JABATAN PENGAIRAN & SALIRAN, SABAH

KAJIAN PELAN INDUK SALIRAN BANDAR SEMPORNA, SABAH

(The Drainage Master Plan Study for Semporna Town, Sabah)

Volume 4 : Baseline Model Report

FINAL REPORT

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Semporna Drainage Masterplan

Baseline Model Report

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Executive Summary

This report presents a summary of the modelling work done thus far and is further described in detail in the subsequent sections. At this stage, the work undertaken was primarily focused on the identification of existing conditions, data collection and management, setting up of the relevant models and application of the model in the flood mapping and determination of the existing drainage system capacity tasks.

The modelling work undertaken includes: -

- **Development of design conditions**
  - Design rainfall for different storm duration (2, 5, 10, 20, 50 and 100 years ARI)
  - Design ocean water level
- **Drainage and inundation model development**
  - Development of catchment runoff model using rain on gird methodology to establish baseline flood condition
  - Development of catchment runoff model using MIKE 11 RR to establish flood mitigation options and sizing of key flood management and mitigation infrastructure
  - Development of hydraulic (HD) model using MIKE 11 HD
  - Development of the inundation model using MIKE FLOOD model
- **Application of the inundation model**
  - Determination of the existing drainage system capacity
  - Development of flood map covering different storm duration (2, 5, 10, 20, 50- and 100-years ARI)

1 Introduction

The Semporna Stormwater Drainage Masterplan (SSDMP) has been undertaken with the aim to develop a solid understanding of the main catchment and drainage processes in order to identify and prioritise drainage improvement measures. An understanding of the important catchment and flow processes has been underpinned by hydrological and hydraulic 1D and 2D simulation models that have been developed for this study. The developed models are both spatially distributed and physically based, which implies that large amounts of data have been collected and processed in order to enable the models to be built and validated against field measurements and data.

This report describes the data that has been collected and processed and provides the methods used for the development and validation of the catchment and coastal models.

2 Modelling Approach

2.1 Scope of Modelling

Semporna town is located on the East Coast of Sabah. The town lies on a flat coastal floodplain between the hilly area of Bukit Sakong to the west and low-lying areas that extend towards the Sulu Sea in both a northerly and easterly direction. The existing urban areas are mainly situated towards the northeast of the catchment. The total catchment area is estimated to be 37,606 hectares with approximately 75% of the catchment consisting of urbanised areas and 25% consisting of associated floodplains and swampy areas.

Semporna is drained by a combination of natural rivers and manmade drains. To the northwest of the catchment, the Gagoyan river drains into an area comprising of swampland of approximately 5 km^2 before discharging into the Sulu Sea via natural outfalls. Similarly, in the southeast of the catchment, a natural unnamed stream drains into a swamp area of approximately 2.2 km^2 before discharging into the Sulu Sea via a natural outfall. The outfall is located next to Kampung Dapdap. In the northeast, the drainage system is more complex and encompasses a mix of natural and man-made channels and drains conveying stormwater from mainly urban areas to several ocean outfalls. The ocean outfalls are predominantly located along the Jalan Causeway and Kampung Air settlement area. The following figure shows the study area inclusive of main rivers or drains within the catchment.

Stormwater drainage in Semporna town is mainly provided through open drainage channels. In the flat coastal areas, many of the drain inverts are at or below mean sea level. As a result, combinations of high tides and stormwater run-off present the primary causes of flooding issues in Semporna town. Over the years, flooding in the town has increased in both frequency and magnitude. The flooding is compounded by both natural and man-made causes. The natural earthen channels are generally flat and have irregular cross-sections and hence are not always able to relay accumulated rainwater from the catchment areas to the sea in sufficient time before the onset of high tide. Man-made causes which aggravate the flood situation include rapid urban development in upstream reaches and the consequent increase in impervious areas and peak runoff, reduction of flood storage in low-lying areas through in-filling and development, and illegal rubbish disposal into the existing drainage system. Many of the cross-drainage structures such as culverts are also under-capacity, exacerbating the flooding issues.

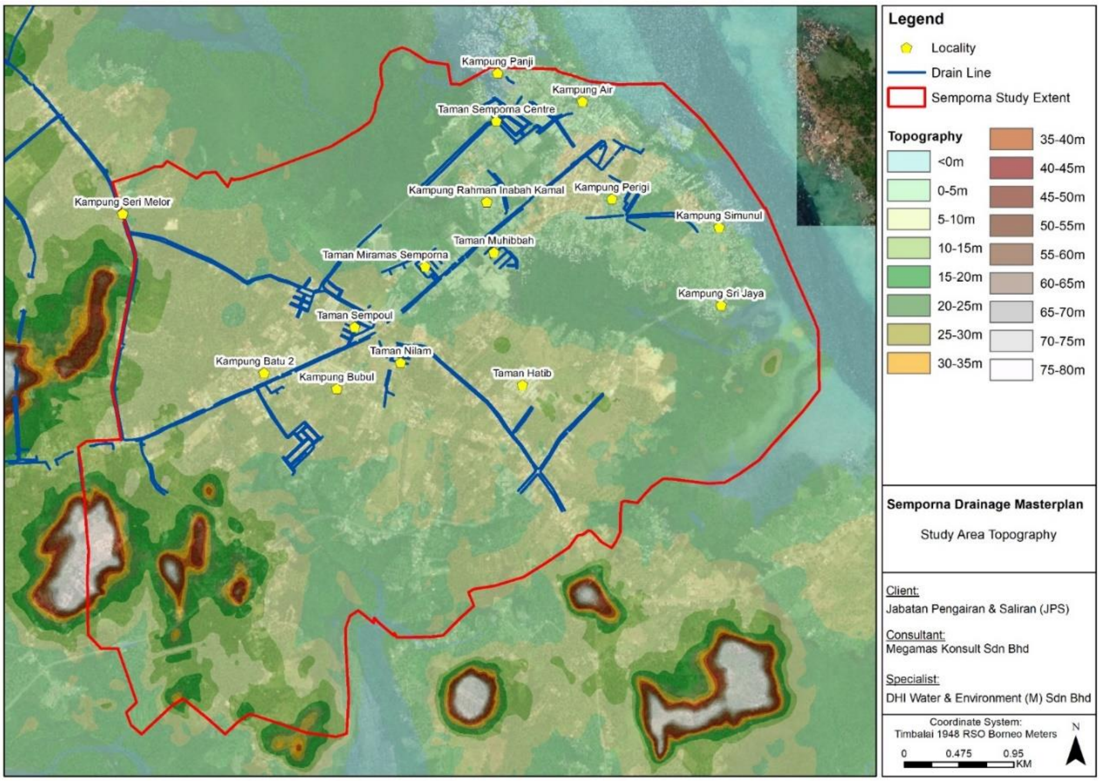

Figure 2-1 Study extent for Semporna

2.2 Semporna Drainage and Inundation Model

The catchment issues within the Semporna urban area are typical of many similar coastal population centres in the region: low topographical relief and exposure to high-intensity tropical rainstorms, often coupled with high tidal levels impede natural drainage and result in flooding on the low-lying coastal plain.

The urban drainage system in Semporna mainly comprises open drainage channels. In the flat coastal areas, many of the drain inverts are at or below mean sea level. As a result, combinations of high tides and stormwater run-off present the primary causes of flooding issues in Semporna town.

Considering the drainage infrastructure and range of issues to be addressed in the Masterplan, a 1d-2d hydrodynamic modelling approach has been adopted, using DHI's MIKE 11 and MIKE FLOOD software packages.

MIKE 11 is a fully hydrodynamic 1-dimensional (1d) modelling system that simulates the movement of water in open channel systems. MIKE 11 utilises river and channel cross-section information to produce water levels and flows at various points within the model domain and is capable of including a wide range of hydraulic structures including, culverts, weirs, bridges, tide gates and pumps.

Mapping of flood extents in cases where water levels spillover channel banks are handled by a 2-dimensional (2d) model, MIKE 21 uses land surface levels, derived from a Digital Elevation Model (DEM), to simulate the spread of floodwaters over a floodplain or low-lying area.

The 1d and 2d components are dynamically linked using MIKE FLOOD, which integrates the MIKE 11 and MIKE 21 models into a single linked model. Water spilling from the river channel onto the floodplain represented by MIKE 21 is controlled by specifying the river bank as a lateral link in MIKE FLOOD, see Figure 2-2.

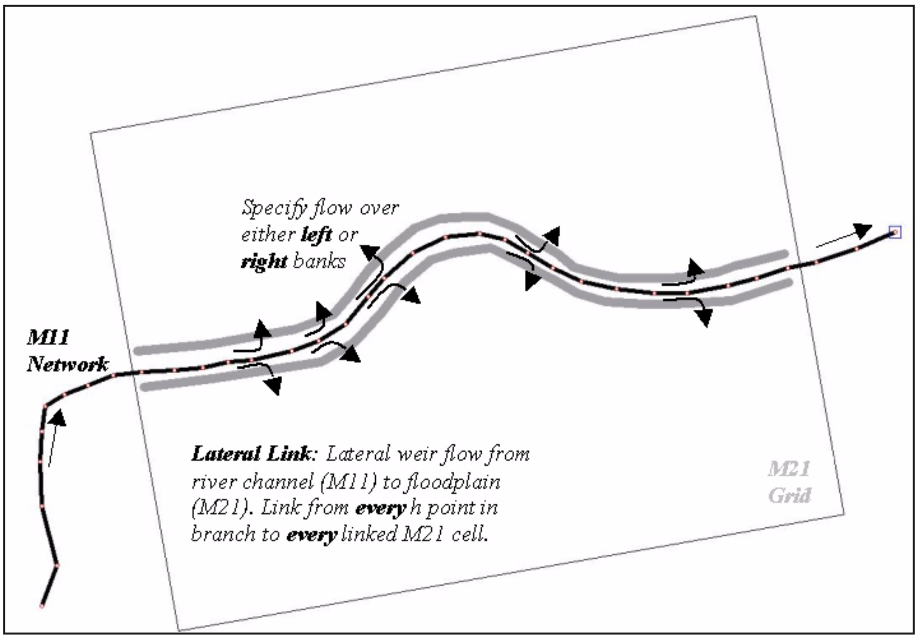

Figure 2-2 Application of lateral links

The drainage and inundation model has been used to assess flood risk under both existing and future conditions. The model includes all of the important elements comprising the drainage system including:

- The main trunk drainage system,
- The secondary drainage system in areas identified as having flood issues
- Major cross drainage structures (culverts)

The MIKE FLOOD model produces the extents and depths of water in flood-prone areas as well as flows and levels in the drainage channel and river systems. Options for flood mitigation are tested by changing existing model elements (e.g. a drain cross-section or pump rate) or introducing new ones, such as a new bypass channel.

3 Data Acquisition and Processing

3.1 Introduction

The Master Plan study includes an extensive data collation and information-gathering programme, covering the following (refer to Appendix for fuller details):

- Map and imagery, including topographic, soil, land cover maps as well as local plan and satellite images (Vol.2: Appendix A and D)
- Hydrological data, including rainfall, evaporation, water level and discharge data (Vol.2: Appendix C)
- Topographic measurements / Fieldwork, including cross-section measurements (main drains and rivers), drainage surveys at key locations for the purpose of numerical modelling (Vol.3: Appendix A, B, C and D)
- Extensive drainage and river surveys for the purpose of drainage asset management / detail design (on-going) (Vol.3: Appendix A, B and C)
- Water level and flow measurements (Vol.3 Appendix E and F)
- Water quality survey campaign (Vol.3, Appendix G)
- JPS flood reports (Vol. 2: Appendix B)
- Drawing plan, JPS drain drawing (Vol. 2: Appendix E)
- The population within Semporna (Vol. 2: Appendix F)
- Soil investigation (Vol. 3: Appendix F)
- Drainage assets (Vol. 3: Appendix H)
- Gross pollutant trap (Vol. 3: Appendix I)

To manage the large quantity of mostly spatial information, a geographical information system (GIS) is being developed to store data including:

- Spatial layers of land cover, roads, boundaries, etc.: (Vol.2: Appendix A and D);
- Satellite imagery (Vol.2: Appendix A, Appendix D);
- Hydrologic and hydraulic data in a time series format (Vol. 2: Appendix C);
- Model data including catchment models, hydraulic networks, etc.: (Vol.2: Appendix A and D);
- Model output including flood maps, hazard maps, etc (Vol. 2: Appendix B);
- Topographic data (Vol.3: Appendix D);
- An inventory of the drainage system (Vol.3: Appendix A and B).

The GIS is flexible and generic, so the data that can be included is by no means limited by this list. The software platform adopted for this study is ArcGIS. This is the most widely used GIS platform has a high degree of interoperability with DHI water modelling software that will be used for the hydrological and hydraulic model

3.2 Topographic Data

Terrain data from publicly available SRTM DEM (90m Digital Elevation Model data from CGIAR-CSI) was used to demarcate the catchment extent. The SRTM digital elevation data was originally produced by NASA for large portions of the tropics and other areas of the developing world. The SRTM 90m DEM has a resolution of about 90m for Malaysia. This is generally appropriate and sufficient for catchment-level study in the macro context. Figure 3-1 shows the SRTM DEM terrain data for Sabah.

Other versions of the terrain data utilised in the present study include IFSAR and LiDAR data. IFSAR DEM (5m Digital Elevation Model) and LiDAR (1m Digital Elevation Model) is a higher resolution DEM if compared to SRTM DEM and is a better option to be utilised in the catchment delineation process. Figure 3-2 shows the available topographic data used for the present study.

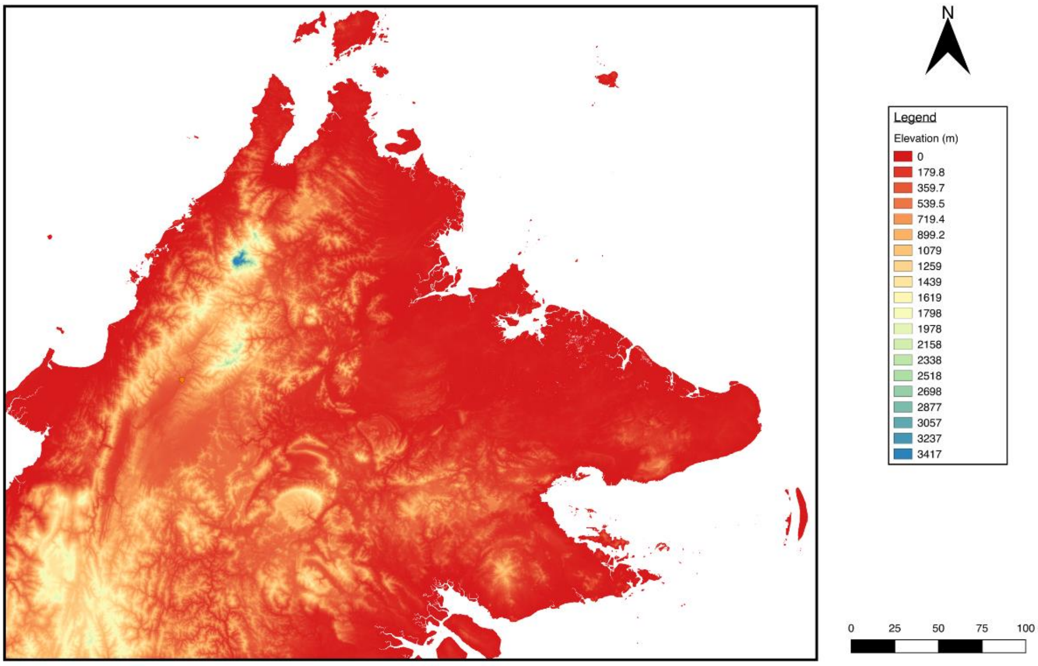

Figure 3-1 Digital Elevation Model (DEM) for Sabah

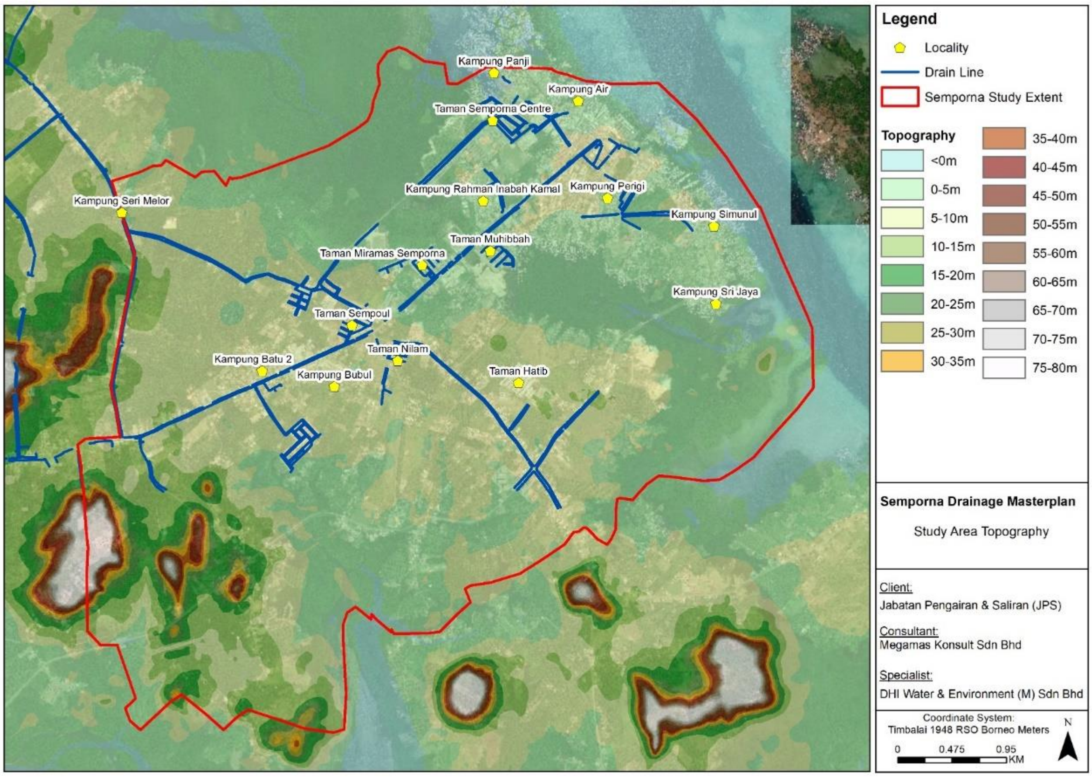

Figure 3-2 Topographic data covering the study extent

3.3 Existing Drainage System

The existing drainage system within the study area is as follows:

- The drainage system comprises a northern and southern region defined by three major drainage outfalls located at Gagoyan river mouth in the north, a natural outlet located next to Kpg. Sri Jaya and Kpg. Bubul in the south-respectively.
- The northern region of the study area includes Sg. Gagoyan and its tributaries. This system drains into the Gagoyan river mouth (Sulu Sea). Other drains located within the northern region, for instance, drainage outlets along Jalan Causeway and Kpg. Air settlement area discharge directly into the Sulu Sea.
- The southern region comprises a mixture of concrete and earth drainage lines that discharges directly into the Sulu Sea through natural outlets located next to Kpg. Sri Jaya and Kpg. Bubul.
- The drainage network in the smaller tributary catchments typically comprise the following types:
  - Feeder drains: Mixture of earth drains and concrete monsoon drains (open and cover)
  - Main drains: Open watercourses, channelized (at most locations) to improve their hydraulic conveyance

Figure 3-4 show the overview of the drainage system overlaid with the sub-catchments together with Figure 3-4 which show the overview of the existing drainage type within the study area and Table 3.1 summarises the drainage characteristics found within the study area. Photo 3.1 and Photo 3.2 show examples of concrete-lined and earth drains located within the study area.

