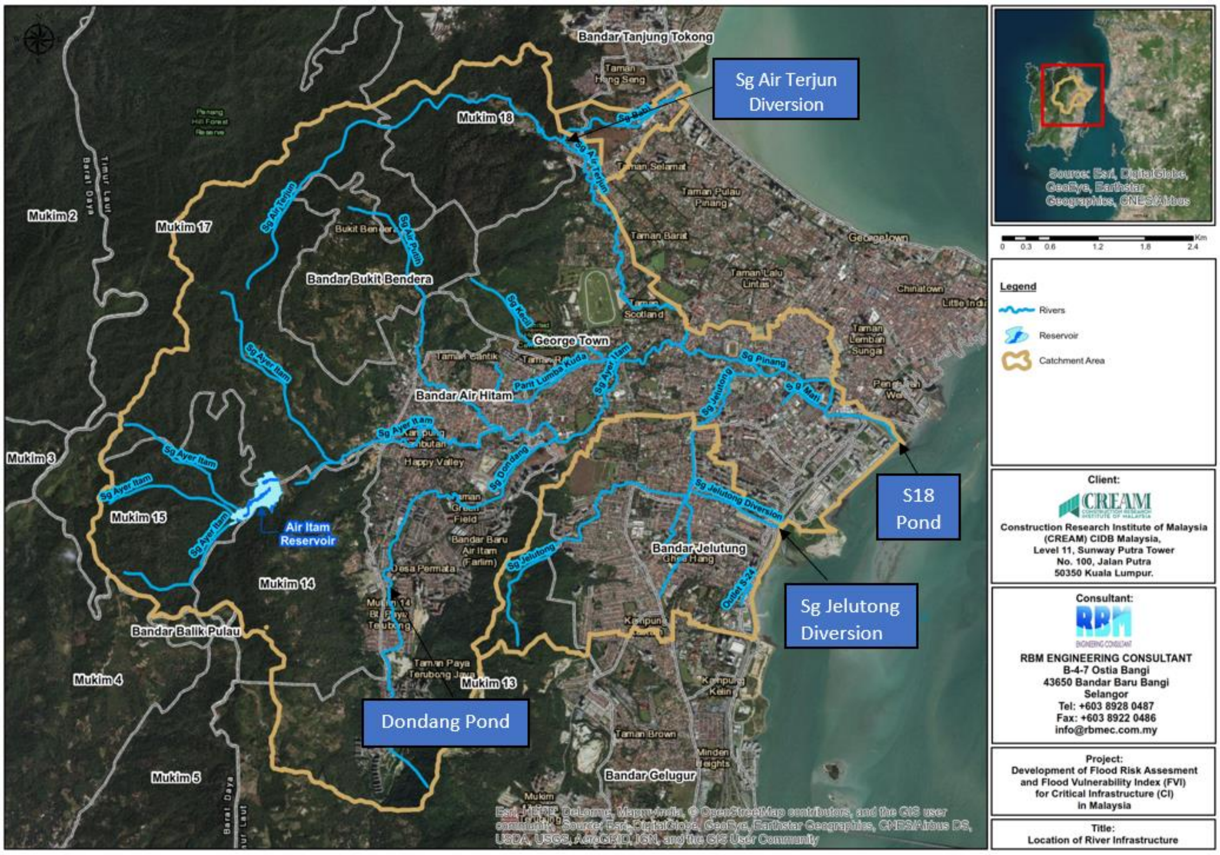


Figure 2.19: Location of River Infrastructure located in the project area

2.8.1 Air Itam Dam

The Air Itam Dam was constructed in 1962 at the upstream of the Sungai Air Itam for the Purpose of water supply. The dam is of the earth-fill type with a capacity of about 2.6 million m3. It has a catchment area of approximately 600 ha and when full the water surface area of the dam is approximately 20 ha. The crest length of the dam is 210 m with the maximum height of about 47 m. Please refer **Figure 2.20** of Air Itam Dam.

[2] Study and Detailed Design for Pollution Prevention and Water Quality Improvement Project for Sungai Pinang, Pulau, Pinang, Interim Report 2006, Jurutera Perunding Zaaba, Unit Perundingan Universiti Malaya

Figure 2.20: Air Itam Dam

2.8.2 S18 and Pumping Station

The S18 pond as shown in **Figure 2.21** comprise an area of 2.4 ha which is located on the seaward side along Lebuh Sandiland. The pond is built as a flood retention pond of about 2m deep and has a capacity of 56,000 m3. A pumping station together with twin 3.0 m x 3.1 m tidal gates along with associated mechanical and electrical facilities are also installed at the S18 pond for proper operation. Around 1 km new drain along Leboh Sandilands and parallel to Sungai Pinang were also constructed to divert runoff to the new retention pond. The location of the S18 pond is as shown in **Figure 2.19.**

Figure 2.21: S18 Pond and Pumping Station

2.8.3 Dondang Ponds

There are 3 offline retention ponds along Sungai Dondang as shown in **Figure 2.22** to reduce the flood impacts within the project area. The ponds were constructed by DID as well as on the maintenance and operation of the ponds. Two of the ponds are classified as dry ponds and doubles as recreational sites (as playground) during normal condition of no flooding. The basic properties of these flood detention ponds are summaries in **Table 2.10**. location of the ponds is as shown in **Figure 2.4**.

Table 2.10: Properties of Dondang Ponds

Pond	Storage Capacity (m3)	Ponding Area (m2)	Pond Depth (m)	Type of Pond
Pond A	79,000	30,500	4.24	Dry
Pond B	73,000	32,700	4.18	Wet
Pond C	46,500	21,200	4.77	Dry

(a)

(b)

(c)

Figure 2.22: Dondang Ponds (a) Pond A (b) Pond B (c) Pond C

2.8.4 Sungai Air Terjun Diversion

Sungai Air Terjun is a 1.55km of concrete box culvert which was constructed in year 2000. It diverts most of the flow of Sungai Air Terjun directly to the Terusan Utara via the Sungai Babi in order to reduce the flooding impact on downstream of Sungai Pinang. The inlet of this diversion is as shown in **Figure 2.23** and the location is as shown in **Figure 2.19**.

Figure 2.23: Inlet of Sungai Air Terjun Diversion beside the Forest Field Apartment

2.8.5 Sungai Jelutong Diversion

The Sungai Jelutong Diversion channel was constructed in 1976 for the purpose of diverting the discharge from the Sungai Jelutong Subcatchment directly to the Terusan Selatan. It has a catchment area of approximately 5 km2 which diverts almost 90% of the flow from the natural Sungai Jelutong catchment. The diversion channel consists of rectangular reinforced concrete channel with a width ranging from 8.22 m to 9.52 m, an average depth of 3.05 m and a gradient of 1 in 833.33. **Figure 2.19** shows the location of the Sungai Jelutong diversion and **Figure 2.24** shows some of the photos in the in the diversion channel before it is being rehabilitated currently.

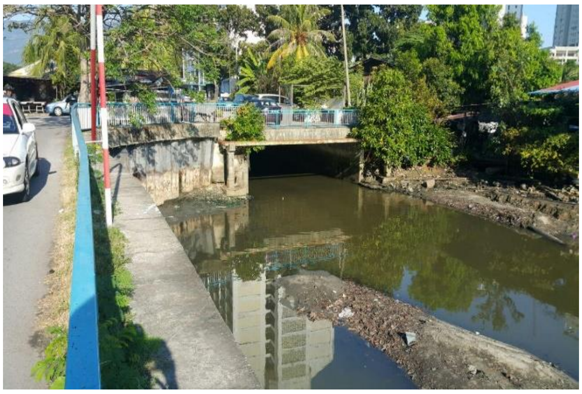


Figure 2.24: (left) Outlet of Sungai Jelutong Diversion (right) Top of Sungai Jelutong Diversion, Jalan Tengku (bottom) Inside the Sungai Jelutong Diversion before it is currently being rehabilitated

2.9 GEOTECHNICAL CONDITIONS

Based on the JICA[3] Study which they have carried out the subsoil investigation and also the data collection, the summary of the findings of the geotechnical condition within the project area are listed as below: -

- In the coastal area there are soft alluvial deposits of sand and clay to a depth of 10 m to 16 m below ground level. Loose sandy and soft clayey sediments are deposited to a depth of about 50 m.
- The middle part of Georgetown is composed of loose to medium dense sand and silty sand with some gravel. Below these strata, there are stiff, silty clay layers and medium dense sand layers. The bearing layer is estimated to be deeper than 20 m.
- Upstream areas consist of granitic rock, talus deposits, boulder deposits and gravel and sand.

[3] The Study on Flood Mitigation and Drainage in Penang Island, Main Report, March 1991, Japan International Coorperation Agency

2.10 HYDROLOGY

2.10.1 Rainfall

Four (4) reliabale rainfall stations in terms of quality and long historical good recorded data within the Sungai Pinang basin has been identified to be used in the further hydrological analysis and modelling. The stations are as shown in **Figure 2.27** and listed below: -

1. Stn.: 5302003 Kolam Takongan A. Itam
2. Stn.: 5402001 Klinik Bkt. Bendera
3. Stn.: 5402002 Kolam Air Bersih
4. Stn.: 5403001 Lorong Batu Lanchang

The preliminary analysis of the rainfall data at the stations are highlighted in **Figure 2.25** for the annual rainfall and **Figure 2.26** for monthly rainfall.

Based on HP No. 1[4], various hydrological parameters have been derived and identified to be used in the further hydrological analysis. The parameters are listed as below: -

1. The Intensity-Duration-Frequency Curves for Rainfall Station 5402001 Klinik Bkt Bendera – **Figure 2.28**
2. The Temporal Pattern for for Region 3 – Perak, Kedah, P Pinang & Perlis – **Table 2.11**
3. The Areal Reduction Factor - **Figure 2.29**
4. The computed Design Rainfall for various return period and durations **- Table 2.12**

[4] Hydrological Procedure No. 1 (Revised and Updated 2015) Estimation of Design Rainstorm in Peninsular Malaysia, JPS Malaysia, 2015

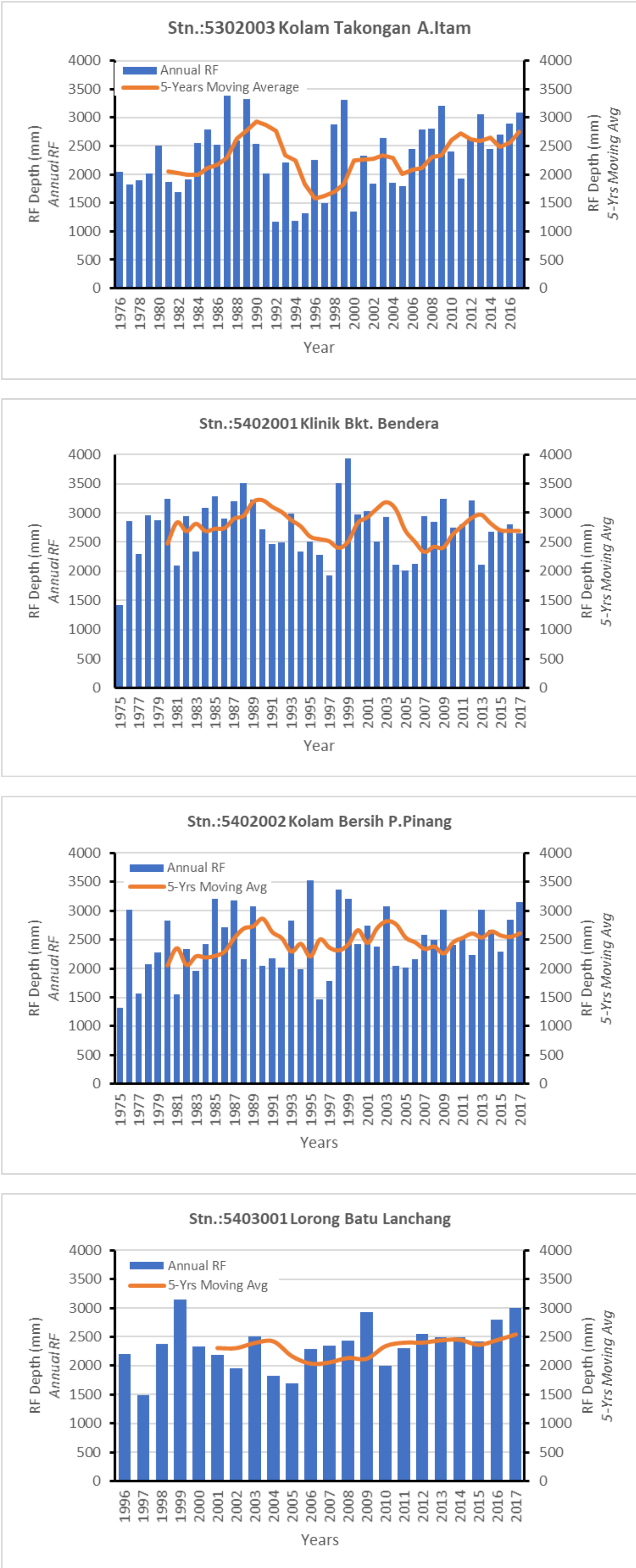


Figure 2.25: Annual rainfall at four stations

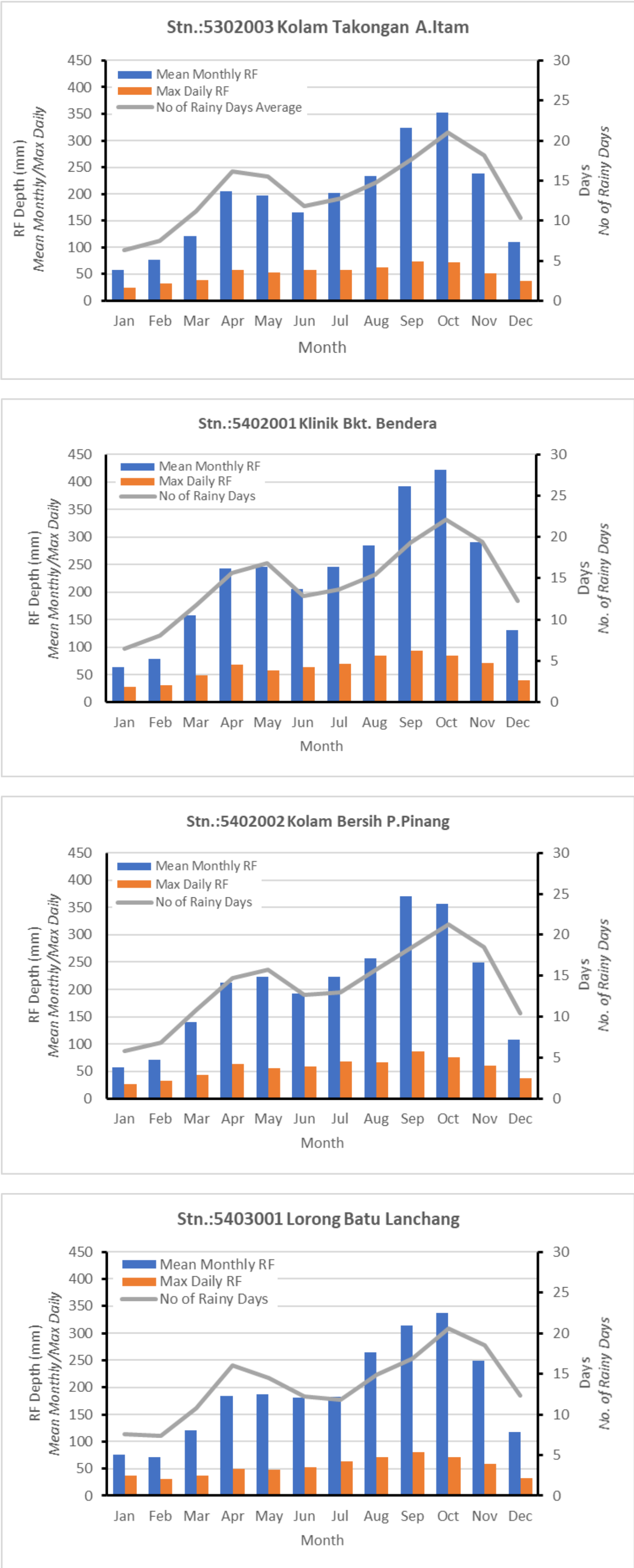


Figure 2.26: Mean monthly rainfall at four stations

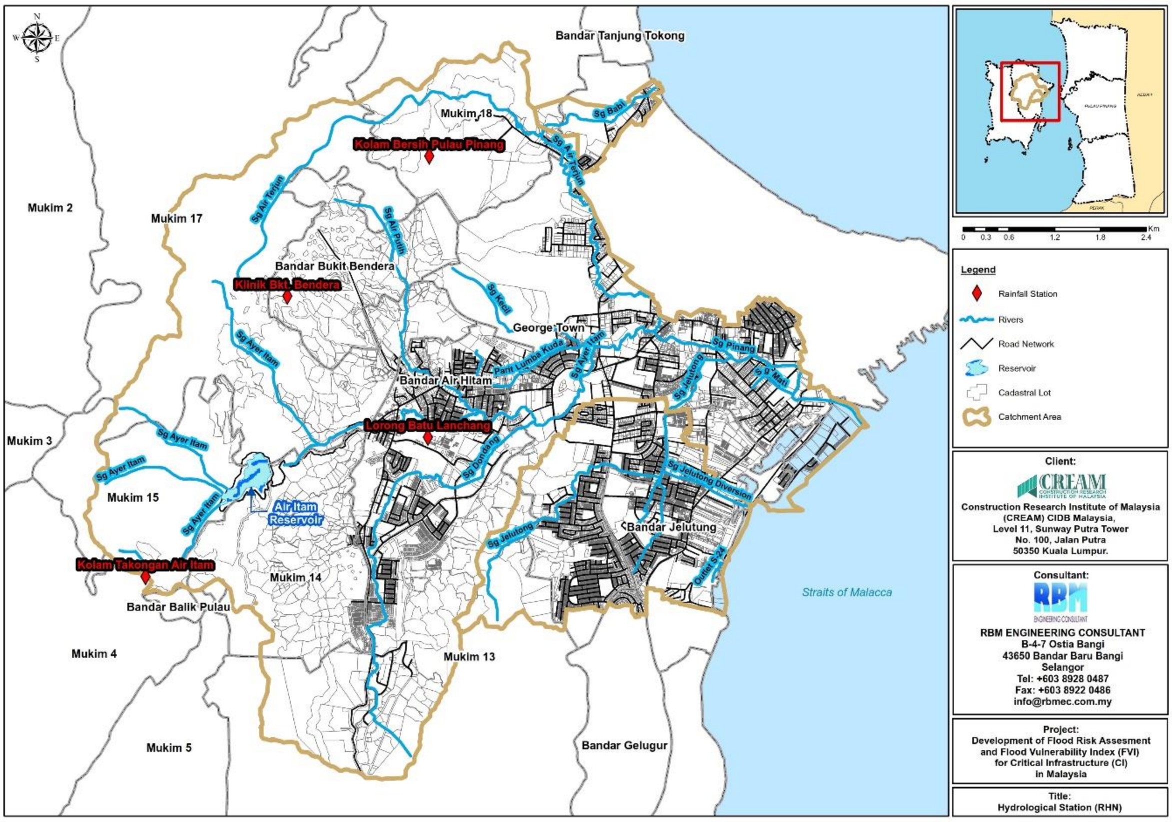


Figure 2.27: Distribution of Hydrological Stations within Project Area

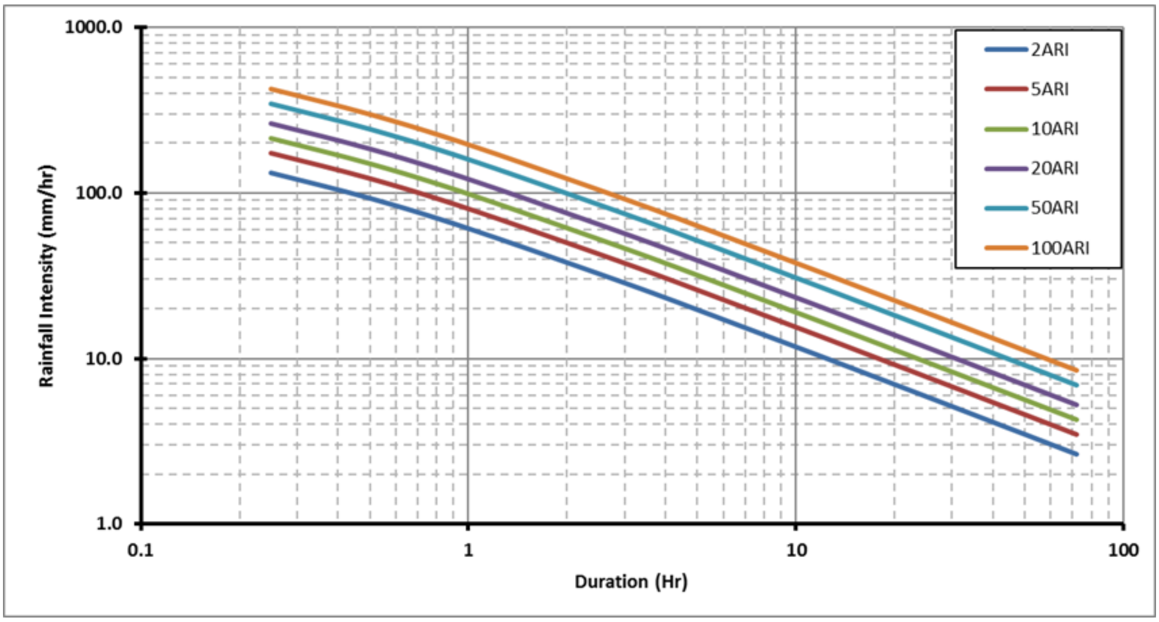


Figure 2.28: IDF Curves at Rainfall Station 5402001 Klinik Bkt Bendera

Table 2.11: Temporal Pattern for Region 3 – Perak, Kedah, P Pinang & Perlis

No. of Block	Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.215	0.158	0.068	0.060	0.045	0.040	0.027	0.015	0.021
2	0.395	0.161	0.074	0.085	0.070	0.060	0.031	0.020	0.023
3	0.390	0.210	0.077	0.086	0.078	0.066	0.033	0.026	0.024
4		0.173	0.087	0.087	0.099	0.092	0.034	0.028	0.025
5		0.158	0.099	0.100	0.113	0.114	0.035	0.038	0.028
6		0.141	0.106	0.100	0.129	0.166	0.036	0.039	0.031
7			0.104	0.100	0.121	0.119	0.039	0.045	0.044
8			0.098	0.088	0.099	0.113	0.042	0.046	0.049
9			0.078	0.087	0.081	0.081	0.044	0.052	0.058
10			0.075	0.085	0.076	0.066	0.053	0.057	0.063
11			0.072	0.063	0.047	0.046	0.056	0.069	0.074
12			0.064	0.059	0.041	0.036	0.080	0.086	0.081
13							0.076	0.073	0.078
14							0.055	0.060	0.070
15							0.048	0.056	0.058
16							0.044	0.046	0.050
17							0.041	0.045	0.044
18							0.039	0.044	0.044
19							0.036	0.039	0.030
20							0.034	0.035	0.026
21							0.033	0.028	0.025
22							0.032	0.021	0.024
23							0.031	0.017	0.022
24							0.023	0.014	0.008

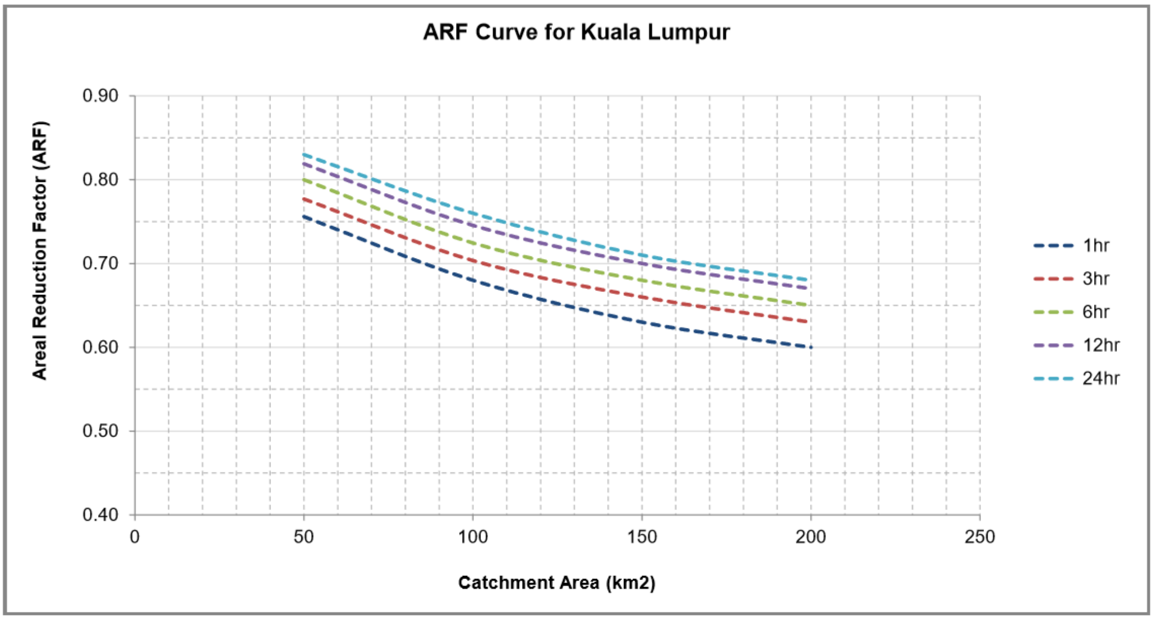


Figure 2.29: Areal reduction factor for Kuala Lumpur

Table 2.12: Design Rainfall for various return period and durations

	2		5		10		20		50		100	
	i (mm/hr)	d (mm)	i (mm/hr)	d (mm)	i (mm/hr)	d (mm)	i (mm/hr)	d (mm)	i (mm/hr)	d (mm)	i (mm/hr)	d (mm)
0.25	158.4	179.0	210.7	52.7	261.4	65.3	324.3	81.1	431.2	107.8	534.9	133.7
0.5	112.3	56.1	149.3	74.6	185.2	92.6	229.7	114.9	305.5	152.7	379.0	189.5
1	73.9	73.9	98.3	98.3	122.0	122.0	151.3	151.3	201.2	201.2	249.6	249.6
3	34.7	104.2	46.2	138.6	57.3	171.9	71.1	213.3	94.5	283.6	117.3	351.9
6	20.9	125.5	27.8	166.8	34.5	206.9	42.8	256.7	56.9	341.4	70.6	423.5
12	12.4	149.3	16.5	198.5	20.5	246.3	25.5	305.5	33.9	406.3	42.0	504.0
24	7.4	176.6	9.8	234.9	12.1	291.4	15.1	361.5	20.0	480.7	24.8	596.3
48	4.3	208.4	5.8	277.1	7.2	343.8	8.9	426.4	11.8	567.1	14.7	703.5
72	3.2	229.4	4.2	305.0	5.3	378.3	6.5	469.4	8.7	624.1	10.8	774.3

2.10.2 River Discharge

Currently Sungai Pinang is an ungauged catchment. Four water level gauging station only existed before 1982.