Table 3.1 Drainage characteristics of major catchment within the study area

Catchment	Drainage Length	Type and Condition	Approx. Drainage Area	Tributaries Type	Outlet(s)
S1	0.5 km	Concrete and earth drain (Medium Vegetation)	0.2 km^2	NA	Natural Outlet at Kpg. Panji – Outlet A (Sulu Sea)
S2	0.2 km	Concrete and earth drain (Medium vegetation)	0.1 km^2	NA	Natural Outlet at Kpg. Air – Outlet B (Sulu Sea)
S4	0.5 km	Concrete drain (Low Vegetation)	0.15 km^2	U-shape concrete drain	Natural outlet at Kpg. Air and concrete outlet behind Inabah Kamal Mosque – Outlet C (Sulu Sea)
S9	1.7 km	Concrete and earth drain (High vegetation)	2.2 km^2	Earth drain	Sg. Gagoyan (Sulu Sea)
S10	1.0 km	Concrete drain (Medium Vegetation) and earth drain (High Vegetation)	0.7 km^2	U-shape concrete drain and earth drain	Natural streams linking to Sg. Gagoyan
S12	2.0 km	Concrete drain and earth drain (Low vegetation)	1.4 km^2	Earth drain	Natural outlet located next to Kpg. Sri Jaya – Outlet D (Sulu Sea)

Catchment	Drainage Length	Type and Condition	Approx. Drainage Area	Tributaries Type	Outlet(s)
S25	0.6 km	Concrete drain and earth drain (High vegetation)	1.1 km^2	Earth drain	Natural outlet located next to Kpg. Bubul – Outlet E (Sulu Sea)
S27	1.0 km	Concrete drain together with earth drain (High vegetation)	1.5 km^2	Earth drain	Natural outlet located next to Kpg. Bubul – Outlet E (Sulu Sea)
S28	2.0 km	Concrete drain together with earth drain (High vegetation)	1.7 km^2	Earth drain	Drain along S9

Photo 3.1 Example of a concrete lined channel located within the study area (Housing drain within Taman Miramas, facing downstream)

Photo 3.2 Example of earth drain located within the study area (Earth drain along with Jalan Hospital, facing downstream)

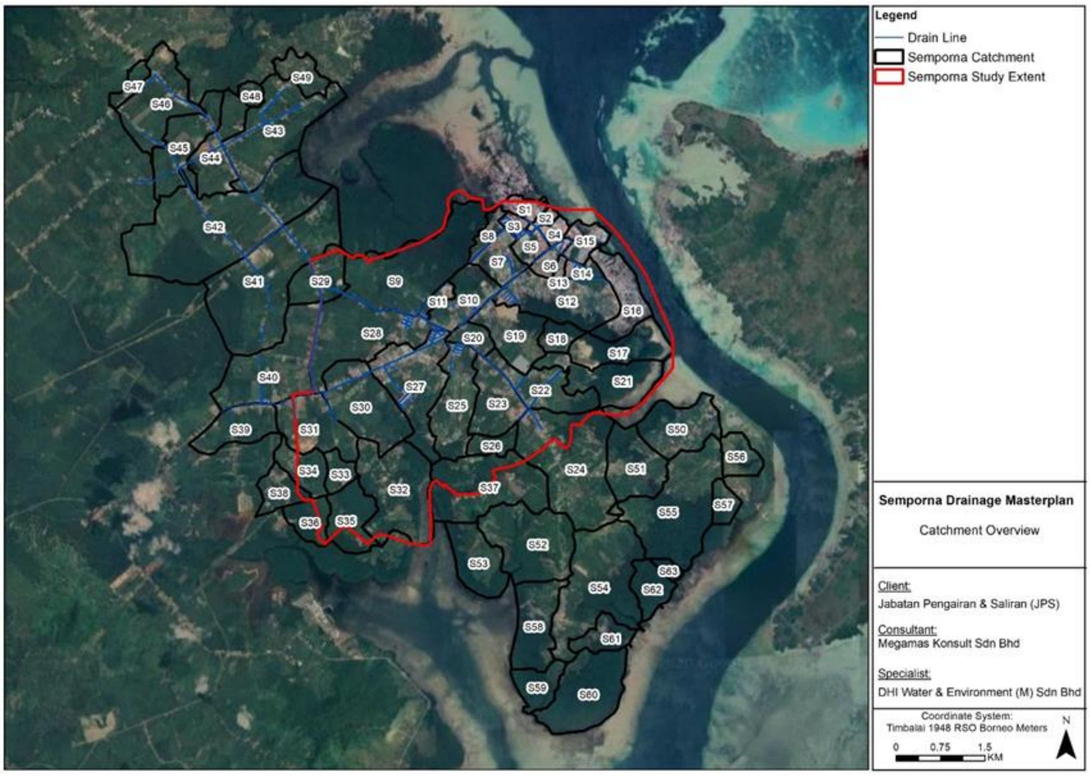

Figure 3-3 Overview of existing drainage system overlaid with delineated sub-catchments

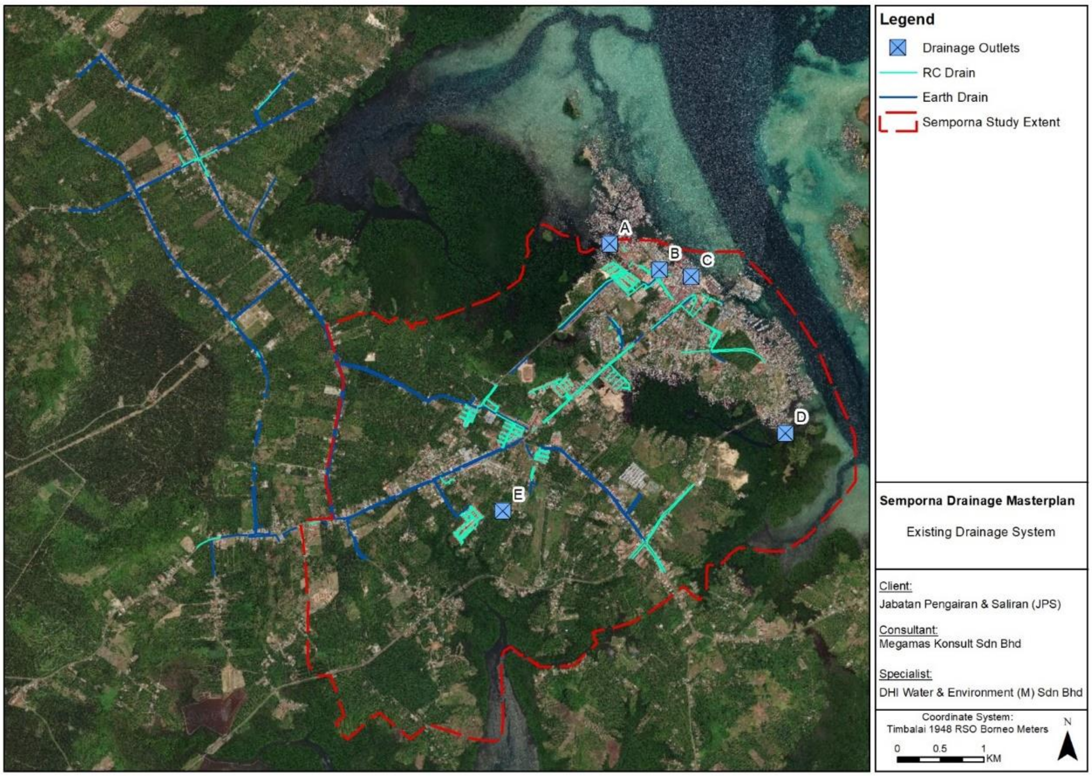

Figure 3-4 Overview of existing drainage type within the study area

3.4 Hydrological Data – Existing Sources

In order to carry out the hydrological analysis, data has been sourced from Jabatan Pengairan dan Saliran Sabah (JPS). The main data has been identified and has been requested from JPS and this is listed below.

1 Rainfall
2 Evaporation
3 River discharge and water level
4 Rating curve

The hydrological network for the present study is shown in Figure 3-5, Figure 3-6 and Table 3.2 summarises the availability and temporal resolution of hydrological station data procured for use in this study.

Table 3.2 List of hydrological stations available from JPS within the study area

Station ID	Station Name	Type	Time Resolution	Period of Data Acquired
4278402	Sg Tawau at kuhara	Discharge	15min & Daily	04 May 1983 – 01 Jan 2020
4278403	Sg Tawau at Jambatan Putih	Discharge	15min & Daily	11 Oct 1994 – 03 Apr 1999
4378401	Sg Tawau at Ladang Iman	Discharge	15min & Daily	12 Jan 2000 – 01 Jan 2020
4381401	Sg Balung at Balung Bridge	Discharge	15min & Daily	18 Aug 1992 – 01 Jan 2020

Station ID	Station Name	Type	Time Resolution	Period of Data Acquired
4581401	Sg Kalumpang at Mostyn Bridge	Discharge	15min & Daily	01 Jan 1969 – 15 Mar 1977
4581402	Sg Kalumpang at Mostyn Bridge	Discharge	15min & Daily	27 Jul 1979 – 01 Jan 2020
4278402	Sg Tawau at kuhara	Water Level	15min & Daily	04 May 1983 – 01 Jan 2020
4278403	Sg Tawau at Jambatan Putih	Water Level	15min & Daily	11 Oct 1994 – 03 Apr 1999
4378401	Sg Tawau at Ladang Iman	Water Level	15min & Daily	12 Jan 2000 – 01 Jan 2020
4381401	Sg Balung at Balung Bridge	Water Level	15min & Daily	18 Aug 1992 – 01 Jan 2020
4581401	Sg Kalumpang at Mostyn Bridge	Water Level	15min & Daily	01 Jan 1969 – 15 Mar 1977
4581402	Sg Kalumpang at Mostyn Bridge	Water Level	15min & Daily	27 Jul 1979 – 01 Jan 2020
4278004	Kuhara	Rainfall	15-minute, Hourly & Daily	26 Jan 1988 – 01 Jan 2020
4474002	Kalabakan	Rainfall	15-minute, Hourly & Daily	02 Jan 1987 – 01 Jan 2020
4486001	Semporna Ariport	Rainfall	15-minute, Hourly & Daily	22 Sept1989 – 01 Jan 2020
4581001	Kalumpang	Rainfall	15-minute, Hourly & Daily	02 Jan 1985 – 12 Dec 2006
4278004	Kuhara	Water Quality	Intermediate Sampling	Nov 1983; July 1985 – Jul 1993; Mar 2001 – Aug 2006
4381501	Balung	Water Quality	Intermediate Sampling	Sept 1992 – Feb 1994; Dec 1997 – Dec 1999; Mar 2001 – Dec 2002; Jan 2005 – Aug 2006
4581502	Kalumpang	Water Quality	Intermediate Sampling	Sept 1970 – Jul 1973; Aug 1980 – Dec 1989; Jan 1990 – Feb 1994; Nov 1997 – Jan 2000
4278301	Tawau Met Stn	Evaporation	Daily	01 Jan 1968 – 24 Mar 1981
5274301	Kuamat Met Stn	Evaporation	Daily	01 Jun 1969 – 30 Dec 2019
5361301	Keningau Met Stn	Evaporation	Daily	01 May 1966 – 30 Dec 2015

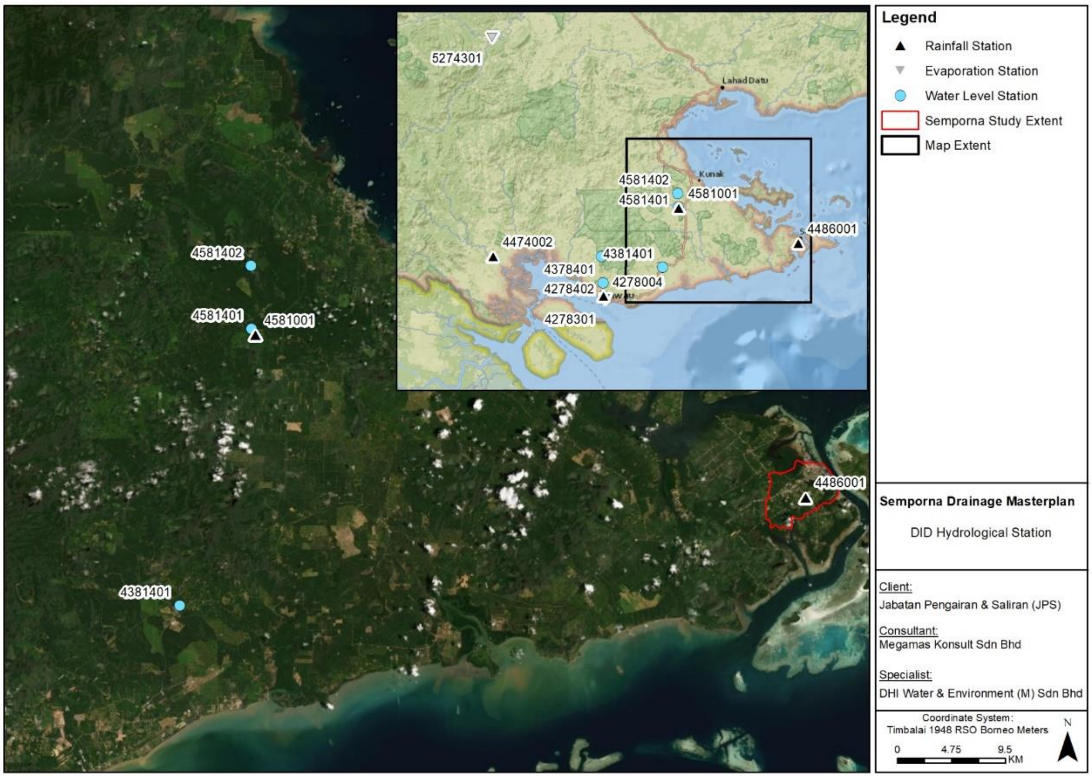

Figure 3-5 JPS hydrological stations located within the proximity of the study area

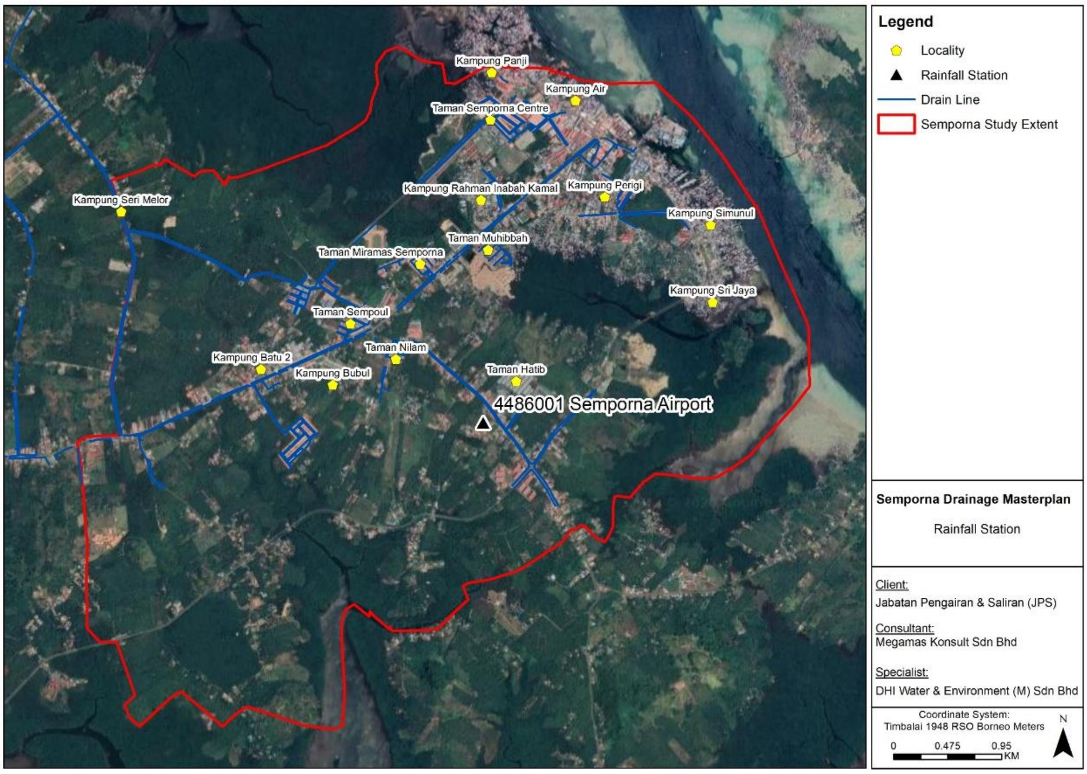

Figure 3-6 JPS hydrological stations located within the study extent

3.5 Water level measurements

As part of the field data collection programme under the study, water level measurements were conducted within the study area. The collected data was used primarily for the purpose of calibrating and verifying the hydrodynamic model.

3.6 Deployment

The water level recorders were deployed at the predetermined location within the study area as defined in Figure 3-7 and Table 3.3.

Table 3.3 Details of water level logger location

Water Level Recorder	Location	Long (WGS84)	Lat (WGS84)	Deployed from	Deployed To
WLR 1	Taman Miramas	118.596°	4.470°	09 October 2019	19 November 2019

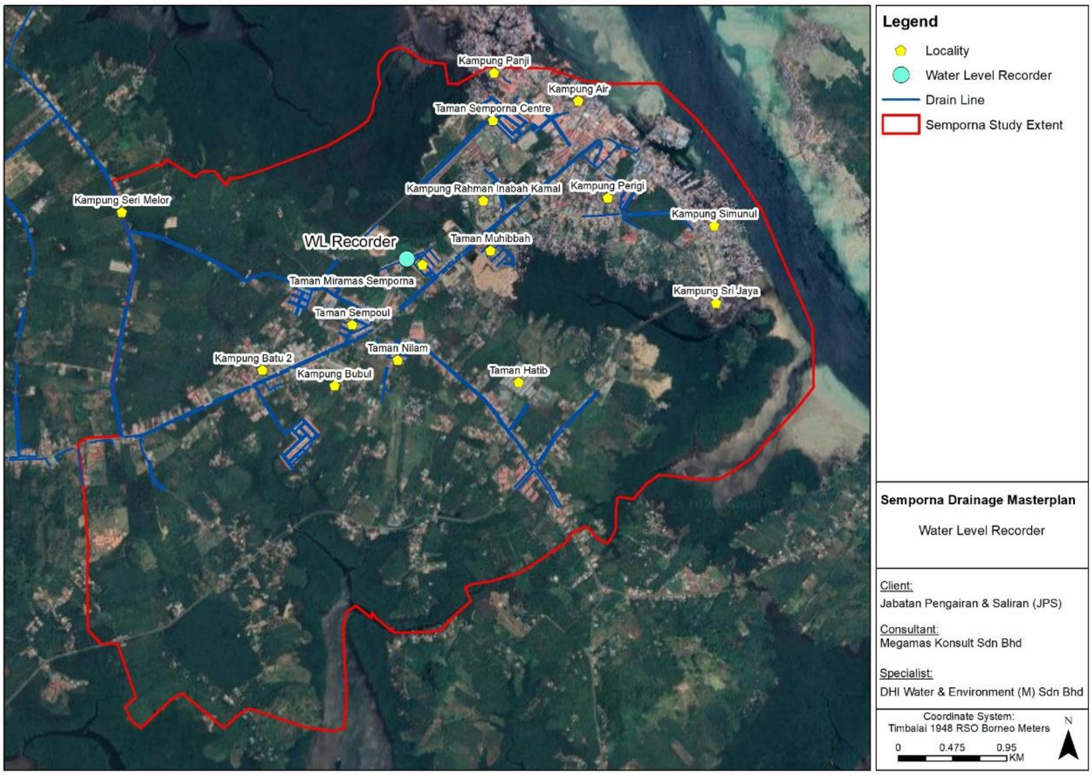

Figure 3-7 Location of water level recorder within the study extent

3.7 Data collected

Examples of water levels recorded during the survey are presented in Figure 3-8.