2.11 TIDAL LEVEL

Data on tide level of Penang Island are available in "Jadual Pasang Surut Malaysia 2018" which was published by the Pusat Hidrografi Nasional. The data was observed at Kedah Pier in Penang Island. The tidal level data obtained from this record is given in Table 2.4 below: -

Table 2.13: Tide Level at Kedah Pier

Highest Astronomical Tide	+ 3.09 m CD
Mean High Water Spring	+2.69 m CD
Mean High Water Neap	+1.96 m CD
Mean Sea Level	+1.71 m CD
Mean Low Water Neap	+1.45 m CD
Mean Low Water Spring	+0.72 m CD
Lowest Astronomical Tide	0.00 m CD
Note: *LAT is 1.555m below Land Survey Datum*	

The tide influences the flow of Sungai Pinang up tp about 2 km above the river mouth. The tidal water level records indicate that the Extreme High Water is 1.615 m LSD while the Lowest Astronomical Tide is -1.22 m LSD. Parts of the Georgetown near the Sungai Pinang river mouth is relatively low in elevation, which are occasionally inundated during high tide[1].

2.12 SUNGAI PINANG RIVERMOUTH CONDITIONS

The bathymetry of Penang Straits at the confluence of Sungai Pinang and surrounding areas are as shown by the admiralty chart in **Figure 2.30** below. Generally, the depth contours of the channel are aligned with north south axis of the straits. A long shoal, known as Middle Bank, divides the channel into two channels which are know as Eastern and Western Channel. In general, the channel is shallow and mainly used by small boats. The depth varies considerably across any east west section, with a minimum of less that 1-meter ACD near the land boundary and about 10 to 20 meters ACD in the deeper part or center of the channel.

The maximum depth of the channel is about 25 m ACD located at the throat section of the channel. Easter channel is mainly used for navigation with the main port facilities located at Prai and Butterworth at the mainland.

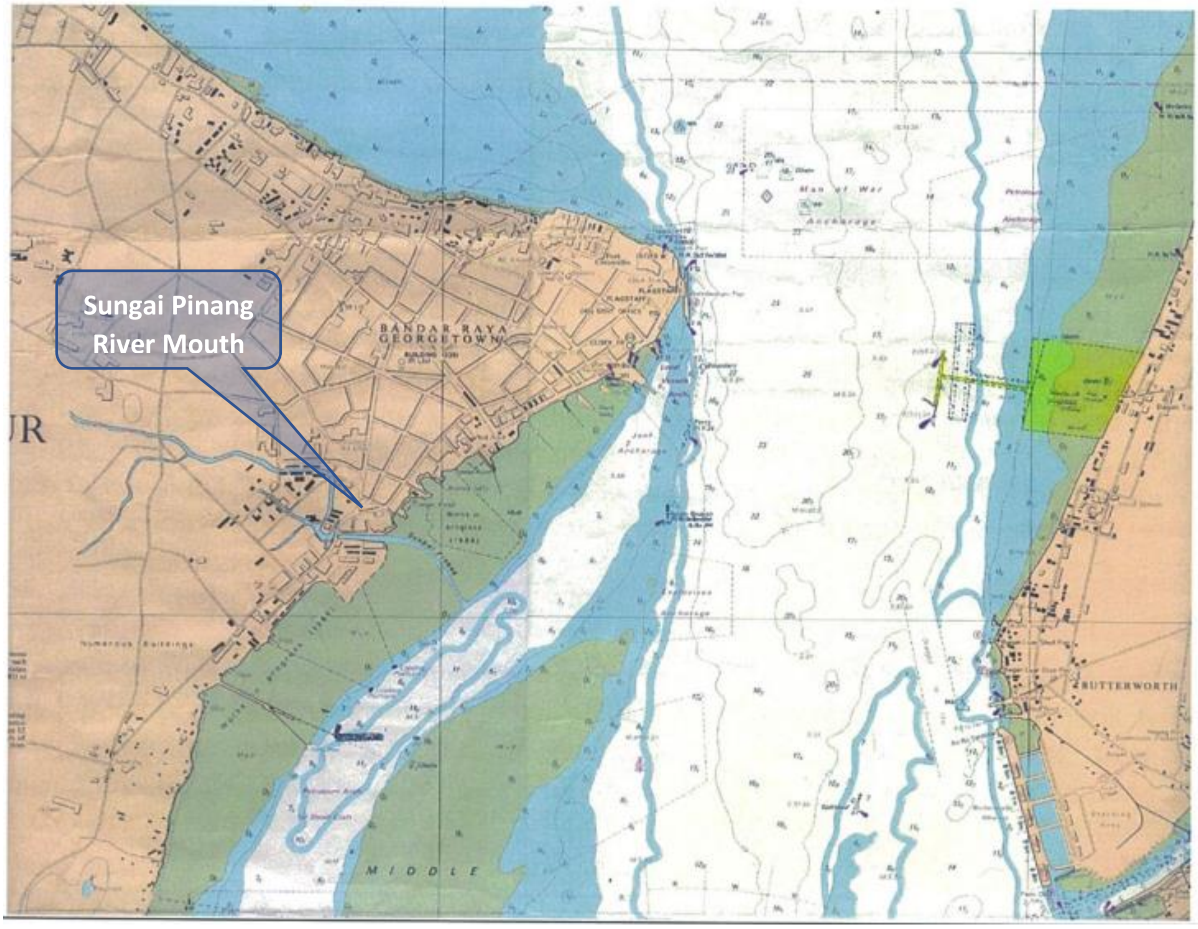


Figure 2.30: Admiralty Chart of Penang Straits

2.13 RIVER WATER QUALITY

Based on the water quality study[1] carried out in 2006/2007, extensive water quality sampling campaign has been executed in various location within the Sungai Pinang river basin as shown in **Figure 2.31**.

On top of that, the river water quality of Sungai Pinang and its tributaries was also assessed using the DOE's data between year 2001 to 2005 which were collected from 11 water quality stations along the river system. The result indicates that it has an overall water quality of Class I and II in upper reaches of Sungai Air Terjun, which represents clear water. All other tributaries other than Sungai Air Terjun, have a very bad quality of water with WQI of Class IV and V. **Figure 2.32** shows an approximation of the water quality classification for the whole river system in 2005.

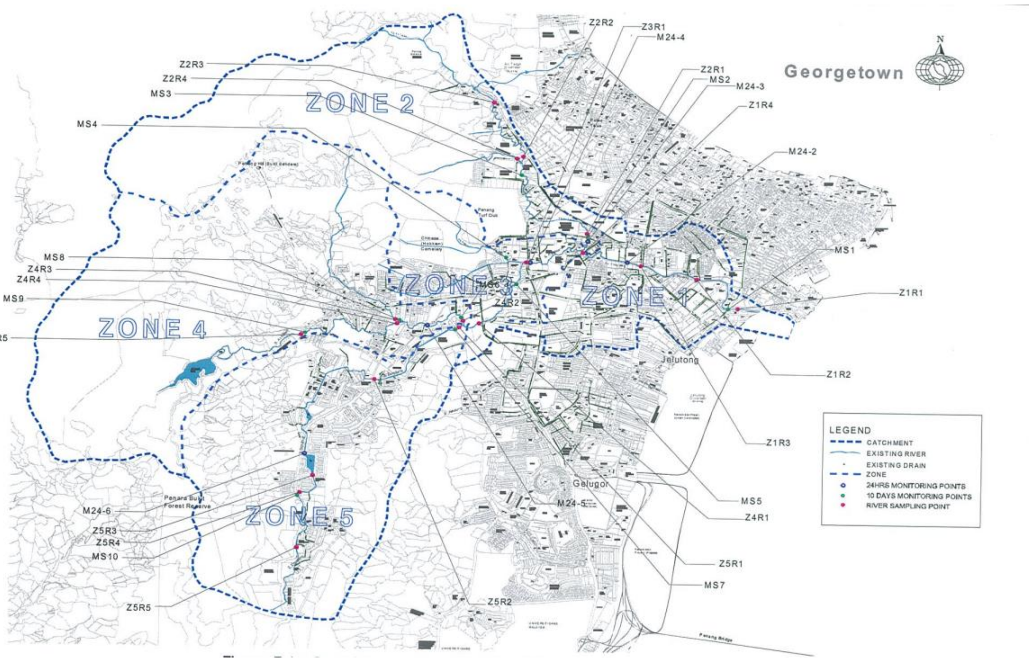


Figure 2.31: Sampling locations for River Water Quality Assessment
(Source: Study and Detailed Design for Pollution Prevention and Water Quality improvement Project for Sungai Pinang, Pulau Pinang, 2007)

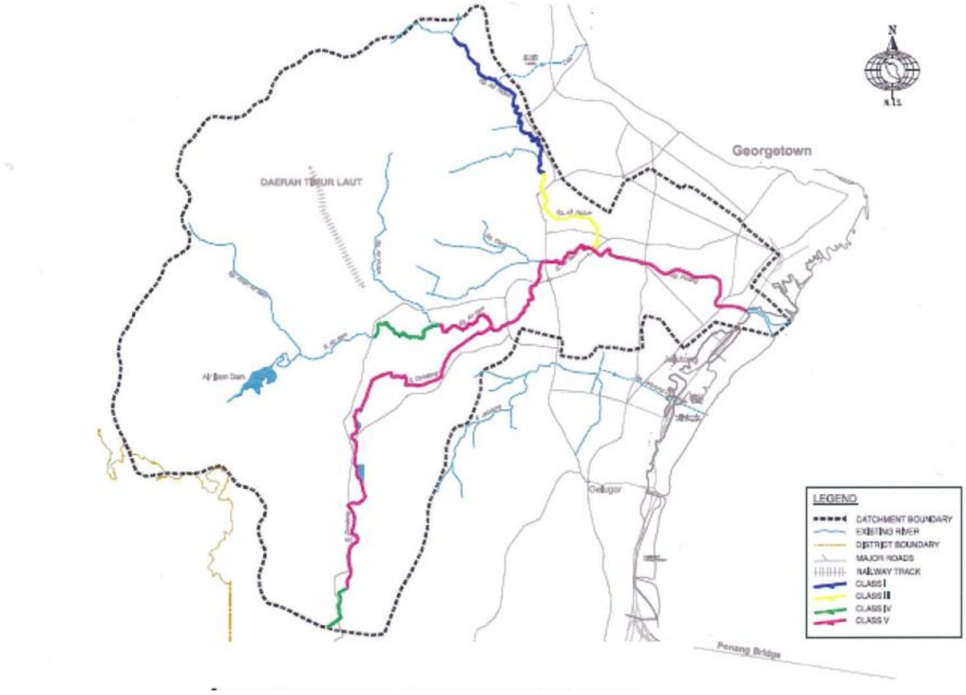


Figure 2.32: Water Quality Classifications along Main Rivers of the Study Area based on DOE Data (2005)
(Source: Study and Detailed Design for Pollution Prevention and Water Quality improvement Project for Sungai Pinang, Pulau Pinang, 2007)

2.14 FLOODING ISSUES

Sungai Pinang Basin is very to sensitive to short duration storm for instance a storm duration between 1-hour and 3-hour with magnitude of precipitation of more than 60 mm depth in an hour. This phenomenon will be caused various flood hot spot locations will be flooded with excess storm water from the river and drain. The flooded areas include Jalan P Ramlee, Kg Rawang, Jalan Langkawi, Lorong Kulit, Kg Makan, Jalan Transfer, Lebuh McNair, Jalan Baru, Jalan Kedah and part of Jalan Patani. The flood usually detained within these areas for approximately between 3 and 10 hours and the peak may raise to about 0.5 m to 1.5 m deep depending on the location and the rainfall storm centre.

2.15 RECENT FLOOD EVENT

Among the severe flood event that occurred recently was during 4th – 5th November 2017 between 2 pm to 6 am. Based on the Laporan Banjir Kilat[5] the precipitation summary depth at various rainfall station within the project area are listed in **Table 2.14** below: -

Table 2.14: 4th November 2017 Storm Event (depicted from Laporan Banjir Kilat[5])

Bil.	Lokasi Data Hujan	Kumulatif Hujan (mm)
1	Stesen Sungai Air Itam @ Jalan Scotland	151 mm
2	Stesen Lorong Batu Lanchang	159 mm
3	Stesen Kolam Bersih @ Sungai Air Terjun	126 mm
4	Stesen Sungai Pinang	150 mm

*** Nota : Beberapa stesen mencatatkan bacaan hujan kumulatif melebihi 60 mm (Very Heavy)

Concurrently occurred during the storm event, tidal condition in Sungai Pinang river mouth was at the high tide of which the tide level is approximately at +2.7 m @ 1:00 am. While the maximum recorded of water level in major rivers are as follows:

- Sungai Pinang = 4.07 m (danger level)
- Sungai Air Itam = 7.955 m (danger level)
- Sungai Dondang = 22.62 m (danger level)

[5] Laporan Banjir Kilat, Pejabat Jurutera Daerah Timur Laut, Jabatan Pengairan dan Saliran Negeri Pulau Pinang, November 2017

The affected areas: -

(1) Jalan P. Ramlee
(2) Sek. Abdullah Munshi
(3) Kampung Masjid.
(4) Kampung Makan
(5) Masjid Negeri, Air Itam
(6) Jalan kebun Lama
(7) Kampung Hashim Yahya
(8) Jalan Langkawi
(9) Parit Lumba Kuda
(10) Halaman Bukit Gambir
(11) Jalan Patani
(12) Jalan Singgora
(13) Astaka Stadium
(14) Persiaran Perak
(15) Jalan Trengganu
(16) Sungai Relau, Taman Sri Angsana
(17) Minden Height Jalan 3
(18) Pangsapuri Sri Saujana
(19) Klinik Kesihatan Sungai Dua
(20) Kampung Rawa
(22) Air Itam
(23) Lebuhraya Thein Teik
(24) Jalan Zoo
(25) Ladang Hong Seng
(26) Kg Baru Air Itam
(27) Kg Kubor, Bt Feringghi
(28) Jalan Abullah Arif
(29) Jalan Goh Guan Ho
(30) Klinik Jalan Perak
(31) Kampung Dodol
(32) Jalan Burma
(33) Lorong Macalister
(34) IPK
(35) Anson Road
(36) Jalan Nordin
(37) Flat Mutiara Indah, Bukit gambir
(38)Lebuh rambai, Paya Terubong
(39)Jalan Tiga Air Itam
(40) Jalan Thein Teik Shell Sheik madar
(41) balai Polis Bandar baru Air Itam

Several photos during the event was captured in the Laporan Banjir Kilat and shows in the following **Figure 2.33** to **Figure 2.38**.

Figure 2.33: Kampung Makam (Flood Event 4th - 5th November 2017)

Figure 2.34: Sungai Pinang (Flood Event 4th to 5th November 2017)

Figure 2.35: Kg Masjid (Flood Event 4th - 5th November 2017)

Figure 2.36: Lintang P Ramlee (Flood Event 4th - 5th November 2017)

Figure 2.37: Masjid Negeri Pulau Pinang (Flood Event 4th - 5th November 2017)

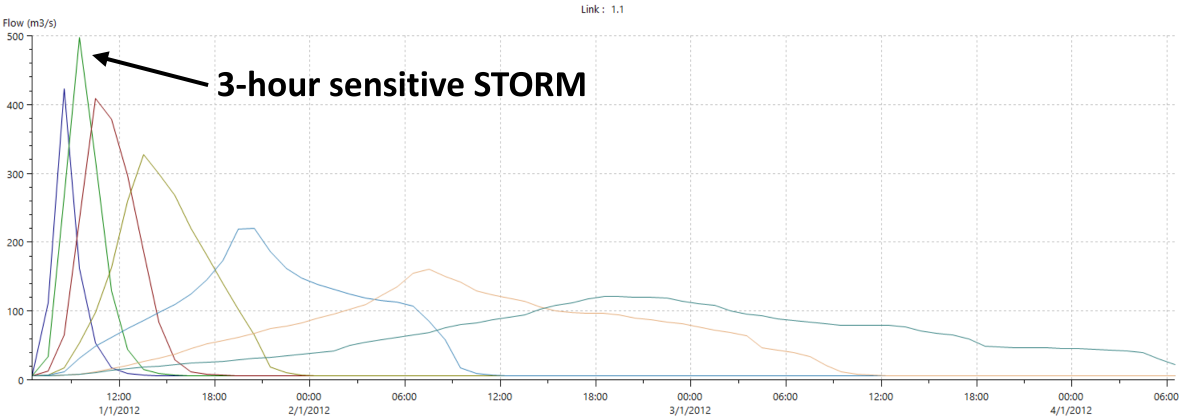
Figure 2.38: Pangsapuri Saujana (Flood Event 4th - 5th November 2017)

2.16 FLOOD HAZARD MAP

The consultant has carried out hydrodynamic model simulation for two flood hazard map scenarios in the Sungai Pinang Basin. The model was developed using the InfoWorks ICM which considering the geometry of major major rivers and storm water drain. The two important scenarios are:

- 100 ARI Flood Event
- 4th – 5th November 2017 Flood Event

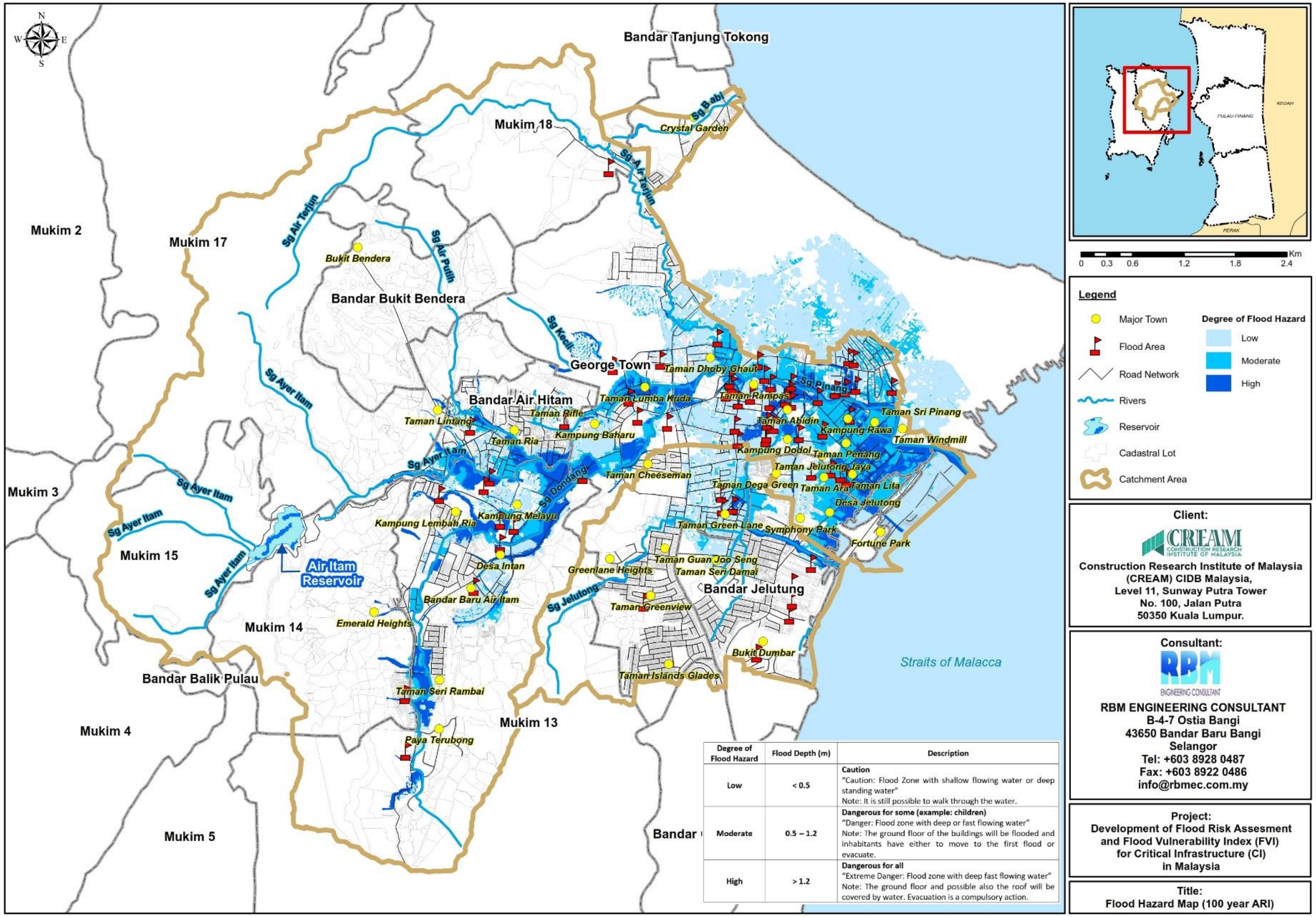
The simulation of 100 ARI Flood Hazard Map is considering the sensitive storm for Sungai Pinang Basin of 3-Hours. **Figure 2.39** below shows the sensitivity analysis of storm duration at the outlet of Sungai Pinang Basin.



	Flow Min	Flow Max
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 1H	5.837	423.404
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 3H	5.837	497.588
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 6H	5.837	409.120
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 12H	5.837	327.357
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 24H	5.837	219.748
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 48H	5.837	160.262
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 72H	5.837	121.358

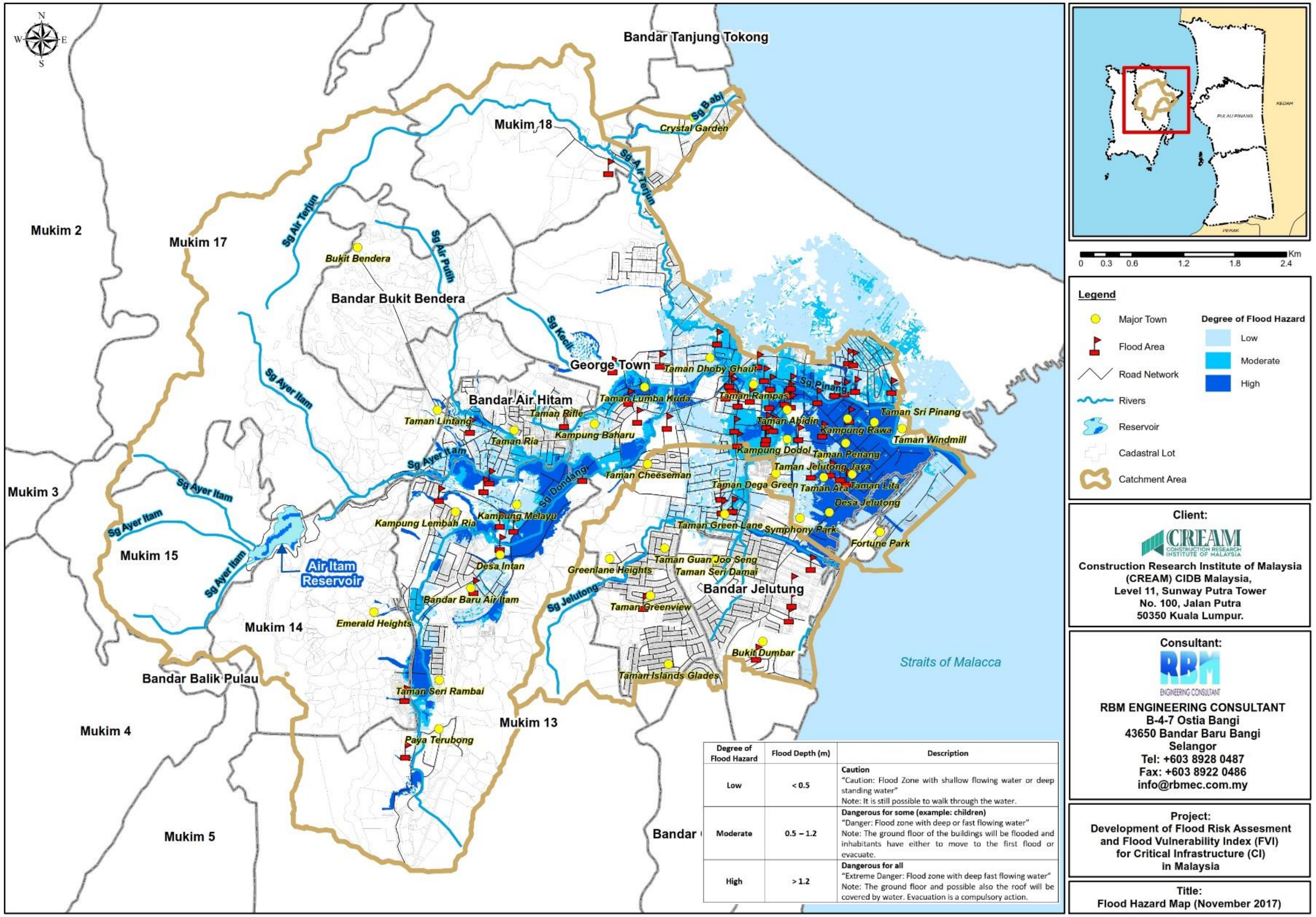
Figure 2.39: 3-Hour storm is the sensitive storm for Sungai Pinang Basin

Figure 2.40 and **Figure 2.41** shows the Hazard Map for Sungai Pinang Basin for 100 ARI and Flood Event of 4th to 5th November 2017 respectively. The inundation area caused by the flood event of 4th to 5th November 2017 is worse than the 100 ARI 3-Hours with more area flooded with flood depth of more than 1.2m.



Degree of Flood Hazard	Flood Depth (m)	Description
Low	< 0.5	**Caution** "Caution: Flood Zone with shallow flowing water or deep standing water" Note: It is still possible to walk through the water.
Moderate	0.5 – 1.2	**Dangerous for some (example: children)** "Danger: Flood zone with deep or fast flowing water" Note: The ground floor of the buildings will be flooded and inhabitants have either to move to the first flood or evacuate.
High	> 1.2	**Dangerous for all** "Extreme Danger: Flood zone with deep fast flowing water" Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

Figure 2.40: Hazard Map for Sungai Pinang Basin for 100ARI 3-Hours



Degree of Flood Hazard	Flood Depth (m)	Description
Low	< 0.5	**Caution** "Caution: Flood Zone with shallow flowing water or deep standing water" Note: It is still possible to walk through the water.
Moderate	0.5 – 1.2	**Dangerous for some (example: children)** "Danger: Flood zone with deep or fast flowing water" Note: The ground floor of the buildings will be flooded and inhabitants have either to move to the first flood or evacuate.
High	> 1.2	**Dangerous for all** "Extreme Danger: Flood zone with deep fast flowing water" Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

Figure 2.41: Hazard Map for Sungai Pinang Basin for Flood Event 4th to 5th November 2017

CHAPTER 3

FLOOD RISK ASSESSMENT, FLOOD VULNERABILITY INDEX AND CRITICAL INFRASTRUTURE

CHAPTER 3

FLOOD RISK ASSESSMENT, FLOOD VULNERABILITY INDEX AND CRITICAL INFRASTRUCTURE

3.1 INTRODUCTION

Floods are known as the most common and destructive natural phenomenon (Yoon, et al., 2014) They can cause severe physical, social and economic damages and losses in both rural and urban areas (Masood, M, Takeuchi, & K, 2011); (Balica, et al., 2012); (Balica, et al., 2013); (Zhang, Y, You, & WJ, 2013); (Albano, et al., 2014). Several studies (IPCC, 2007); (Yilmaz & AG, 2014) reported an increase in frequency and magnitude of extreme rainfalls, which have aggravated the flood related concerns.

Global warming is one of the main reasons for the increase in frequency and magnitude of extreme rainfalls (therefore floods) since the warmer atmosphere with enhanced humidity leads to a more active hydrological cycle (Mailhot, et al., 2007). (Katz & Brown, 1992) stated that even a small change in the mean rainfall due to global warming can cause significant changes in extreme rainfalls. Also, urbanization is another driver which increases intensity and frequency of floods. (Alaghmand, et al., 2010) showed that there is a direct relationship between urbanization and hydrological characteristics such as infiltration, runoff frequency and flood depth in an urban area. They stated that increased urbanization increases floods, both in frequency and magnitude. The effects of urbanization and global warming on floods will increase in future (due to more urbanization to accommodate increased population in cities and rises in greenhouse gas emissions) (IPCC, 2013)

Considering the above, flood vulnerability assessment is essential to identify high risk areas and develop cost-effective flood mitigation and/or adaptation strategies. Flood Vulnerability Index is the most commonly used approach and it is a useful tool that can assist urban planners and policy makers in prioritizing flood mitigation strategies and in increasing public awareness by providing information through highlighting hot spots for the flood risk, communities vulnerable to floods and so on (Balica, SF, N, Wright, & NG, 2009). While flood risk assessment analyses the overall impact of the social system, vulnerability assessment aims to explore the distributive patterns among affected populations and communities, considering that different people or groups can be exposed to different magnitudes and types of loss.