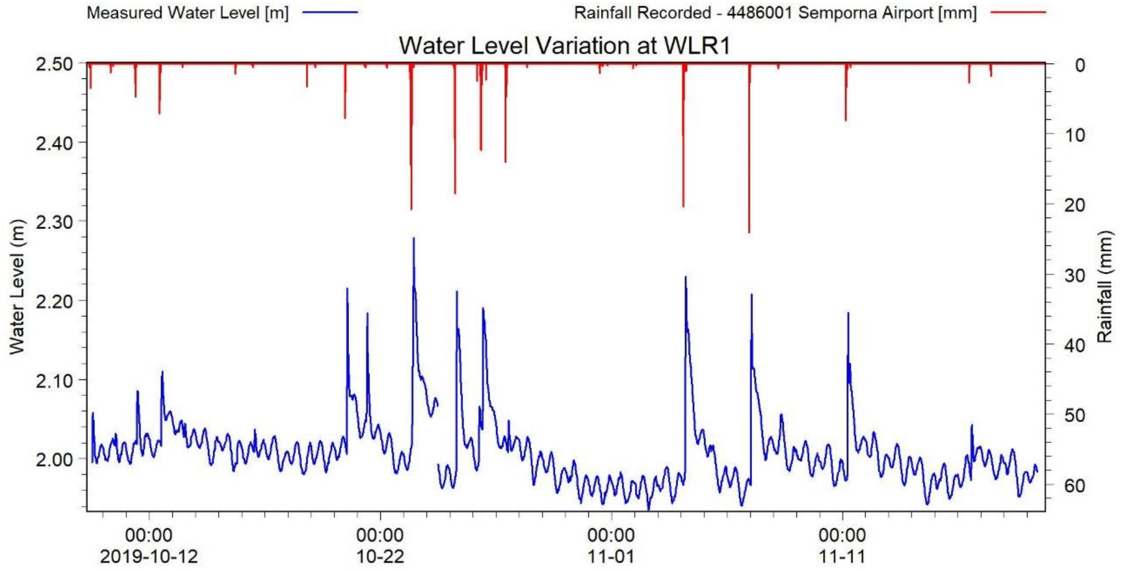

Figure 3-8 Water level recording sample at WLR1

3.8 Flood Extents and Depths

Information related to flood extents and depths were collected from JPS Semporna, JKR Semporna, based on on-site observation, extraction of data from flood reports and interview with local residents conducted during site visits to Semporna town in August 2019. Based on the information collected, ten (10) areas consisted of Taman Miramas, Kampung Perigi, Kampung Bubul Lama, Kolej Poly-Tech MARA, Kampung Bubul, Police Headquarters, JKR STP, Taman Sutera, SMK Datuk Pg. Abdullah and Pejabat KEMAS were identified where the occurrence of frequent flooding occurred. Table 3.4, Figure 3-9 to

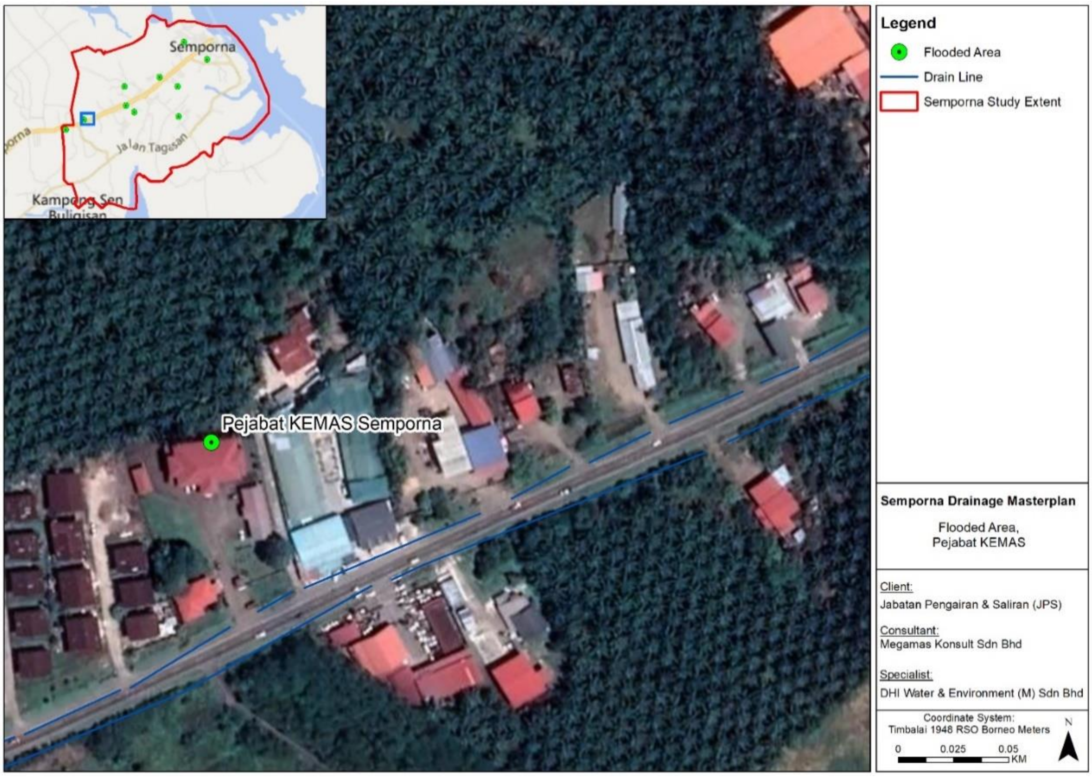

Figure 3-18 show the location of the area subjected to frequent flooding and the max flood depth.

Table 3.4 Identified flooding area and flood depth

Flood Area	Flood Depth (cm)
Taman Miramas	70
Kampung Perigi	70
Kampung Bubul Lama	70
Kolej Poly-Tech MARA	30
Kampung Bubul	70
Police Headquarters	NA
JKR STP	NA
Taman Sutera	NA
SMK Datuk Pg. Abdullah	NA
Pejabat KEMAS	NA