3.2 URBAN FLOODING AND CONSEQUENCES

Flood can be regarded as natural hazards except for dam breaks and failing flood defences. Floods are seldom on purpose but obviously flood risks do not classify as risks taken voluntary. Floods may have enormous consequences in terms of many fatalities and damage, but flood still can be controlled and manageable. Floods may cause disasters affecting a whole country's sense of control (Brujin, 2004). Urban flooding is significantly different from rural flooding as urbanization leads to developed catchments which increases the flood peaks from 1.8 to 8 times and flood volumes by up to 6 times. Consequently, flooding occurs very quickly due to faster flow times (in a matter of minutes). Urban areas are densely populated and people living in vulnerable areas suffer due to flooding, sometimes resulting in loss of life. It is not only the event of flooding but the secondary effect of exposure to infection also has its toll in terms of human suffering, loss of livelihood and, in extreme cases, loss of life. Increasing trend of urban flooding is a universal phenomenon and poses a great challenge to urban planners the world over. Problems associated with urban floods range from relatively localized incidents to major incidents, resulting in cities being inundated from hours to several days. Therefore, the impact can also be widespread, including temporary relocation of people, damage to civic amenities, deterioration of water quality and risk of epidemics (National Disaster Management Authority Government of India).

Urban flooding is specific in the fact that the cause is a lack of drainage in an urban area. As there is little open soil that can be used for water storage nearly all the precipitation needs to be transporting to surface water or the sewage system. High intensity rainfall can cause flooding when the city sewage system and draining canals do not have the necessary capacity to drain away the amounts of rain that are falling. Water may even enter the sewage system in one place and then get deposited somewhere else in the city on the streets. Sometimes you see dancing drain covers (FloodSite, 2009). According to (FloodSite, 2009), floods are infrequent phenomena for which it is difficult to establish the exact probability distribution. Next, the reliability of flood defences is difficult to define, and so is the location where defences may fail. The consequences of frequent floods are rarely well documented, but the consequences of more rare floods can often only be established by calculation because they may never have occurred yet. And the results of such calculations cannot be validated by empirical data because of a lack of such data. All in all, we have to work with uncertain figures and, since we multiply these with each other, this results in risk metrics that are even more uncertain.

According to (Neal, 2014), the effects of urbanization new development gives rise to the concrete world of buildings, roads, and infrastructure all made of impermeable 50 materials. This disrupts the natural drainage area in a floodplain which leads to a specific type of flooding called urban flooding. Although several factors attribute to urban flooding such as river, coastal, and flash floods this type is specific due to a lack of drainage in an urban area. Human factors are the basis of urban flooding. As urbanization grows the natural landscape of a floodplain is replaced by new development. During rainfall water is absorbed into the soil as groundwater and is slowly discharged into streams over time. In natural situations the water is absorbed through vegetation, grasslands and depressions in the ground. Impermeable surfaces reduce the amount of surface area for infiltration of the surface water to groundwater to occur. This causes large volumes of overland flow water to move quickly into a stream or river. In an urban environment water infrastructure such as storm sewers and drainage systems must carry this water to its proper destination. When the surface water does not have a way to the soil the storm systems become overwhelmed and increase the runoff to nearby streams. Once water enters a drainage network, it flows faster than it would under normal circumstances leading to flooding conditions that are occurring more frequently and severely in nature.

Urban flooding is an increasing problem and is more and more under discussion all over the world. Urban flooding happened because of man-made. The growth of dense urban areas increases the discharge volume from impermeable areas might not have sufficient capacity for the additional sewage. This problem influences separate systems as well as combined systems. In addition to the increasing urban flood due to increased surface sealing, changed storm patterns and intensities, increased water consumption and deteriorating of sewer networks contribute to an increase urban flood (König, Sægrov, & Schilling, 2012)There are three types of categorisation of consequences urban flooding which are direct damage, indirect damage and social consequences. Direct damage is the first category includes all material damages, which have been caused by the water velocity itself. Some of these damages can be repaired but certain damages need to replace, with the exception of loss of human and animal life. The direct damage is mainly connected to buildings and their interior. The range of severity goes from perished storage goods, over rotten floors and wall panelling, to substantial structural damage like cracks in foundations (König, Sægrov, & Schilling, 2012).

Besides, the second category of consequences urban flooding is indirect damage. This category includes consecutive damages and side-effects caused by irregularities due to the flood. The second category included administrative and labour costs. The persons concerned do not have to be directly affected by the flood and the damage does not necessarily occur where the flood occurs. Indirect damages are not continuous but last for the duration of the flood and a short time after. Next, the third category is social consequences. Under the third category all negative long-term effects belong, which are caused by the frequency and severity of flooding. These consequences have a more psychological character and are not easy to identify explicitly. They are often combined with further aspects. These damages cannot be removed directly after a flooding occurs. The monetary evaluation of the damage is difficult, but their importance might be crucial (e.g. when the consequences are major political decisions). When a city experiences severe flooding frequently, the regional development will be restrained. The economic development will be slowed down, and the social well-being is affected. Frequent floods reduce quality of life, and environmental pollution might increase. A more concrete example is the limited possibility to utilise basements in frequently flooded areas. Also, property values will decrease in these areas (König, Sægrov, & Schilling, 2012)

3.3 VULNERABILITY AND RISK ASSESSMENT ON CRITICAL INFRASTRUCTURE

3.3.1 Definition and factors of vulnerability

Vulnerability is an important concept in human-environment research, its conceptualization has developed over time and reflects contribution from a wide range of disciplines. Concept of vulnerability has changed frequently since it has been used in different disaster studies and as a result there are several attempts to define the term vulnerability. Some definitions of specific vulnerabilities refer to climate change (IPCC, 1992, 1996, 2001), some others for environmental hazard (Blaikie, et al., 1994); (Klein & Nicholls, 1999), and some refer to floods (McCarthy, et al., 2001). An elaboration of the definition of vulnerability is given based on some literature review.

(Cannon, 1990) was described vulnerability as a measure of the degree and type of exposure to risk generated by different societies in relation to hazards. While, based on research that have done by (Hebb & Mortsch, 2007) vulnerability was define as the degree of exposure and the capacity to cope and recover or adapt. In this definition, three factors of vulnerability are mentioned. First factor is about the hazard itself and the objects in danger (e.g. exposure to hazards, the geographical location). Second factor consists of the preconditions of being harmed (e.g. the conditions that make populations more vulnerable, before the hazard occurs). And the third factor encompasses the capacity to cope, adapt and recover from the hazard. Other research by (Klein & Nicholls, 1999) explained that the vulnerability as a function for the natural environment using three components: resistance, resilience and susceptibility and (Lewis, 1999) described that “vulnerability is the root cause of disaster”. While (Mitchell, 2002) explained vulnerability as a function of resistance, resilience and exposure (Messner & Meyer, 2006) and (Merz, Thieken, & Gocht, 2007)stated that it’s a function of the vulnerability definition to elements at risk, exposure and susceptibility. (Kasperson, et al., 2005), (Adger, 2006), and (IPCC, 2007) combined the above concept of vulnerability into a vulnerability function related to exposure, sensitivity and resilience.

Based on the similarity between all these studies, the researcher was agreed on the three factors that define vulnerability. Sometimes other name was used for the factor, but the main principle is the same, flood vulnerability will be defined as “the function of the factors exposure, sensitivity and resilience of a system”.

3.3.1.1 Exposure

Exposure is defined as the predisposition of a system to be disrupted by a flooding event due to its location in the same area of a system to be disrupted by a flooding event due to its location in the same area of influence (Balica S. F., 2007). Also, exposure can be understood as the values that are present at the location where floods can occur. These values can be goods, infrastructure, cultural heritage, agriculture fields or people. Exposure is the extent to which property is in flood risk areas and is generally described as patterns and processes which estimate its intensity and duration. (Messner & Meyer, 2006) also define it as the various elements at risk, similar as (Fuchs, Kuhlicke, & Meyer, 2011), who define it as the relationship of elements at risk to the hazard.

3.3.1.2 Susceptibility

Susceptibility is often described as the potential of a system to be harmed by a hazardous event as flooding, caused by some level of fragility, relative social or economic weaknesses or disadvantageous conditions. (Programme, 2011); (Cardona, 2003); (Balica S. F., 2007).

3.3.1.3 Resilience

Resilience is referred to as adaptive capacity or resistance, and often also used as lack of resilience (internal vulnerability, defencelessness). Resilience is the ability of a system to adjust to changes or threats, to avoid, mitigate or absorb potential damage or harm, to cope with the consequences without loss or to even take advantage of opportunities (IPCC, 2007). (Balica S. F., 2007) summarizes the different characteristics of resilience as 'maintaining significant levels of efficiency in its components'. And (Cardona, 2003) summarizes the many characteristics of lack of resilience as 'the limitations of access and mobilization of the resources', like (Balica S. F., 2007).

3.4 FOOD VULNERABILITY INDEX (FVI)

Human population worldwide is vulnerable to natural disasters. In recent years the impacts of floods have gained importance because of the increasing amount of people who are exposed to its adverse effects. The aim of vulnerability studies is to recognize correct actions that can be taken to reduce vulnerability before the possible harm is realized. Flood Vulnerability Index is a powerful tool for policy and decision-makers to prioritize investments and makes the decision-making process more transparent. Identifying areas with high flood vulnerability may guide the decision-making process towards a better way of dealing with floods by societies.

Vulnerability Equation

Vulnerability = Exposure + Susceptibility – Resilience

All societies are vulnerable to floods, under different cases and situations, which make them somewhat unique; understanding the distinctions amongst them, may help to plan and provide policy ideas to improve the quality of life of the people living in them

3.5 INDICATOR OF FLOOD VULNERABILITY INDEX (FVI)

Since a direct measurement of vulnerability is not possible, an indicator or a set of indicators should be used to quantify the condition of a system as an inherent (Balica, et al., 2012). (Gomez, 2001) noted that indicators should focus on quantifiable and understandable small aspects of a system and give people a sense of a bigger picture. In fact, indicators are input data can be used in indicator-based method to decide flood vulnerability of a region. Considering specific indicators can help to assess the systems vulnerability, which can lead to identifying actions needed to decrease the vulnerability (Balica, et al., 2012).

In the indicator-based vulnerability assessment, the first step is selecting proper minimum number of indicators (Sullivan, 2002). Routine practice for indicator selection is following a conceptual framework to prepare a list of them considering suitability, usefulness and recollection process (Balica, et al., 2012). Selected indicators should cover actual conditions and reflect the essentials of flood disaster in any system (Li, Li, Wu, & Hu, 2013).

Based on research about flood vulnerability assessment on a commune level by (Veenstra, 2013) the numbers correspond with the selection of literature with indicator overviews that are used in the research listed as follows and **Table 3.1**.

1. (Balica, 2007) and (Balica, 2012)
2. (Balica, Wright, & van der Meulen, 2012)
3. (UNCHS (Habitat), 2001)
4. (Kha, Anh, & Son, 2011)
5. (Bowen & Riley, 2003)
6. (Fekete, 2009)
7. (Aall & Norland, 2005)
8. (Vári, Ferencz, & Hochrainer-Stigler, 2013)
9. (Elena-Ana, Costache, Dan, Dogaru, & Sima, 2013)

Table 3.1: Considered indicators on commune level

	Indicator	1.	2.	3.	4.	5.	6.	7.	8.	9.
Exposure	Population in flood prone area	x	x	x	x	x	x	x		
	Cultural heritage	x	x	x						x
	Water and sedimentation quality	x		x		x				
	Land use (map and data)	x		x	x	x				
	Flood danger (map and data)	x	x	x	x			x		
Susceptibility	Mobility/health of people	x	x	x			x	x		x
	Warning system	x		x	x					
	Awareness	x	x	x	x					x
	Spatial planning		x	x	x			x		
	Flood protection measures	x	x	x	x			x		
Lack of resilience	Shelters	x	x	x			x			
	Preparedness	x	x	x				x	x	x
	Recovery time	x	x	x					x	x
	Social security	x		x		x			x	
	Past experience	x		x					x	x
	Availability of drinking water	x		x		x				x
	Income/employment	x		x		x	x	x	x	x
	Infrastructure	x		x				x		x
	Energy Supply	x		x						
	(Tele)communication	x		x						
	Emergency service	x		x	x			x	x	
	Financial flood support	x		x	x					

<u>'Population in flood prone area'</u>

Characteristics as population number, density, growth rate (urban and rural), population in inundation area, proximity to inundation, proximity to river (Balica, et al., 2012) will be merged into the 'Population in flood prone area', because this is the indicator relevant for the direct vulnerability of the people. The indicator will assess whether the people are affected by every small flood in their commune (they live in a highly flood prone area) or not even by extreme floods (they do not live in a flood prone area).

<u>'Cultural heritage'</u>

The indicator 'Cultural heritage' consists of cultural heritage, religious places like churches and pagodas and historical sites and monuments. When assessing this indicator, it is about the presence of any cultural heritage that will be irreversibly damaged by a flood and about the importance of for the people in the commune.

'Water and sedimentation quality'

Characteristics that request a lot of detailed data are for example, SO2 concentration, toxic industries, pesticide/fertilizer use, wastewater, number of spills, waste treatment (Aall & Norland, 2005). But also, characteristics as oil spills, fertilizer use, POP, poisoning (Bowen & Riley, 2003). They all influence the quality of the water or sediment left behind after a flood. Therefore, these characteristics will be merged to the indicator 'Water and sedimentation quality'. This indicator assesses the effect of the flooding water on the area, if it will be good for the crops and safe for humans and animals, or if it is poisonous for everything in the area.

'Land use (map and data)'

Land use could consist of characteristics like natural reservations, forest, forest change rate, unpopulated area, uncontrolled planning zones, vegetated area, over used areas, percentage of urban/rural areas, cadaster survey (Balica S. F., 2007). These characteristics will be merged into the indicator 'Land use (map and data)'.

'Flood danger (map and data)'

When assessing the danger of a flood, many characteristics are important. For example, flood duration, velocity and depth, degraded area, river discharge, topography (e.g. slope), (heavy) rainfall, return periods of floods, soil subsidence, ground water level, drainage system quality (Balica S. F., 2007), dry/wet periods, length of waterline (Aall & Norland, 2005). Because the characteristics of flooding, and its danger, is important for vulnerability, they will be merged into the indicator 'Flood danger (map and data)'.

'Mobility/health of people'

The characteristics disabled people, handicapped people, percentage of children, percentage of >65 people as mentioned by (Balica, et al., 2012) and (Tapsell, Penning-Rowse, Tunstall, & Wilson, 2002), people with special needs (Aall & Norland, 2005); (Balica S. F., 2007), percentage of (single) female households (Fekete, Validation of a social vulnerability index in context to river-floods in Germany. Nat. Hazards Earth Syst. Sci., 2009); (UNCHS, 2001) (King & MacGregor, 2000), human health and life expectancy index (Balica S. F., 2007) can be merged into to the indicator 'Mobility/health of people'. The indicator will assess the ability of people to move or flee if necessary and help the immobile people.

<u>'Warning system'</u>

The indicator 'Warning system' indicates the speed of the flood warning or forecast, but also the quality and accuracy of the details about the overall danger or the depth, velocity or duration of the upcoming flood. The communication penetration rate (Balica S. F., 2007) is also a characteristic that is merged into the indicator.

<u>'Awareness'</u>

'Awareness' consists of the actual awareness of the people in the commune and of a training they did or things like manuals or instructions which causes the people to know what to do when the area floods.

<u>'Spatial planning'</u>

Indicates the amount of spatial planning, for example using a flood danger map when deciding which land to use for which purposes.

<u>'Flood protection measures'</u>

Indicates the need for and the provided flood protection measures by the government, for example dams, dikes, pumping stations, drainage systems, levees and reservoirs for water storage.

<u>'Shelters'</u>

Indicates the availability of shelters such as high grounds, hospitals or other places where the affected people can seek shelter during and after the flood.

<u>'Preparedness'</u>

Characteristics like awareness, having a solution, taking individual measures, or having food available in storage all indicate a level of preparedness. These characteristics are merged in this research to the indicator 'Preparedness', this merged indicator is also used by many researchers like (Balica S. F., 2007), (Balica, et al., 2012), (UNCHS, 2001), (Aall & Norland, 2005), (Vári, Ferencz, & Hochrainer-Stigler, 2013), (Elena-Ana, Costache, Dan, Dogaru, & Sima, 2013).

'Recovery time'

Indicates the amount of time needed for recovery to the previous efficient state. It consists of recovery of infrastructure, communication lines, businesses, jobs and houses.

'Social security'

Indicates the social security and cohesion of a commune, possible help from friends and commune members, but also the level of trust in institutions and each other.

'Past experience'

Past experience makes it easier for people to come up with solutions to avoid or cope with floods. Education is also often seen as a vulnerability indicator. A linear connection between education level and vulnerability could be arguable. It is more plausible that practical and logical thinking, which often increases because of education, makes people less vulnerable in the same way as past experience. The characteristics education, literacy rate and past experience (Balica S. F., 2007) are merged in the indicator 'Past experience'.

'Availability of drinking water'

In Vietnam, tap water can be connected to a water system in a city, but in the countryside, people often use water from a river or the mountains. This tap water is almost never drinkable, so drinking water comes from bottles or by cooking the water from the tap. Drinking water is important to survive, characteristics like access to drinking water, quality of water supply, population without access to sanitation or water (Balica S. F., 2007) are therefore merged to the indicator 'Availability of drinking water'.

Income/employment'

Characteristics as unemployment, high/middle/low income, expectancy of employment (Aall & Norland, 2005); (Balica S. F., 2007); (Fekete, Validation of a social vulnerability index in context to river-floods in Germany. Nat. Hazards Earth Syst. Sci., 2009); (UNCHS, 2001) and GDP (Gross Domestic Product) per capita, population under poverty (Balica S. F., 2007); (Bowen & Riley, 2003); (Fekete, Validation of a social vulnerability index in context to river-floods in Germany. Nat. Hazards Earth Syst. Sci., 2009), damage to business, damage to income can be merged into the indicator ‘Income/employment’. This indicator assesses the possible loss of income and the time it takes to get it back.

‘Infrastructure’

Indicates the remaining quality of the infrastructure after a flood, and the remaining possibilities to use it for supplying or evacuation.

‘Energy supply’

Indicates the remaining quality of energy supply possibilities after floods by sources as electricity, gas, coal and wood.

‘(Tele) communication’

Indicates the remaining quality of (Tele) communication after floods and the possibilities to contact others and get help from them.

‘Emergency service’

Indicates the quality and speed of emergency service, help or support from institutions after floods. For example, searching for people in need, rescuing and taking (health) care of people, providing food and other help, cleaning the area.

‘Financial flood support’

Indicates the financial flood support of the government and insurance, but also the possibility to get money in other ways, for example borrowing it from others.

3.6 MEASURING FLOOD VULNERABILITY INDEX (FVI)

According to research that have been done by (Brigitt & Villordon, 2014) vulnerability is the result of the interplay of the indicators in the exposure, susceptibility and resilience category. The five components for measuring the flood vulnerability index in the study are the following; hydrogeological, social, economic, socio-behavioural and politico-administrative component. The relationship between flood vulnerability components and its indicators is illustrated in Table 3.2.

Table 3.2: Relationship between components and indicators

Flood Vulnerability Components	**Vulnerability Indicators**		
	Exposure Abb.	**Susceptibility Abb.**	**Resilience Abb.**
A. Hydro Geological Components	A. Frequency of Flooding (FF) B. Height of flooding (HF) C. Houses reached by floods (HRF) D. Houses not on elevated area (HNE)	A. Number of Typhoons per year (50%) (NTY)	A. Land Use Management And Structural Design (LUMSD)
B. Social Components	A. Open disposal of animal waste (ODAW) B. Unwillingness to vacate and be relocated (UVR)	A. Educational Attainment (High School Level and below) (EA)	A. Water Treatment or Sterilization Practice (WT) B. Social Networks (SN)
C. Economic Components	A. Houses with NO access to improved sanitation (HNIS) B. Houses with NO access to an improved water source (HNIW) C. Presence of rats in the vicinity (PRV) D. Presence of water logged areas in the vicinity (PWLV)	A. Housing Conditions (semi-concrete, tent light materials, and plastic materials) (HC)	A. Family Income (3000-10,000) (FI) B. Property Insurance (PI)
D. Socio-Behavioural Components	A. PRACTICES of households on flood resilience (hazards, risks, exposure, preparedness, response, recovery, coordination, adaptation strategies) (PHFR) B. PRACTICES of households on E. coli (nature of E. coli, mode of transmission, prevention, signs and symptoms, it is fatal, treatment, financial cost of treatment) (PHEC) C. PRACTICES of	A. ATTITUDE of households on flood resilience (hazards, risks, exposure, preparedness, response, recovery, coordination, adaptation strategies) (AHFR) B. ATTITUDE of households on E. coli (nature of E. coli, mode of transmission, prevention, signs and symptoms, it is fatal, treatment, financial cost of treatment) (AHEC) C. ATTITUDE of	A. KNOWLEDGE of households on flood resilience (hazards, risks, exposure, preparedness, response, recovery, coordination, adaptation strategies) (KHFR) B. KNOWLEDGE of households on E. coli (nature of E. coli, mode of transmission, prevention, signs and symptoms, it is fatal, treatment, financial cost of treatment) (KHEC) C. KNOWLEDGE of

	households on Liptospirosis (same factors with letter B above) (PHL) D. PRACTICES of households on Dengue Fever (same factors with letter B above) (PHDF)	households on Liptospirosis (same factors w/letter B above) (AHL) D. ATTITUDE of households on Dengue Fever (same factors with letter B above) (AHDF)	households on Liptospirosis (same factors w/ letter B above) (KHL) D. KNOWLEDGE of households on Dengue Fever (same factors with letter B above) (KHDF)
E. Politico-Administrative Components	A. Land Use & Management & Structural Design (LUMSD) B. The River's Natural Resources & Natural Features Management and Program (RNRMP)	A. Governance (Warning and Evacuation, Emergency Response, Disaster Recovery) (G)	A. Post-risk Assessment and Integration (PRAI) B. Sustainable Community Livelihood Prog. (SCLP) C. Relocation Site Project (RSP) D. Health & Prevention Program of E. coli, Liptospirosis & DF (HPP)

3.7 FLOOD RISK

The risk of a flood to occur and to cause damage depends on the existence of a hazard and of people and objects that are in the hazard zone and that do not have sufficient capacities to avert the damage. According to (Deltares, n.d.), flood risk is rising sea-levels, population growth and economic activity are driving an increase in demand for flood risk forecasting and possible protective measures. Flood risk is defined as the probability that floods of a given magnitude and a given loss will occur within a given time span (Thieken, Merz, Kreibich, & Apel, 2006) . Flood risk itself involves the characteristics of the elements at risk. The term that been used for elements at risk are including all elements of the human system, the built environment and the natural environment that are at risk of flooding in a given area such as population, building and civil engineering works, economic activities and ecosystems (Thieken, Merz, Kreibich, & Apel, 2006). Please refer to **Figure 3.1**.

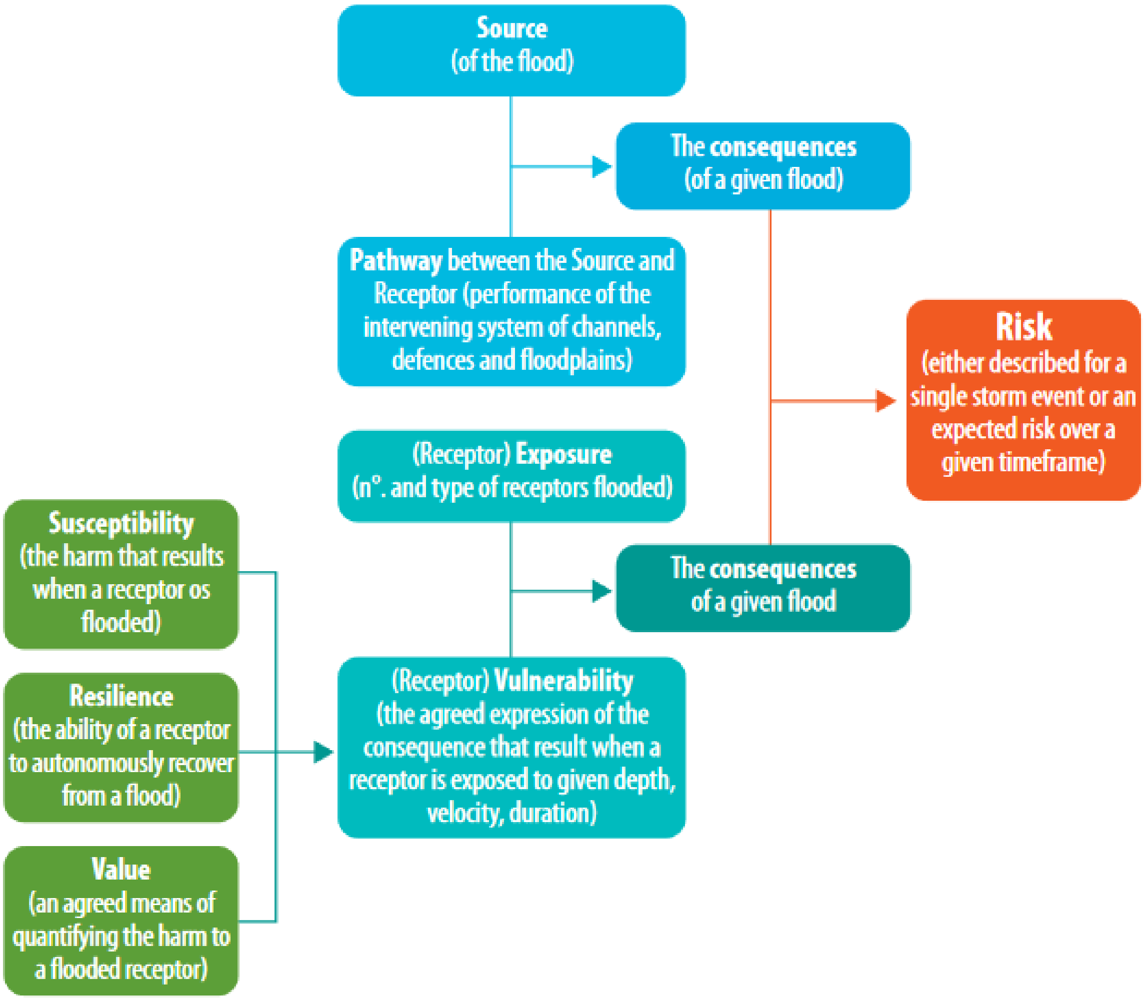


Figure 3.1: Component of risk

(*Source: Flood Risk Management A Strategic Approach, UNESCO 2013*)

Flood risk is also defined in at least two alternative ways, each of which has certain advantaged in different applications.

1. **Risk = (flood) hazard * (exposure) * vulnerability (of the society/ area)**
2. **Risk = probability (of the flood) * consequences**

The first definition specifies the two quintessential elements of flood risk, namely floods posing a hazard, which means that they potentially have harmful effects, as well as a vulnerable society/ area, which means that it can harmed by those floods. Obviously, without exposure to a certain flooding depth, not even a very vulnerable society/ area will be harmed. Hence, if there is no any of these elements which means there is no flood risk (UNESCO, 2013).