Figure 3-9 Flood area – Taman Miramas

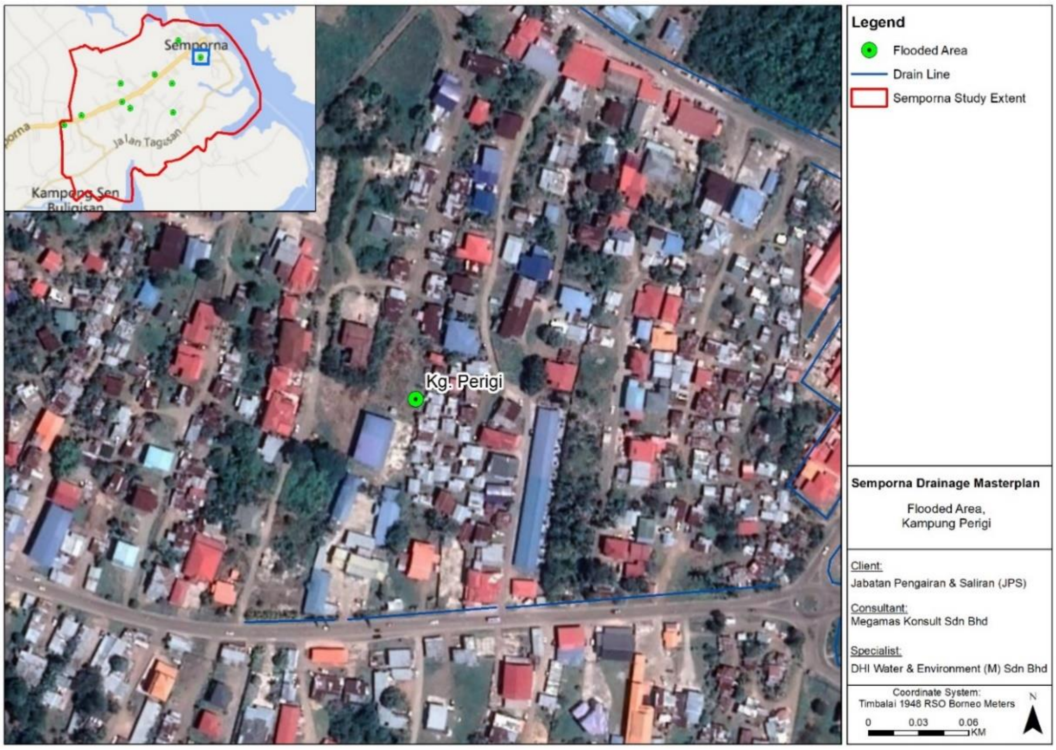

Figure 3-10 Flood area – Kampung Perigi

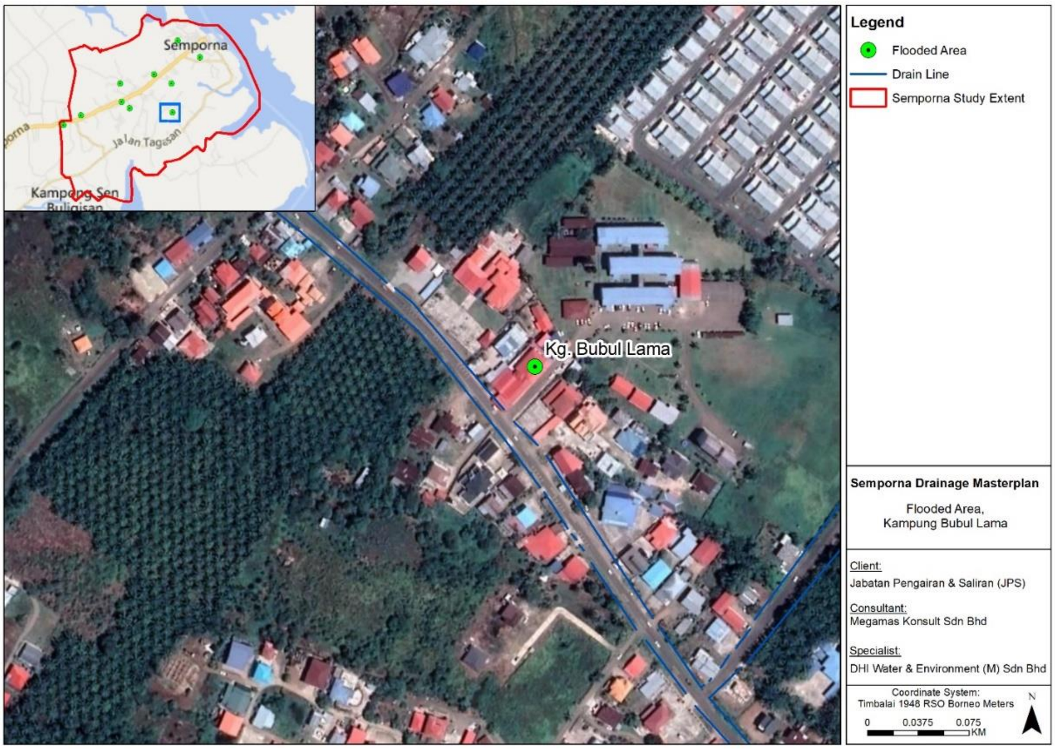

Figure 3-11 Flood area – Kampung Bubul Lama

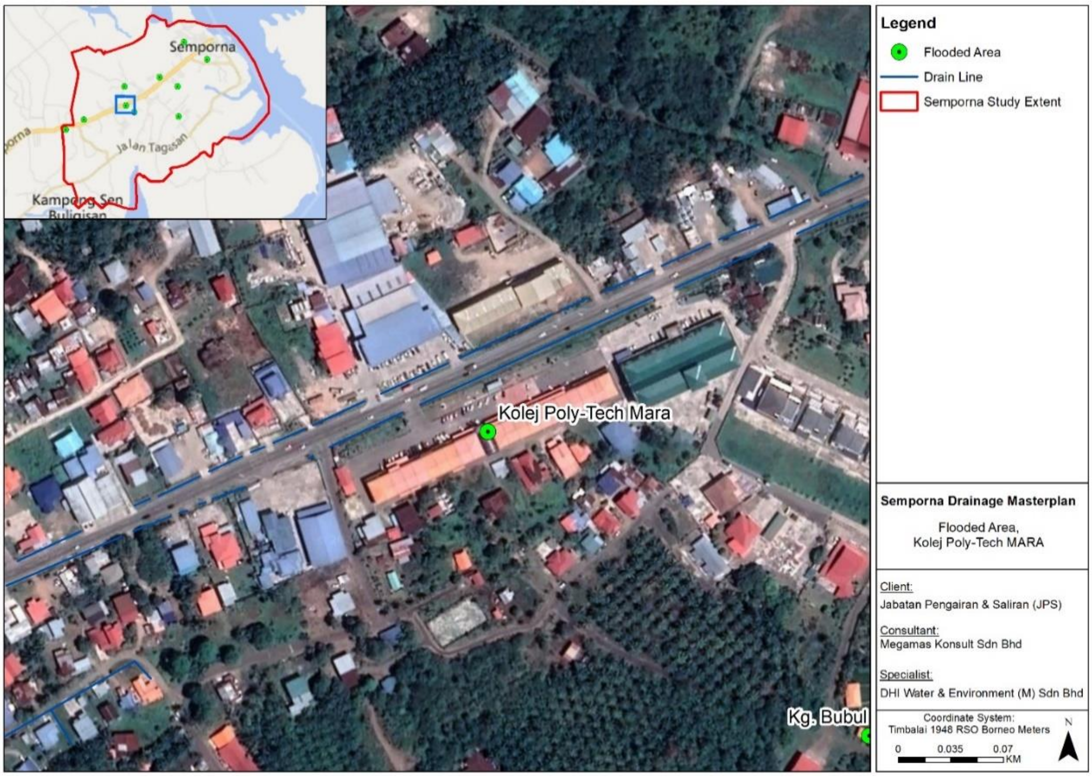

Figure 3-12 Flood area – Kolej Poly-Tech MARA

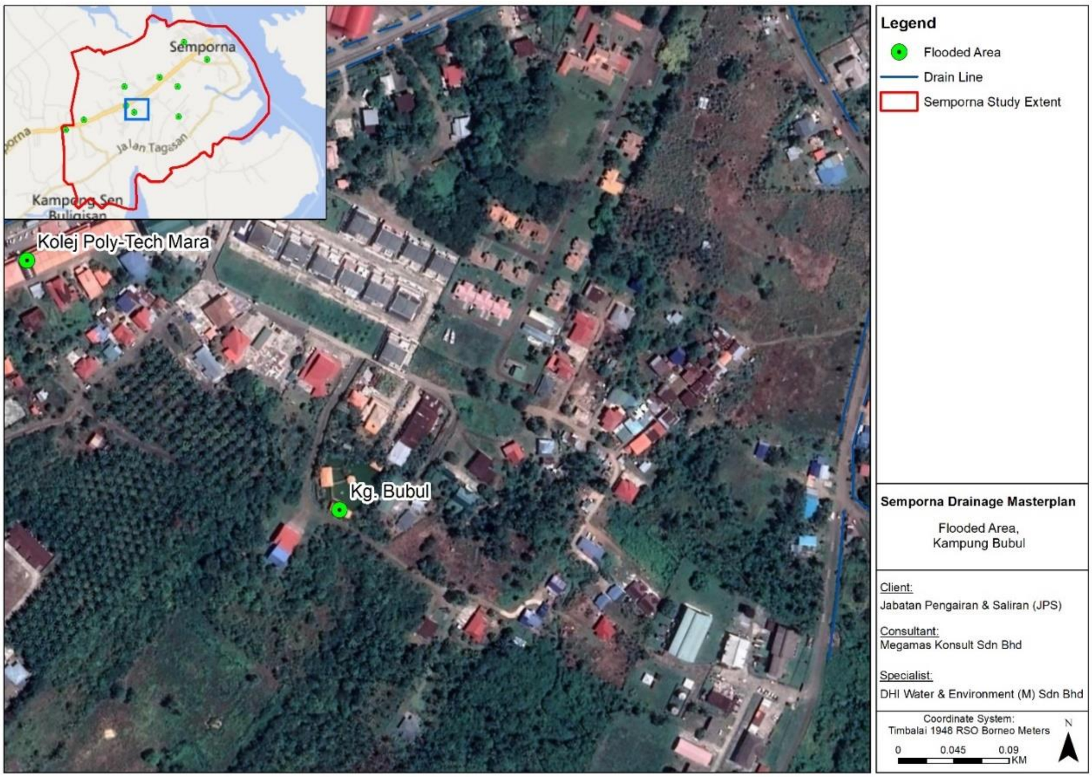

Figure 3-13 Flood area – Kampung Bubul

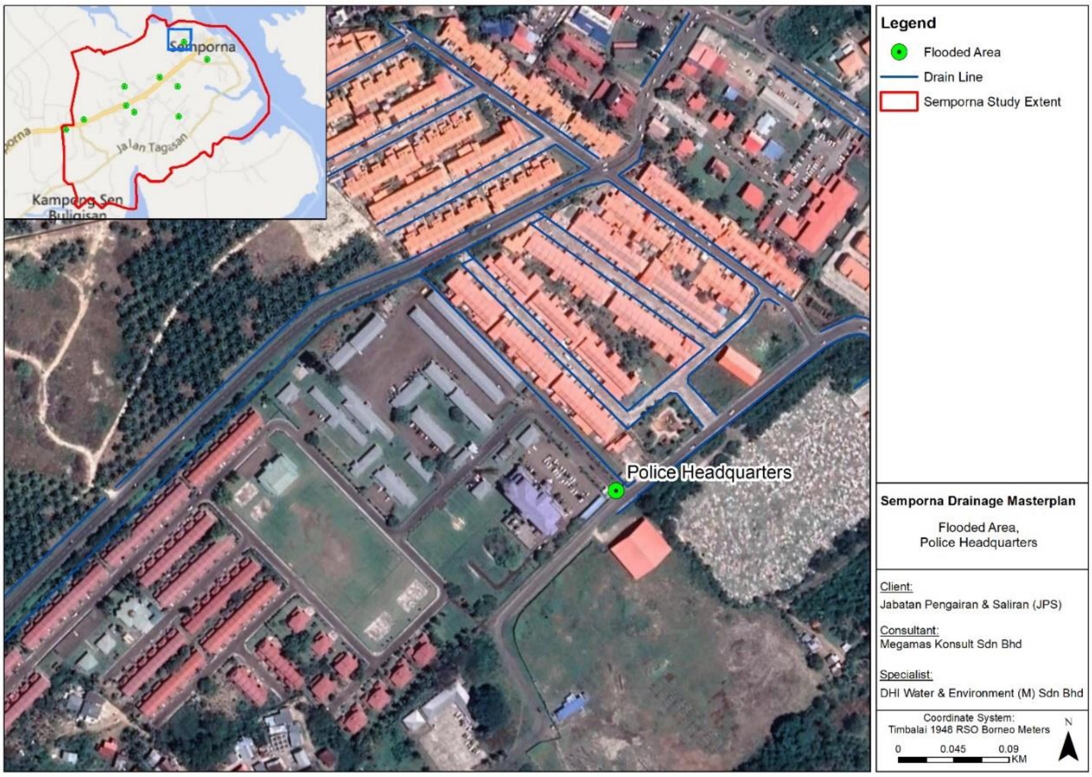

Figure 3-14 Flood area – Police Headquarters

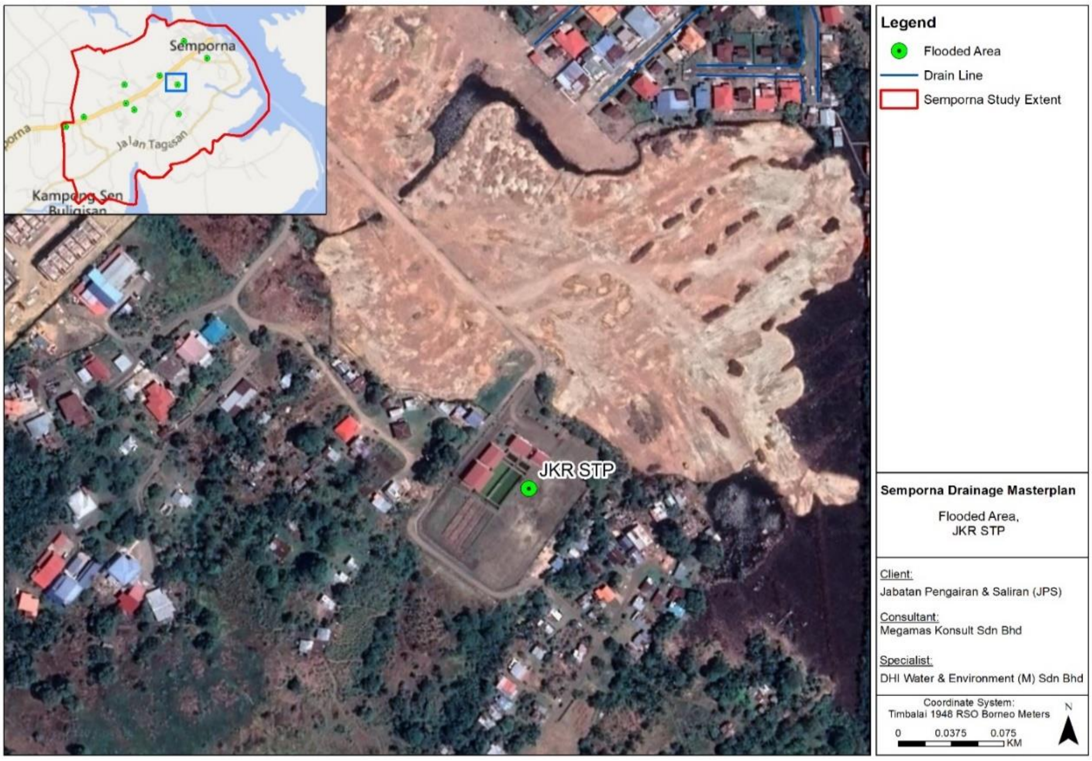

Figure 3-15 Flood area – JKR STP

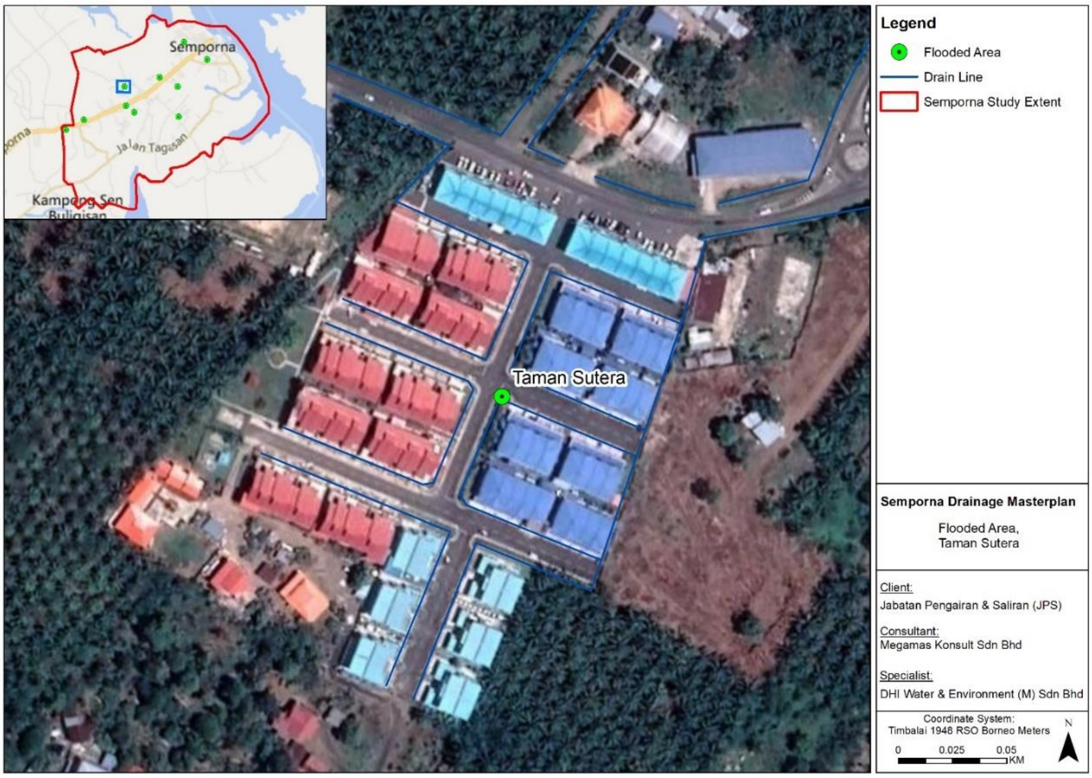

Figure 3-16 Flood area – Taman Sutera

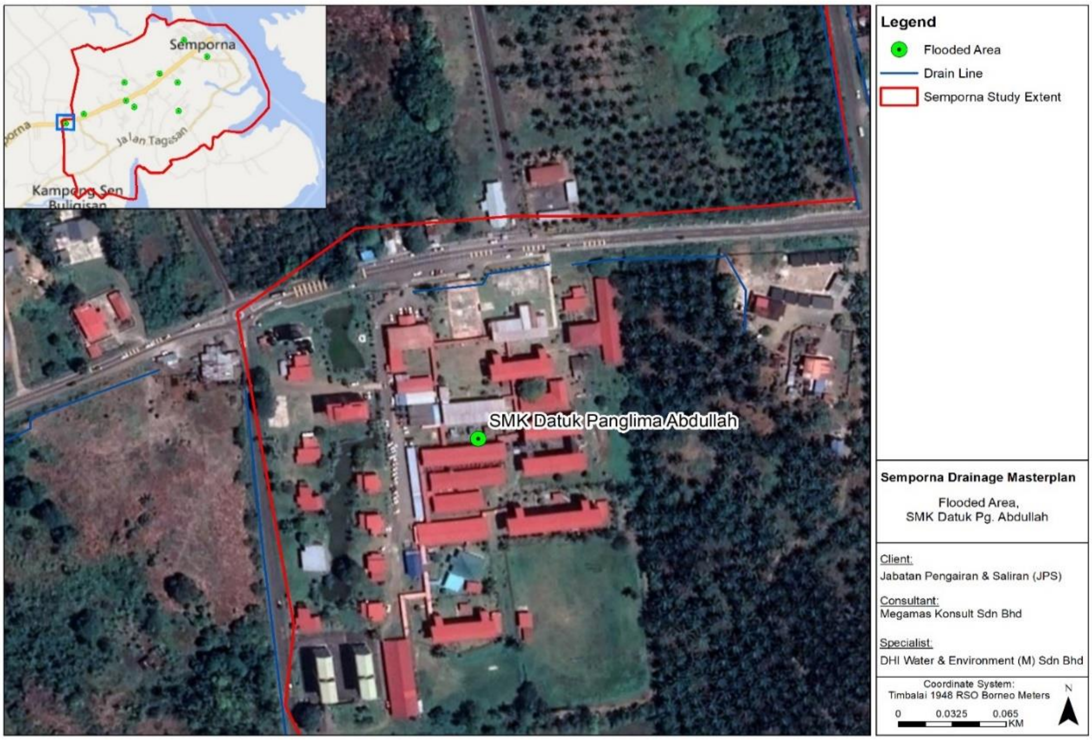

Figure 3-17 Flood area – SMK Datuk Pg. Abdullah

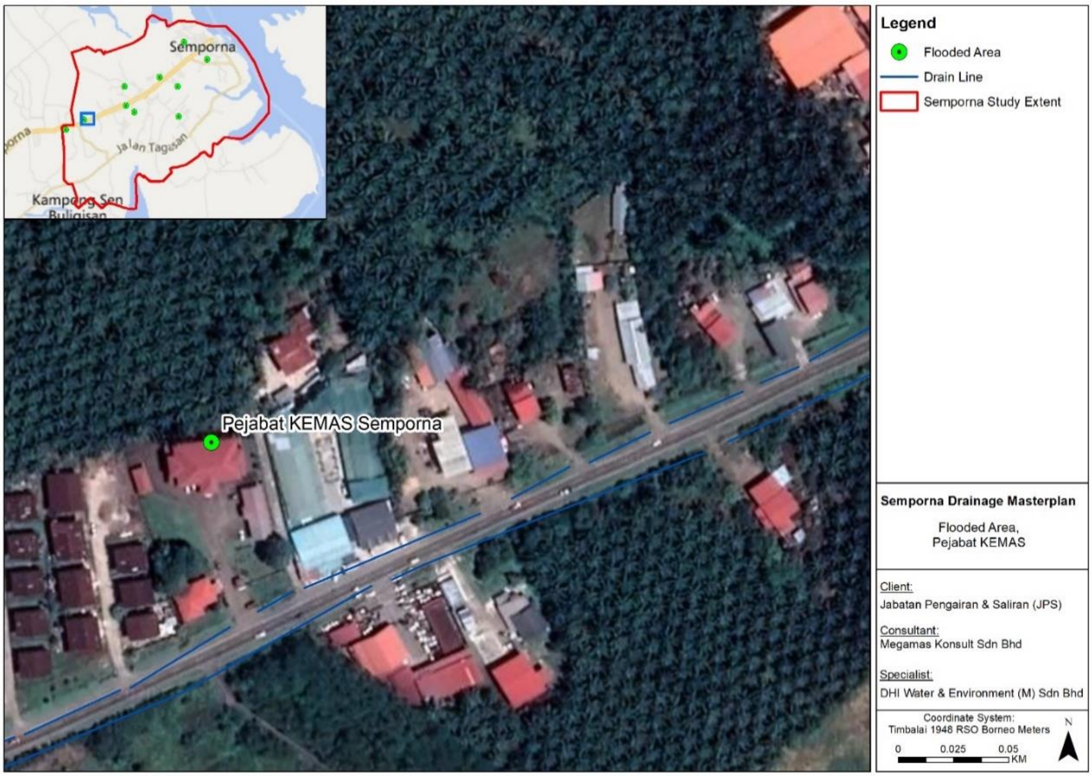

Figure 3-18 Flood area – Pejabat KEMAS

Photo 3.3 Picture of drain outlet from Taman Miramas

Photo 3.4 Picture of residential located within Kampung Perigi

Photo 3.5 Picture of drain along Jalan Kabongan

Photo 3.6 Picture of a concrete drain in front of Kolej Poly-Tech Mara

Photo 3.7 Picture of existing earth drain located within Kampung Bubul

Photo 3.8 Picture of earth drain located in front of Police Headquarters along with Jalan Balai Polis

Photo 3.9 Picture of internal concrete drain within JKR STP along Jalan Loji Pembentungan

Photo 3.10 Picture of housing drainage within Taman Sutera

Photo 3.11 Picture of earth drain in front of SMK Datuk Pg. Abdullah along Jalan Balung-Semporna

Photo 3.12 Picture of earth drain in front of Pejabat KEMAS along Jalan Balung-Semporna

3.9 Tide Data

Based on Malaysia Tide Tables 2019 published by National Hydrographic Centre, Royal Malaysian Navy (RMN), Semporna tidal station is the nearest to the project site whereas Lahad Datu tidal station is about 70 km north, as shown in Figure 3-19. Characteristic tidal levels for Semporna and Lahad Datu tidal stations are listed in Table 3.5.

Figure 3-19 Location of the tidal stations.

Table 3.5 Tidal levels around the study area.

Station	**Semporna (118.616667°E, 4.483333°N)**		**Lahad Datu (118.346111°E, 5.018889°N)**	
Tidal Level	**m CD**	**m MSL**	**m CD**	**m MSL**
Highest Astronomical Tide (HAT)	2.55	1.38	2.54	1.35
Mean High Water Spring (MHWS)	2.04	0.87	2.05	0.86
Mean High Water Neap (MHWN)	1.38	0.21	1.40	0.21
Mean Sea Level (MSL)	1.17	0.00	1.19	0.00
Mean Low Water Neap (MLWN)	0.95	-0.22	0.98	-0.21
Mean Low Water Spring (MLWS)	0.29	-0.88	0.33	-0.86
Lowest Astronomical Tide (LAT)	0.00	-1.17	0.00	-1.19

4 Design Conditions

4.1 Rainfall

4.1.1 Rainfall Data

The rainfall stations considered for the derivation of design rainfall as listed in Table 4.1. Locations are indicated in Figure 3-5

Table 4.1 Rainfall stations considered for the derivation of design rainfall

No	Station Name	Station ID	Duration
1	Semporna Airport	4486001	1989-2017

4.1.2 IDF Curves

Intensity-Duration-Frequency (IDF) curves were derived based on the IDF parameters extracted from the Hydrological Procedure HP26 (JPS Malaysia). Figure 4-1 indicate the derived IDF curve for the Semporna (4486001) covering the 2-year to 100-year ARI for durations extending from 15-minutes to 72 hours.

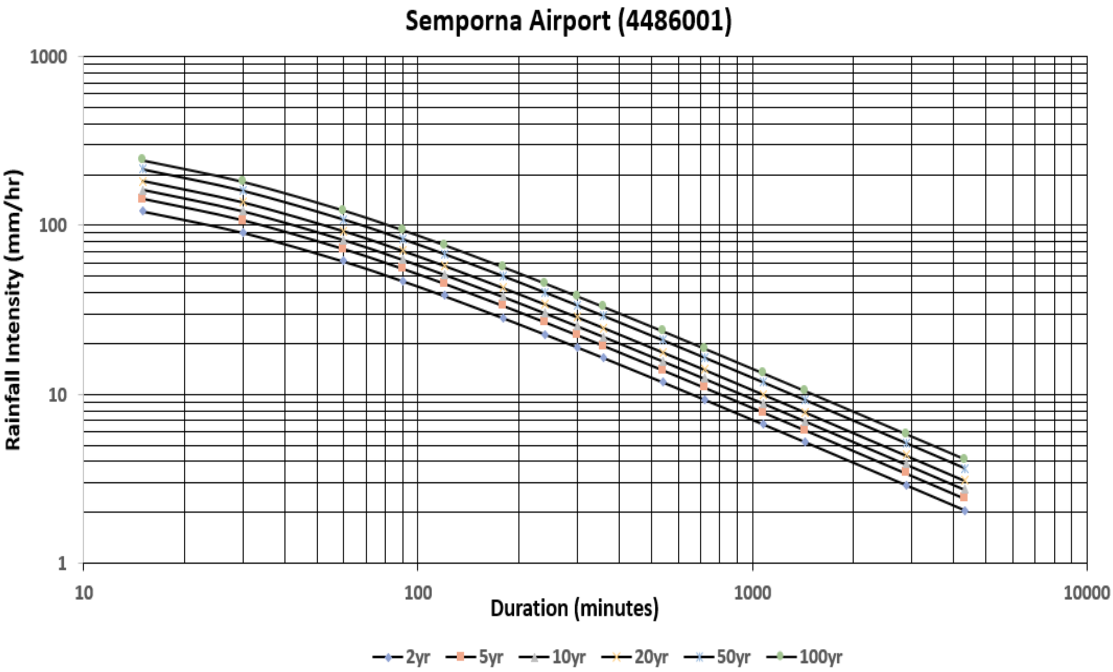

Figure 4-1 Derived Semporna rainfall station IDF curve

4.1.3 Design Rainfall Hyetographs

The design rainfall temporal distribution hyetographs for the present study were based on the design rainfall temporal pattern data for Sabah (Region 1) extracted from JPS's Hydrological

Procedure HP26 document (refer to Table 4.2). The adopted design rainfall temporal patterns are shown in Table 4.2.

Table 4.2 Normalised temporal pattern (Source: Hydrological Procedure HP26 – JPS Malaysia)

No. of Block	Duration								
	0.25	0.5	1	3	6	12	24	48	72
1	0.288	0.147	0.049	0.039	0.035	0.041	0.009	0.011	0.022
2	0.401	0.161	0.071	0.059	0.049	0.046	0.021	0.019	0.025
3	0.311	0.170	0.083	0.076	0.077	0.052	0.025	0.023	0.027
4		0.200	0.089	0.095	0.088	0.087	0.027	0.025	0.034
5		0.164	0.092	0.105	0.108	0.099	0.032	0.027	0.035
6		0.158	0.099	0.112	0.114	0.142	0.033	0.034	0.036
7			0.101	0.116	0.119	0.149	0.040	0.039	0.039
8			0.096	0.108	0.111	0.124	0.045	0.045	0.042
9			0.090	0.099	0.098	0.094	0.048	0.052	0.045
10			0.084	0.089	0.084	0.076	0.057	0.054	0.050
11			0.077	0.062	0.075	0.048	0.070	0.072	0.059
12			0.069	0.040	0.042	0.042	0.074	0.080	0.063
13							0.077	0.080	0.098
14							0.072	0.077	0.059
15							0.059	0.065	0.050
16							0.056	0.053	0.048
17							0.047	0.050	0.044
18							0.040	0.045	0.040
19							0.039	0.035	0.038
20							0.032	0.029	0.036
21							0.029	0.026	0.035
22							0.027	0.024	0.027
23							0.024	0.022	0.025
24							0.017	0.013	0.023

4.2 Design Ocean Water Levels

Water level variations in coastal areas are dominated by astronomical tides and general seasonal fluctuations, whereas extreme water levels tend to be induced by storm surge and wave setup. For the design or management of a master plan, long-term variations in sea-level rise due to climate change shall be considered.

In this assessment the following components have been considered:

- Tidal levels;
- Residuals (including storm surge and seasonal fluctuations); and
- Predicted sea-level rise due to climate change.

4.2.1 Tidal Levels

Total water level measurements at Lahad Datu station have been provided by the Client sourcing from the Department of Survey and Mapping, Malaysia (DSM), which is also known as Jabatan Ukur dan Pemetaan Malaysia (JUPEM). The data covers a period of ten (10) years from 2009 to 2018, with hourly temporal resolution. It is noted that Semporna station is not available from JUPEM therefore the water level assessment has been based on the available from Lahad Datu station.

Harmonic tidal analysis has been carried out using the measurements to separate the tidal (harmonic) and non-tidal (residual) components. The analysis is based on the Admiralty method. For the tidal water levels, an exceedance analysis is carried out to evaluate the tidal levels associated with various exceedance probability. A summary of the exceedance analysis is provided in Table 4.3 and the exceedance curve is shown in Figure 4-2. Tidal level exceeded one (1) day per year is at 1.17 m MSL, which is slightly above the average of MHWS and HAT at Lahad Datu (1.11 m MSL) and Semporna (1.13 m MSL).

Table 4.3 Exceedance of tidal water levels at Lahad Datu tidal station.

Exceedance Probability	Tidal Water Level [m MSL]
1 day per year	1.17
6 hours per year	1.24
1 hour per year	1.29

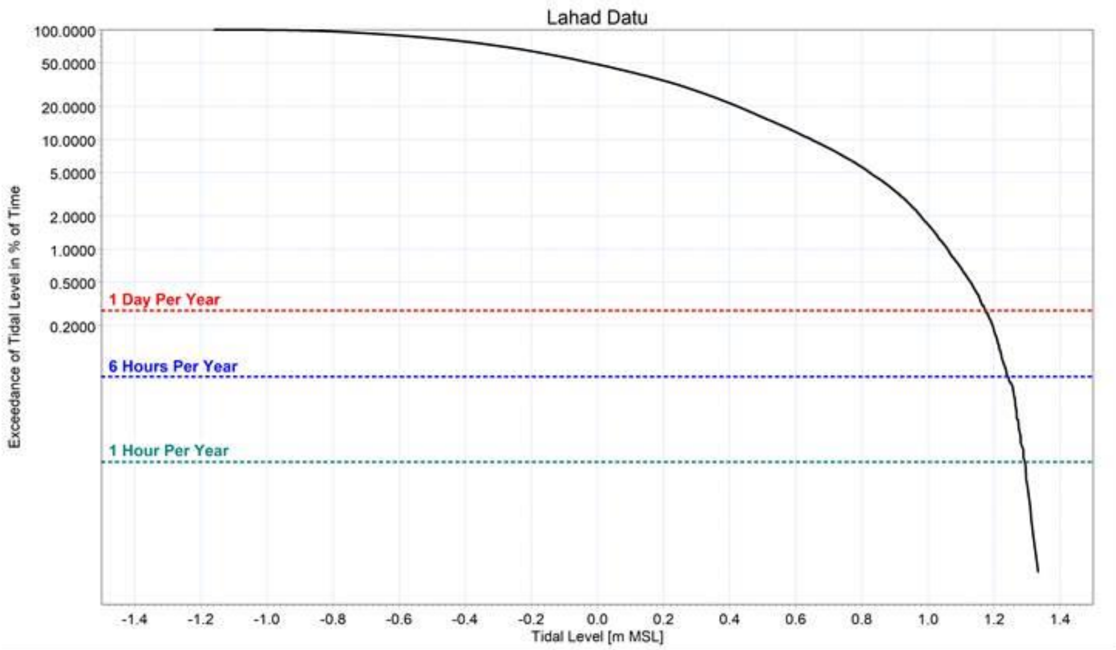

Figure 4-2 Exceedance curve of tidal water levels at Lahad Datu station.

4.2.2 Residual Levels

The residual separated from the harmonic analysis can be interpreted as a result of seasonal variations, storm surge and wave setup. An illustration of this is shown in Figure 4-3.

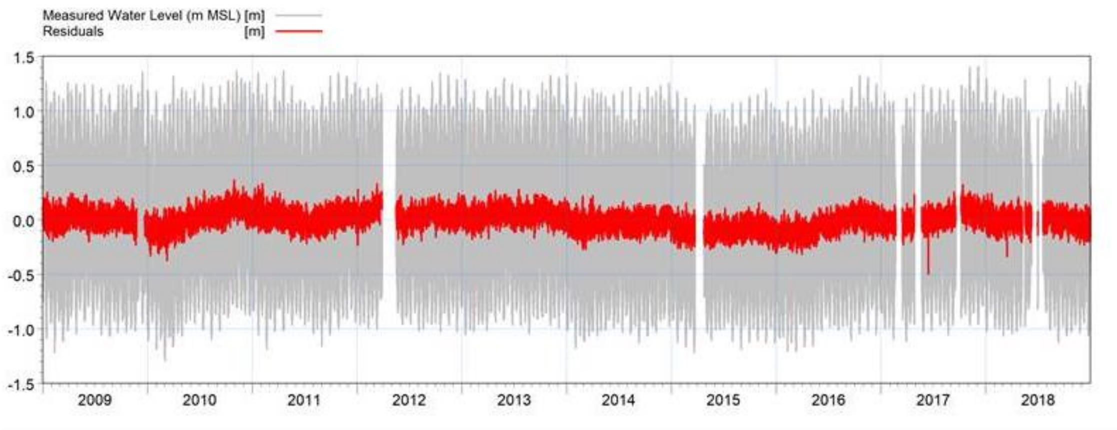

Figure 4-3 Measured water levels [m MSL] and residuals at Lahad Datu between 2009 and 2018.

It is possible to statistically estimate the extreme positive storm surge at Lahad Datu by extreme value analysis (EVA) of the 10-year residuals. Testing against different candidate distributions has shown that Gumbel distribution best model the extreme events using the least-square method. The results of the EVA for positive residuals are shown in Figure 4-4. The resulting central estimates for return periods of 2, 5, 10, 20, 25, 50 and 100 years are given in Table 4.4.