Flood risk is also measured in terms of probability of occurrence of events and the related consequences (Smith, 1996). This means that risk and improbability in water resources take place from the natural inconsistency of geophysical progressions and alterations in difficult socioeconomic features (Khan, Iqbal, & Yosufzai, 2010).

3.8 FLOOD RISK ASSESSMENT

Flood risk assessment (FRA) is an assessment of the risk of flooding from all flooding mechanisms, the identification of flood mitigation measures and should provide advice on actions to be taken before and during a flood (Wikipedia, n.d.). Flood risk assessment is needed concerning the existing and proposed development. Flood risk assessment consists of a detailed analysis of available data at an individual site and it can be recommended to the developer any mitigation measures. Flood risk assessment takes into account the risk and impact of flooding on the site and takes into consideration the implication of development on local area. Flood risk assessment also provides recommendations as to how the risk of flooding to the development can be mitigated. Flood risk assessment also consider the source of flooding including fluvial, groundwater, surface water runoff and sewer flooding (Wikipedia, n.d.).

On the other hand, a risk assessment should be incorporate the interaction between the nature of the event and the characteristics of the population or area at risk (objects) (Green, Parker, & Tunstall, 2000). Besides, if the assessment only focusses on hydrological study, it is reduced to a conventional flood risk assessment. In flood risk assessment, two components interact which the physical (hydrologic and hydraulic) and the socioeconomic (Cançado, Brasil, Nascimento, & Guerra, 2008). Risk assessment is performed on the measurement of the probabilities of occurrence of flood and their consequences (Kaczmarek, 2003). Flood risk assessment is identifying the level of flood risk to your property or site. This will enable to identify the measures that are necessary to make property or site safer. Flood risk assessment investigated the flood process chain from precipitation, runoff generation and concentration in the catchment, flood routing in the river network, possible failure of flood protection measures, and inundation to economic damage (Thieken, Merz, Kreibich, & Apel, 2006).

3.9 INDICATOR FLOOD RISK ASSESSMENT

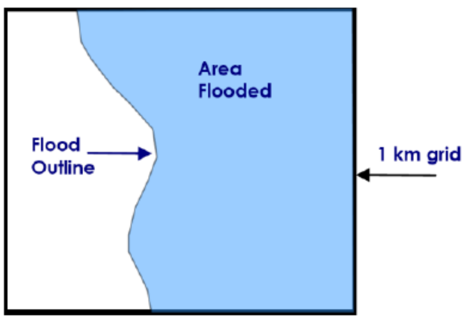
To calculate flood risk indicators (FRI) is based on intersecting national flood outlines and receptor data within a geographical information system (GIS). Various guidance and scoping documents have recommended FRIs as a transparent means for assessing potential adverse consequences to human health, economic activity, environment and cultural heritage for regional flood risk appraisals (Adamson, Sullivan, J.O., & Bedri, 2016) (Hankin, Metcalfe, & Johnson, 2017). They represent measures of the consequences of flooding that are easily understandable, such as the number of properties in a flood outline for a given "reporting unit" area, typically a regular spatial grid (Environment Agency 2010a). Accordingly, FRIs can provide an efficient, intuitive basis for identifying areas at significant risk across multiple flood sources and impact groups.

The **approach for calculating** the three principal types of flood risk indicator. These are:

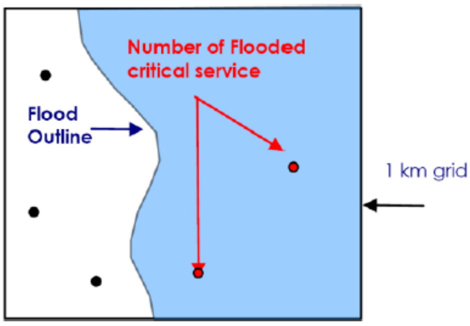
- A simple **count** of property or asset points in an outline (note that properties can also be identified by their footprint/outline which is discussed in Environment Agency (2010b));
- The **length** of key infrastructure within an outline;
- The **area** of a special designation within an outline.

Individual FRIs can be combined to give an overall measure of the potential adverse consequences associated with a mapped flood outline. Please refer to **Figure 3.2**.

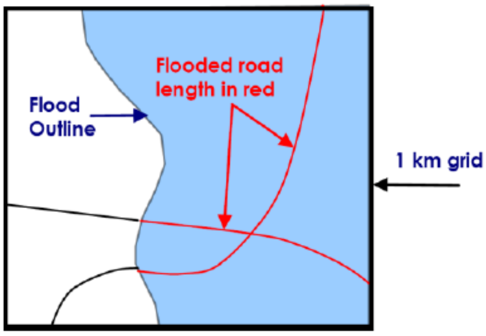
(a) Flood outline within one-km grid square reporting unit



(b) A count of point receptor data



(c) A length measure of polyline receptor data



(d) An area measure of polygon receptor data

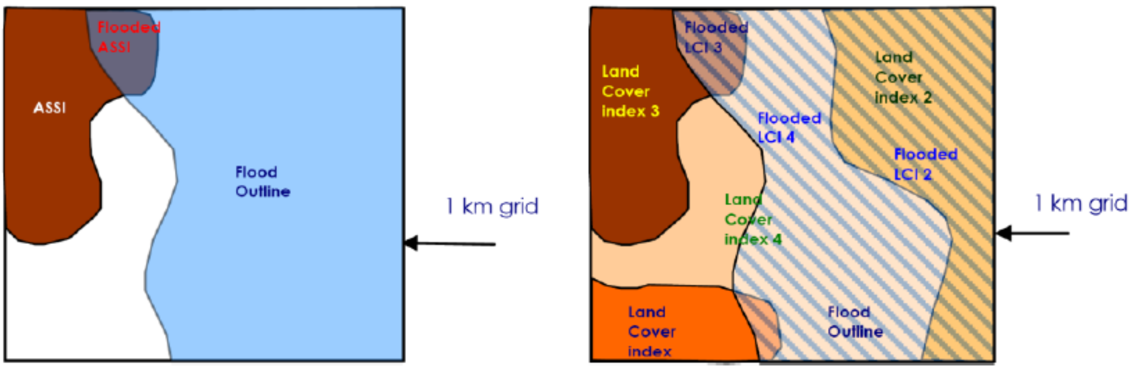


Figure 3.2: Point, polyline and polygon – based flood risk indicators

(*Source: Environment Agency, 2014*)

The set of indicators can be used by authorities on the one hand to show the complexity of problem. This indicator can be used to define and control development directions and to identify problematic areas, such as areas with a high number of people exposed or areas with unfavourable usage. By bringing the indicators into relation it can be demonstrated – at least in a qualitative or directional way – how different processes interact and influence the flood risk. The development of indicators and target values can already be seen as a tool for vulnerability reduction (Birkmann, 2005). Please refer to Table 3.3.

Table 3.3: Set of indicators used for the flood risk analysis and consecutive risk assessment

Indicator	**Data source**	**Type of scale**
Hazard related indicators		
Amount of precipitation per event	Measured data	Ratio scale
Runoff	Measured data	Ratio scale
Capacity of the water course	Measured data	Ratio scale
Water height in flooded area	Model result	Ratio scale
Land use/land cover	Satellite data	Nominal scale
Local topography	GIS data	Ratio scale
Vulnerability indicators		
Position of building in relation to street	GIS	Nominal scale
Main construction material of wall, floor & roof	Census data	Nominal scale
Location of household within the building	Questionnaire	Nominal scale
Knowledge about private protection measures	Questionnaire	Ordinal scale
Availability of flood protection on buildings	Field survey	Nominal scale
Age	Census data	Ratio scale
Gender	Census data	Nominal scale
Social status	Census data, Satellite data	Nominal scale
Settlement density	Census data, GIS	Ratio scale
Urban structure type	Satellite data, GIS	Nominal scale
Proportion of green spaces	Satellite data, GIS	Ratio scale
Number of lifelines	GIS data	Ratio scale
Household (HH) size	Census data	Ratio scale
Level of education	Census data	Ordinal scale
Employment status	Census data, Questionnaire	Nominal scale
Knowledge about flood hazard	Questionnaire	Ordinal scale
Experience with floods	Questionnaire	Nominal scale
Indicators referring to the elements at risk		
Number of people in hazard zone	Census data	Ratio scale
Number of critical infrastructures in hazard zone	GIS	Ratio scale
Developments of new settlements in hazard zones	Satellite data	Nominal scale

Source: Flood risk assessment in Santiago de Chile

3.10 MEASURE FLOOD RISK ASSESSMENT

There are various techniques for assessment of flood risk such as assessing meteorological parameters, hydrological parameters, socioeconomic factors and combination of hydrometeorological and socioeconomic factors along with assessment based on geographical information system (Ologunorisa & Abawua, 2005). Besides meteorological parameters have been widely used in most countries such as Malaysia, Korea, USA, Australia and Pakistan. Risk also assessed via annual flood peak discharge, the techniques is termed as assessment of flood through hydrological parameters (Khan, Iqbal, & Yosufzai, 2010).

Besides, the flood risk assessment can be measured by using GIS analysis. The GIS analysis required to calculate flood risk indicators can be run in four steps using functionality available within most GIS software.

Step 1 – Identify/generate reporting unit polygons and pre-process source datasets

Users must first identify or generate a set of reporting unit polygons for which counts, lengths and areas of affected receptors will be reported. Reporting units can be regular grids, or they can be irregular catchments or administrative units (such as districts, wards or parishes). Each reporting unit is required to be a single polygon object with a unique identifier.

Depending on the GIS software being used to make the FRI calculation, it may be possible to pre-process the source datasets globally, that is, clip, union or intersect the flood outline and receptor data to the reporting unit coverage in a single step. However, as the analysis is ultimately carried out on a reporting unit-by-reporting unit basis, this section describes the process for calculating FRIs within individual reporting units. In order to calculate the desired FRIs, it is often necessary to filter the receptor data. For example, FRIs were calculated for residential and non-residential properties using the National Receptor Dataset (NRD) Property Point dataset. However, by default, all property types are combined within the Property Point dataset meaning that data relevant to each FRI will need to be filtered via their attributes. This process is described in detail in Environment Agency (2010a). Step 1 may require the extraction of several subsets of receptor data from the original source and therefore the creation of new GIS files. Strong data management throughout the calculation process is therefore essential. Please refer to **Figure 3.3**.

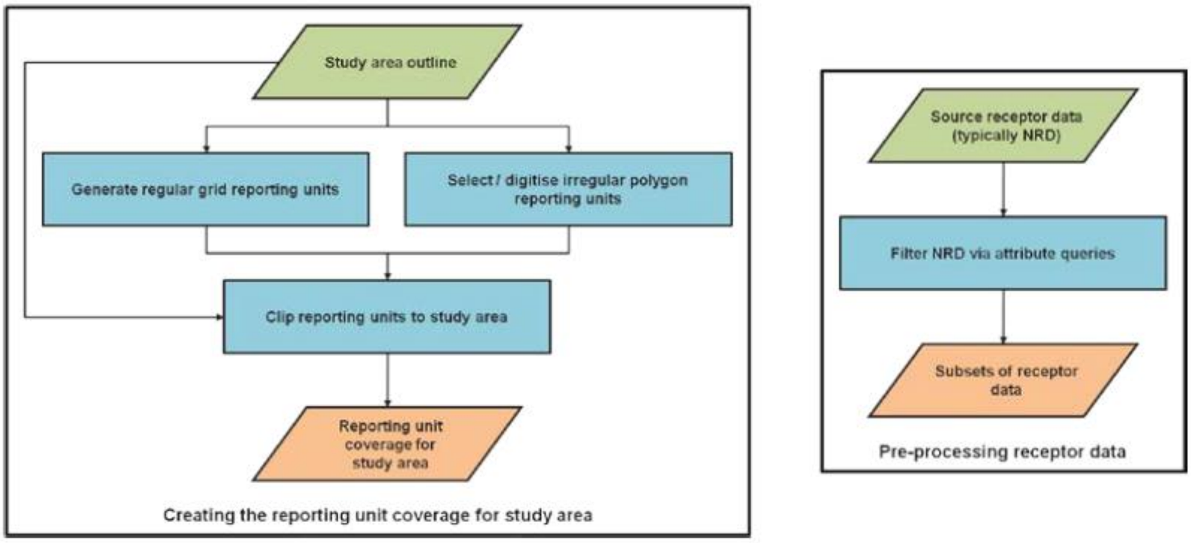


Figure 3.3: Step1 of calculating flood risk indicators

(*Source: Environment Agency, 2014*)

Step 2 – Clip flood outline and receptor data to the extent of each reporting unit

Next, flood outlines that describe the hazard affecting chosen receptors are clipped to the extent of each reporting unit. The same process is also undertaken for each of the receptor datasets, such as property points, road and rail polylines and designated environmental area polygons. This results in each reporting unit polygon having a set of clipped flood outlines and receptor data available for intersection analysis (Step 3). Please refer to **Figure 3.4**.

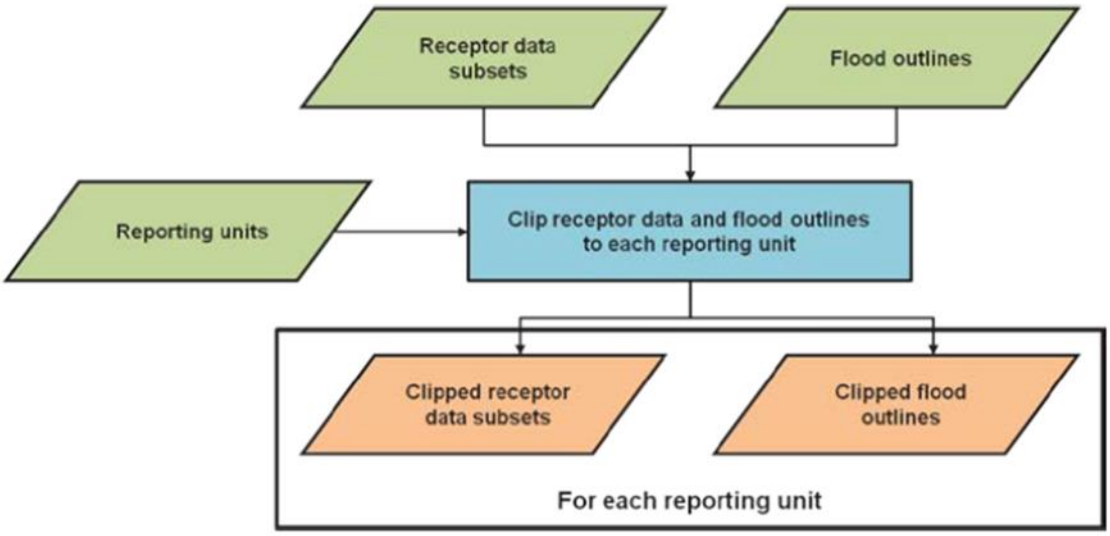


Figure 3.4: Step 2 of Calculating Flood Risk Indicators
(*Source: Environment Agency, 2014*)

Step 3 – Spatial intersections to calculate basic flood risk indicators

The third step is to identify and record the spatial relationship between the flood outlines and receptor data within each reporting unit. For point data, the number of points that intersect the flood outline is calculated and this value is added to the attributes of that reporting unit as a new field. If required, this step is repeated for all lengths of polyline and areas of polygon data that intersect the flood outlines within the same reporting unit. Please refer **Figure 3.5**.

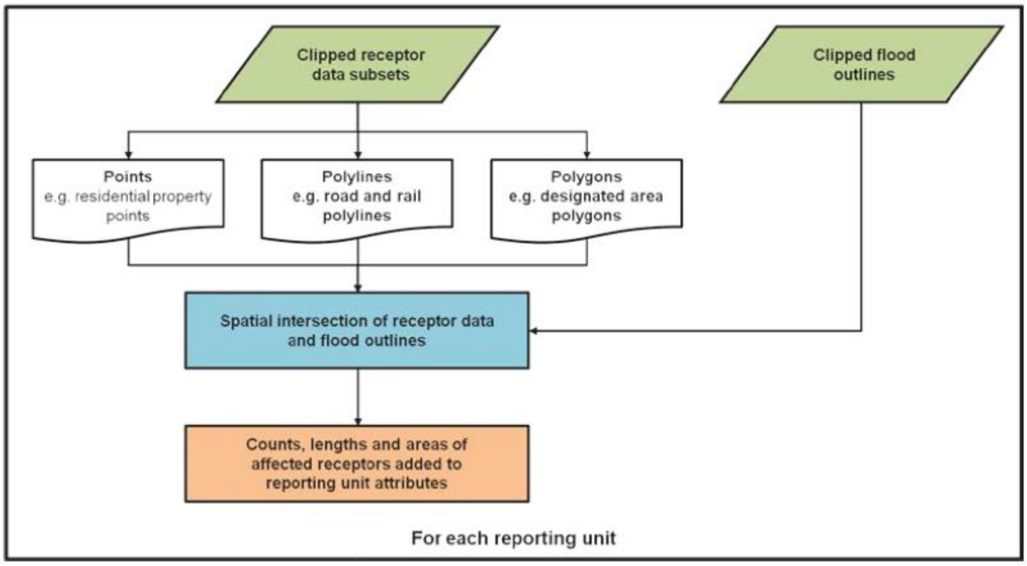


Figure 3.5: Step 3 of Calculating Flood Risk Indicators
(*Source: Environment Agency, 2014*)

Step 4 – Calculate extended flood risk indicators

FRIs can simply be counts, lengths or areas of the various geometries that fall within each of the reporting units or may require additional processing to produce the final indicator value. For example, for the England and Wales PFRA, the number of people at risk of flooding within each 1 km square reporting unit was calculated by multiplying the count of residential properties flooded by 2.34.

Post-processing may be necessary to sum related subsets of data into a single composite FRI. For example, the count of critical services used within the PFRA analysis is actually the sum of counts of affected hospitals, police, fire and ambulance stations, schools, electricity installations and sewage works, all of which have been filtered individually from the NRD

Property Point dataset by means of attribute queries. Once calculated, the sum total is added to the reporting unit as a new attribute and can be taken into account in the subsequent consequence analysis. Please refer **Figure 3.6**.

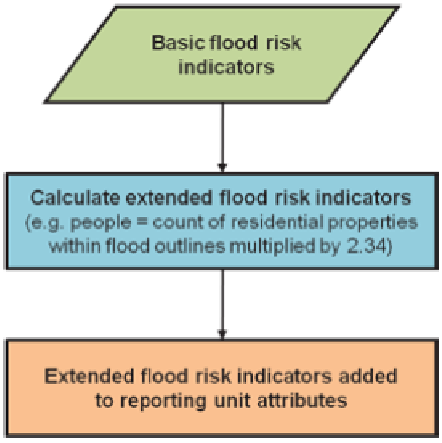


Figure 3.6: Step 4 of Calculating Flood Risk Indicators
Source: Environment Agency, 2014

3.11 DEFINITION OF CRITICAL INFRASTRUCTURE (CI)

Infrastructure refers to systems that physically tie together metropolitan areas, communities, and neighbourhoods, and facilitate the growth of local, regional, and national economies. Infrastructures also described as the basic facilities, services, and installations needed for the functioning of a community or society such as transportation and communications systems, water and power lines, and public institutions including schools, post offices and prisons. The concept of critical infrastructure came into public view around the middle of the last decade of the 20th century, when the US started to acknowledge that is had identified that there were a set of facilities and services that came together to provide the elements that were ‘critical’ to the running of a country and the well-being of its citizens. Many definitions of Critical Infrastructures (CIs) were found (Fekete, 2011); (Moteff & Parfomak, 2004); (Fulmer, 2009); (McBain, Wilke, & Retter, 2010). For example, “Canada’s critical infrastructure consists of those physical and information technology facilities, networks, services and assets which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of Canadians or the effective functioning of governments in Canada” (Gordon & Dion, 2008). Although no generic definition was found, most definitions are comparable with the Canadian one.

In this report, the focus is on vulnerability of the critical infrastructure to flooding. In the frame of this work, critical infrastructure is defined as follows: Critical infrastructure includes all networks and buildings that are essential for the functioning of society during the flood event and for the recovery from the flood event. Critical infrastructure is considered 'critical' because an outage of the infrastructure has a serious effect on many people over a long period. Criticality can thus be expressed by (McBain, Wilke, & Retter, 2010).

- the severity of the effect (number of fatalities/wounded or monetary damage),
- the extent of the area or the number of people affected
- the rate of recovery from the outage.

Typically, the following list of CIs is used as a basis for assessment:

- Utility services (electricity, water supply and drainage systems, transportation, telecommunication and gas supply, etc),
- Welfare and social systems (e.g. food distribution centres, financial centres, etc),
- Administrative and emergency service buildings (e.g. fire stations, police stations, flood warning and forecasting office, etc)

3.12 THE COMPOUNDS OF CRITICAL INFRASTRUCTURE (CI)

Most authors identify the following compounds as CIs: electricity networks, water supply and drainage networks, communication related infrastructure, and roads. Some authors also include schools and hospitals, monuments, banks, financial institutes, nuclear power plants, gas supply, or sanitation. Which elements are included depends on the scale (national or regional), the type of hazard considered (terrorists, cyber viruses, natural hazards or others) and the aim of the CI analysis executer. From a national perspective, the focus generally lies on nuclear installations, gas winning, and other sectors of national importance. From a regional perspective, electricity, water supply and wastewater drainage systems, and communication systems, are the most commonly accounted for when considering CIs. According to the documents of the United Nations, critical infrastructure represents the infrastructure that consists of physical and information technology facilities, networks, services and property, which if collapsed or destroyed can have a serious impact on health, safety and economic well-being and effective functioning of government.

3.13 CRITICAL INFRASTRUCTURE IMPACT ASSESSMENT

3.13.1 Differences with "common vulnerability assessments"

Vulnerability assessments or damage assessments of CI differ from general damage assessments (Bruijin, 2012). Whereas general vulnerability assessments focus on direct economic damage and generally only mention possible indirect effects, criticality assessments aim at assessing the indirect and secondary effects of infrastructure impairment. Direct damages to the infrastructure itself are of minor importance compared to the indirect effects of their outage. The indirect effects, such as loss of income due to an electricity outage, loss of lives in hospitals due to communication interruptions, broken roads or electricity service interruptions are more relevant than damage to the cables and transformation stations themselves. Furthermore, when assessing CI, the secondary effects of outage outside the flooded area and interdependencies and cascading effects to other sectors are relevant. Failure of e.g. the power grid, may affect a wide range of other infrastructures, e.g. water supply and information technology. Vulnerability assessments need to determine the consequences and damages of such interdependencies. For getting a full picture of failure, it is thus necessary to capture second and third order consequences both inside and outside the flooded area (Fekete, 2011).

3.13.2 Steps in vulnerability assessment of CI

To assess the flood vulnerability of the CI in a certain city or region, there is first the need to make a rough inventory of the CI and the flood hazards. This can be made by experts and/or municipalities. For those regions were floods may occur and CI may be vulnerable to flooding, more detailed analyses can be carried out. The vulnerability analysis of CI involves the following five steps (Bruijin, 2012):

1) Network analysis
2) Analysis of the resistance and resilience of the network elements
3) Analysis of the effects of element failure on the network (resilience of network, redundancy)

4) Effect of failure of the network on other networks: interdependency
5) Effects of failure of the networks and the corresponding costs

3.14 INTERDEPENDENCIES BETWEEN CRITICAL INFRASTRUCTURE NETWORKS

Most critical infrastructure systems interact through direct connectivity, policies and procedures, or geospatial proximity. These interactions often create complex relationships, dependencies, and interdependencies that cross infrastructure boundaries. The modelling and analysis of interdependencies between critical infrastructure elements is a relatively new and very important field of study (Pederson, Dudenhoeffer, Hartley, & Permann, 2006). It illustrates common representations of infrastructures based on the scenario of a flooding event and the subsequent response. There are ties and dependencies within each infrastructure and between the different sectors. The solid lines in crossing sectors and connecting nodes represent internal dependencies, while the dashed lines represent dependencies that also exist between different infrastructures. Please refer **Figure 3.7**.

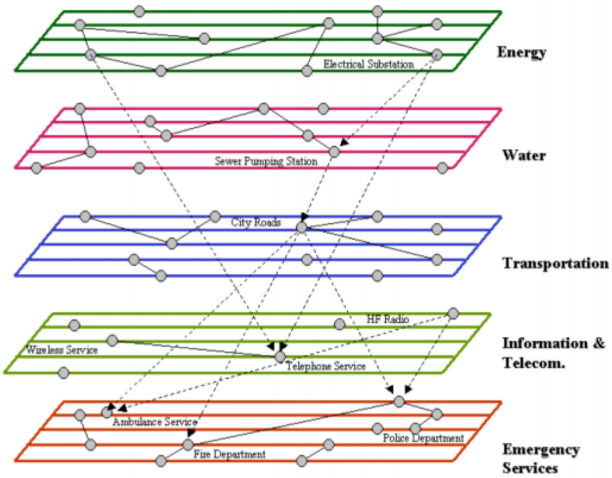


Figure 3.7: Critical infrastructure interdependency modelling (Pederson, Dudenhoeffer, Hartley, & Permann, 2006)

3.15 FLOOD VULNERABILITY ASSESSMENT VS. FLOOD RISK ASSESSMENT

The concept of vulnerability assessment is explained in comparison with the flood risk assessment. As both concepts are highly convoluted, some clarifications are made in terms of initiations and functions (Fang, 2009).

3.15.1 The initiations

The initiation to introduce vulnerability in flood management was due to the re-recognition of disaster. Instead of linking hazard directly to disaster, the disaster is regarded as the final product of external hazard and internal vulnerability within the social system. Vulnerability focuses on exploring the essential strength and weakness of the elements within the social system. It stresses more on the sustainability of different social groups, the coping capacity of the critical infrastructures, the efficiency of the government, and the robustness of economic structures. Regarding the field of flood management, vulnerability analysis can help identify how robust the social system can cope with the flood and where the inherent weakness is. In comparison, flood risk assessment is more oriented to evaluate the potential consequences of the affected social system with certain flood probabilities. As the consequences are mainly quantified by the economic loss, flood risk assessment is more adopted by cost-benefit analysis (CBA) to evaluate the potential benefit of flood control measures.

3.15.2 The functions

In the field of flood management, both assessments are oriented to assist the flood mitigation activities, but for different aspects. The flood risk assessment to large extent facilitates the prevention phase with the economic loss as the main evaluator; vulnerability assessment tells the government which social elements high exposure to flood have as well as which elements may exemplify the potential hazard. Thus, it gives more consideration to the social dimension along all the phases.

Moreover, while flood risk assessment analyses the overall impact of the social system, vulnerability assessment aims to explore the distributive patterns among affected populations and communities, considering that different people or groups can be exposed to different magnitudes and types of loss.

3.16 FLOOD IMPACT ON CRITICAL INFRASTRUCTURE

Critical infrastructure is a combination of systems and technologies that are essential to our health, safety, security and economic well-being; for example, electricity production, water supply, telecommunication and security services. If any are disrupted or damaged, this could lead to further detrimental consequences. Damage to critical urban infrastructure assets, during flooding, can result in significant secondary consequences, which can be just as serious as the direct consequences. For example, the loss of power supply can impede the health service of an entire urban community. Risk impacts associated with natural disasters are usually classified under three categories; economic, social and environmental impacts. Many of the values related to these impacts are not quantifiable therefore they are identified by monetary and non-monetary terms (Neal, 2014). Table 1 illustrates the quantifiable impacts of disasters. Please refer to **Table 3.3**.

Table 3.3: Summary of Quantifiable Disaster Impacts

	Monetary		Non-Monetary	
Social				
Household			Number of Casualties Number of Injured Number affected	Increase of diseases Stress Symptom
Economic				
Private Sector Household	House damaged or destroyed	Loss of wages, reduced purchasing power		
Public Sector Education Health Water & Sewage Electricity Transport Emergency Spending	Assets destroyed or damaged: buildings, bridges, machinery, etc.	Loss of infrastructure services		
Economic Sector Agriculture Industry Commerce Services	Assets destroyed or damaged: crops, machinery, etc.	Losses due to reduced production		
Environmental			Loss of natural habitats	Effects on biodiversity

Besides that, the example of flood impact on critical infrastructure that happen on Cork City. Cork is the largest city in the southwest of Ireland. It suffered severe flooding in 2009. The flood lasted less than 24 hours but there was substantial damage: the closure of main transportation routes, the temporary closure of the roads to and from the hospital, severe damage to the university and a two-week interruption in the supply of fresh water to residents. Approximately 87,000 persons were affected by a lack of drinking water in their homes, the majority in the north of the city. Some urgent flood protection measures have already been implemented to prevent a repeat of similar events. Additional measures have been proposed for the areas in and around Cork. Information about flood risks is crucial to evaluate the past, current and future vulnerability of critical infrastructure (CI) to flooding. Whereas general flood impact and risk analysis methods focus on direct damage due to the force of water on objects, damage related to critical infrastructure is generally associated with interruptions in services. The impact depends mainly on the network structure and the dependence of society and other networks on the services, and less on the nature of the actual flood.

3.17 FLOOD VULNERABILITY AND RISK MANAGEMENT

According to (UNESCO, 2013), the concepts of flood risk management (FRM) have been widely used. In many instances this conceptual acceptance has resulted in changes to decision – making practice, highlighting risk management as potentially more complex but more efficient and effective delivering multiple goals than a traditional engineering standards-based approach. According to European Commission, flood risk management is aims to reduce the impact of floods. The development of flood risk management programmed incorporating a few elements which prevention are, protection, preparedness, emergency response and recovery and lessons learned. The elements of prevention are preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas; by adapting future developments to the risk of flooding and by promoting appropriate land use. Besides, the element of protection is taking measures, both structural and non-structural, to reduce the impact of floods in a specific location. Next is preparedness by informing the population about flood risks and precautions of a flood. For the emergency response is developing emergency response plans in the case of a flood. Please refer **Figure 3.8**.

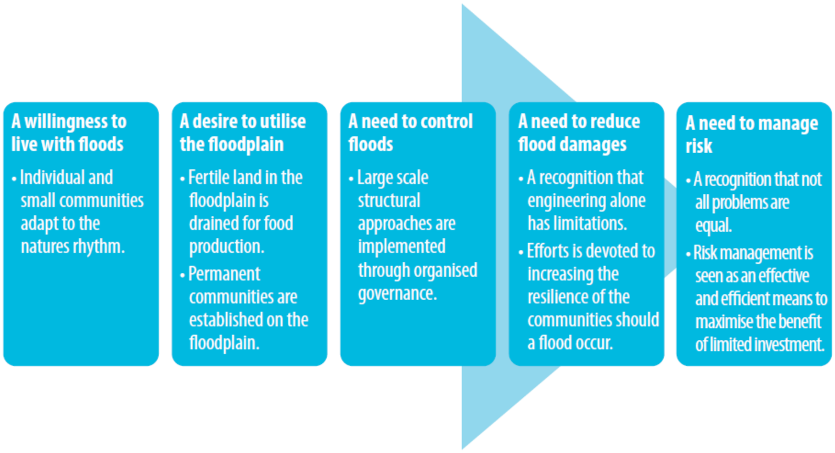


Figure 3.8: Evolution of Flood Risk Management Practice
(*Source: UNESCO, 2013*)

Flood risk management therefore embeds a continuous process of adaptation that is distinct from the 'implement and maintain' philosophy of a traditional flood defence approach. Taking a longer term, whole-system view places a much higher demand upon those affected by flooding and those responsible for its mitigation. It involves collaborative action across governments, the public sector, businesses, voluntary organizations and individuals. This places an increasing emphasis on effective communication of the residual risks and actions to be taken. These characteristics form the building blocks of good FRM and represent an approach that concurrently seeks to make space for water while supporting appropriate economic use of the floodplain. Refer **Figure 3.9**.

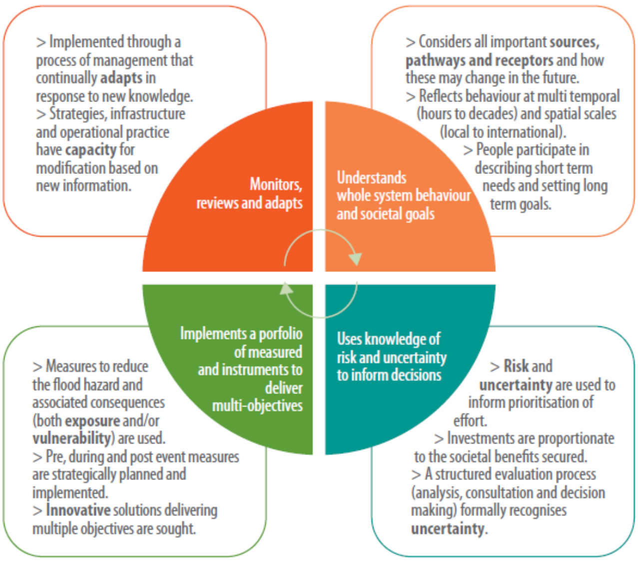


Figure 3.9: Characteristic of Good Flood Risk Management

Source: UNESCO, 2013

Flood risk management can be done by doing building resilience and adaptive capacity. By delivering resilience involves much more than simply reducing the chance of damage through the provision of strong structures and adaptive management involves much more than simply the 'wait and see' approach. Both are purposeful approaches that actively manage uncertainty – minimizing damage when storm events exceed notional design values and enabling strategies to change with minimum regret as the future reality unfolds (**Table 3.4**).

Table 3.4: The Recognition of Uncertainty Has A Profound Impact on Strategy Development; Forcing the Traditional Linear Design Model to Be Replaced with Adaptive Strategies (*Source: UNESCO, 2013*)

Stages of strategy development	Traditional (certain) model of strategy development and decision-making	Adaptive (uncertain) model of strategy development and decision-making
Deciding what to do	Predefined system of goals, objectives and desired outcomes. Defined set of activities and resource demands.	Emerging pattern of goals, objectives and desired outcomes. Flexible configuration of resources and priorities.
Deciding how to do it	Sequential process of planning, programming and implementation. Top-down strategy development. Reliance on single solutions to deliver defined standards.	Continuous alignment of plans, programmes and implementation activities with the changing world. Continuous reconciliation of the bottom-up initiatives and top-down strategies. Use of sustainable approaches that are easily adaptable.
Understanding the external and internal influences	Stable system of decision-making. Predictable (deterministic) future change – climate, demographics, deterioration, preferences etc.	Changing decision processes and priorities. Unknown future change – climate, demographics, deterioration, preferences etc.

The main purpose of flood risk management is reduction these human loss and economic costs to acceptable level. It is not possible to avoid flood risks completely, so it is necessary to manage them. On the other word, flood management does not attempt to eliminate flood risk, but its aim is mitigating them. Avoiding, reduction or shifting the impacts of flood through processes for mitigation and adaptation are flood risk management 's main goal (UNISDR, 2009). The main steps of risk management are flood planning mitigation measures (preparedness-before disaster), Response measures (during disaster) and Recovery (after disaster) **Invalid source specified.**. Refer to **Figure 3.10**

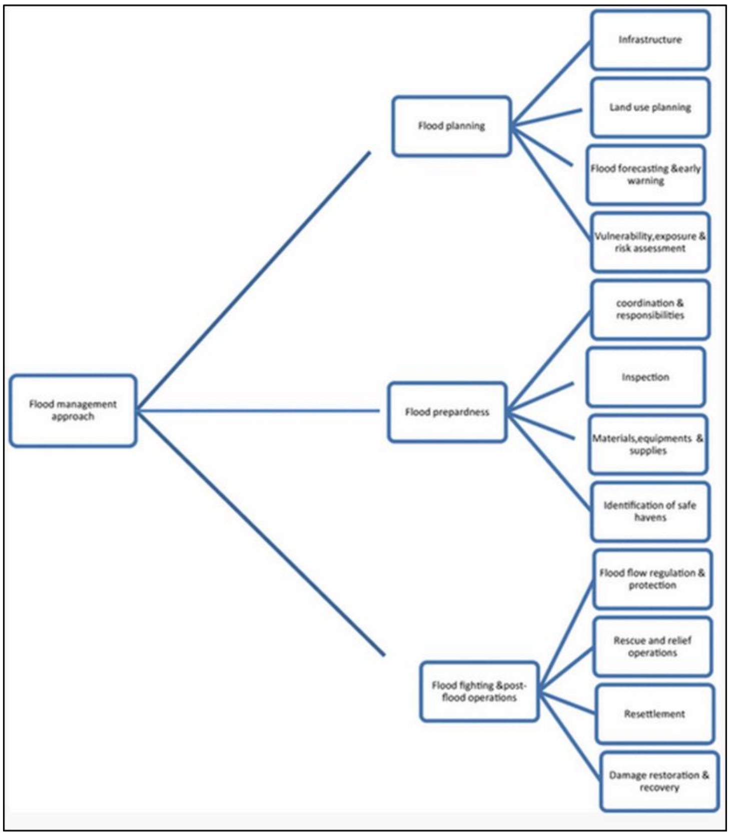


Figure 3.10: Flood Risk Management Process
(*Source: Sustainable Water Resources Management, 2016*)

3.18 CONCLUSION

Flood is natural hazards. There are many factors that cause flooding such as heavy rainfall and monsoon season, but some of the floods also happened because of failing in flood defenses. Many actions were taken to overcome the problems of flood and although it has caused many damages to the critical infrastructure and fatalities, flood can still be controlled and managed. Therefore, flood vulnerability assessment is essential to identify high-risk areas and to develop cost-effective flood mitigation and adaptation strategies. Through a flood vulnerability index, a tool and indicator for policy and decision-making for flood management can be properly developed. Meanwhile, flood risk assessment will evaluate the risk of flooding and identify flood mitigation measures related to the existing and proposed development. Thus, flood vulnerability index and flood risk assessment can be incorporated to reduce, control and manage flood from various aspects.

CHAPTER 4

APPROACH AND METHODOLOGY

CHAPTER 4

APPROACH AND METHODOLOGY

4.1 INTRODUCTION

The appreciation of the study area, environment and problems that may encountered both at the study location as well as during the course of study execution is very important to be understood and well familiarise before formulating a good and comprehensive approach and methodology.

In order to fulfil the objectives as well as in preparing and drawing up a comprehensive and concise methodology, manpower requirements and work program for the timely and satisfactory implementation of the Project, the Consultant is fully aware of the need for a thorough appreciation of the Project. Extensive literature search and review of relevant background documents and reports has been carried out in order to acquire better understanding and appreciation particularly the relevant approach and methodology which available and suitable to to fulfill the stipulated objectives of the study.

Realising the complexity of the Project, the Consultant Team comprising a panel of senior and highly experienced staff has been formed to ensure a carefully prepared proposal that is responsive to the Project objectives and the Client's requirements. The Consultant Team has hence conducted the following: -

- A detailed appraisal of the TOR;
- Preliminary discussions with various parties that have been involved in the Project area;
- A site visit to the Project area to further enhance and appreciate the existing conditions of the site as well as the current problems faced at the site to get an in-depth and first-hand knowledge about the Project requirements;
- Extensive literature search and review of relevant background documents and reports.

4.2 PHASING OF CONSULTANT ACTIVITY

The scope of work has been examined carefully for the requirements of the TOR and the timing for the completion of the Project. This is followed by a comprehensive correlation and integration of our appreciation of the Project with the requirements of the TOR. Based on this and the milestones of the Study, the consultant activity will be phased out into four (4) phases as follows: -

- Phase I – Inception and Planning Stage
- Phase II – Analysis and Synthesising Stage I
- Phase III – Analysis and Synthesising Stage II
- Phase IV – Maps and Deliverables Production Stage

Please refer **Figure 4.1** and **Figure 4.2** for the proposed approach and methodology for this study.

Besides the delineation of the Project through time phases, the provision of the work will be geared towards the acquisition of the data which is very important task in determining to produce the quality and good deliverables of the study.

Based from the experience of the consultant in previous related project, the data acquistion processes require plenty of time due to various reasons. Among others were the procurement process for the appointment of the third party data collection vendors by the client and disclosure approval of the data varies from difference agencies. However, the consultant will work together with the client diligently in the acquisition data processses in view of the tight time schedule given.

The approach and methodology to the Project will be described in accordance with the Project phases identified above. To provide a concise and informative description of the adopted methods, the phases are further broken down into individual tasks. In addition to the tasks identification by the phases, the identification of project management requirements that cover all the four phases will also be presented in this chapter.

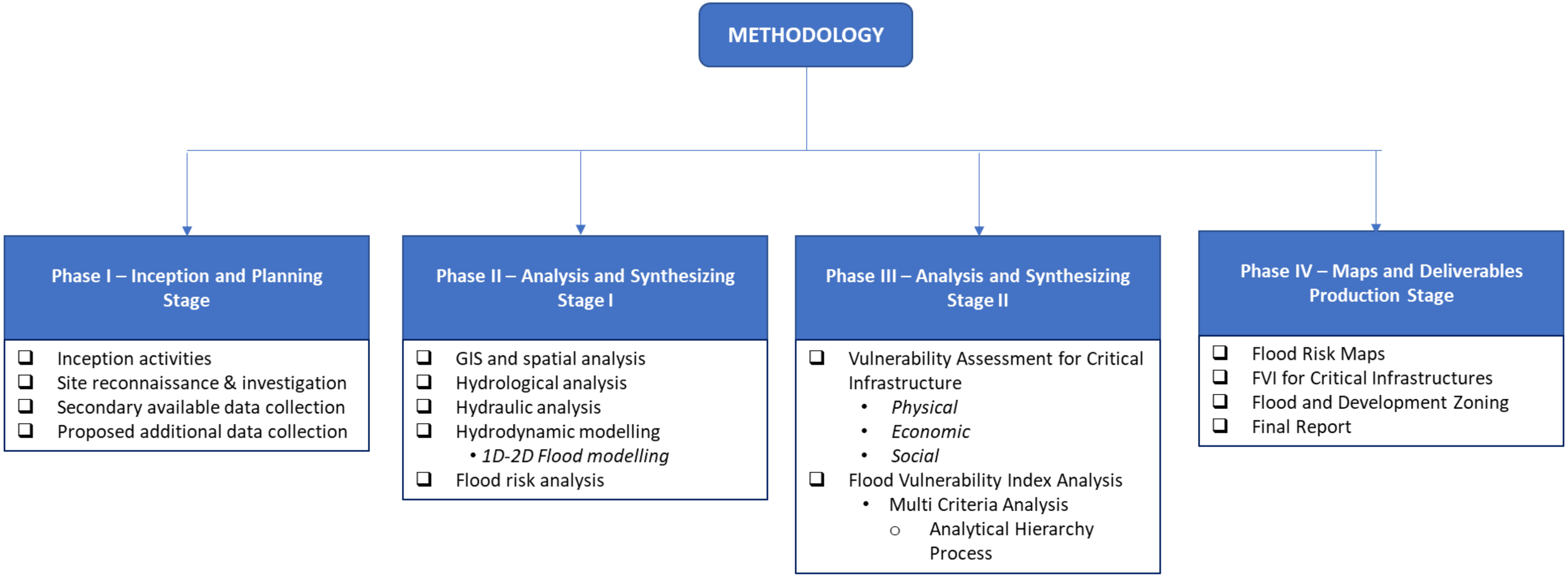


Figure 4.1: Work Process for the Approach and Methodology

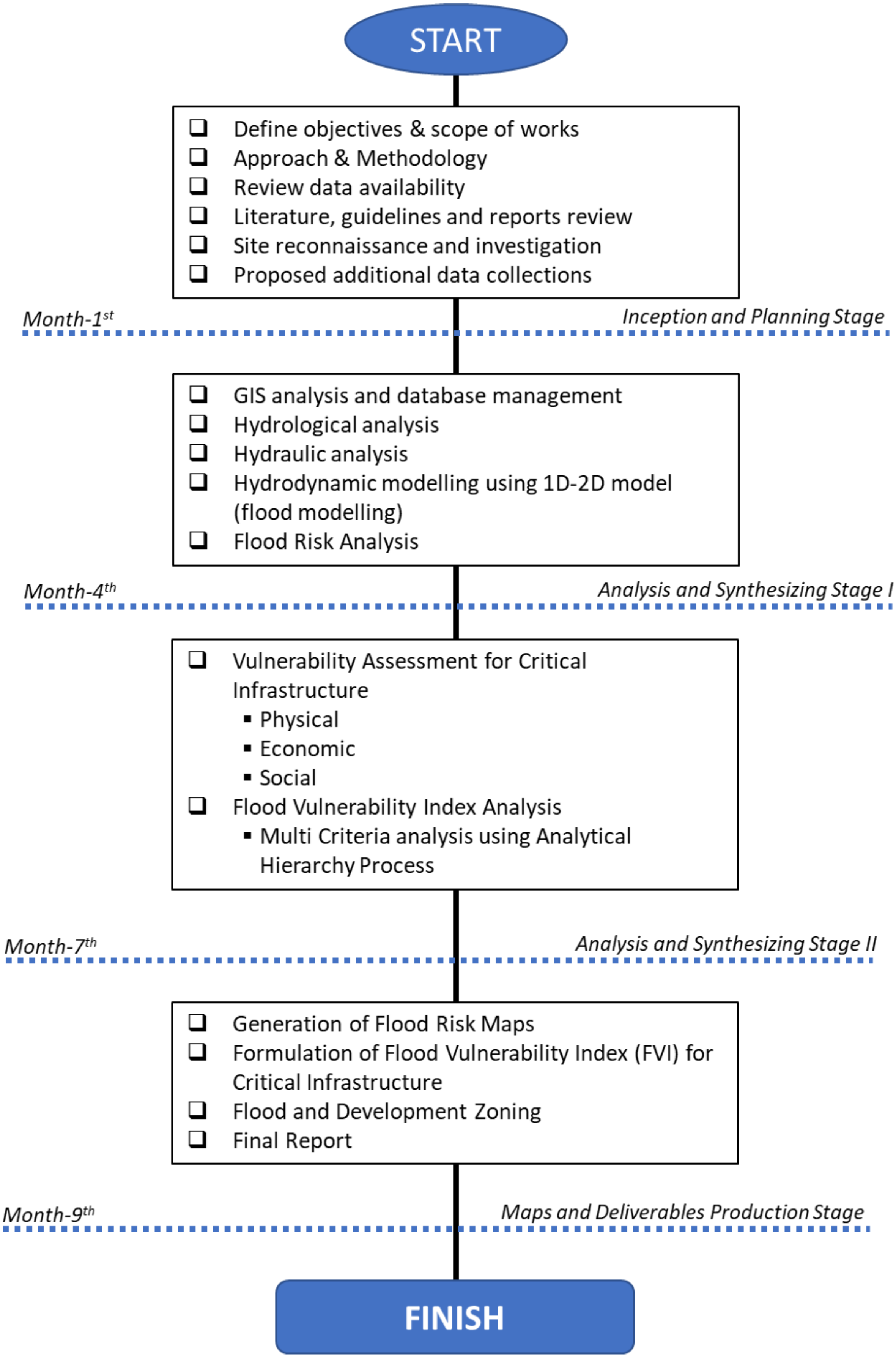


Figure 4.2: Timeline for the Works Process for the Approach and Methodology

The Consultant Team fully understands the input requirements of the Project which entail a wide spectrum of scopes, specialty and coverage in terms of physical areas in the Sungai Pinang River Basin. With the complexity and the scale of the Project in mind, the Consultant Team is of the opinion that it is vital at this stage to establish the modus operandi for the overall project management team, comprising of the Consultant Team, the Client, relevant agencies and interested parties working together in an integrated cohesive manner.

Lines of communication and responsibilities of all the team members will be clearly and explicitly spelt out. It is of particular important for the coordination between the Consultant Team, the Client and relevant agencies and interested parties so that the Project can be carried out smoothly and timely.

Development of the scope and requirements is necessary upon taking cognizance of the needs of the study. The Consultant Team will advice on the strategic plan for the implementation of the project and will seek approval from the Client accordingly. In doing so, the Consultant Team will identify all study components, technical requirements and conditions, and parties to be invited to provide services to the project as well as potential issues and constraints during the course of the project.

Among the key policy issues that will need to be resolved at an early stage are matters related to data acquisition which will require appointment of the third party vendor and the approval from various agencies which has wide spectrum of process and timeline approval. These include levels and limits of documentation, lines of communication, reporting procedures and systems.

The Consultant Team will assist the individual members in formulating appropriate management procedures and systems for the tasks required from their specialist input. The Consultant Team will also assist the individual members to identify areas or disciplines in which additional support is required to ensure that there are no aspect of the project that is not well managed and implemented in relation to others.

Internal review, monitoring and coordination meetings will be held at regular intervals and at more frequent intervals when the completion of individual work components draws near its stated completion date. The meetings will serve to disseminate information, acquaint the staff with current status of the Project, identify constraints and deficiencies in undertaking the study and establish future actions to correct them if necessary.

Further explanation on detail for each phase are described in the succeeding paragraphs.

4.3 PHASE I: INCEPTION AND PLANNING STAGE

The first phase of the Project will focus on start-up activities including establishment of the project team and mobilisation of staff. One of the most important activities at this phase will be to introduce key personnel in the Project team to the Client in order to establish a close working relationship. During this stage, the approach and methodology of the Project will be fined-tune and firmed up. Likewise, the work programme will also be modified if necessary with the new findings.

4.3.1 Site Reconnaissance and Investigation

Site inspections will be carried out so that the team members will be familiar with the Project area, existing drainage systems and causes of flooding. This will also enable them to appreciate the site conditions with reference to the available maps, reports and previous studies.

4.3.2 Data Collections Site Recconaissance and Investigatio

Collection of relevant and available data and information is another important in the inception and planning stage. The data and information to be collected include hydrological data, river engineering survey, socio-economic survey, previous study and design reports, topographic maps, orthophoto maps, geological maps, planning and zoning maps, landuse maps (current and future), Critical Infrastructures, Places of Interest, existing numerical models for Sungai Pinang basin. This will also include reviewing the available literatures that relevant to the topic and key words of the study.

For any data identified require further fresh and new collection due to unavailable or for any reason during this course of study, the consultant will advice the client on the specifications and details required to ensure process of acquisition could be carried out by the client in a separate procurement or by other means.

4.4 PHASE II: ANALYSIS AND SYNTHESISING STAGE I

Prior approval by the Client on the proposed approach and methodology for this study, the consultant will progress into the essence process of this study into the detailed analysis and synthesizing stage. At this stage various technical process will be carried out and explained comprehensively as follows:-

4.4.1 Spatial Analysis using GIS Tools

Initially, GIS database will be established specially for this study upon appointment by the Client. The database would contain information (e.g. existing river network, present/future landuse, Local Plan, geological map, DEM/DTM, photographs, etc) from various sources and output (e.g. drainage network, proposed bund alignment, design hydrographs, proposed cross-sections, etc) from this study. Commonly used state-of-the-art GIS software such as ArcGIS would be employed for the development of the GIS database. Figure 4.3 below shows example of the GIS Database in ArcGIS system.

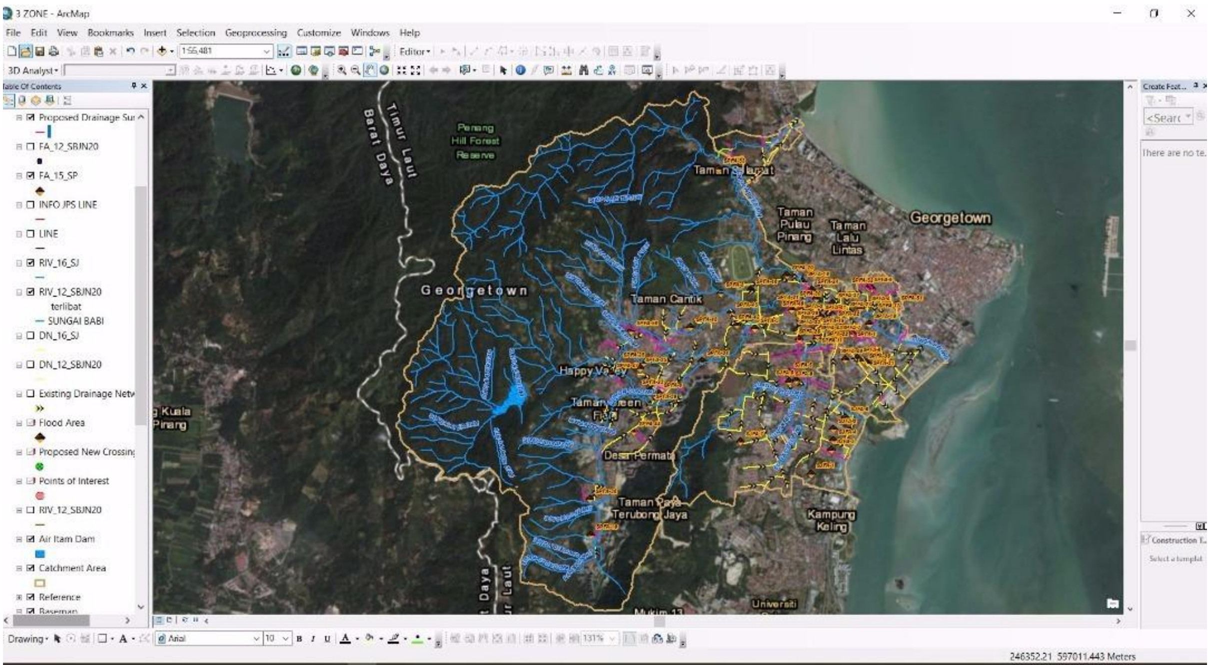


Figure 4.3: Example of GIS Database in ArcGIS System

Geographic Information System or GIS will be extensively used as a powerful tool in analyzing mainly in various work process in this study and certainly in formulating the Flood Vulnerability Index (FVI). GIS enables spatial data to be stored, manipulated, linked and analyzed in digital form and represents geographic data as useful information (Chrisman, 2002). It also provides a set of procedures for processing the geographic data to obtain information for decision making.

In a GIS framework, Multi-Criteria Analysis (MCA) approach can be used to combine and transform geographic data (input maps) as well as the decision maker 's preferences into a resultant decision (output map) (Malczewski, 2010). In constructing a FVI, it depends on complicated indices and weighting of their subjective. Eighty per cent (80%) of data used by decision maker are geographically related and integrate GIS with MCA techniques (Yalcin & Akyurek, 2004). Each of the criteria has to be associated with sub-criteria class. Based on the input from decision makers, all the criteria and sub-criteria should be ranked, and standardized score should be calculated (Chen et al, 2010). Integration with GIS allow user to manage spatial data, attribute data and therefore generate flood vulnerability maps (Hadi et al, 2017).

4.4.2 Hydrological Analysis

The hydrological analysis will involve rainfall-runoff modelling to obtain the inflow hydrograph. This will be repeated for various average recurrence intervals (ARIs of 2, 5, 10, 20, 50 and 100 years) to determine the design flood hydrographs for the respective ARIs. The Hydrological Procedure No. 1 (revised and updated 2015): Estimation of Desgn Rainstorm in Peninsular Malaysia will be used for this process. In this connection, the unit hydrograph method is suitable for the rainfall-runoff analysis.