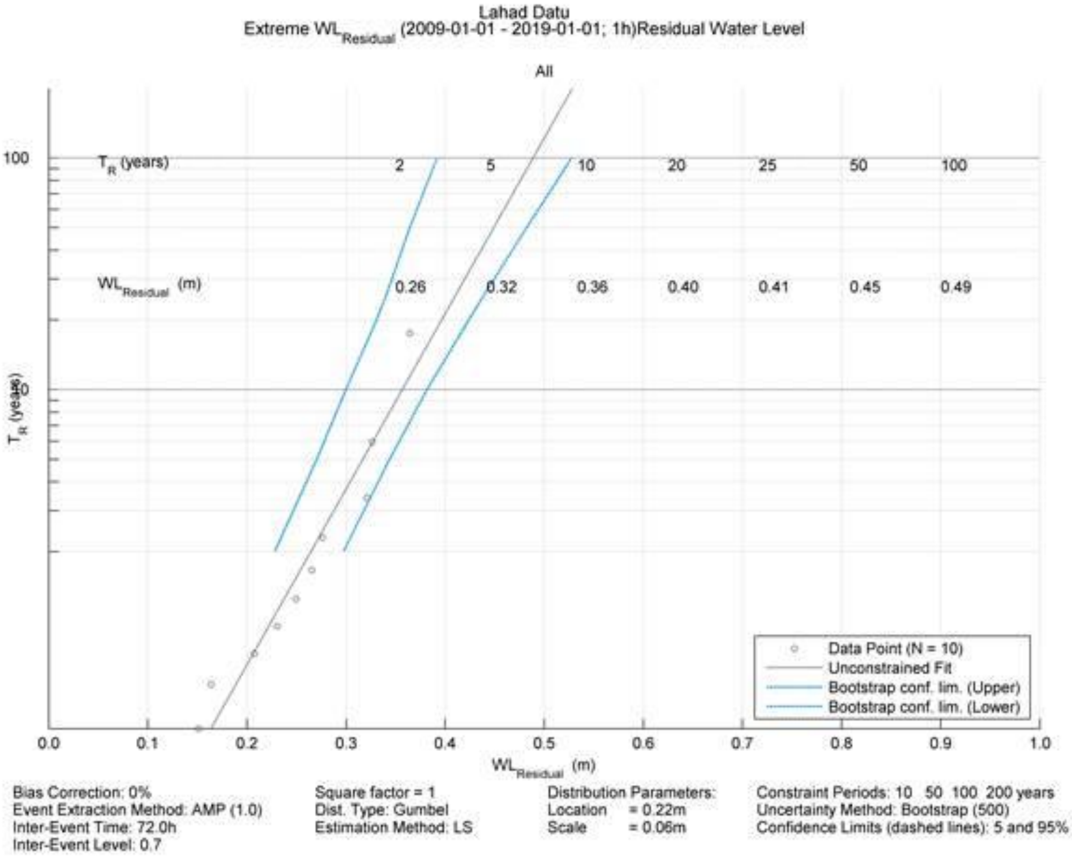

Figure 4-4 Extreme value analysis (EVA) for positive residual water levels at Lahad Datu.

Table 4.4 Central estimates of positive residual water levels [m] for return periods of 2, 5, 10, 20, 25, 50 and 100 years.

Parameter	Return Period (years)						
	2	5	10	20	25	50	100
Positive Residual Water Level [m]	0.26	0.32	0.36	0.40	0.41	0.45	0.49

4.2.3 Sea Level Rise (SLR)

A study by NAHRIM in 2010 was done specifically for Malaysia by adapting the global mean sea level rise projections from the IPCC simulations to the satellite altimeter observations. From the NAHRIM study, the nearest reference locations for the study area at Semporna have been identified as (119°E, 4°N) and (119°E, 5°N) as shown in Figure 4-5. The mean and 95th confidence limit of sea-level rise projections relative to a datum level set out in 2020 is listed in Table 4.5.

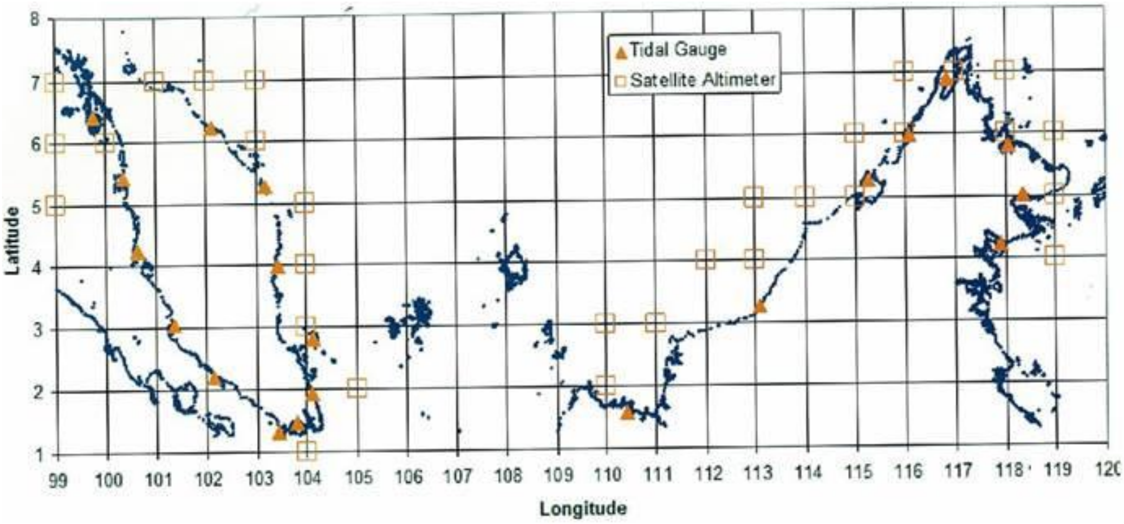

Figure 4-5 Nearest reference locations: (119°E, 4°N) and (119°E, 5°N) for projected sea-level rise (SLR) values from NAHRIM.

Table 4.5 Predicted sea-level rise (SLR) values relative to a datum level in the year 2020.

Year	(119°E, 4°N)		(119°E, 5°N)	
	Mean	95th Confidence Limit	Mean	95th Confidence Limit
2040	0.17	0.66	0.16	0.62
2060	0.39	1.58	0.37	1.50
2080	0.65	2.68	0.62	2.54
2100	0.94	3.95	0.90	3.74

4.2.4 Design Static Water Levels

In conclusion, the design water levels suggested as a summation of the most probable high tide, residual of a return period selected as per required, and future mean sea level rise.

The most probable high tide can be selected as the MHWS level, or a level exceeded one (1) day per year as conservative as this value is slightly above the average of MHWS and HAT at Lahad Datu and Semporna.

The extreme analysis for residual in various return periods are provided in Table 4.4 and the projected sea-level rise values are provided in Table 4.5.

A summary of the recommended design water level is set out in Table 4.6.

Table 4.6 Design water levels [m MSL] considering most probable high tide, residual water level and future mean sea level rise at Semporna

Return Period (years)	Astronomical Tide MHWS (m)	Storm Surge Residual and Seasonal Variation (m)	Global Sea Level Rise Due To Global Warming (m)	Design Water Level (m)
2	0.87	0.28	0.01	1.16
5	0.87	0.32	0.04	1.23
10	0.87	0.36	0.08	1.31
20	0.87	0.40	0.17	1.44
25	0.87	0.41	0.23	1.51
50	0.87	0.45	0.52	1.84
100	0.87	0.49	0.94	2.30

4.3 Combined events

Design rainfall and design ocean conditions have been determined for a range of selected return period events.

Flooding within the study area is affected by two conditions – rainfall and tide levels. The extent to which different rainfall and storm events are interdependent is important when determining the overall probability of a given event for design purposes. Flooding within most of the study area is caused by reasonably short but high-intensity rainfall. Flooding may be exacerbated by high tides.

Table 4.7 sets out the basis for this, showing the combinations to be tested by modelling, from which the “worst case” is to be. The rationale behind Table 4.7 can be explained as follows (and is based on standard international practice):

- Because local catchments within the Semporna drainage area are small, and the ‘critical case’ for flooding is short-duration events these events are unlikely to always coincide with high tide levels.
- Conversely, high tide levels are unlikely to always coincide with heavy rainstorm events as high tide levels are generally prolonged compared to the urban catchment response.

Based on this assessment “worst-case” scenarios with tide and rainfall as the main drivers have been constructed according to Table 4.7 below. Storm and tide-dominated events for each return period are assigned the ARI of the overall event respectively. The minimum tide level assigned is a 2-year ARI to provide some conservatism in the design.

Table 4.7 Design event combinations of tide and storm

Return Period Event	Select worst of:	Return Period (years)	
		Rain	Ocean Level
2	Storm	2	2
	Tide	NA	NA
5	Storm	5	2
	Tide	2	5
10	Storm	10	2
	Tide	2	10
20	Storm	20	2
	Tide	2	20
50	Storm	50	2
	Tide	2	50
100	Storm	100	5
	Tide	5	100

Based on the frequency analyses of rainfall and tide, the actual tide and discharge values used for existing and future design conditions are shown in Table 4.8. For future design scenarios, sea-level rise is included in the tide condition and is indicated in brackets in the table.

Table 4.8 Design rainfall and tide level.

Return Period Event	Select worst of:	Design ARI / Level / Flow	
		Rain (ARI)	Ocean Level (with climate change) (m)
2	Storm	2	1.16
	Tide	NA	NA
5	Storm	5	1.16
	Tide	2	1.23
10	Storm	10	1.16
	Tide	2	1.31
20	Storm	20	1.16
	Tide	2	1.44
50	Storm	50	1.16
	Tide	2	1.84
100	Storm	100	1.23
	Tide	5	2.30

4.4 Event timing

Given the above combinations of rainfall, tide and flow magnitudes there remains the question of the timing of events for the design modelling scenarios and analysis. The main considerations are:

1 Where tidal flow dynamics are important, a suitable tidal boundary is needed that reflects the peak design tide levels in Table 4.6**Error! Reference source not found.**. A design dynamic tide has been developed by superimposing a 24-hour storm surge (with a peak magnitude equalling the residuals indicated in Figure 4-3) over a spring tide event, plus seasonal and climate change components.

2 The relative timing of the tide and rainstorm event may be important. Given the above findings that these events are somewhat related, the design event condition assumes that the start of the rainstorm event occurs at the peak of the tide.

5 Drainage and inundation model development and calibration

5.1 Overview

To generate the catchment runoff covering the study area, two strategies have been implemented. The first strategy makes use of the rain on-grid methodology and has been used to establish baseline flood conditions over the Semporna Basin due to the fragmented nature of the existing drainage system where many drains are observed to have blocked outlets and other issues persist. The second strategy employed uses two types of hydrological models to quantify runoff into the major drains and natural watercourses. DHI's NAM Model will be used in modelling rural area while Urban Model will be used in modelling urban area. These models will be used for establishing flood mitigation options and sizing key flood management and mitigation infrastructure. The second strategy is being employed to allow flood mitigation options to be optimised efficiently.

The following subsection will further describe the hydrological models in detail.

5.2 Model Description

5.2.1 Distributed Model - Rain on Mesh

Traditionally lumped sub-catchments, which generally make use of simple hydrological models composed of the reservoir and simple routing components, were abandoned for the development of a baseline flood model in favour of a "rain-on-mesh" approach. The reason for the adoption of the Rain-on-mesh methodology for establishing baseline flooding is due to the fragmented nature of Semporna's drainage system where many drains terminate in blocked outlets or do not have readily defined discharge points.

Rain-on-mesh involves directly applying rainfall to the hydrodynamic surface-flow model, which accounts for infiltration and is dynamically connected to the stormwater drainage system. The model was built using the MIKE by DHI MIKE FLOOD software, incorporating open channel and 2D surface components into a dynamic flood model.

The rain on mesh concept is simply the application of precipitation and evaporation directly to a mesh topographic surface for the purpose of performing 2D hydraulic calculations. This approach is also referred to as direct precipitation, direct rainfall modelling, and rain-on-mesh. This approach is typically used for high-level planning, flooding outside the floodplain, establishing overland flow paths, and evaluating spills between sub-catchments particularly in low lying catchments.

The rain on mesh approach in this instance has been applied to DHI's MIKE FLOOD model and incorporates spatially varying rainfall, hydrological losses, and triangulated mesh to represent the surface. This approach also makes use of the functionality available within MIKE FLOOD for establishing overland flow modelling which is described further in Section 5.5.

5.2.2 Conceptual Models

NAM Model

The purpose of the hydrological modelling is to simulate the land phase of the hydrological cycle, as demonstrated in Figure 5-1. The hydrological model translates point and spatial rainfall and potential evaporation to runoff from the catchment.

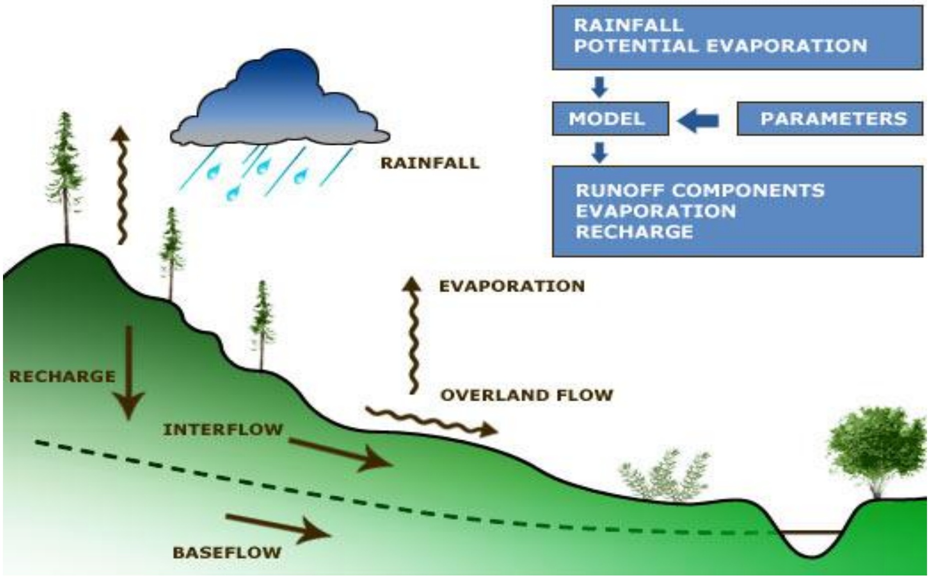

Figure 5-1 Overview of Rainfall / Runoff Process

The hydrological model will be set up using the MIKE 11 Rainfall-Runoff (RR) module. This model takes rainfall as an input and predicts discharge. The quantity of runoff is dependent upon the amount of rainfall and the nature of the catchment (land use, vegetation, slope, etc.) Catchment characteristics will be assessed from satellite and topographic data. The model is a parametric, lumped, continuous loss model. It can be used to generate continuous time series outputs of discharge for as long as the available rainfall data permits.

The hydrological parameters in NAM are related to the catchment topography, rainfall intensity, vegetation, land use, soil type, geology and are as follows (refer to Figure 5-2):

- Maximum water content in surface storage (U_{MAX}): interpreted as the water content in the interception storage, surface depressions and the top few centimetres of the ground.
- Maximum water content in the root zone storage (L_{MAX}): interpreted as the maximum soil moisture content in the root zone available for vegetative transpiration.
- Overland flow runoff coefficient (CQOF): determines the fraction of excess rainfall that generates overland flow.
- The time constant for interflow (CKIF): this determines the rate at which surface water (U) drains into interflow storage.
- The time constant for routing interflow and overland flow ($CK_{1,2}$): determines the shape of the hydrographs for the overland and interflow components.
- Root zone threshold value for overland flow (TOF): no overland flow occurs until the relative moisture content of the lower zone storage (L) is above this value.
- Root zone threshold value for interflow (TIF): as for TOF, except applicable to interflow.
- The baseflow time constant (CKBF): determines the shape of the baseflow hydrograph (similar to CK_{12}).
- Root zone threshold value for groundwater recharge (TG): as for TOF, except applicable to groundwater flow.

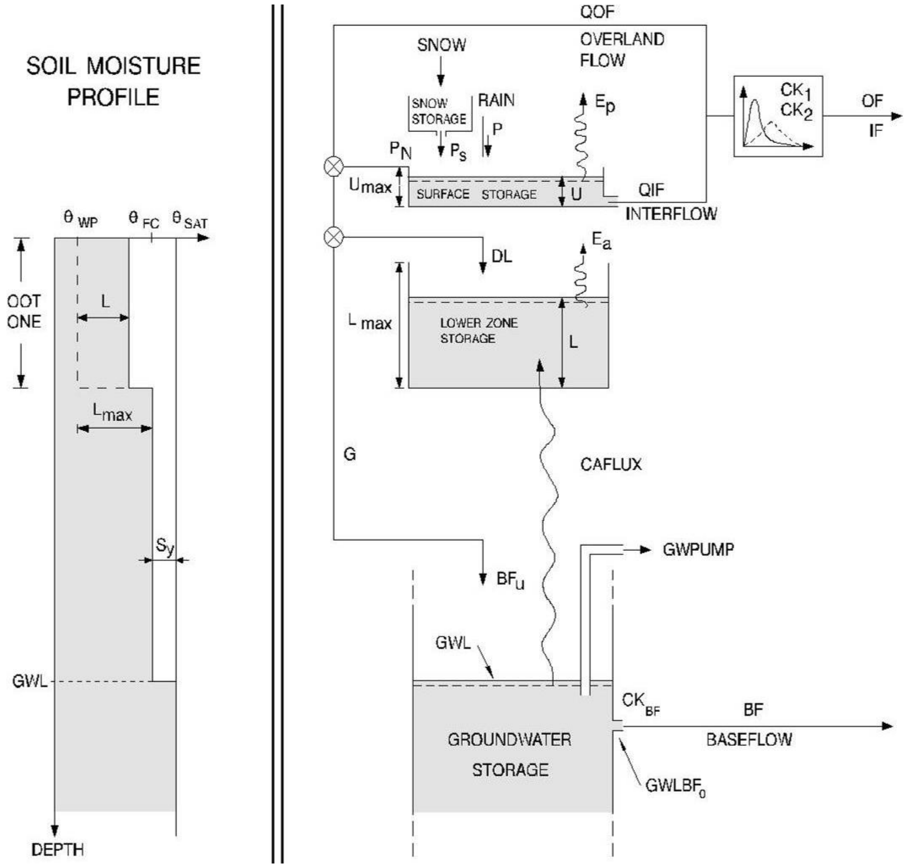

Figure 5-2 NAM Model Components

Given the present study area does not have any available JPS or other sources of discharge measurements data, no calibration and validation process will be undertaken for the MIKE 11 RR model. It will however utilise the hydrological parameters derived from surrounding nearby calibrated catchments to generate long-term discharges based on similarity in catchment characteristics (topography, geology, land cover, etc.). The sensitivity of the hydrological model to selected parameters will be evaluated and discussed in later reports.

Urban Model

For catchment modelling in urban areas, the ‘Urban’ model will be applied. There are two different urban runoff computational models comprising Urban Model A and Urban Model B.

Urban Model A is based on a “Time-Area” method where the shape of the runoff hydrograph is controlled by the concentration-time and by the time-area (T-A) curve and is used to generate runoff in the urbanised catchment. These parameters represent a conceptual description of the catchment reaction speed and the catchment shape.

The runoff amounts are based on the following parameters: -

- Impervious Area: represents the reduced catchment area that contributes to surface runoff
- Initial Loss: defines the precipitation depth, required to start the surface runoff.
- Hydrological Reduction: runoff-reduction factor (accounts for water losses) on the contributing area.
- Time/Area Curve: accounts for the shape of the catchment layout, determines the choice of the available T/A curve (refer to Figure 5-3).
- Time of Concentration: Defines the time required for water from the most distant part of the catchment to reach the catchment outlet.

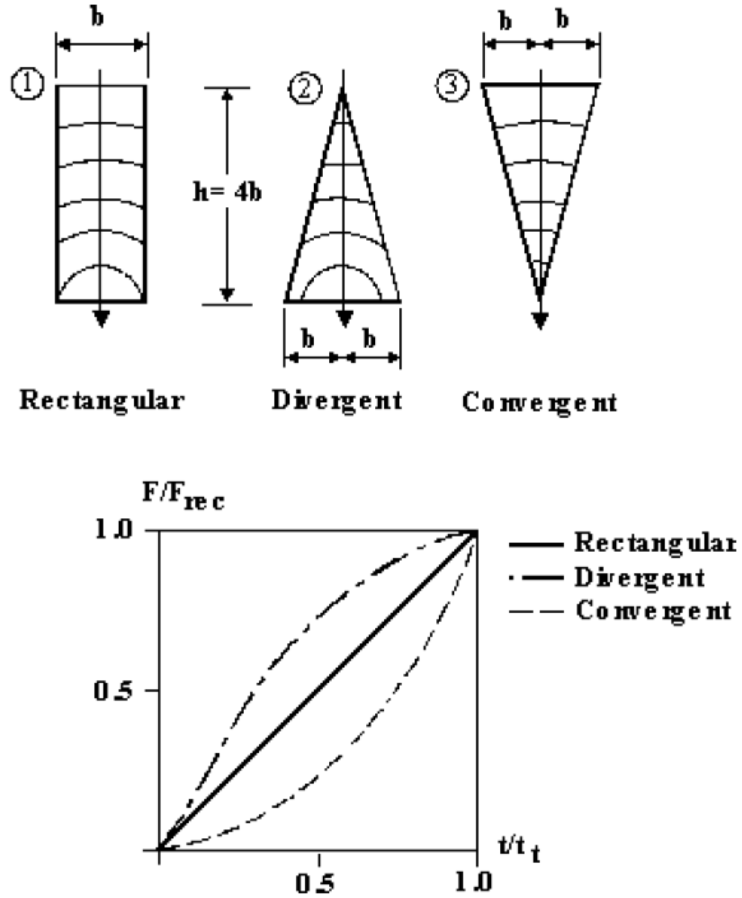

Figure 5-3 Pre-defined Time/Area curve

Urban Model B is based on the kinematic wave computation where the surface runoff is computed as flow in an open channel having the same area as the contributing catchment, taking the gravitational and friction forces only. The runoff amount is controlled by various hydrological losses and the size of the area contributing to the runoff.

The runoff amounts are based on the following parameters: -

- Length: defines the catchment shape as a flow channel and assume a prismatic flow channel with a rectangular cross-section.
- Slope: the average slope of the catchment surface used in the Manning equation for runoff.
- Area (percentages): distribution of percentages of sub-catchment with different distinct hydrological properties within the catchment area.

The output from the NAM and Urban model can further be used as an input to the advanced hydrodynamic model in MIKE 11 (refer to Section 5.3).

5.2.3 Catchment Delineation

Catchment delineation has been carried out based on the main drainage basins together with reference to the terrain information from IFSAR and LiDAR terrain model sourced for the study together with the collected drainage cross-sections and flow direction data covering the study area (refer to Figure 3-3 and Figure 5-4).

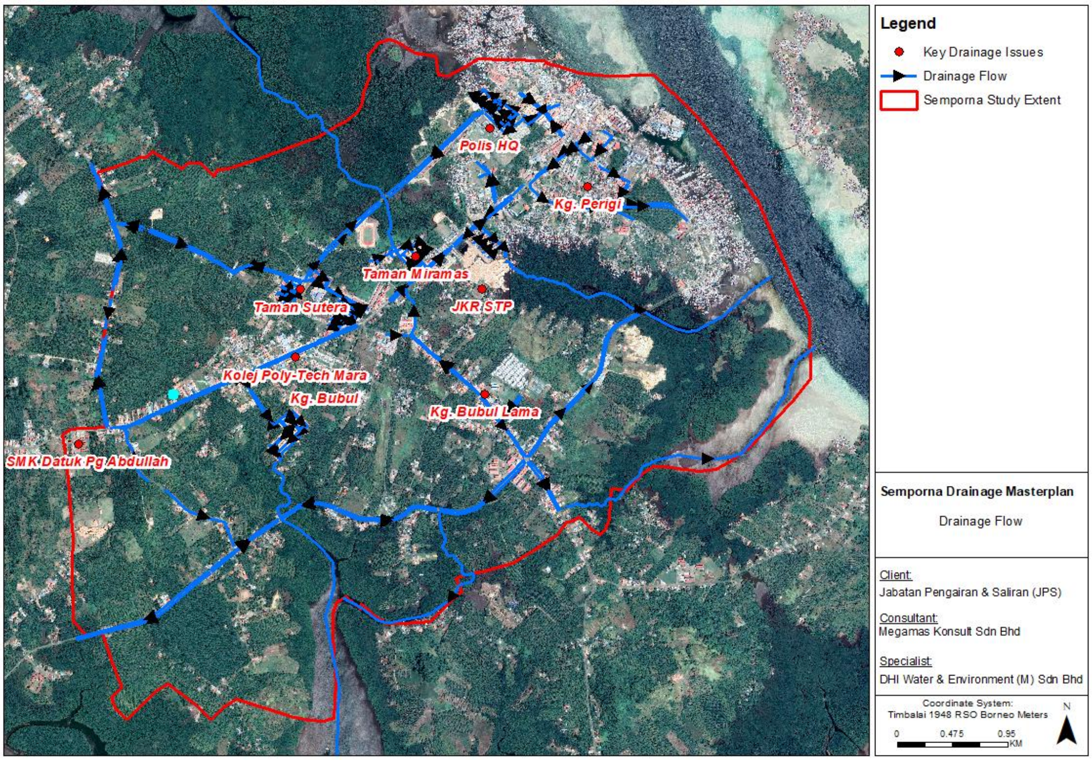

Figure 5-4 Overview of the existing drainage flow path

5.2.4 Conceptual Hydrological Model Parameters

Table 5.1 details the hydrological model to be applied to the various sub-catchments within the study extent. This will be based on the existing and future land use characteristics where Urban Model A will be primarily applied to urban-based sub-catchments while NAM Model will be applied to rural-based sub-catchments within the study extent.

5.2.4.1 NAM Model

The NAM model will be used to model runoff for rural-based catchments. The hydrological parameters (see Section 5.2.2) will be based on the catchment topography, rainfall intensity, vegetation, land use, soil type and geology condition for each individual sub-catchments within the study extent. The NAM hydrological parameters for these catchments will be determined through calibration to observed discharge or streamflow measurement values based on rainfall and evaporation data available from hydrological stations within the catchments area.

5.2.4.2 Urban Model A

For the urban catchment modelling, the rainfall-runoff modelling will be carried out using the Urban Model A hydrological model. The Urban Model A is based on the “Time-Area” method where the shape of the runoff hydrograph is controlled by the time of concentration and by the time-area (T-A) curve and is used to generate runoff in urban catchments. The existing runoff for Urban Model A to be generated will be based on the following parameters: -

- Impervious Area: percentage fraction of impervious area within the catchment area and based on the existing land use[1] map (refer to Figure 5-5)

[1] Land use map derived from Google satellite imagery information and site verification

- Initial Loss: 1.5 mm (based on recommended Loss Values for Rainfall Excess Estimation, MSMA 2nd Edition)
- Hydrological Reduction: 0.9
- Time/Area Curve: Curve No. 1
- Time of Concentration: overland flow time generated based on the following formula,

$$t_c = t_o + t_d$$

t_o, Overland Flow

$$t_o = \frac{107.n^* L^{1/3}}{S^{1/5}}$$

t_d, Drain flow

$$t_d = \frac{L}{V}$$

where, t_c – time of concentration (minutes)

t_o – Overland sheet flow travel time (minutes)

t_d – Drain flow (minutes)

L – Overland sheet flow path length (m)

for Steep Slope (>10%), L 50 m

for Moderate Slope (<5%), L 100 m

for Mild Slope (<1%), L 200 m

n^* – Horton's roughness value for the surface

S – Slope of overland surface (%)

V – Velocity: 1 m/s

Table 5.2 and Table 5.3 details the NAM and Urban Model A parameters applied based on the existing condition of the study area. The NAM and Urban Model A parameters applied for the existing condition will be subject to further refinement before being applied to generate future catchment runoff based on design rainfall condition together with the application of areal reduction factor.

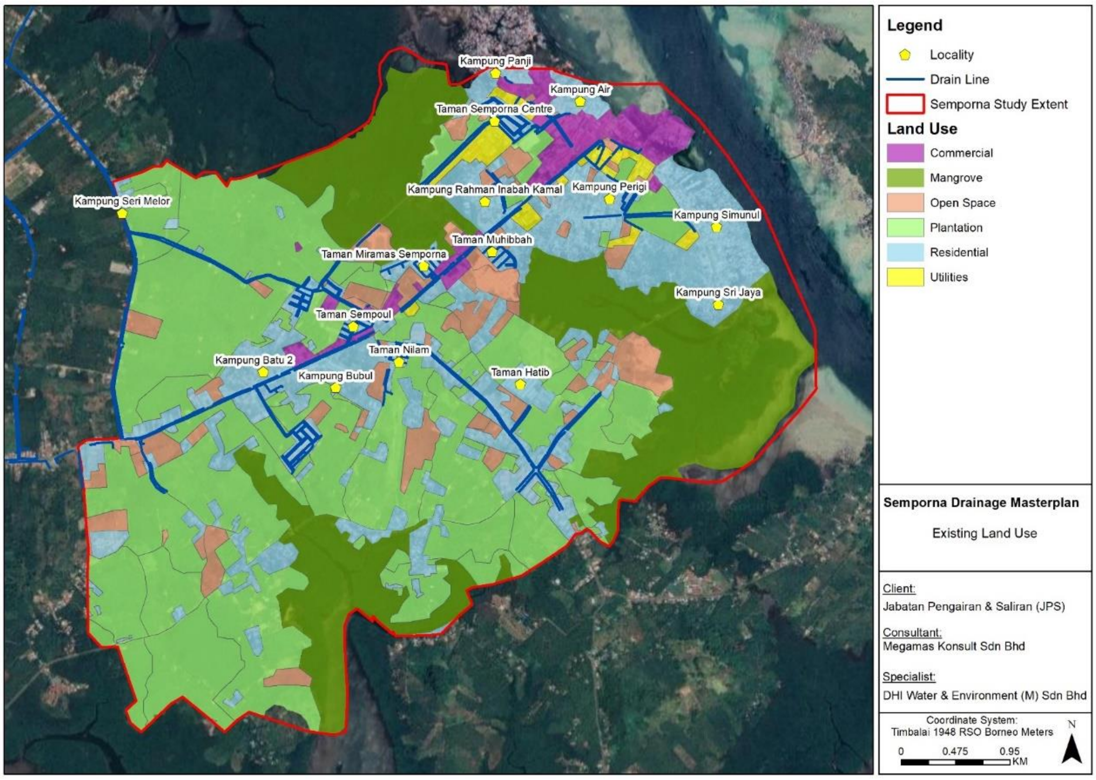

Figure 5-5 Existing land use map of the study area

Table 5.1 Application of hydrological model in various sub-catchments within the study extent for the existing condition

Sub-Catchments	Area (km^2)	Residential Area (%)	Commercial Area (%)	Utilities & Others[2] Area (%)	Plantation (%)	Mangrove (%)	Open Space (%)	Hydrological model
S1	180	42	56	0	0	0	2	Urban
S2	100	75	20	0	0	0	5	Urban
S3	90	49	0	51	0	0	0	Urban
S4	150	19	81	0	0	0	0	Urban
S5	293	16	41	0	29	0	14	Urban
S6	210	55	0	23	0	0	22	Urban
S7	476	44	0	28	0	12	16	Urban
S8	221	20	0	0	72	8	0	NAM
S9	2182	2	0	0	46	52	0	NAM
S10	706	13	14	0	9	43	21	NAM

[2] Include areas designated for Government usage, Schools, Utilities

Sub-Catchments	Area (km²)	Residential Area (%)	Commercial Area (%)	Utilities & Others[2] Area (%)	Plantation (%)	Mangrove (%)	Open Space (%)	Hydrological model
S11	159	13	0	0	29	0	58	NAM
S12	1388	49	0	6	7	27	11	Urban
S13	64	100	0	0	0	0	0	Urban
S14	167	41	7	0	52	0	0	NAM
S15	357	0	68	19	7	0	6	Urban
S16	780	81	0	0	0	19	0	Urban
S17	863	0	0	0	0	81	19	NAM
S18	296	17	0	0	3	62	18	NAM
S19	904	23	4	0	32	19	22	NAM
S20	273	0	0	4	96	0	0	NAM
S21	1086	4	0	0	21	69	6	NAM
S22	885	25	0	0	45	24	6	NAM
S23	845	25	0	0	71	0	4	NAM
S24	650	23	0	0	60	17	0	NAM
S25	1126	23	0	0	64	9	4	NAM
S26	278	13	0	0	87	0	0	NAM
S27	1515	45	5	0	40	10	0	Urban
S28	1683	4	1	0	95	0	0	NAM
S29	375	12	0	0	88	0	0	NAM
S30	1408	4	0	0	96	0	0	NAM
S31	814	7	0	20	73	0	0	NAM
S32	1713	6	0	0	51	36	7	NAM
S33	275	4	0	0	96	0	0	NAM
S34	345	3	0	0	97	0	0	NAM
S35	576	0	0	0	100	0	0	NAM
S36	136	0	0	0	100	0	0	NAM
S37	688	5	0	0	44	51	0	NAM
S38	34	0	0	0	100	0	0	NAM
S40	13	0	0	0	100	0	0	NAM
S41	1	0	0	0	100	0	0	NAM

Table 5.2 NAM model parameters applied for the existing condition

Catchments	Area (km^2)	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF	TG	CKBF
S10B	0.4	14	235	0.56	1000	1.32	0.7	0.7	0.8	2000
S11	0.2	11	204	0.47	1000	0.93	0.7	0.7	0.8	2000
S12A	0.4	15	244	0.6	1000	1.29	0.7	0.7	0.8	2000
S14	0.2	12	207	0.62	1000	0.95	0.7	0.7	0.8	2000
S17A	0.2	10	200	0.4	1000	0.96	0.7	0.7	0.8	2000
S17B	0.7	15	245	0.6	1000	1.63	0.7	0.7	0.8	2000
S18	0.3	14	229	0.6	1000	1.18	0.7	0.7	0.8	2000
S19A	0.2	11	200	0.59	1000	1.03	0.7	0.7	0.8	2000
S19B	0.7	12	215	0.55	1000	1.63	0.7	0.7	0.8	2000
S20	0.3	11	209	0.54	1000	1.14	0.7	0.7	0.8	2000
S21	1.1	14	234	0.57	1000	1.93	0.7	0.7	0.8	2000
S22B	0.6	13	224	0.52	1000	1.53	0.7	0.7	0.8	2000
S23B	0.6	11	211	0.49	1000	1.55	0.7	0.7	0.8	2000
S24A	1.2	11	214	0.46	1000	1.99	0.7	0.7	0.8	2000
S24C	0.9	13	224	0.53	1000	1.78	0.7	0.7	0.8	2000
S25	1.1	12	211	0.53	1000	1.96	0.7	0.7	0.8	2000
S26	0.3	11	212	0.5	1000	1.15	0.7	0.7	0.8	2000
S27A	0.6	12	220	0.49	1000	1.56	0.7	0.7	0.8	2000
S28B	1.3	11	213	0.45	1000	2.08	0.7	0.7	0.8	2000
S29	0.7	11	213	0.47	1000	1.63	0.7	0.7	0.8	2000
S30	1.4	12	214	0.51	1000	2.13	0.7	0.7	0.8	2000
S31	1	11	210	0.49	1000	1.9	0.7	0.7	0.8	2000
S32	1.8	13	223	0.53	1000	2.32	0.7	0.7	0.8	2000
S33	0.3	11	213	0.46	1000	1.15	0.7	0.7	0.8	2000
S34	0.5	11	213	0.48	1000	1.46	0.7	0.7	0.8	2000
S35	0.8	12	219	0.47	1000	1.7	0.7	0.7	0.8	2000
S36	0.5	13	230	0.54	1000	1.39	0.7	0.7	0.8	2000
S37	1.9	13	225	0.53	1000	2.36	0.7	0.7	0.8	2000
S38	0.4	11	212	0.5	1000	1.36	0.7	0.7	0.8	2000
S40	1.7	11	213	0.47	1000	2.31	0.7	0.7	0.8	2000
S41	2.9	11	214	0.48	1000	2.81	0.7	0.7	0.8	2000
S8	0.2	11	211	0.52	1000	1.05	0.7	0.7	0.8	2000
S9	2.2	13	230	0.53	1000	2.54	0.7	0.7	0.8	2000

Table 5.3 Urban Model A parameters applied for the existing condition

Catchments	Area (km^2)	Impervious Area (%)	Initial Loss (mm)	Hydrological Reduction	Time/Area Curve	L (m)	tc (min)
S1	0.22	98	1.5	0.9	2	602	14.4
S2	0.1	95	1.5	0.9	2	551	12.4
S3	0.09	100	1.5	0.9	2	496	21
S4	0.15	100	1.5	0.9	2	522	12.6
S5	0.29	58	1.5	0.9	2	692	45.4
S6	0.21	78	1.5	0.9	2	806	43.4
S7	0.48	84	1.5	0.9	2	947	49.2
S10A	0.31	62	1.5	0.9	2	1117	39.9
S12B	1.01	79	1.5	0.9	2	2048	84.3
S13	0.06	100	1.5	0.9	2	376	12.4
S15	0.36	87	1.5	0.9	2	863	30.2
S16	0.78	81	1.5	0.9	2	1498	27.2
S22A	0.3	70	1.5	0.9	2	1273	57.3
S23A	0.24	82	1.5	0.9	2	1338	45.7
S24B	0.38	59	1.5	0.9	2	1680	60.9
S27B	0.89	87	1.5	0.9	2	1474	78.1
S28A	0.36	50	1.5	0.9	2	1455	66.3

5.3 MIKE 11 Hydrodynamic Model Development

5.3.1 Channel Description

River and drainage modelling was carried out using DHI's MIKE 11 1-D hydrodynamic model ('HD') covering the extent of available collected cross-sectional data. The model geometry consists of a concrete channel, earth drain, and river cross-sections data extracted from cross-sectional surveys conducted by a licensed surveyor. The developed model network for the study area is shown in Figure 5-6.

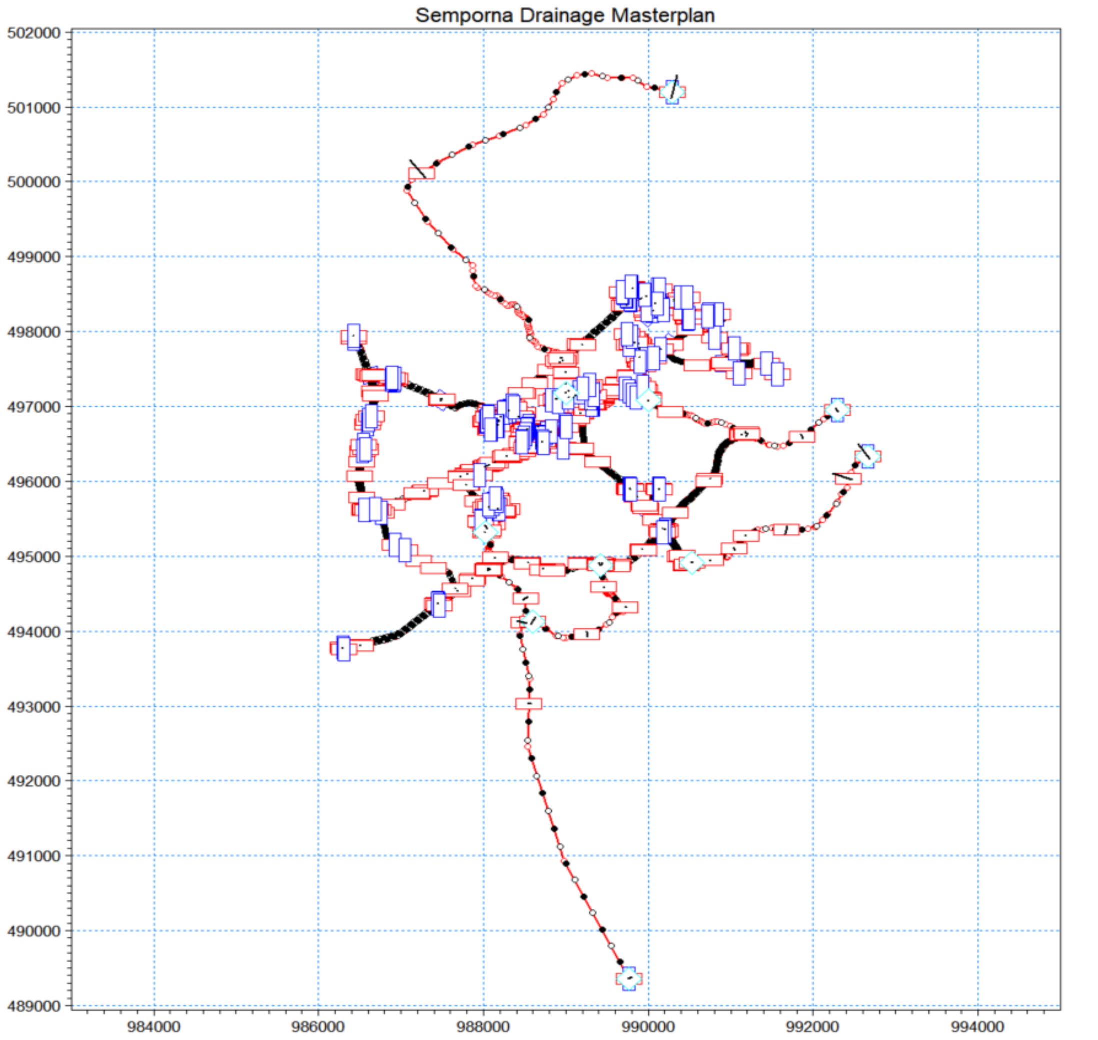

Figure 5-6 Developed MIKE 11 HD model covering the study extent

5.3.2 Cross-section

The MIKE 11 HD model has utilised the river and drain cross-sections collected as part of the present study. Cross-section datum levels in some cases required correction and these were assessed by comparing the surveyed bank levels to the IFSAR land level data. A total of 548 cross-sections were surveyed and applied in the hydrodynamic model covering a total length of almost 61 km (refer to Figure 5-7 and Table 5.5). Surveyed river topographic data (for example refer to Figure 5-9) have been extracted from AutoCAD format and included as input into cross-section data. A total of 34 river cross-sections were surveyed and applied in the hydrodynamic model covering a total length of 21.9 km (refer to Figure 5-8 and Table 5.4).

Photo 5.1 and Photo 5.2 provide an example of the drain topographic survey work conducted as part of the study.