The general procedure/methodology to be adopted for the rainfall-runoff modelling is:-

- Input data processing -All records from the rainfall and water level gauging stations will be examined and the adequacy and reliability of the data will be assessed. This is important in determining the rainfall-runoff model to be used to obtain the design discharges;

- Model setup -InfoWorks ICM/RS is to be used to estimate the design flood hydrographs, relevant data will be gathered for the setting-up of the model. The basic requirements for the input data to set up the model are as follows:
    - Topographical maps to extract various catchment scharacteristic such as catchment area, river length and slope, land use cover, location of important features such as dams and gauging stations etc;
    - Present land use maps from topographical maps, aerial photographs, etc;
    - Future land use plans from JPBD and local council such as local plans, structural plans and master plans;
    - Relevant topographical survey data; and
    - Relevant previous reportand studies on the catchment as well as other important features.

In the model setup, the information such as the sub-catchment areas, drainage and river length and slope, present and future land use, locations of the gauging stations for stream flow and rainfall, proposed highway/railway alignment, recorded flood events etc. will need to be processed and input in accordance with the model requirements.

- Model calibration and verification -From a few identified critical observed flood events and the model setup, the model parameters will be calibrated in order to match the simulated flood hydrographs with the observed ones using the observed rainfall as the model input. The process of calibration is to fit the simulated results with the observed data by varying the model parameters. Subsequently, the calibrated model parameters are verified by using other flood events to check whether the model can reproduce the flood hydrographs close to the observed flood hydrographs without changing the parameters obtained from the calibration.

  However, Sg Pinang River Basin is an ungauged river basin where there is no streamflow station in the basin available to compare any historical records of discharge. The Consultant will seek alternative method to calibrate (if available) the discharge from the river system vis-a-vis output from the model or otherwise to advice Client on other possibilities.

- Design flood hydrographs -Prior to the estimation of the design flood hydrographs using the model parameters obtained from the calibration and verification, the following parameters listed below needs to be defined:-

    - The loss model parameters to be used which are the initial loss values and runoff coefficient for the pervious area;
    - The base-flow values to be added into the surface runoff flood hydrographs;
    - Assignment of design rainfall depths to each sub-area of the model;
    - The critical rainfall temporal pattern to be adopted to generate the design flood hydrographs; and
    - Analysing for the present and future land-use conditions.

- After defining the above parameters, the design flood hydrographs will be produced from the calibrated model setup using the design rainfall depth. Flood hydrographs for the present and future land use and various average recurrence intervals (ARI) will be generated at various strategic locations for the subsequent hydraulic analysis.

4.4.3 Hydraulic Analysis and Hdyrodynamic Modelling

Normally, the hydraulic analysis requires extensive manpower and is very time consuming due to the complexity of the drainage systems with various hydraulic features. Besides the open and closed drainage systems, other features such as floodplain, detention ponds, gate operation, inflow and outflow structures, drainage loops and backwater flow in flat terrain, culverts and other waterway crossings, interconnecting ponds, pumping systems in low-lying areas may be incorporated into the system. In order to achieve reliable simulation, a full hydrodynamic modelling system that allows the simulation of all the features mentioned above is needed. One such sophisticated system is InfoWorks RS or InfoWorks ICM. The InfoWorks RS/ICM is a hydraulic modelling system requires substantial data collection, data processing and input data. Nevertheless, it is worth the efforts since InfoWorks RS/ICM can simulate very closely the actual conditions at site and has the flexibility to include various configurations, hydraulic structures and operation procedures for planning and design purposes.

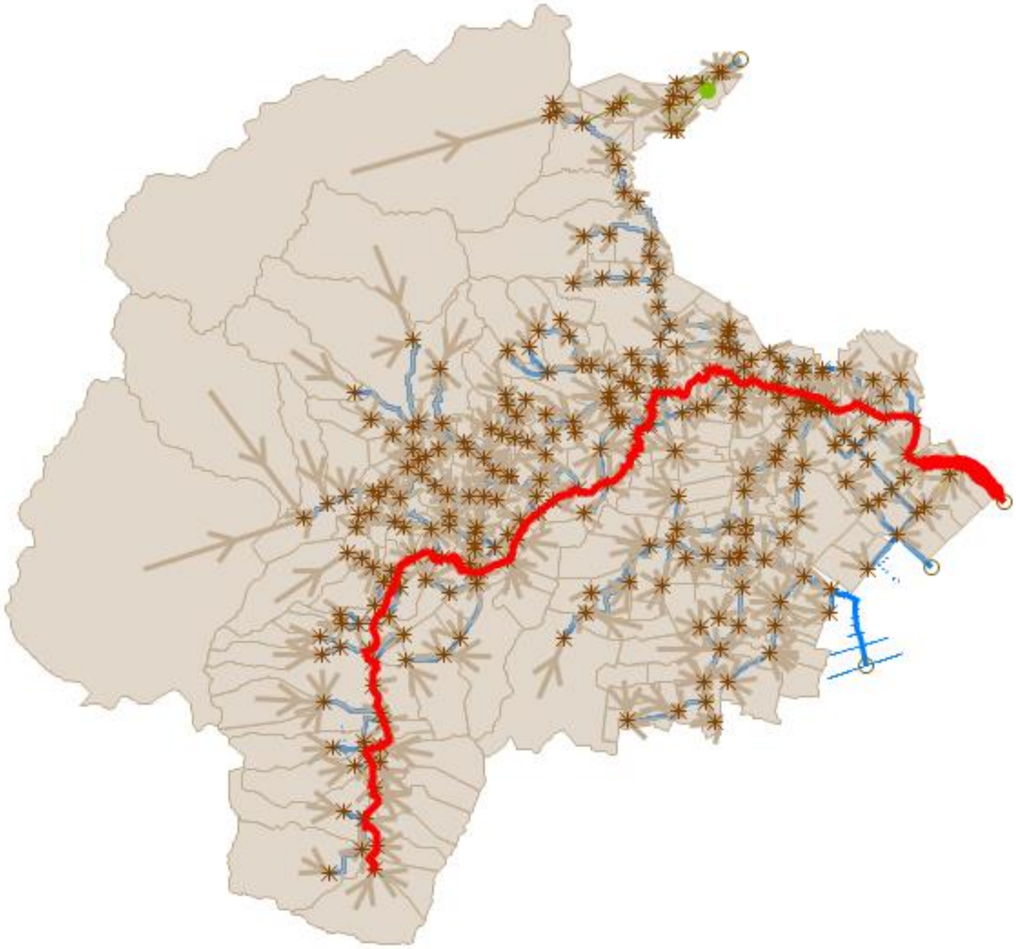
The hydrodynamic modelling will be performed using the InfoWorks Modelling packages. The general description of the InfoWorks model is illustrated in **Figure 4.4**. The approach and methodology adopted for the InfoWorks model are as follows: -

The data requirements of InfoWorks RS/ICM can be summarised as follows:

- River and channel cross sectional data. The interval of the data can be estimated using the stability criteria of the models and normally the larger the interval, the simulation become more stable;
- Boundary conditions of the model system where the variation of water levels with time is required for the estuary boundary and discharges input for the main river and all the tributaries;
- Roughness factor;
- Initial conditions of the model; and
- Configuration and hydraulic parameters of each hydraulic structures and if any, the operation procedures of the hydraulic structures.

The general approach/methodology to be adopted for the hydrodynamic models is as follows:

- Model setup -In order to use the model, the setting up of the model is very vital to the overall simulation process. It will form the back-bone of the study where various requirements of the model will have to be complied and all the limitations of the model will be observed in order to provide accurate simulation;
- Calibration and verification -These processes have to be carried out in order to ensure that the model can carry out simulations reliably.
- Simulation – Running the model to test the hydraulic behaviour under various conditions and input hydrographs of various ARIs.



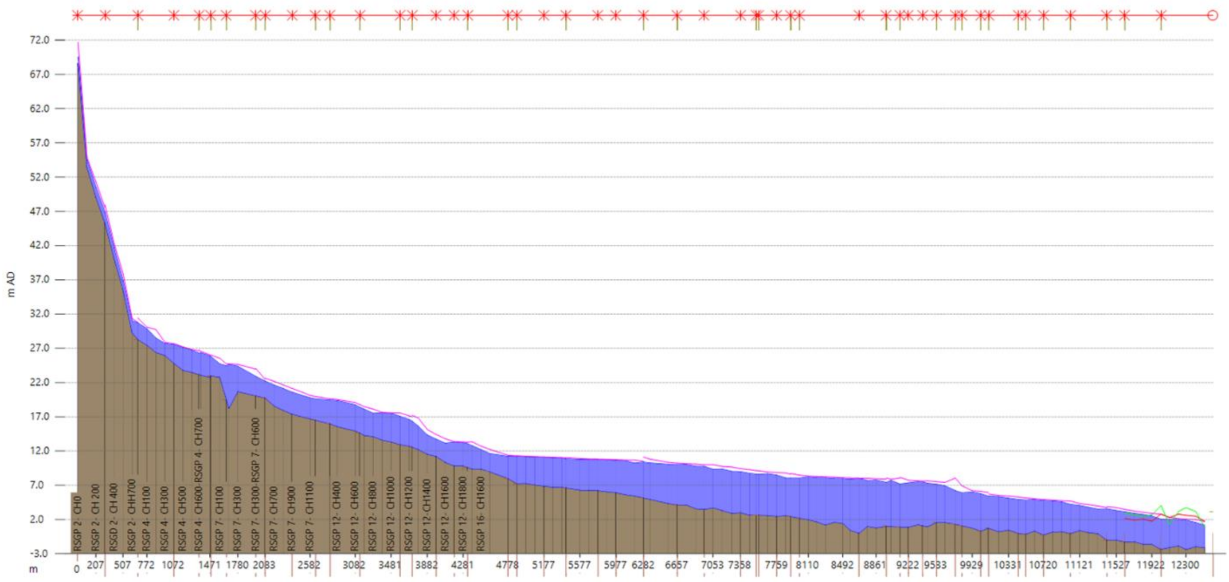


Figure 4.4: (above) Layout of Sg Pinang hydrodynamic Model
(below) longitudinal section of Sg Pinang

The hydrodynamic models will also be used to define flood levels, extent of inundation, flow velocities and flow behaviour for a range of flooding conditions. From the simulations, they can also provide important information for the flow pattern and its effects to the Study area. The complex networks of waterways system in the development can be modelled using the advanced structure module such as flow over hydraulic structures, including possibilities to describe structure operation such as overflow weirs, gate operation, pumps, culverts, etc. The formulations can also be applied to looped networks and quasi two-dimensional flow simulation on flood plains, extending from steep river flows to tidally influenced estuaries.

Various mitigation measures can be tested for their effectiveness. Due to the flexibility of the InfoWorks RS/ICM model, various complex options can be simulated to provide vital information so that the impact of the works can be fully appreciated. The InfoWorks RS/ICM model will also be coupled with 1-D and 2-D simulation to simulate 2-D flows over the flood plain such that the extent and depths of flooding can be. This will aid greatly in the evaluation of the various flood mitigation options for an optimum solution or one that is economically viable but still acceptable.

The model will be run for a range of storm durations so that the critical storm duration can be ascertained for all locations. InfoWorks RS/ICM includes full solution modeling of open channels, floodplains, embankments and hydraulic structures. Rainfall-runoff simulation is available using both event based and conceptual hydrological methods. Full interactive views of data are available using geographical plan views, sectional view, long sections, spreadsheet and time varying graphical data. The underlying data can also be accessed from any graphical or geographical view. Please refer to Figure 4.5 for illustration of the Hdyrodynamic Modelling Process Using InfoWorks ICM/RS.

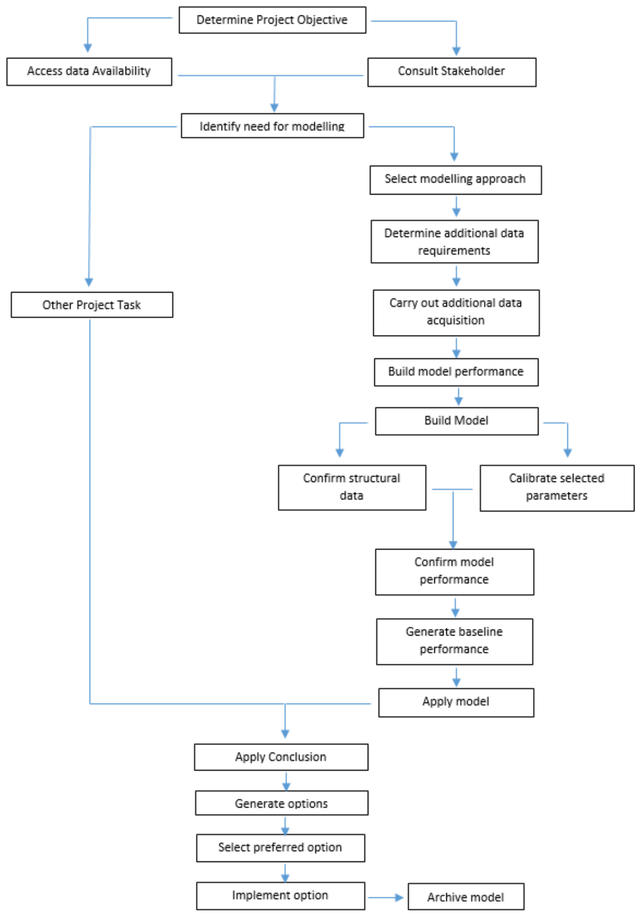


Figure 4.5: Hdyrodynamic Modelling Process Using InfoWorks ICM/RS

In river, hydraulic analysis the development of river and flood plain can be divided into two components which are the in-bank model and out-bank model. The in-bank model shall consist all related features which influences water flowing within the river bank without spill out to the flood plain. The most important information is as below: -

i. River cross section.

River cross section shall be added at suitable interval which shall depend on the river gradient. As the rules of thumb, the steeper the river the interval must be shorter. Cross sections should generally not be more than 20B apart, where B is the top width of the channel. Sections should generally not be more than 1/(2s) apart, where s is the mean slope of the river. Sections should generally not be more than 0.2 D/s apart where D is the typical depth of flow (or bank full depth for a flood model).

In areas where the mean flow velocity exceeds 1m/s, the wetted cross-section area should not change by more than about 35% between sections. As the river, cross section shall be provided by the client, there will be cases where the interval does not meet the requirement above. Under this circumstance, some interpolation shall be requiring ensuring the stability of the model.

The computation of section conveyance is governed by the Manning equation which is part of the St Venant equation. Detail explanation of the computation is explained below.

ii. Manning Section

The *Manning Section* models the flow of water in natural and man-made open channels based on the one-dimensional shallow water or Saint-Venant equations, which express the conservation of mass and momentum of the water body. Pseudo two-dimensional modeling of floodplain flow is also possible with the *Manning Section* when different conveyances are calculated for different areas of the channel cross section.

Static floodplain storage and sinuosity can also be incorporated. Localized regions of supercritical flow can be modeled approximately. The equations used by a *Manning Section* are the mass conservation or continuity equation: -

Equations

The equations used by a *Manning Section* are the mass conservation or continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \qquad \textbf{(1)}$$

where:

Q = flow (m^3/s)
A = cross section area (m^2)
q = lateral inflow ($m^3/s/m$)
x = longitudinal channel distance (m)
t = time (s)

and the momentum conservation or dynamic equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{\beta Q^2}{A}\right) + gA\frac{\partial H}{\partial x} - g\frac{AQ|Q|}{K^2} + q\frac{Q}{A}\cos\alpha = 0 \qquad \textbf{(2)}$$

where:

H = water surface elevation above datum (m)
β = momentum correction coefficient
g = gravitational acceleration (m/s^2)
α = angle of inflow
K = channel conveyance
$K^2 = A^2 R^{4/3} / n^2$
n = Manning's roughness coefficient
R = hydraulic radius = (A/P)
P = wetted perimeter

iii. Bridge Afflux formulae

The water afflux of flow through bridges or a constriction can be model using various technique. The following list describes the options for modeling a bridge structure:

- The HR Wallingford arch bridge method
- The USBPR design method
- The use of the culvert ("Conduit") options
- The use of a sluicegate option to generate an orifice equation
- The use of discrete ("Bernoulli") energy losses.

iv. US BPR Bridge

The flood behavior is very much influence by the present of infrastructures in the flood plain. Infrastructure may include road and bridges. InfoWorks has the capabilities to compute flood level due to the constriction of bridges based on *US BPR Bridge method. USBPR computes* the afflux at bridges using the methodology developed by the US Bureau of Public Roads (US BPR). Input data for the *US BPR Bridge* principally comprises two cross sections:

The river bed of the un-obstructed river channel along the toe of the bridge and extending into the floodplain (if appropriate) arch/opening and pier details. A practical expression for backwater has been formulated by applying the principle of conservation of energy between the point of maximum backwater upstream from the bridge, and a point downstream from the bridge at which normal stage has been re-established.

The expression for computation of backwater upstream from a bridge constricting flow is:

<u>Backwater expression:</u>

$$h_1^* = K^* \alpha_2 \frac{V_B^2}{2g} + \alpha_1 \left[\left(\frac{A_B}{A_4}\right)^2 - \left(\frac{A_B}{A_1}\right)^2 \right] \frac{V_B^2}{2g}$$

Where:

h1* = total backwater (or afflux)

K* = total backwater coefficient

a1 = kinetic energy coefficient at the upstream section

a2 = kinetic energy coefficient in the constriction

VB = average velocity in constriction

AB= gross water area in constriction

A4 = water area in downstream section

A1 = total water area in upstream section including that produced by the backwater

The value of the overall backwater coefficient, K*, which was determined experimentally, varies with: -

- Stream constriction as measured by the bridge opening ratio M
- Type of bridge abutments
- Number, size, shape and orientation of piers in the constriction

- Eccentricity, or asymmetric position of bridge with the floodplains
- Skewness of bridge and floodplain

K* consists of a base curve coefficient, Kb, to which is added incremental coefficients to account for the effect of piers (Kp), eccentricity (Ke) and skew (Ks). The value of K* is nevertheless primarily dependent on the degree of constriction of flow at a bridge

v. Weir/ Barrage/tidal gate

The modelling of moving structure such as weir, tidal gate or barrage can be carried out using gated structure option. The movement of gate can be modelled using logical control which is determine by either water level or flow which can be referred to upstream and downstream location or remotely. The weir and orifice equation are used to compute water level and flow within the structure. The mode of computation will be determining during simulation and can be summarized as follow and as shown in **Figure 4.6**: -

- Dry Crest
- Gate closed, upstream and downstream level below gate top
- Gate closed, free flow over gate
- Gate closed, drowned flow over gate
- Free weir flow under gate
- Drowned weir flow under gate
- Free gate flow
- Drowned gate flow
- Free over gate and free under gate flow
- Free under the gate drowned under the gate
- Drowned over gate and drowned under gate flow
- Sample of formula and condition one of the flows is shown below:

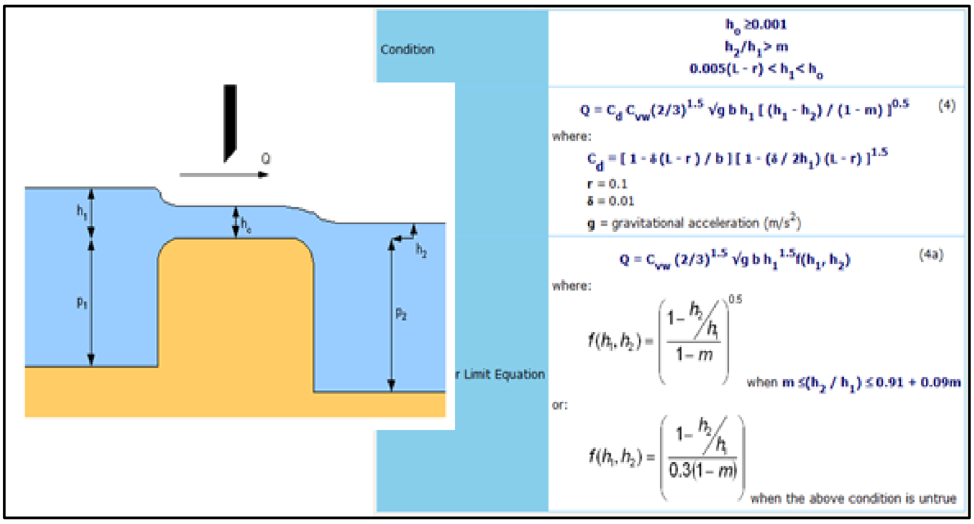


Figure 4.6: Drowned flow under the gate

vi. Dam/Pond

From the previous studies, various proposals had been made reduce flood risk which includes the construction of dam. All dams shall be incorporate in the model as storage/reservoir. Flow through reservoir and lake shall be using pool routing / reservoir routing which are part of the full St Venant Equation.

vii. 2D Floodplain component

Development of Flood Risk Map require input from the 2D Flood Plain Modelling. For 2D modelling, flow is not constrained to follow the direction specified by the modeler as in 1D modelling but is allowed to spread freely over the ground surface under the influence of gravity. The modelled area is represented by a **2D mesh of calculation elements using finite volume method** as shown in **Figure 4.7**. The InfoWorks 2D engine uses a finite volume technique, so it can take advantage of unstructured meshes. The engine is fully integrated within the InfoWorks GUI and so benefits from the full range of data import, validation, version control and audit trail functionality.

2D finite volume methods are used to solve the shallow water flow equations, using the Rienmann solver with a TVD shock capturing model that makes it particularly suitable for rapidly varying flood flows associated with bank overtopping or breaching. The 2D engine runs simultaneously with the 1D engine allow for a time step by time step exchange of water between each zone. This ensures that there is feedback between the two simulations. Links between the 1D and 2D zones can either be lateral i.e. 1D channel and 2D floodplain or in-line, i.e. a 1D reach that feeds in to a 2D reach or vice versa. Each model network can have multiple 1D and 2D zones.

Key to the efficiency and ease of use of the 2D engine is the automatic generation of the computational mesh. The mesh generator includes functionality to control the resolution by both maximum triage area and or minimum triangle angles. These can also be varied for differing parts of the mesh to enable high resolution to be maintained around key features, while using lower resolution for flatter, featureless, less important regions.

The mesh generator can also include voids (buildings), break lines and walls to add further definition to the hydraulically important features and use a range of polygons to specify individual roughness zones. In addition, the engine also simulates flow through walls, using a porosity coefficient, and either the partial or total collapse of the walls as a result of the hydraulic loadings. These lines and polygons can import from background layers, external files or 1D network features.

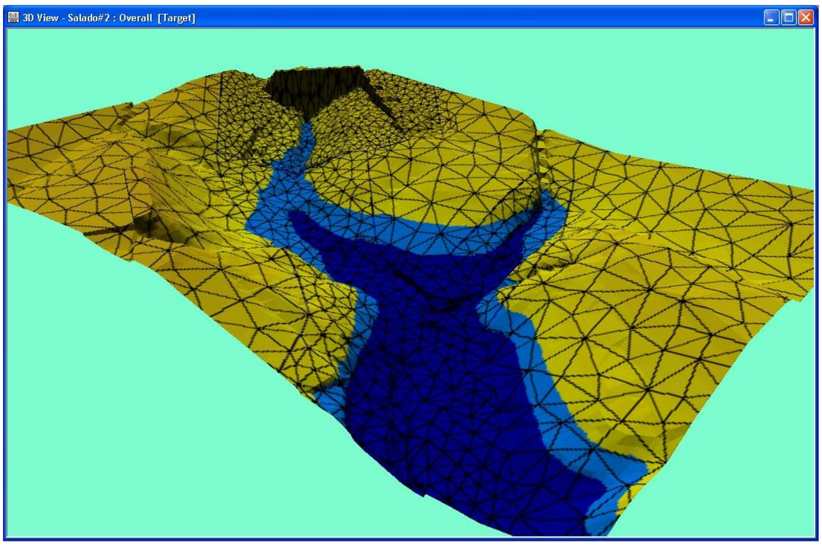


Figure 4.7: 2-Dimensional Mesh in finite volume in InfoWorks ICM

The 2D engine produces water levels at the center of each triangle and velocities across each of the triangle faces. These are fully integrated with 1D model results and the full range of graphical, tabular summaries and flood inundation mapping functionality is available for results presentation. In addition, the 2D engine offers thematic mapping of the velocity vectors using either direction arrows whose length indicates the magnitude of the velocity colored contouring. Please refer **Figure 4.8** for river and flood plain represented in 1-D and 2-D (mesh)

viii. Flood plain representation -Mesh Polygon

Firstly, a flood plain is represented by 2D polygon which contains the definition of the mesh. The information includes the mesh size and roughness. The elevation for each mesh is taken from the ground model either from IFSAR of LiDAR. The connection between the main river and the flood plain is through the bank line. If the geometry is complex such as valley, then another polygon can be specifying with finer mesh. **Figure 4.9** illustrates the finer mesh within the coarse mesh.

ix. Building representation

If building within the flood plain is considered significant, polygon of building from another GIS layer can be imported to represent as a void. Certain percentage of water can be allowed to get to the building by defining the porosity. **Figure 4.10** shown the representation of building

x. Road and bund representation

Road and bund in the flood plain play significant role to flood behavior. The extent of flooding can be limited by high road level constructed along the flood plain. The representation of road and bund in the flood plain is easily done using porous wall. Balancing culvert between the two sides of the road is modeled by conduit. **Figure 4.11** shows the effect of porous wall.

xi. Roughness in the flood plain.

Roughness value in the flood plain can be entered as a single value in the mesh polygon. However, if more detail land use is available, the roughness value of any particular area can be set to more accurate value. **Figure 4.12** shows the different value of roughness.