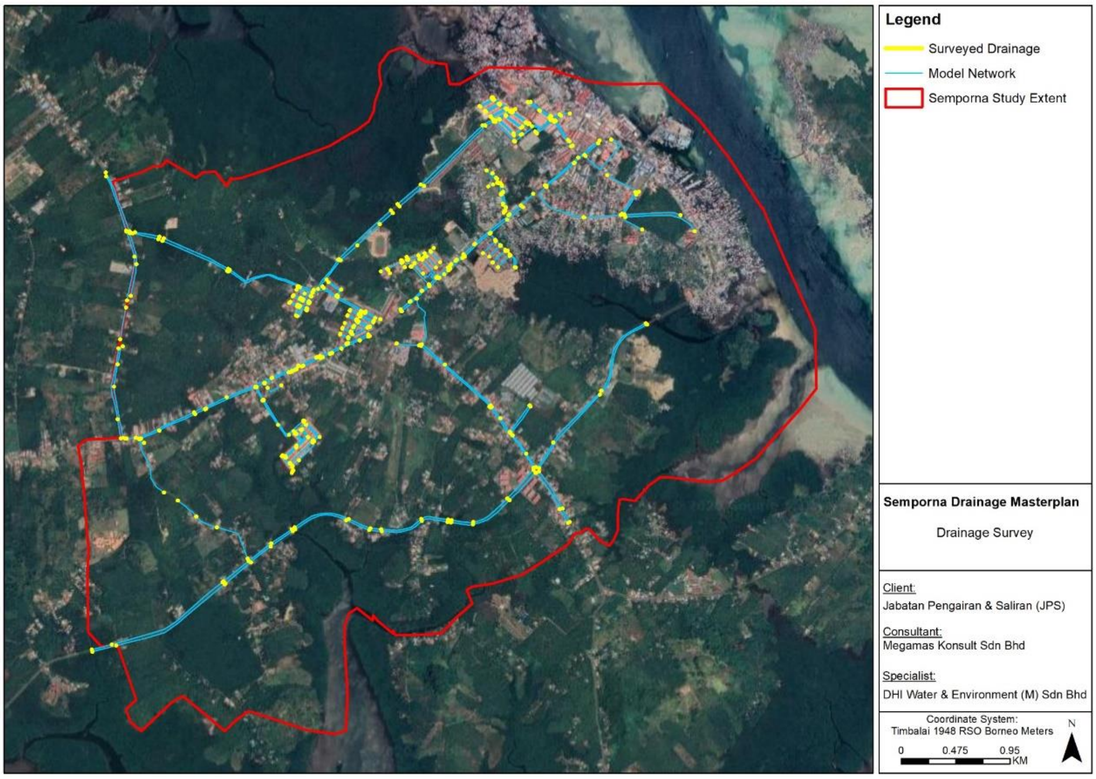

Figure 5-7 Extent of drain topographic survey

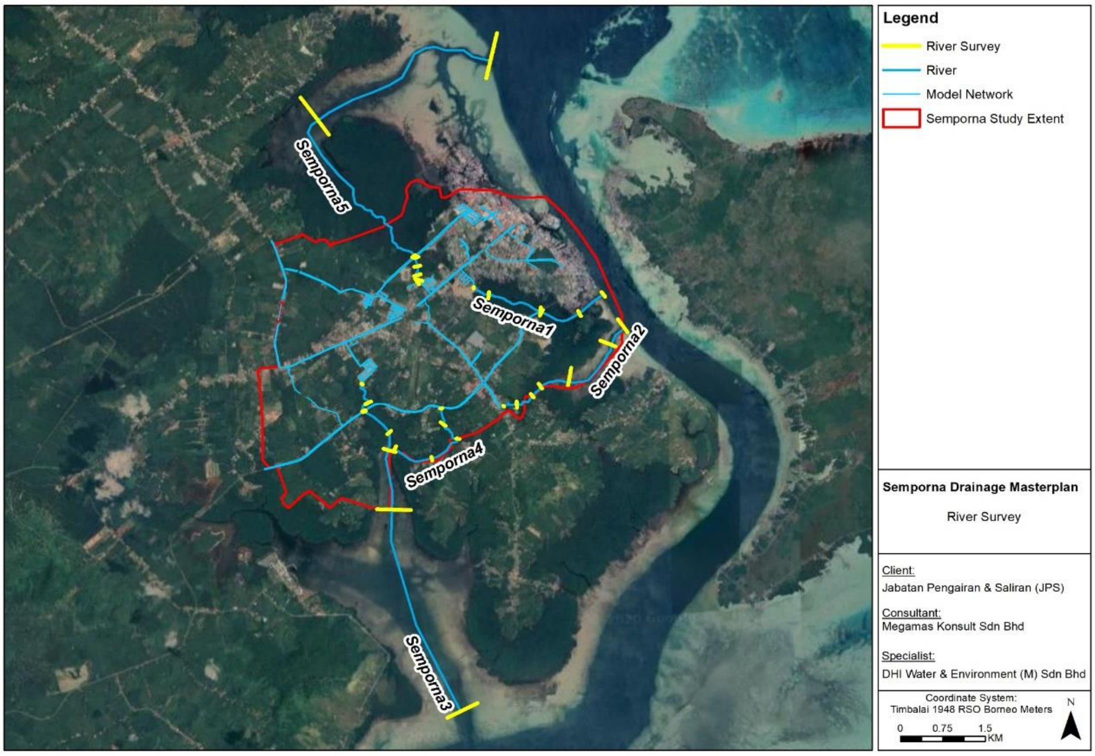

Figure 5-8 Extent of river survey

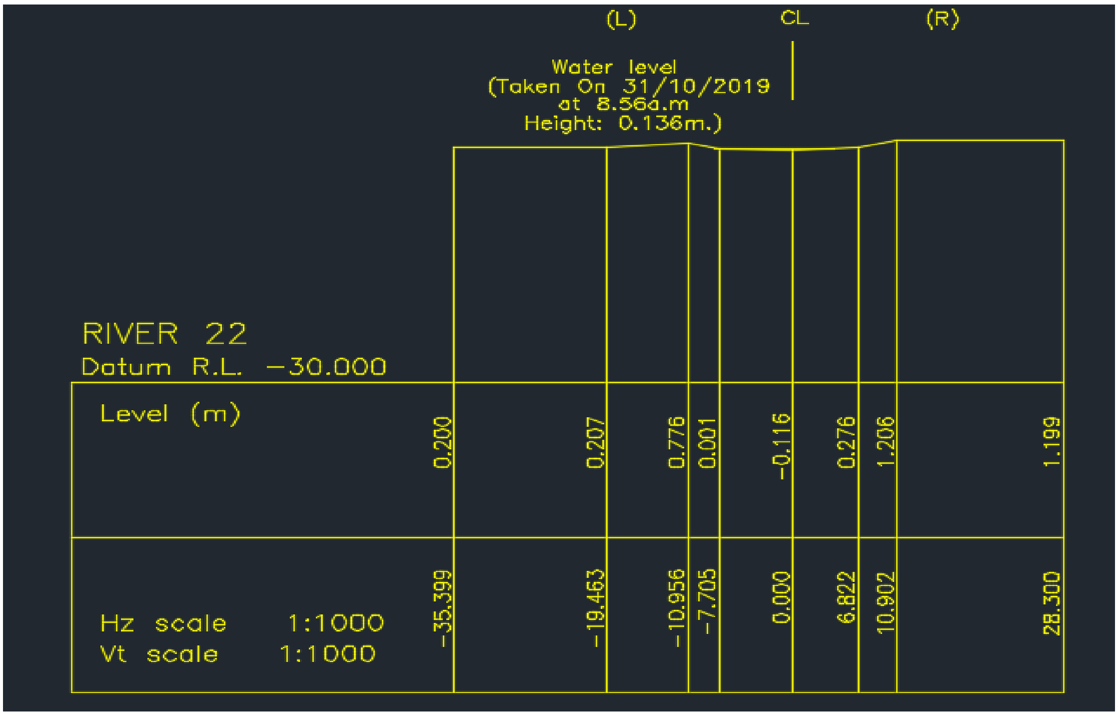

Figure 5-9 Sample of surveyed river topographic data at point R22 linking to Sg Gagoyan (Jalan Seri Melor)

Table 5.4 List of surveyed river cross-sections

Rivers Name	Total Surveyed Length [km]	No. River Cross-Sections Surveyed
SEMPORNA1	2.7	6
SEMPORNA2	2.9	7
SEMPORNA3	6.6	8
SEMPORNA4	2.1	5
SEMPORNA5	7.6	8
TOTAL	21.9	34

Table 5.5 List of surveyed drain cross-section data

No	Branch/ Network	Total Surveyed Length [km]	No. Drain Cross Sections Surveyed and Applied in Model
1	Jln Balai Polis01	0.54	4
2	Jln Balai Polis02	0.14	2
3	Jln Balai Polis03	0.28	3
4	Jln Balai Polis04	0.18	2
5	Jln Balai Polis04a	0.04	3
6	Jln Balai Polis05	0.37	10
7	Jln Balai Polis06	0.05	2
8	Jln Balai Polis07	0.18	3
9	Jln Balai Polis08	0.18	2

No	Branch/ Network	Total Surveyed Length [km]	No. Drain Cross Sections Surveyed and Applied in Model
10	Jln Balai Polis09	0.18	3
11	Jln Balai Polis10	0.2	2
12	Jln Balai Polis11	0.13	2
13	Jln Balai Polis12	0.13	2
14	Jln Balai Polis13	0.13	2
15	Jln Balai Polis14	0.13	2
16	Jln Balai Polis15	0.13	2
17	Jln Balai Polis16	0.13	2
18	Jln Balai Polis17	0.12	3
19	Jln Habirun Extention01	0.31	2
20	Jln Habirun01	0.54	2
21	Jln Hospital01	0.2	2
22	Jln Hospital02a	0.04	3
23	Jln Hospital02b	0.08	2
24	Jln Hospital03	0.23	4
25	Jln Hospital04	0.21	2
26	Jln Hospital05	0.38	6
27	Jln Hospital06	0.26	2
28	Jln Hospital07	0.26	4
29	Jln Inabah Kamal01	0.33	12
30	Jln Inabah Kamal02	0.43	10
31	Jln Inabah Kamal03	0.08	3
32	Jln Kabongan01	0.2	2
33	Jln Kabongan01a	0.81	3
34	Jln Kabongan01b	0.65	2
35	Jln Kabongan02	0.81	3
36	Jln Kabongan02a	2.3	10
37	Jln Kabongan02b	0.45	2
38	Jln Kabongan03	0.29	2
39	Jln Kabongan04	0.29	2
40	Jln Kabongan05	1.64	3
41	Jln Kabongan07	0.52	3
42	Jln Kabongan08	0.52	3
43	Jln Kabongan09	0.92	5
44	Jln Kabongan10	0.9	4
45	Jln Kabongan11	0.91	5
46	Jln Kabongan12	0.93	5
47	Jln Kabongan13	0.75	4
48	Jln Kabongan14	0.75	4

No	Branch/ Network	Total Surveyed Length [km]	No. Drain Cross Sections Surveyed and Applied in Model
49	Jln Kabongan15	1.31	3
50	Jln Kabongan16	1.33	3
51	Jln Kabongan17	0.515	2
52	Jln Kabongan18	0.49	4
53	Jln LPPB01	0.15	2
54	Jln LPPB02	0.14	2
55	Jln LPPB03	0.15	2
56	Jln LPPB04	0.14	2
57	Jln LPPB07	0.38	10
58	Jln LPPB08	0.17	2
59	Jln Pinggir Bakau01	0.7	3
60	Jln Pinggir Bakau02	0.35	3
61	Jln Pinggir Bakau03	0.86	3
62	Jln Pinggir Bakau04	0.23	2
63	Jln Senalang Lama01	0.53	2
64	Jln Senalang Lama03	0.87	4
65	Jln Seri Melor01	1.12	4
66	Jln Seri Melor01a	0.155	3
67	Jln Seri Melor02	1.12	4
68	Jln Seri Melor03a	0.9	5
69	Jln Seri Melor03b	0.57	5
70	Jln Seri Melor04	0.31	2
71	Jln Seri Melor04a	0.63	2
72	Jln Tanjong Kapor01	0.8	3
73	Jln Tanjong Kapor02	0.82	4
74	Jln Tanjong Kapor03	0.29	2
75	Jln Tanjong Kapor04	0.62	3
76	Jln Tanjong Kapor04a	0.51	2
77	Jln Tanjong Kapor05	0.58	4
78	Jln Tanjong Kapor05a	0.56	2
79	Jln Tawau Semporna01	0.63	3
80	Jln Tawau Semporna02	0.16	2
81	Jln Tawau Semporna03	0.11	2
82	Jln Tawau Semporna04	0.31	2
83	Jln Tawau Semporna04a	0.57	3
84	Jln Tawau Semporna05	0.84	7
85	Jln Tawau Semporna06	0.3	2
86	Jln Tawau Semporna06a	0.74	4
87	Jln Tawau Semporna06b	0.24	3

No	Branch/ Network	Total Surveyed Length [km]	No. Drain Cross Sections Surveyed and Applied in Model
88	Jln Tawau Semporna07	0.33	6
89	Jln Tawau Semporna07a	0.09	2
90	Jln tawau Semporna08	2.25	26
91	Jln Tawau Semporna08b	0.06	2
92	Jln Tawau Semporna09a	2.23	12
93	Jln tawau Semporna10	0.2	3
94	Jln Tawau Semporna11	0.09	3
95	Jln Tawau Semporna12	0.33	3
96	Jln Tawau Semporna13	0.26	5
97	Jln Tawau Semporna14	0.11	2
98	Jln Tawau Semporna15	0.33	9
99	Jln Tinagayan01	0.59	3
100	Jln Tinagayan02	0.72	4
101	Jln Tinagayan03a	0.64	3
102	Jln Tinagayan03b	0.23	2
103	Jln Tinagayan04	0.63	2
104	Jln Tinagayan04a	0.22	2
105	Jln Tinagayan05	0.8	2
106	Lorong01	0.4	6
107	Lorong01a	0.05	2
108	Lorong02	0.24	3
109	Lorong03	0.13	2
110	Lorong04	0.12	2
111	Lorong05	0.13	4
112	Lorong06	0.16	3
113	Lorong06a	0.04	2
114	Lorong07	0.2	3
115	Lorong08	0.03	2
116	Lorong09	0.07	3
117	Tmn Pelangi01	0.75	6
118	Tmn Pelangi02	0.56	2
119	Tmn Pelangi03	0.56	6
120	Tmn Pelangi04	0.2	8
121	Tmn Pelangi05	0.13	2
122	Tmn Pelangi06	0.26	3
123	Tmn Pelangi06a	0.32	2
124	Tmn Pelangi07	0.16	2
125	Tmn Pelangi08	0.16	3
126	Tmn Pelangi09	0.2	3

No	Branch/ Network	Total Surveyed Length [km]	No. Drain Cross Sections Surveyed and Applied in Model
127	Tmn Pelangi10	0.01	2
128	Tmn Pelangi11	0.13	2
129	Tmn Pelangi12	0.2	3
130	Tmn Pelangi13	0.19	3
131	Tmn Pelangi14	0.03	2
132	Tmn Sempol01	0.25	5
133	Tmn Sempol03	0.07	3
134	Tmn Sempol05	0.12	3
135	Tmn Sempol06	0.2	5
136	Tmn Sempol07	0.17	3
137	Tmn Sempol08	0.1	2
138	Tmn Sempol09	0.1	2
139	Tmn Sempol10	0.15	2
140	Tmn Sempol11	0.13	4
141	Tmn Sempol12	0.09	3
142	Tmn Sempol13	0.14	3
143	Tmn Sempol14	0.1	3
144	Tmn Sempol15	0.14	4
145	Tmn Sempol16	0.08	2
146	Tmn Sempol17	0.14	4
147	Tmn Sempol18	0.08	2
148	Tmn Sempol19	0.13	3
149	Tmn Sutera01	0.2	5
150	Tmn Sutera02	0.3	6
151	Tmn Sutera03	0.24	6
152	Tmn Sutera05	0.05	2
153	Tmn Sutera06	0.05	2
154	Tmn Sutera07	0.17	4
155	Tmn Sutera08	0.06	2
156	Tmn Sutera10	0.06	2
157	Tmn Sutera11	0.22	3
158	Tmn Sutera12	0.17	2
159	Tmn Sutera13	0.13	2
160	Tmn Sutera14	0.06	2
TOTAL		60.9	552

Photo 5.1 Example of drain topographic survey conducted at Taman Miramas

Photo 5.2 Example of drain topographic survey conducted along Jalan Kabongan

5.4 Culverts and Weirs

A large number of culverts were surveyed as part of the present study. Those that represented constrictions to flow or were located in areas where flooding issues had been reported were incorporated in the model. Flows above the culvert road levels have been taken into account by inserting weirs at roads crossing to represent overtopping situations. The culverts and weirs included in the model are indicated in Table 5.6 and shown in Figure 5-10.

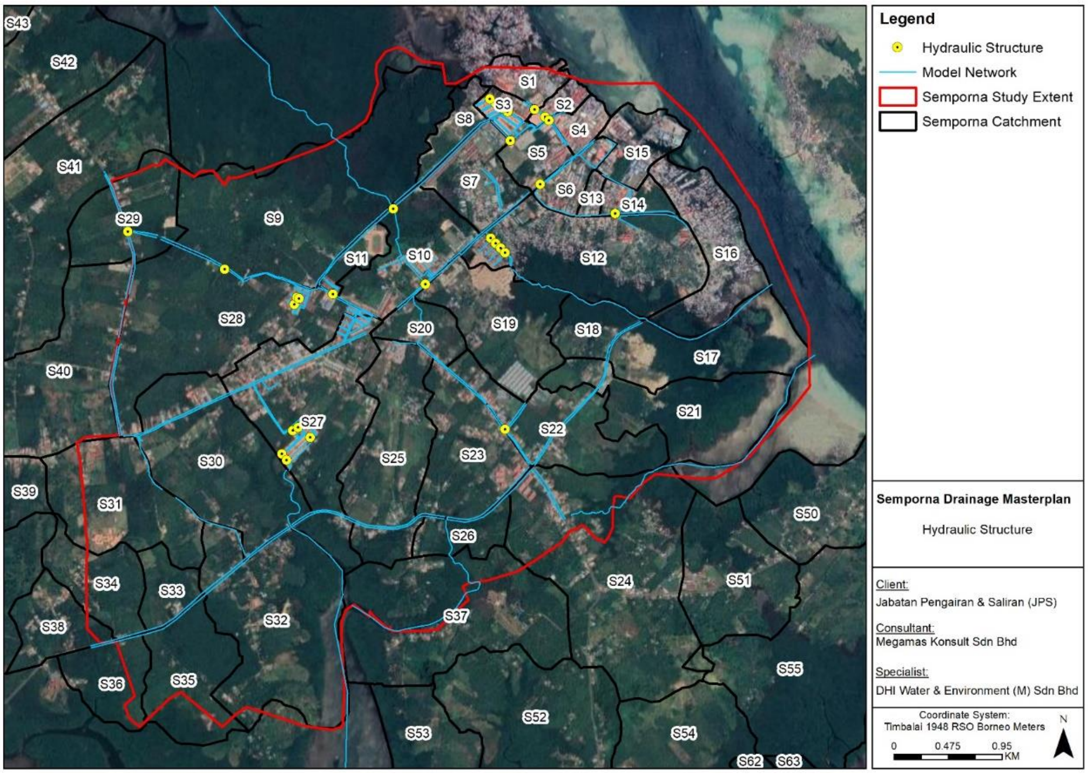

Figure 5-10 Location of surveyed hydraulic structure

Table 5.6 List of number of culverts and weirs included in the model setup

No	Sub-Catchments	No. Culverts	No. Weirs
1	S2	2	2
2	S3	4	4
3	S5	4	4
4	S10	2	2
5	S11	1	1
6	S12	4	4
7	S14	1	1
8	S22	1	1
9	S27	5	5
10	S28	4	4
11	S29	1	1
TOTAL		**29**	**29**

Photo 5.3 Example of culvert structure survey conducted along Jalan Hospital (Catchment S2)

5.5 MIKE FLOOD model development

The floodplain modelling was carried out using DHI's MIKE FLOOD, a tool that integrates the MIKE 11 and MIKE 21 models into a single, dynamically coupled modelling system. Using a coupled approach enables the best features of both models to be utilised, while at the same time avoiding some limitations that may be encountered when using the components separately.

5.5.1 Overland flow (M21 FM) component

MIKE 21 Flow Model FM was used as the 2D model to represent the study area and its floodplains. Floodplain topography was derived from the IFSAR and LiDAR surveys (refer to Section 3.2**Error! Reference source not found.**). The LiDAR data only captured the main roads (Jalan Balung-Semporna, Jalan Lapangan Terbang, Jalan Tagasan, Jalan Pinggir Bakau, Jalan Bubul, Jalan Hospital, Jalan Seri Melor Tinagayan and Jalan Tanjung Kapor) within the study area.

MIKE 21 Flow Model FM is based on a flexible mesh description. The mesh is designed to provide higher resolution where needed (for example close to the river channels). The downstream open boundaries were included in the MIKE 21 FM to model the flows between the local drainage and the lower reaches of the major outlet within the system (refer to Figure 5-11).