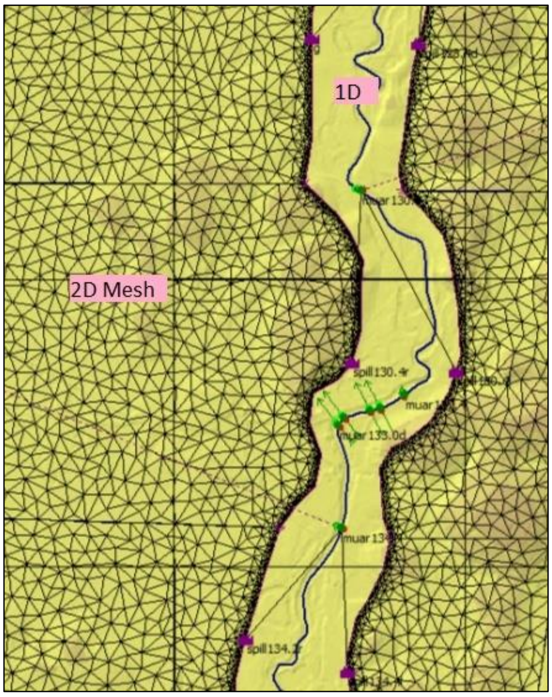


Figure 4.8: River and flood plain represented by 1D and 2D (mesh)

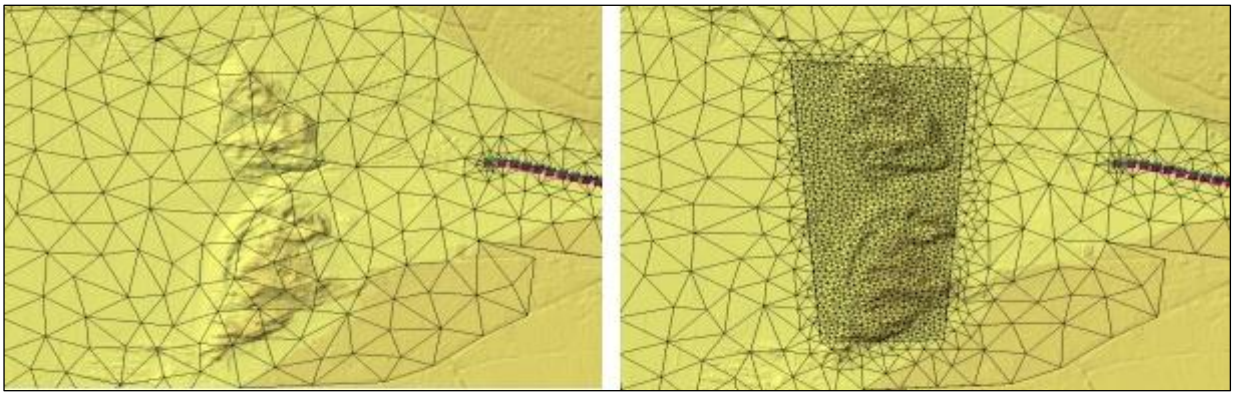


Figure 4.9: Mesh size variation to handle areas where there is a complex geometry

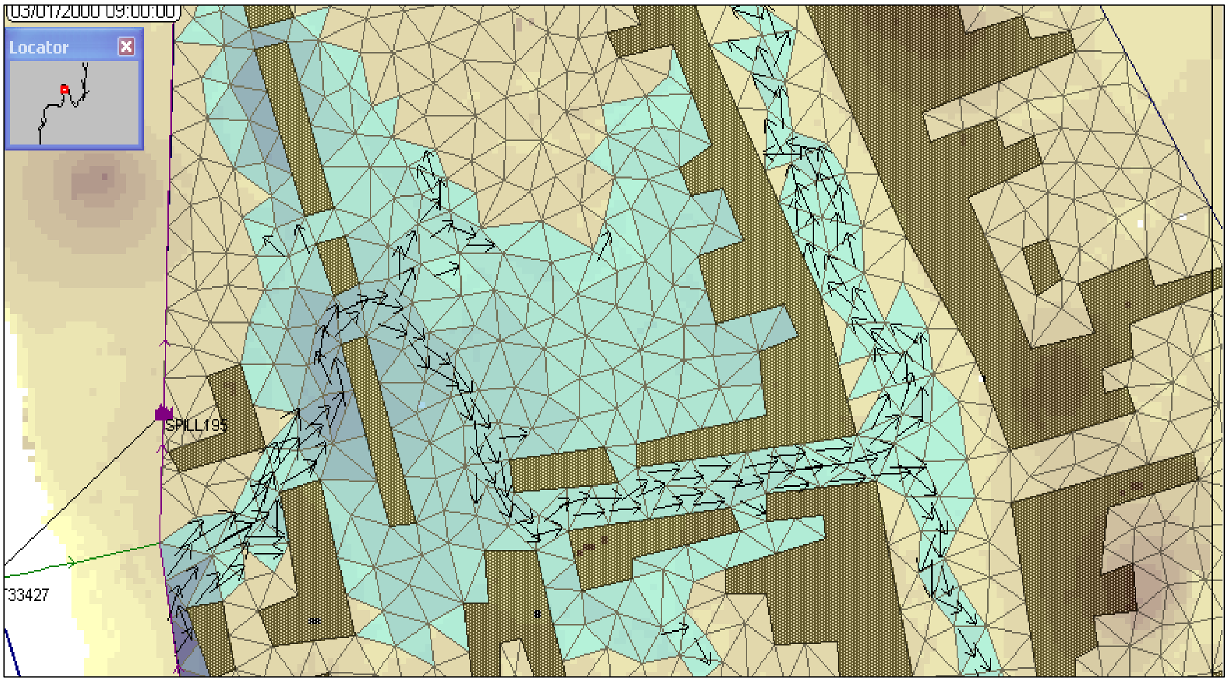


Figure 4.10: Building represented by polygon to allow water flows around buildings

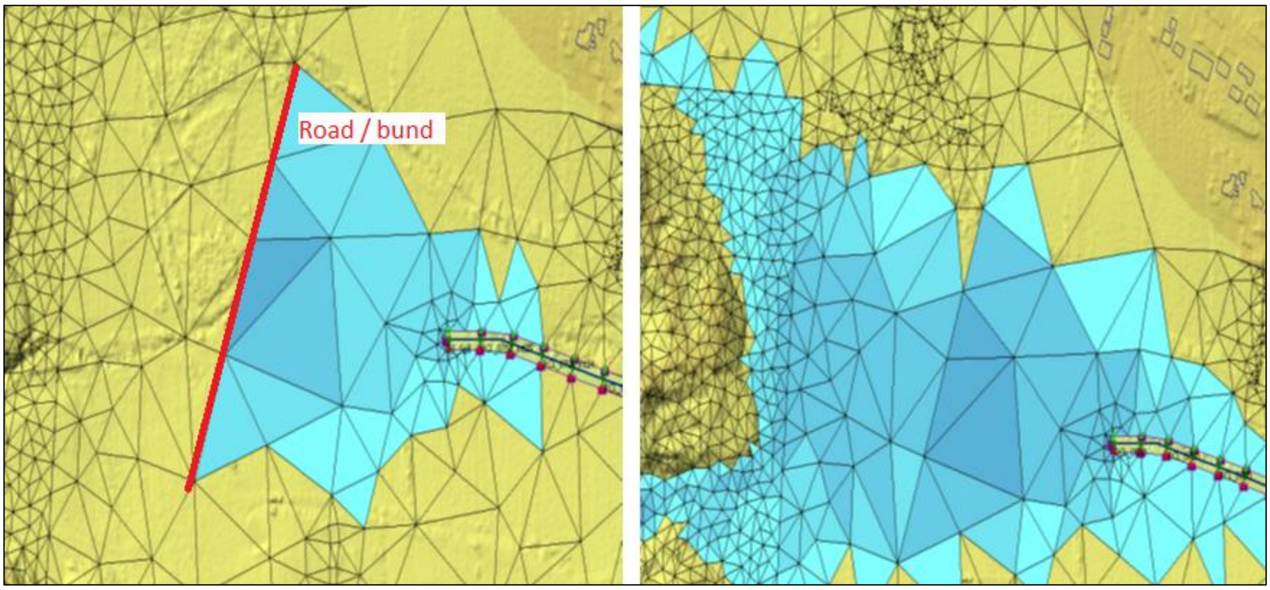


Figure 4.11: Representation of road or bund along the flood

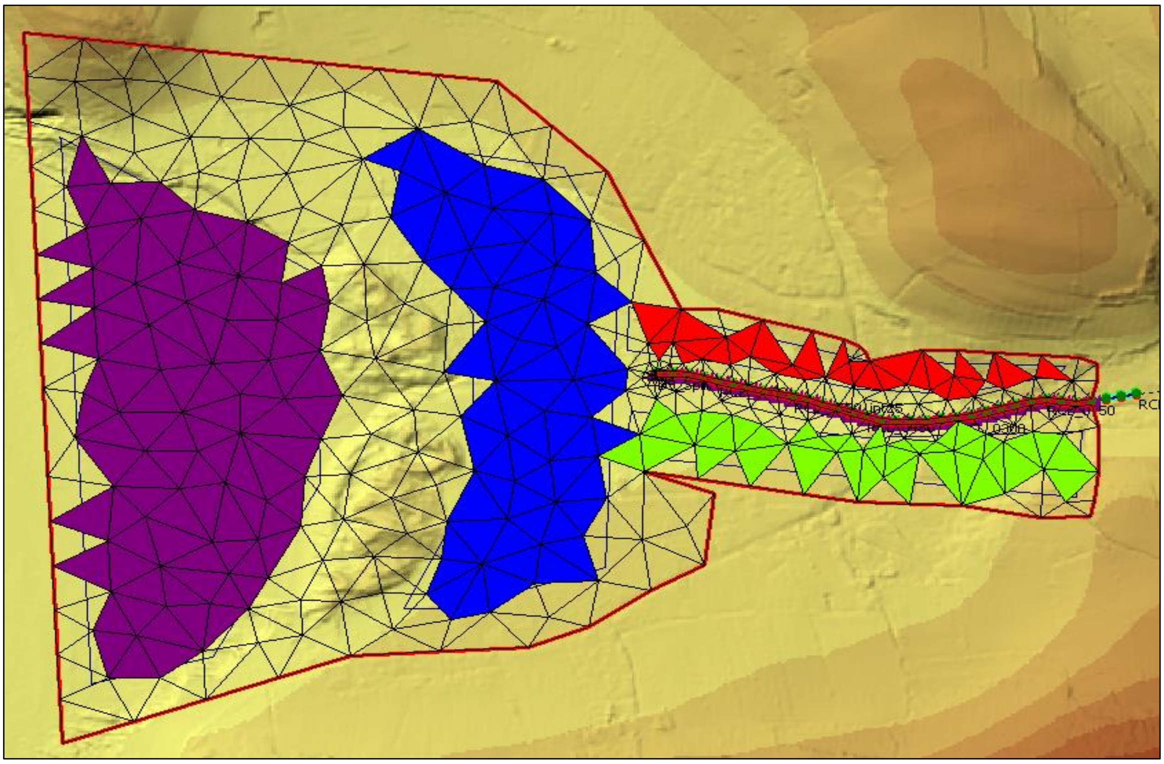


Figure 4.12: Roughness variation in the flood plain

According to (Sabri, Ratnarajah, Adnan, Wan Hazdy Azad, & Mohd Fisham, 2018) Flood hazard rating is an indication of how damaging the floodwaters can be, depending on its depth and velocities. Flood waters with high depth but low velocities may not cause much damage because the water is calmer or stagnant temporarily. On the contrary, low flood depths with high velocities can cause severe damage and risks to human lives and properties. High flood depths and high velocities, of course, produce high flood damages and thus are given high hazard rating. Low flood depths and low flood velocities typically do not cause much damage and thus is given a low hazard rating. Flood hazard is a key component affecting flood risk to people, to properties and to the various land uses. High flood hazards ratings typically produce high flood risks [Ranhill 2017].

Development of Flood Hazard Map in general can be divided into three main components which are hydrology, hydraulic and flood plain components. The three components are interrelated but can be simplify as shown in **Figure 4.13** below.

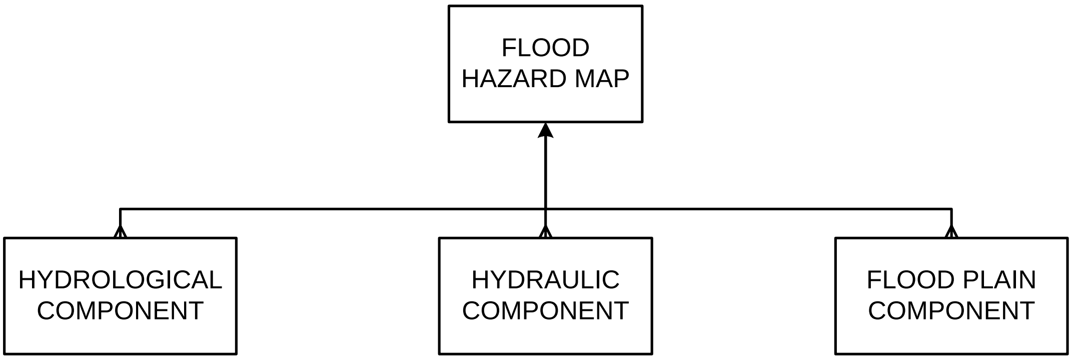


Figure 4.13: Main components for Flood Hazard Map project

Flood hazard map is produced from the overlying of water level from the hydraulic simulation over the 3-Dimensional ground information. The conventional way to achieve this objective is using 1-D approach in which the flood plain is represented by storage. However, this approach does not take into account the hydrodynamic of water flowing in the flood plain.

For the past 20 years, research on the use of 2-D modeling for the flood plain had been carried out. However only in the recent 5 years, 2-D representation of the flood plain had become popular due to various factors such as the available of high-speed computer to carry out huge amount of hydraulic computation. 2-D simulation techniques are available in the form of Grid and Mesh. Comparison by the two techniques has indicated that the Mesh technology is more flexible to represent complex geometry of flood plain and capturing infrastructure such as road which influence the flow behavior. The consultant shall also had chosen to use suitable applications i.e. ArcGIS, Global Mapper, Surfer, and InfoWorks ICM for the GPS, spreadsheet in processing data and analysis for hydrology, hydraulic, flood plain and flood hazard map at different stages of the process

4.4.4 Flood Risk Analysis

According to (Leonard Shabman, 2014), flood risk is the likelihood (or often referred to as probability of occurrence) and the adverse consequences of flooding. Flood risk for assets and people at any location in a floodplain is a function of flood hazard at that location and their exposure and vulnerability to the flood hazard see an illustration as **Figure 4.14** below.

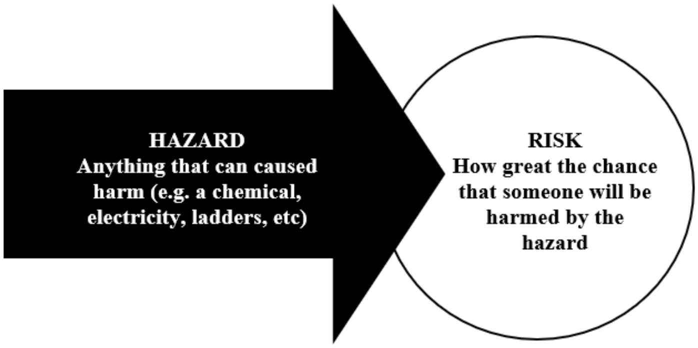


Figure 4.14: Hazard and Risk relationship

Flood risk is a measure of the statistical probability of flooding combined with the adverse consequences of the flooding. The practical determination of future flood risk is made up of four major components (DRB HICOM, 2017):

a) the probability of flooding;
b) the exposure of the receptors-at-risk to different flood characteristics;
c) the value of receptors-at-risk; and;
d) the vulnerability of these receptors-at-risk.

(Sabri, Ratnarajah, Adnan, Wan Hazdy Azad, & Mohd Fisham, 2018) described Flood Risk Assessment to determine the flood risk index is based on flood damage. Flood damage refers to all varieties of harm caused by flooding. It encompasses a wide range of harmful effects on humans, their health and their belongings, on public infrastructure, cultural heritage, ecological system, industrial production and the competitive strength of the affected economy. Although the terminology differs occasionally, flood damages are mostly categorized firstly in direct and indirect damages and, secondly, in tangible and intangible damages.

(Sabri, Ratnarajah, Adnan, Wan Hazdy Azad, & Mohd Fisham, 2018) suggested the formulae and methodology for carry out the flood risk assessment as follows: -

$$R = \sum_{i=1}^{n} \frac{1}{i} D_i$$

Where,

R = Flood Risk

i = Return Period (2yr, 5yr, 10yr, 20yr, 50yr and 100yr ARIs)

D_i = Damage for Return Period *i*

Operating the formulae requires the implementation of a 3-step procedure as illustrated in **Figure 4.15** in order to produce the flood risk value.

Step 1: Determine the *unit damage rates* for a range of return periods.

Step 2: For each return period, multiply the corresponding *unit damage rates* with the relevant *damage factors* to produce the *estimated flood damage*.

- *The applicable factors are flood depth, duration and strata (urban and rural).*

Step 3: Multiply the *estimated flood damage* for each return period with the probability of occurrence to compote the flood risk index.

- *The probability of occurrence is, of course, equal to 1/Return Period. For each return period, multiply the probability with the corresponding estimated flood damage.*

The *Unit Damage Rates* will be referred from study carried out by JPS Malaysia, December 2012[6]

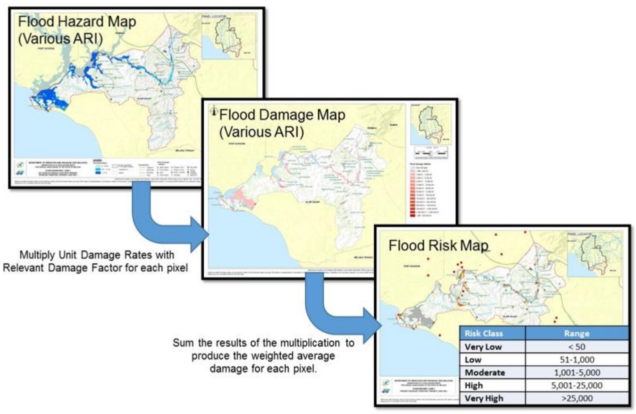


Figure 4.15: Procedure for Generating Flood Risk Index and Producing Map

[6] Updating of Condition of Flooding and Flood Damage Assessment in Malaysia, JPS Malaysia, December 2012

4.5 PHASE III: ANALYSIS AND SYNTHESISING STAGE II

4.5.1 Flood Vulnerability Assessment

(Vojinovic & Abbott, 2012) described the purpose of the Flood Vulnerability Assessment is to evaluate how vulnerable are urban communities (which can be relate in this study to Critical Infrastructure) to flood related hazards that can be incurred by all kinds of floods under present circumstances. It involves the application of different types of techniques and they range from ground survey and questionnaire-based interviews to the use of numerical models and remote sensing.

For this study, the consultant will address three (3) dimension of vulnerability assessment that will significantly be related to the Critical Infrastructure in Sungai Pinang river basin as follows: -

4.5.1.1 Physical Vulnerability Assessment

The Physical Vulnerability Assessment usually refers to the capacity of the built environment (e.g. buildings, structure, etc.) to cope with floods and flood-related disasters and it encompasses the characteristics of objects to sustain or resist potential physical damage, (Vojinovic & Abbott, 2012).

Each identified critical infrastructure will be assessed its vulnerability to the physical charatecteristics of the flood i.e. flood depth, flood velocity and the submergence time by superimposing with the results of the flood hazard maps.

4.5.1.2 Economic Vulnerability Assessment

The economic vulnerability assessment will be focusing on the each identified critical infrastructure to resist and recover from negative impacts of floods

4.5.1.3 Social Vulnerability Assessment

The social vulnerability assessment is defined as assessment of the social aspects within the perspective of the identified critical infrastructure on its susceptibility to a particular flood hazard due to Sungai Pinang flooding phenomenon. Among the aspects that will be considered in the assessment is confined to the following lists: -

- Demographic characteristics
- Degree of exposure to flood risks
- Living conditions
- Ability to understand messages that come from authorities about risk and protective behavior
- Ability to react in the event of disaster
- Access to insurance
- Physical and psychological well being
- Ability to recover from flood impacts
- Access to health care and other support

4.5.2 Flood Vulnerability Index Analysis of Critical Infrastructure

The aim of Flood Vulnerability Index Analysis of Critical Infrastructure is to produce an Index which comprise of identified dimension or components to evaluate how vulnerable are the Critical Infrastures to flood related hazard that can be incurred by the Sungai Pinang flooding phenomenon under the present circumstances. For this case, three dimensions or component will be proposed namely the *Physical, Economic and Social*.

The analysis will involve the application of different types of techniques and they range from questionnaire-based interviews, statistical analysis i.e. multi criteria analysis (analytical hierarchy process) to the use of numerical models and spatial analysis using state-of the art hydrodynamic models and GIS-Based tools.

Based on discussion by (Florina, 2007) on the application of Flood Vulnerability Index (FVI) equation derived by (Connor, 2005) to various river basin in the world including Philippines, the Consultant has rationalized the equation to suit the locality, timeline and resources of this project to be used in formulating the FVI for the identified Critical Infrastructure within the Sungai Pinang river basin to be read as follow: -

$$\mathbf{FVI} = {}_{wp}\mathbf{P} + {}_{we}\mathbf{E} + {}_{ws}\mathbf{S}$$

Where,

P is the *physical dimension*; E is the *economic dimension;* and S is the *social dimension*; w_p, w_e and w_s are the weightage for the respective dimensions

4.5.3 Multi-criteria Evaluation (MCE)

Multi-criteria evaluation methods (MCE) are often used as tools for sustainable environmental planning, strategic environmental assessments, and examining the impacts of proposed new flood vulnerability index based on multi-criteria assessment of the critical infrastructure (Malczewski, 1999; Malczewski, 2004; Biotto et al., 2009; Khalid, 2013). In this study, the investigation GIS and MCE would be used to identify potential sites for flood vulnerability index, which was assumed to be areas likely to experience critical infrastructure. This approach involves five steps namely to: *define the objectives*, *identify the criteria*, *determine weights the factors*, *standardized and map the criteria*, and *combine all the criteria based on decision rules* (Malczweski, 1999; Narimah, 2002; Khalid, 2013). These steps are used flood vulnerability index and likely to experience critical infrastructure in the near future (Khalid, 2013).

MCE approach allows decisions from various stockholders to be involved in the decision making (Narimah, 2002; Khalid, 2013). Therefore, affected residents, planners, experts or decision makers would be able to contribute and give opinion and influence decision making. **Figure 4.16** shows MCE-GIS framework used in this study, where 4 factors were included, and expert survey was conducted to derive weights for each criterion.

As mansion above, the objective of this analysis was to determine potential sites or areas likely to flood vulnerability index of the critical infrastructure in Sungai Pinang. Weights which were derived from expert survey and calculated using pairwise comparison approach (Khalid, 2013). The score for each criterion was standardized using fuzzy approach as available in the idrisi Kilimanjaro soft used to conduct GIS-MCE analysis. Weighted linear summation approach was used to combine all criteria (Khalid, 2013).

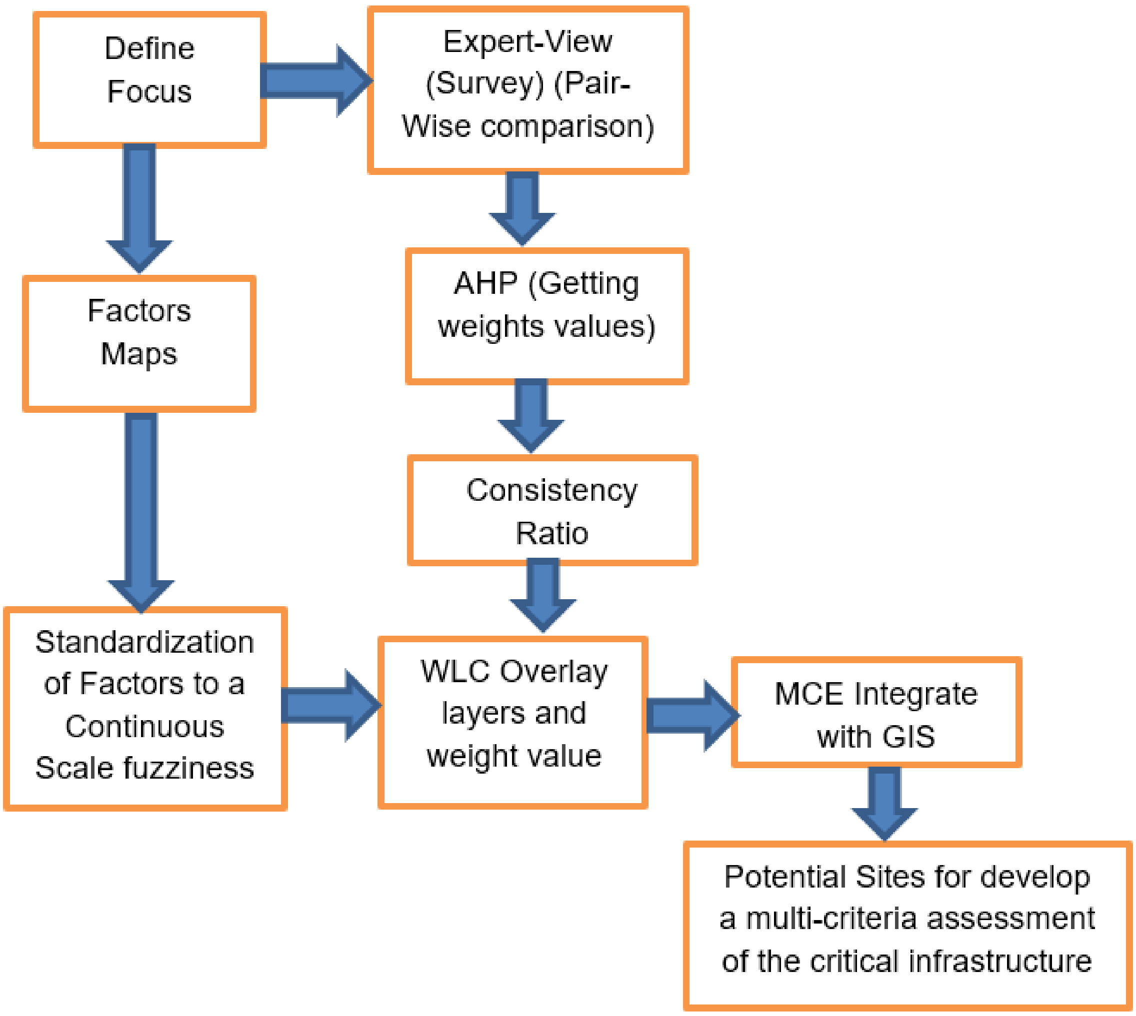


Figure 4.16: MCE-GIS Framework to Identify Areas Suitability for Flood Vulnerability Index for Critical Infrastructure *(Source: Khalid, 2013)*

4.6 PHASE III: MAPS AND DELIVERABLES PRODUCTION

Production of flood risk maps will be based on concepts that has been highlighted by (Sabri, Ratnarajah, Adnan, Wan Hazdy Azad, & Mohd Fisham, 2018) and are described below: -

4.6.1 Production of Flood Risk Maps

Probability of occurrence for a flood event is the reciprocal of its return period. The various return periods will be converted into probabilities as shown in **Table 4.1** below.

Table 4.1: Return Period vs Probability

Return Period	Probability
2	0.5
5	0.2
10	0.1
20	0.05
50	0.025
100	0.001

The production of flood maps requires combination input from several sources including the results hydraulics model and GIS data input. With the results of the 2D hydraulic analysis, the flood extent and flood depth will be calculated directly. Processing and producing flood hazard maps using GIS software requires combination input from several essential sources including the results of hydrodynamic models, Digital Elevation Model (DEM) and GIS base maps. The flow of the map generation is as shown in **Figure 4.17** below.

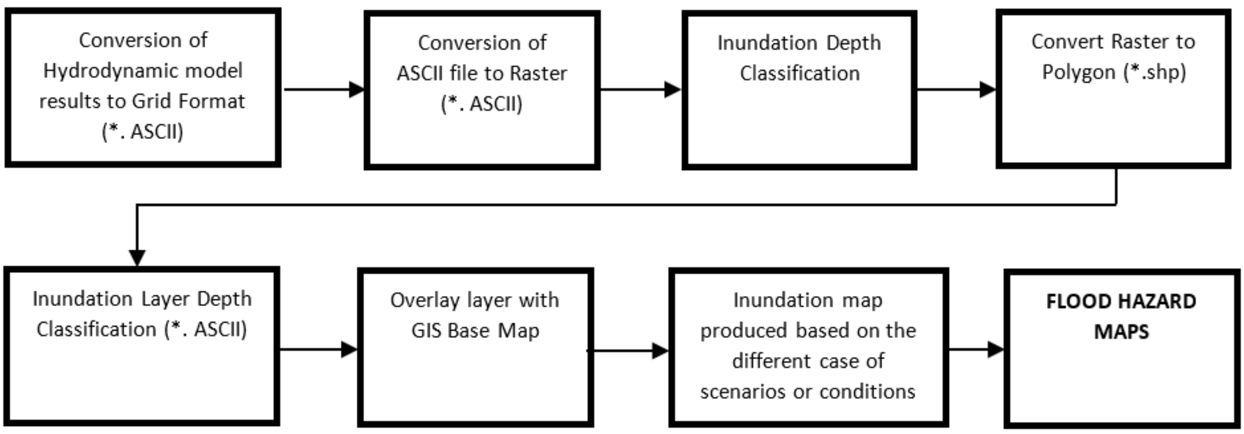


Figure 4.17: Work Flow for Flood Maps Generation

The computation and mapping of flood risk involves six (6) steps as illustrated as **Figure 4.18**. For each flooded pixel (location) that we set to 100m x 100m or 1 hectare per pixel, the following computational steps can be adopted in order to produce the flood risk map (DRB HICOM, 2017):

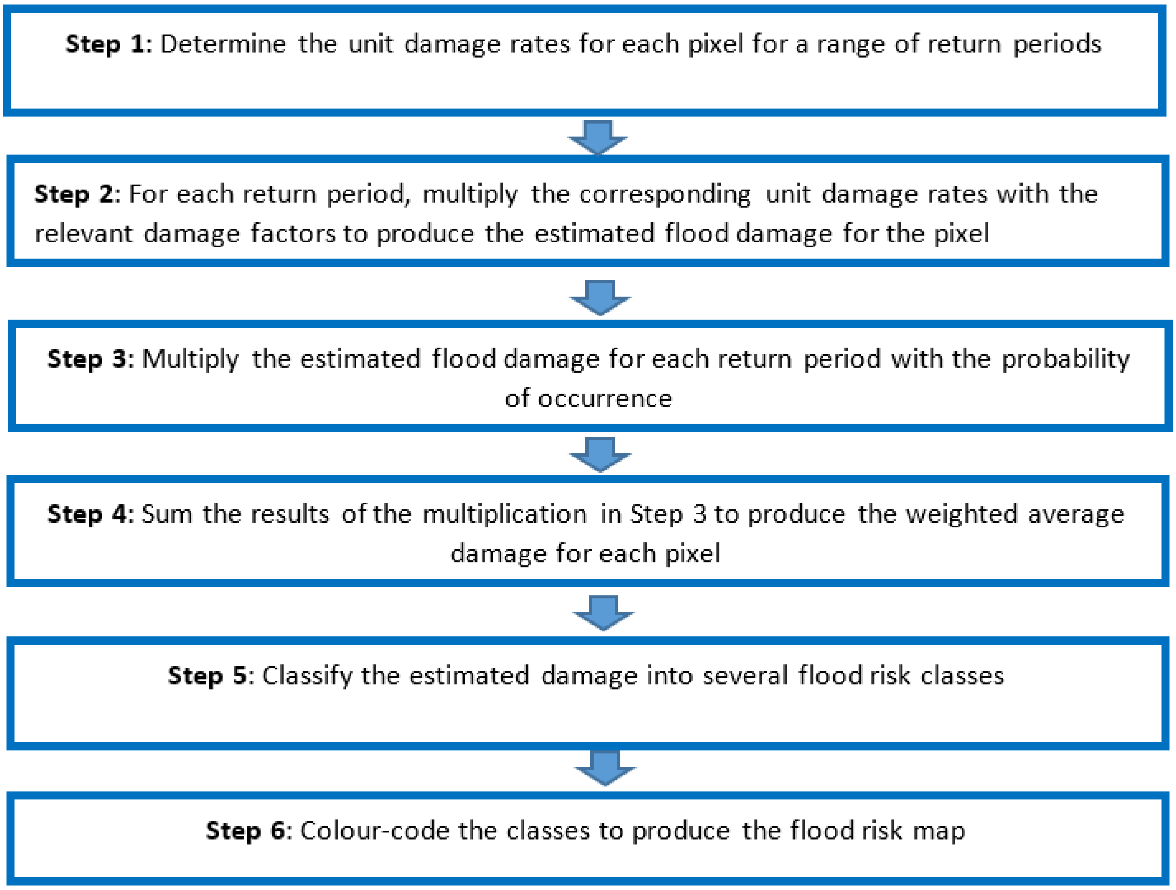


Figure 4.18: Computational Steps for Flood Risk Map Production

The production of flood risk maps shall be on 100-year ARI at the scale of 1:25,000 for present and future land use conditions. The flood risk maps for the specified ARIs must clearly indicate flood risk zone, flood extent, location of flood evacuation centres, major towns, transportation network and points of interest. The flood risk zone shall be denoted by the colour scheme as shown in **Table 4.2** below:

Table 4.2: Flood Risk Map Colour Scheme

Colour	Flood Risk Class	Range	Colour Name	R	G	B
	Very Low Risk	< 50	Grey	178	178	178
	Low Risk	51–1,000	Sky Blue	135	206	235
	Medium Risk	1,001–5,000	Yellow Green	154	205	50
	High Risk	5,001–25,000	Orange	255	170	0
	Very High Risk	> 25,000	Red	225	0	0

The categorization of flood risk values into five risk classes requires end values (range) to be determined from a large set of data points (pixels of weighted average damage). In order to ensure that the range for all risk classes is valid, the set of data points must not only represent a variety of return periods, but also derived from river basins that cover all land uses. This is especially pertinent since the end values obtained in this Study will be used as a basis for classification of flood risk for the entire country. The end values (range) must be determined using a rich enough data set that covers all land uses of interest.

4.6.2 Production of Flood Hazard Map

The results of the simulation of hydrodynamic analysis, the flood outline for various ARIs can be defined. The results of a 2D model can be extracted as the water depth directly. Other hydraulic dimensions such as speed of current are also available for the areas calculated by a 2D model. The generation of flood area and depth maps will be done by exporting the hydrodynamic model results to ArcGIS. Comparison of field records corresponding to the selected historical events will be done to verify whether the modelling of flow and terrain conditions is successful. Accordingly, a set of flood hazard maps associated with 5-year, 10-year, 20-year, 50-year and 100-year ARIs can be established.

The completed flood map is then exported as a shapefile. ArcGIS is then overlaid the flood map with another layer such as landuse map to produce flood hazard. The surface flood levels and flood depths were determined in order to produce the flood hazard, flood evacuation and flood risk maps. General information of these maps included at least the following information:

a) Title *(what kind of information on which the location is presented)*;

b) Location of the map as part of the catchment or country;

c) North and scale *(preferably scale pole as this allows for changes in page sizes)*;

d) Date of publication; and

e) Disclaimer, including remarks on the quality of information.

All maps should have consistent information (e.g. consistent extents for given event probability) although the content, format and dissemination may differ depending on the purpose and target audience. Flood hazard maps shall be produced based on 2, 5, 10, 20, 50 and 100-year ARIs at the scale of 1:25,000 for present and future land use conditions as clearly stated in the Scope of Works. The flood hazard maps for the specified ARIs must clearly indicate flood depth and flood extent. The flood depth shall be denoted by the colour scheme as showed in **Table 4.3** below:

Table 4.3: Flood Hazard Map Colour Scheme

Colour	**Degree of Flood Hazard**	**Flood Depth**	**R**	**G**	**B**
	Low	0–0.5m	190	232	255
	Moderate	0.5–1.2m	0	197	255
	High	1.2m-2.5m	0	92	230

The explanation of flood hazard relation between depth and degree of flood hazard are as below (DRB HICOM, 2017):

a) **Low < 0.5m = "Caution:** Flood zone with shallow flowing water or deep standing water". Note: It is still possible to walk through the water.

b) **Moderate** between **0.5 and 1.2m = Dangerous for some (example: children)** "Danger: Flood zone with deep fast flowing water". Note: The ground floor of the buildings will be flooded, and inhabitants have either to move to the first floor or evacuate.

c) **High** between **1.2 and 2.5m = Dangerous for all (Level 1)** “Extreme Danger: Flood zone with deep fast flowing water”. Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

d) **Very High > 2.5m = Dangerous for all (Level 2)** “Extreme Danger: Flood zone with deep fast flowing water” Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

CHAPTER 5

DATA COLLECTION AND DATABASE MANAGEMENT

CHAPTER 5

DATA COLLECTION AND DATABASE MANAGEMENT

5.1 INTRODUCTION

This chapter discusses the data collection and database management system developed for this study. Gathering and managing data is major part of developing successful of this study particularly when dealing with various spatial data and various scales, sources and formats.

The database system will be developed by organising data files, both spatial and attribute systematically and represent them using suitable graphical symbols. Standard datasets, symbol and maps will be used to make the database system user friendly and easy manageable so that it can be useful even for the non-technical officers. The database system includes a summary of river basins and sub-basin data on a series of map overlays in digital format.

5.2 DATA REQUIREMENT

The preparation of a comprehensive database with spatial information and associated attributes in the development of the database system will be based on the requirement to fulfill the objectives of the study.

The database system will contain various information and features that can be retrieved from the ESRI ArcGIS Desktop version 10 project files (*.mxd). For this study is concerned, the database system generally will be able to compile the required data for the Sungai Pinang river basin. Among the required data and be compiled into the proposed database system shall include the following lists: -

- Base map
- Geological map
- Soils type map
- Topographical map
- Drainage Networks
- Road Networks
- Critical Infrastructure Data
- Evacuation Centres
- Land use map (current & future)
- Satellite / aerial images
- Existing drainage assets inventories
- Cadastral, structure and local plans
- Flood records and reports
- Previous studies, projects and literatures

The description and proposed content for the maps are as follows: -

a) Base Map

The base map includes the fundamental framework of river basin, sub-catchments, streams, roads and state/municipal boundaries for the Study area. The base map will provide several observations concerning the sub-basin and the relevant municipalities in the basin. The sub-basin information will serve as the basic hydrologic planning unit for identifying basin environmental condition and conducting data collection.

b) Geological Map

The geology map summarizes the subsurface bedrock characteristics which affect surface and groundwater quality and quantity. Geologic data can provide estimates of depth to bedrock and permeability which are needed for understanding the hydrological soil properties of the basin. Delineation of geologic features can also assist in identifying vulnerable recharge area that could be protected from contamination. The geology data base includes the following:

- Geologic Formation
- Depth to Bedrock
- Depth to Groundwater Table
- Sinkholes, Latitude/longitude and status
- Quarries
- Faults
- etc.

c) Soil Type Map

The soil type map provides indications of permeability and drainage which are necessary to estimate groundwater recharge, erodibility and stormwater runoff. The permeability of soils are dependent on the type of soil (sand, silt or clay) and hydrologic soil group A, B, C and D. Soils are used to delineate floodplains, identify fragile erosion prone slopes and define the limitation of septic systems. Generally, silts and clays are less permeable, generate greater stormwater runoff and sustain greater sediment loads. In contrast, sands and gravels provide greater groundwater recharge and less runoff and sediment loads. The soils data base includes:

- Soil Association
- Brief Description
- Depth to Groundwater Table
- SCS Hydrologic Soil Group
- Permeability (in/hr)
- Soil Type (sand, loam, clay)
- etc.

d) Topographical Map

This map provides the land contours for the Sungai Pinang river basin. Topographic data is used to identify fragile steep slopes, estimate stormwater runoff and estimate sediment loads. It shall be in the format of iFSAR or LiDAR with the recent acquisition exercise.

e) Land Use Map (current and future)

Along with soil data, land use is a fundamental indicator of stormwater loads and impacts on the quality of receiving waters. Land use data is used to identify and estimate pollutants as well as provide indicators of basin management needs in the basin. The land use map present land use maps which include at least the following categories:

- Residential Area
- Industrial Area
- Commercial Area
- School Area
- Public Institution
- Other Institution
- Religious Facilities
- Health Facilities
- Squatters

- Open Land
- Bare Land
- Electricity Reserve
- Drainage/River Reserve
- Water Supply Reserve
- Graveyard
- Etc.

f) Zoning

The zoning map provides a delineation of potential or future land uses at the planned fully built scenario. The zoning map also provides an opportunity to review the land use plan and zoning ordinance within the basin and identify possible modifications that may be more usable for representing hydrological response units. Zoning can also be used to estimate pollutant loads for future land use scenarios. The following zoning classifications can be mapped in the basin:

- Residential Area
- Industrial Area
- Commercial Area
- School Area
- Public Institution
- Other Institution
- Religious Facilities
- Health Facilities
- Squatters
- Open Land
- Bare Land
- Electricity Reserve
- Drainage/River Reserve
- Water Supply Reserve
- Graveyard
- Etc.

5.3 APPLICATION OF RELATED DATA

Data collection is one of the most important activities during the inception phase of a study. The quality of analyses and results as well as the conclusions and proposed measures draw heavily upon the quality and adequacy of the data for hydrologic and hydraulic modelling and assessment. This is particularly so because of the extent of the coverage of the study area covering the area of approximately 51km^2.

The project team will make several site reconnaissance and visits to the study area and carry out preliminary interviews with the locals and authority in order to understand the cause and phenomenon of the flooding within the study area. The formulation of the required data for this project will be create based on the understanding of the study area and related issues that requires attention.

In general, three categories of data are used to adequately characterise the conditions for flooding situations and to carry out relevant analysis of hydrologic and hydraulic modelling assessment for Sungai Pinang river basin. The categories are as follows: -

- Category 1: Physical and natural features
- Category 2: Land use and population characteristics
- Category 3: Waterbody conditions

The acquisition of the required data will be made in several methods: -

- Direct purchase from the supplier by the Client
- Application through the client's office to respective agencies
- Application to client's office for relevant data
- Field works

Table 5.1 below list the data required at this stage and will update from time to time to the client.

Table 5.1: Data required for this study

No.	Description	Agency	Status
1	Hydrological data i) Rainfall (Daily, Hourly, Annual Maximum) ii) Water level (hourly, daily) iii) Streamflow (hourly, daily)	**JPS Malaysia** Format: Text/Data	
2	River and Drainage network survey data	**JPS Malaysia** Format: ACAD	
3	Satellite Images (Recent) • Ikonos/Quickbird	**Agensir Remote Sensing Negara** Format: Softcopy Projected Image to MRSO/GDM2000	
4	Land use map (Rancangan Tempatan) • Current • Future (2030)	**PLANMalaysia/PLANMalaysia@Penang** Format: Shapefile Projected to MRSO/GDM2000	
5	Hydrological Soil Type Map	**Department of Agriculture** Format: Shapefile Projected to MRSO/GDM2000	
6	Geological map	**Jabatan Mineral & Geosains** Format: Shapefile Projected to MRSO/GDM2000	

No.	Description	Agency	Status
7	Cadastral map (standard sheet)	**Jabatan Ukur dan Pemetaan Malaysia** Format: Shapefile Projected to MRSO/GDM2000/Cassini	
8	Digital Terrain Model	**Jabatan Ukur dan Pemetaan Malaysia** Format: iFSAR/LiDAR Projected to MRSO/GDM2000	
9	Census data • Demographic • Population, etc	**Jabatan Perangkaan Malaysia** Format: Data/Text	
10	Drainage network	**PEGIS** Format: Data/Text	
11	Places of Interest	**GIS Company** Format: Shapefile Projected to MRSO/GDM2000	
12	Critical Infrastructure • Public buildings • Education buildings • Health buildings • Religious buildings • Heritage sites/zones	**Pejabat SUK Pulau Pinang/Jabatan Pendidikan Pulau Pinang/Jabatan Kesihatan Pulau Pinang/** Format: Data/Text/Shapefile	

CHAPTER 6

STUDY TEAM ORGANISATION & WORK PROGRAMME

CHAPTER 6

STUDY TEAM ORGANISATION AND WORK PROGRAMME

6.1 INTRODUCTION

This chapter will describe the work programme and the Consultant team organisation to execute the project. Work programme and deliverable item of this consultancy service will follow the requirement as stated in Term of Reference (TOR).

6.2 WORK PROGRAMME

As mentioned explicitly in the TOR, the Study period shall be completed within 9-months from the date of commencement of the Study which is started on 17th November 2018 and end on 17th July 2019. By comparing the scope of works which is very wide and detailed with the time period available for the Study, the tasks as highlighted in the approach and methodology have to be carefully planned and coordinated so that the Study can be completed as per schedule. All the milestones provided in the TOR also need to be adhered to strictly so that the Study will not be off-track in meeting the requirements and objectives.

6.2.1 Milestone of the study

In performing the services, the Term of Reference stipulates the submission of various documents that will form the milestones for the scheduling of the work to its completion. All milestones submission date must be strictly follow to prevent the study from off-track. **Table 6.1** are the milestone of study for the submission of the various reports:

Table 6.1: Milestone of Study

Deliverables	Quantity	Dateline
Inception Report	5 Hard Copy with PDF	1-month after appointment
Interim Report	5 Hard Copy with PDF	4-month after appointment
Draft Final Report	5 Hard Copy with PDF	7-month after appointment
Final Report	15 Hard Copy with PDF	9-month after appointment

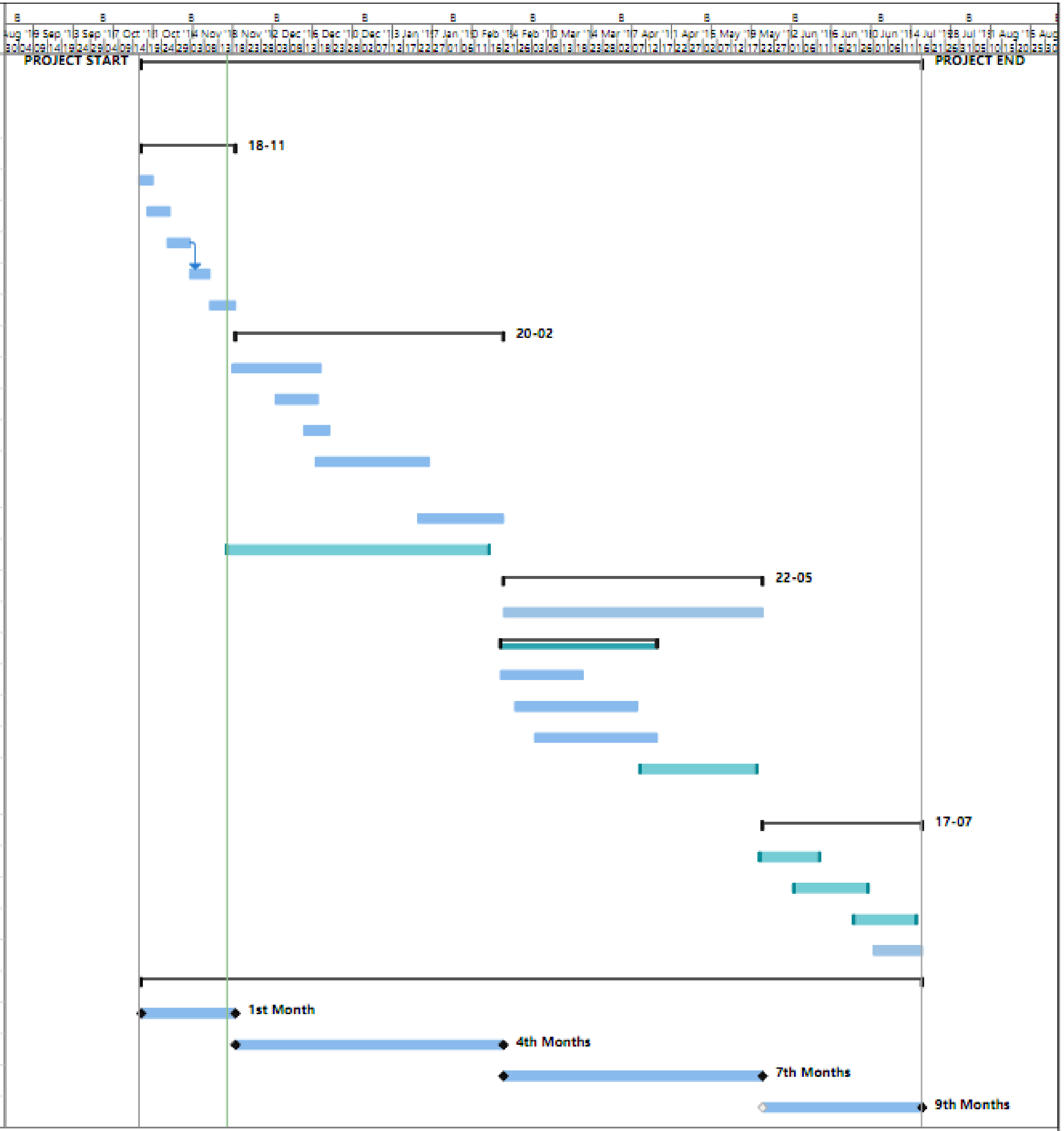
6.2.2 Study Work Programme

The work programme for this Project integrates the proposed approach and methodology with the proposed Project team organisation, milestones of the project and the identified activities and tasks to ensure the disciplined management of the Project to yield the required outputs in a timely and satisfactory manner. The work programme of this study is presented in **Figure 6.1**. The Study commenced on 17^{th} November 2018 for a period of 9-calendar-months. This program will be further expanded and breakdown into more detailed tasks and be used throughout the Study period to monitor the progress of each work component.

6.3 PROJECT TEAM ORGANISATION

The successful and timely completion of the project hinges upon the tapping of relevant and competent expertise to carry out individual area of study and design in an in-depth, coordinated and comprehensive manner. After careful examination of the TOR and bearing in mind the fulfilment of the scope of work required of the Consultant in accordance with the approach and methodology as laid out in Chapter 4, the Consultant team has been organized into various disciplines to take charge of their respective specialisation. For this project, the proposed organisation of the Consultant team as illustrated in **Figure 6.2**.

ID	Task Name		
1	**DEVELOPMENT OF FLOOD RISK ASSESSMENT (FRA) AND FLOOD VULNERABILITY INDEX (FVI) FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA: A CASE STUDY IN SUNGAI PINANG, PULAU PINANG**	**Wed 17-10-18**	**Wed 17-07-19**
2	**PHASE I - INCEPTION AND PLANNING STAGE**	**Wed 17-10-18**	**Sun 18-11-18**
3	Approach and Methodology	Tue 16-10-18	Sat 20-10-18
4	Define Objectives and Scope of Works	Fri 19-10-18	Fri 26-10-18
5	Review of Data Availability	Fri 26-10-18	Fri 02-11-18
6	Literature, Guidelines and Reports Review	Sat 03-11-18	Fri 09-11-18
7	Proposal for Additional Data Collection	Sat 10-11-18	Sun 18-11-18
8	**PHASE II - ANALYSIS AND SYNTHESIZING STAGE 1**	**Mon 19-11-18**	**Wed 20-02-19**
9	Geographic Information System (GIS) Analysis and Database Managemen	Sun 18-11-18	Tue 18-12-18
10	Detailed Results/Findings from The Hydrological Analysis	Mon 03-12-18	Mon 17-12-18
11	Detailed Results/Findings from The Hydraulic Analysis	Thu 13-12-18	Fri 21-12-18
12	Hydrodynamic/Flood Modelling using 1 and 2 Dimensional (1D and 2D) Models	Mon 17-12-18	Fri 25-01-19
13	Flood risk analysis	Tue 22-01-19	Wed 20-02-19
14	Questionnaire and Survey	Fri 16-11-18	Fri 15-02-19
15	**PHASE III - ANALYSIS AND SYNTHESIZING STAGE 2**	**Thu 21-02-19**	**Wed 22-05-19**
16	Analysis Questionnaire and Survey	Thu 21-02-19	Wed 22-05-19
17	Vulnerability Assessment for Critical Infrastructure	Wed 20-02-19	Mon 15-04-19
18	Physical	Wed 20-02-19	Wed 20-03-19
19	Economic	Mon 25-02-19	Mon 08-04-19
20	Social	Mon 04-03-19	Mon 15-04-19
21	Flood Vulnerability Index Analysis with Multi Criteria Analysis Using Analytical Hierarchy Process	Wed 10-04-19	Mon 20-05-19
22	**PHASE IV - MAPS AND DELIVERABLES PRODUCTION STAGE**	**Thu 23-05-19**	**Wed 17-07-19**
23	Generation of Flood Risk Maps	Wed 22-05-19	Tue 11-06-19
24	Formulation of Flood Vulnerability Index (FVI) for Critical Infrastructure	Mon 03-06-19	Fri 28-06-19
25	Flood and Development Zoning	Mon 24-06-19	Mon 15-07-19
26	Data Base	Mon 01-07-19	Wed 17-07-19
27	**REPORTING MILESTONES**	**Wed 17-10-18**	**Wed 17-07-19**
28	PHASE I - INCEPTION AND PLANNING STAGE	Wed 17-10-18	Sun 18-11-18
29	PHASE II - ANALYSIS AND SYNTHESIZING STAGE 1	Mon 19-11-18	Wed 20-02-19
30	PHASE III - ANALYSIS AND SYNTHESIZING STAGE 2	Thu 21-02-19	Wed 22-05-19
31	PHASE IV - MAPS AND DELIVERABLES PRODUCTION STAGE	Thu 23-05-19	Wed 17-07-19



Task | Inactive Task | Manual Task | Manual Summary | External Tasks | Critical | Manual Progress
Split | Inactive Milestone | Duration-only | Start-only | External Milestone | Critical Split
Milestone | Inactive Summary | Manual Summary Rollup | Finish-only | Deadline | Progress

Figure 6.1: Work Programme

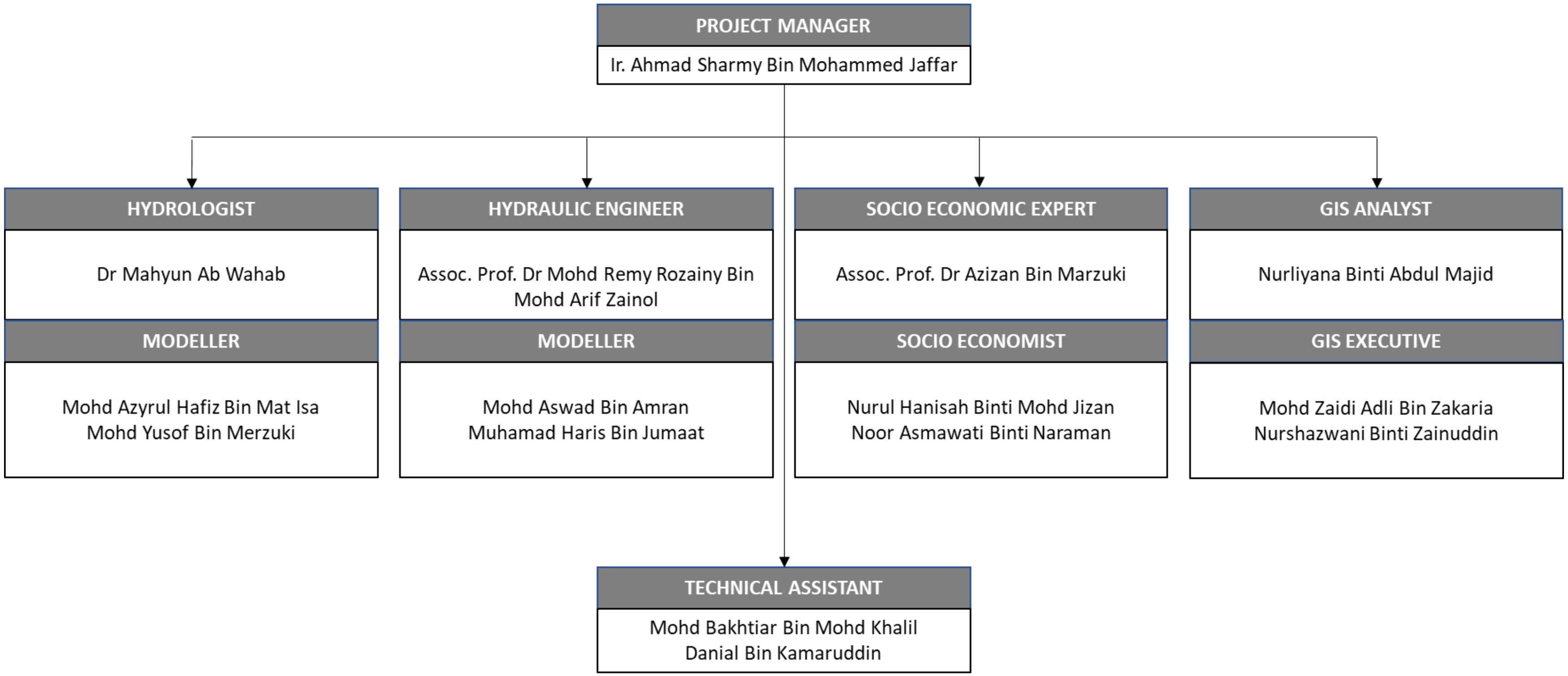


Figure 6.2: Study Organisation Team

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