Elsewhere the 2D boundaries are closed, which represents a zero-flow exchange across the boundary. During extreme events, water depths along the catchment boundary is greater than the ground level inundating the floodplain. The closed boundary condition will during such events prevent flow from discharging from the model area and hence no net exchange of flow between the floodplains and boundaries occurred.

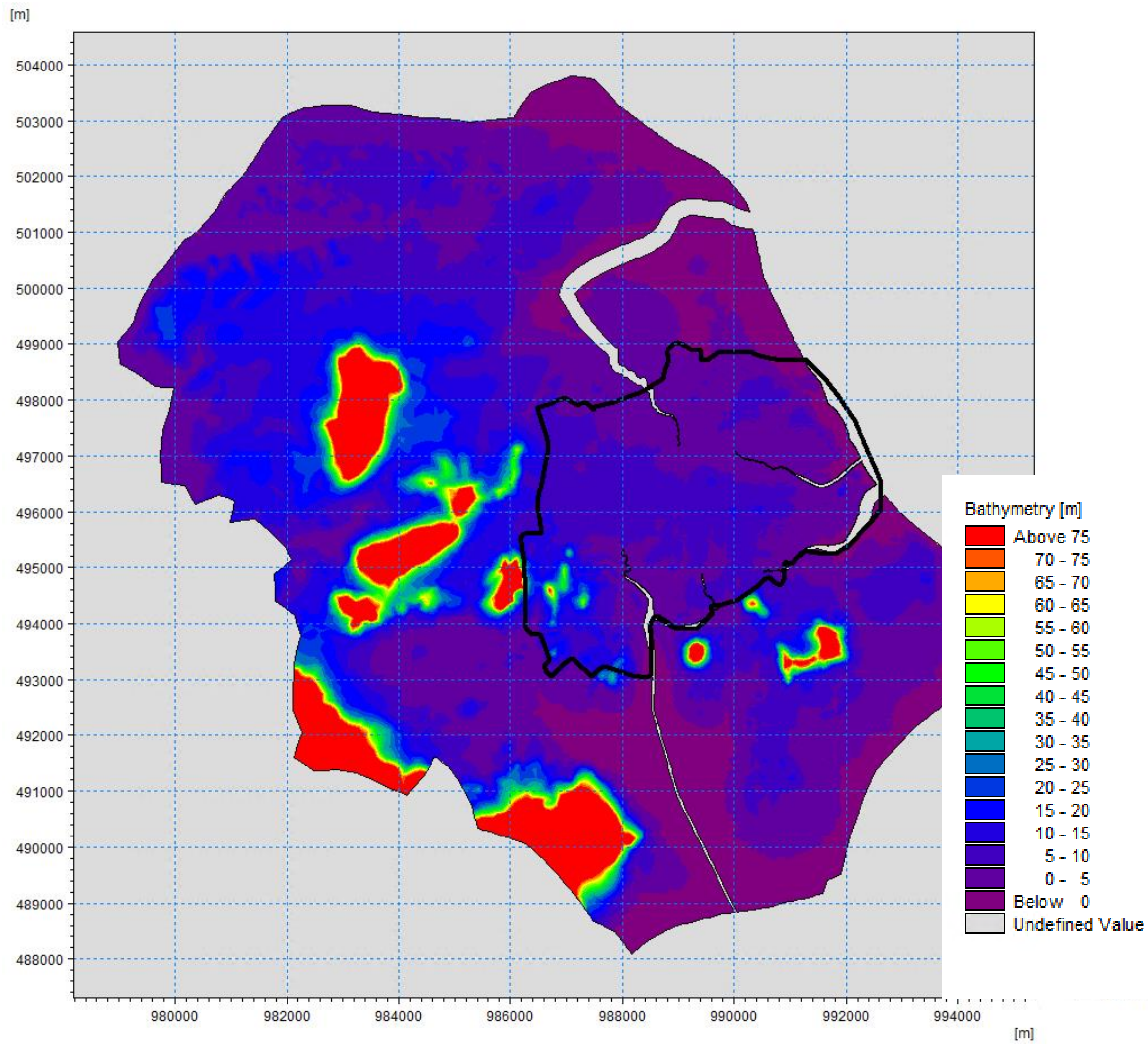

Figure 5-11 Semporna flood model 2D extent

5.5.2 MIKE FLOOD Links

The floodplain and main drainage systems e.g. Sg. Gagoyan modelled in 2D (MIKE 21) are linked with the main drainage system ("in bank", modelled in 1D with MIKE 11) using MIKE FLOOD lateral links. This type of link is suitable for the simulation of overflow from the main rivers and tributaries to the floodplain areas. Model setup will be based on the following input:

The model geometry (i.e. bathymetry) is primarily based on the LiDAR / IFSAR topographic dataset.

- A lateral link allows a string of MIKE 21 cells/elements to be laterally linked to a given reach ii MIKE 11, either a section of a branch or an entire branch. Flow through the lateral link is calculated using a structure equation. This type of link is particularly useful for simulating overflow from a river channel onto a flood plain Figure 5-12). A full description of the lateral links can be found in the MIKE FLOOD user manual (DHI 2019).

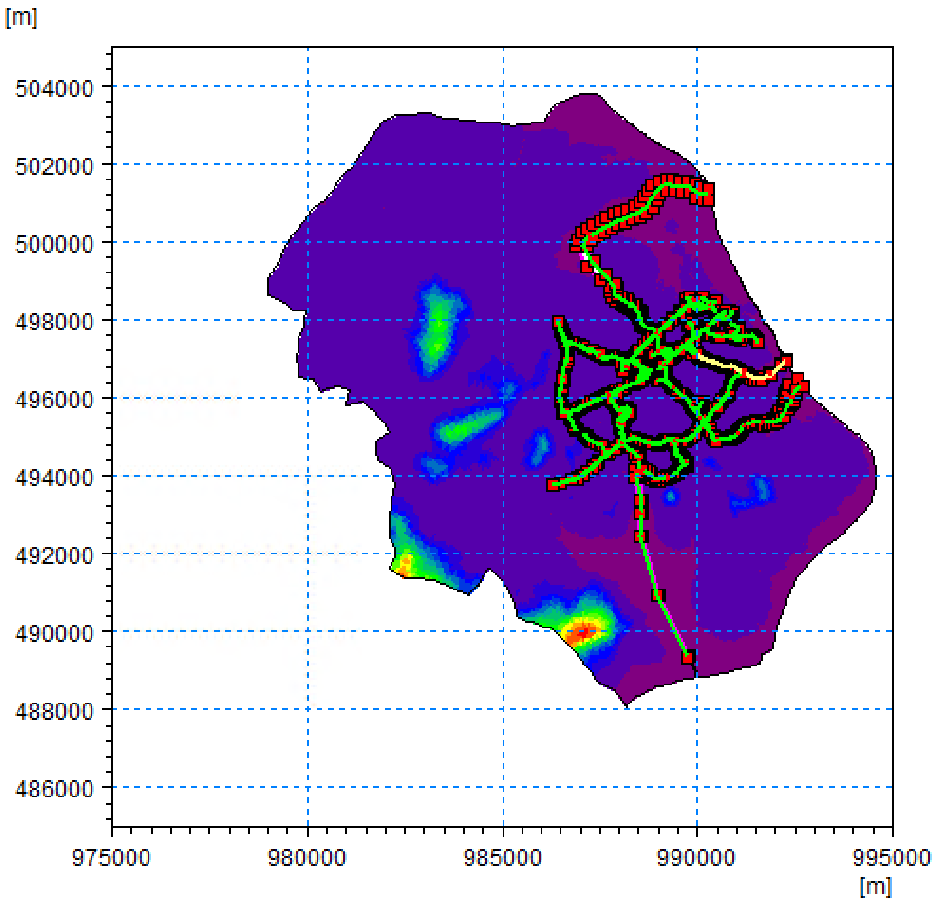

Figure 5-12 Application of lateral links in MIKE FLOOD model

Model boundaries consist of the following:

- Designed water levels applied to the downstream boundary of e.g. major natural and / or man-made outlets within the study area.;

  Inflows from hydrological models (Section 5.2.4);

  a Sub-catchment inflows from the sub-catchments distributed along with the main drainage system (i.e. as lateral inflows).

5.6 Model Calibration

Calibration is the process where model parameters are tuned within justifiable limits to match field measurements. The end result is a model that has a demonstrated ability to represent physical conditions accurately. The model calibration was executed by comparing model predictions (in terms of flood extent and water depth) against collected flood data within the study area (refer to Section 3.8). Figure 5-13 below indicate the flood extent model based on the 26th July 2017 event detailed in the available JPS flood report. The model calibration plots shown in Figure 5-14 to Figure 5-16 indicates a good representation of the flood extent for Taman Miramas, Kpg. Perigi and Kpg. Bubul Lama as detailed in the JPS flood report.

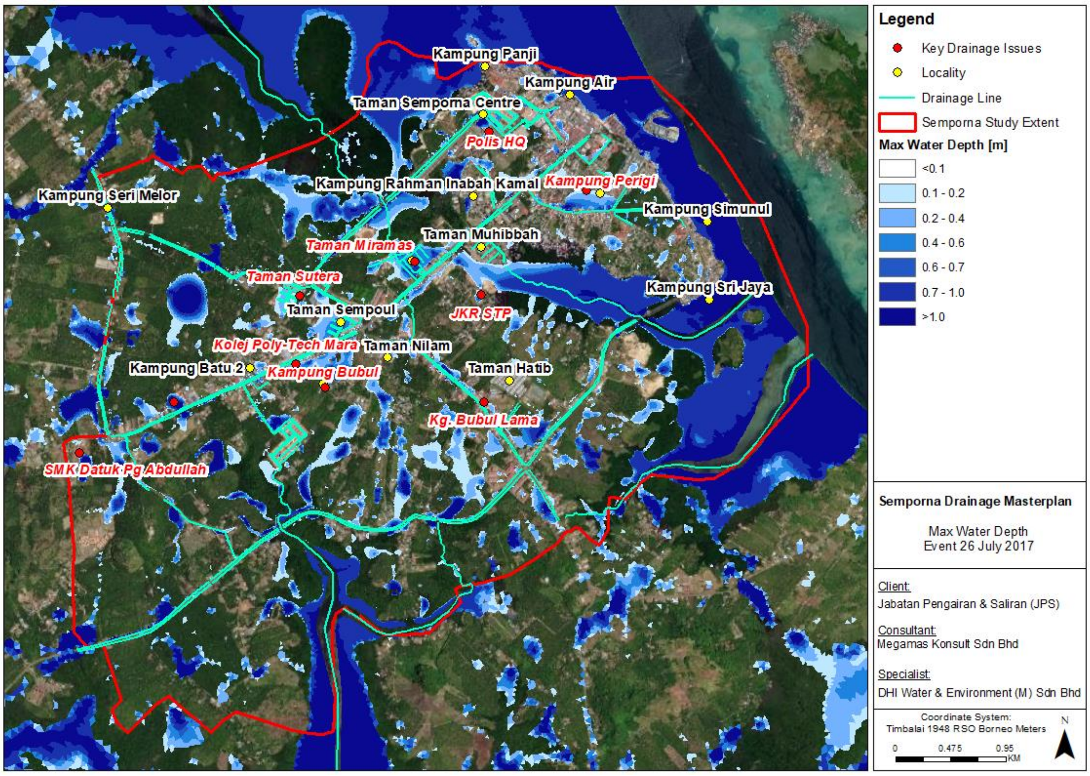

Figure 5-13 MIKE FLOOD calibration model result for flood event occurring 26th July 2017

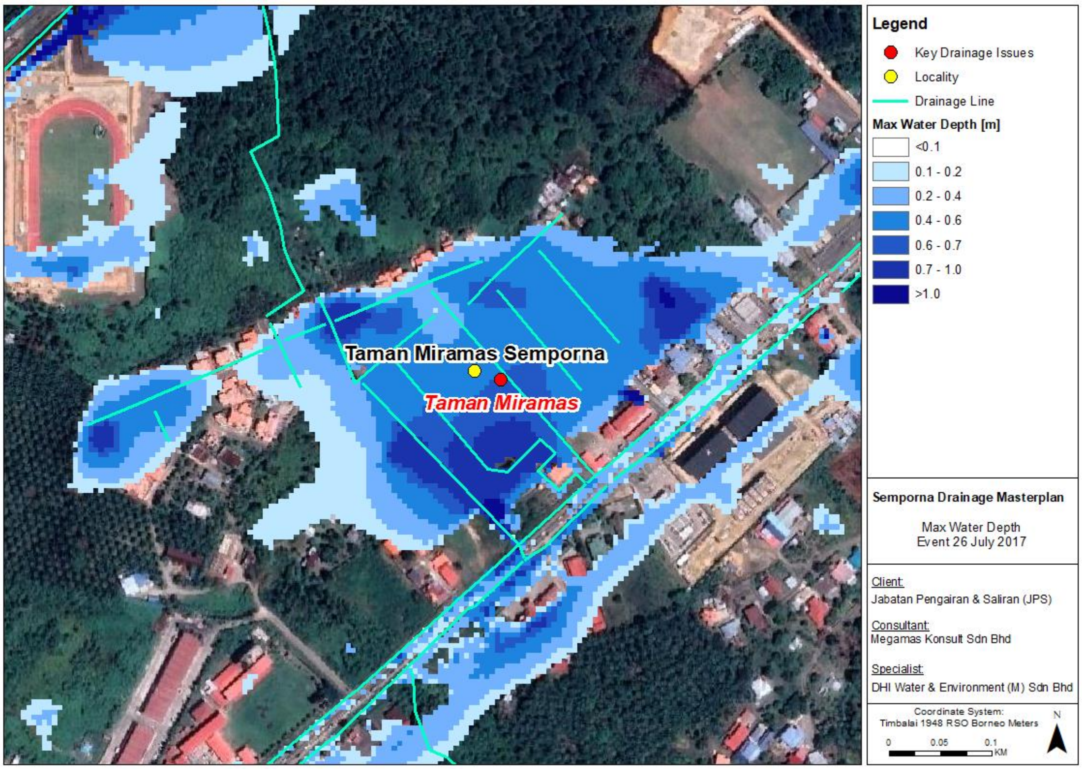

Figure 5-14 Zoom in MIKE FLOOD calibration model result for Taman Miiramas occurring on 26th July 2017

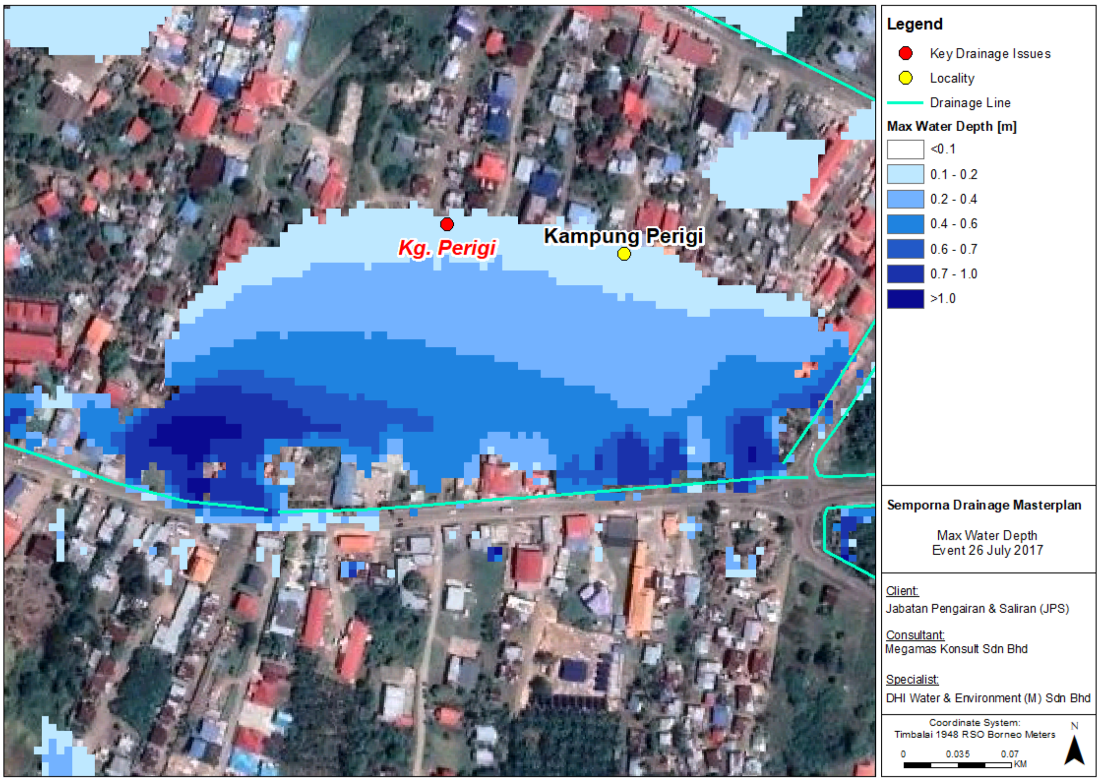

Figure 5-15 Zoom in MIKE FLOOD calibration model result for Kpg. Perigi occurring on 26th July 2017

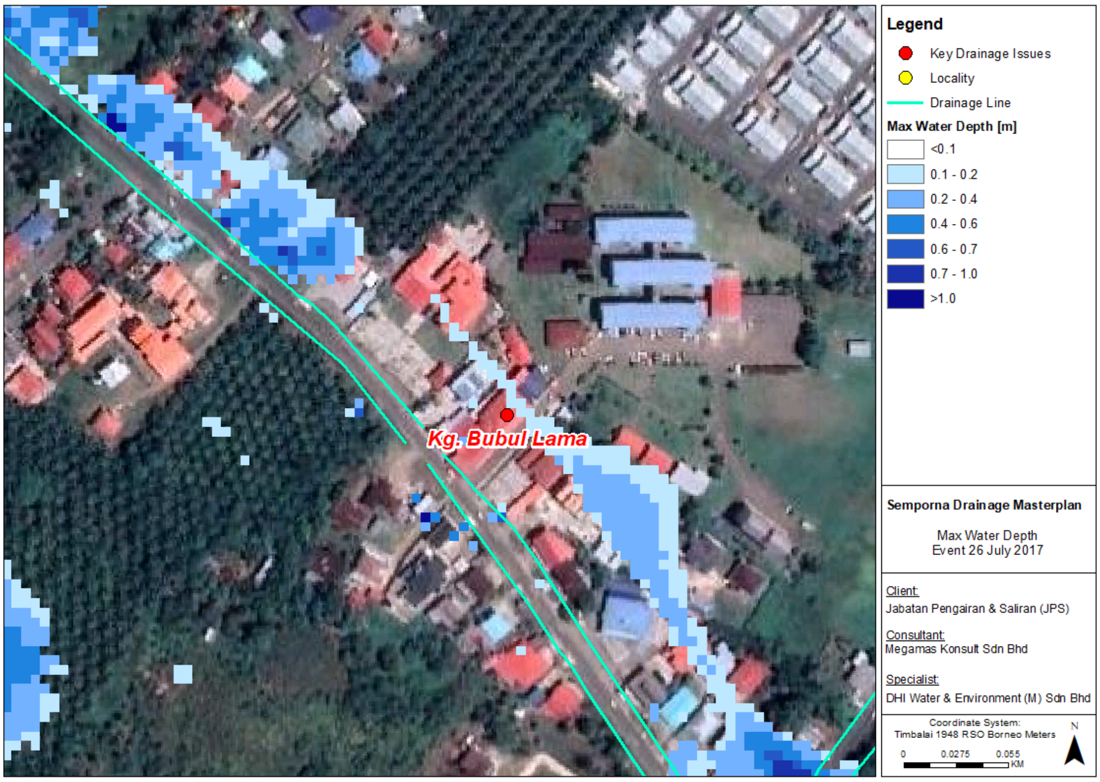

Figure 5-16 Zoom in MIKE FLOOD calibration model result for Kpg. Bubul Lama occurring on 26th July 2017

5.6.1 MIKE FLOOD Validation

Validation of the MIKE FLOOD model was performed to ensure that the MIKE FLOOD model can reproduce known flood behaviour within the study area. The MIKE FLOOD model produces inundation extents and depths in locations where local drains or river channels are overtopped or are unable to carry local drainage inflows. Hence assessing simulated flood extents for design storms against observations is a way in which the model can be validated.

The MIKE FLOOD model has been validated against field data collected which demonstrate the flood extents as well as measured water depths (where available) for the study area. Field data has been collected since the start of the project and has incorporated feedback from JPS Tawau Drainage engineers as well as stakeholders from local authorities. Field staff have also carried out interviews with residents to obtain further information as to the extent and depth of recent flood events. Site visits across Semporna have targeted flood-prone areas as identified by stakeholders and residents. Site visits have also taken place to confirm the findings of the flood maps established for use in this study and to confirm model findings.

Taman Miramas

Flood events with a return period of 5 years were modelled as this indicates the frequent flooding occurrence within the study area. Based on the site survey conducted, the occurrence of flooding within the study area appears to have resulted from a combination of factors including surface runoff from the intense rainfall, backwater effect and the limited capacity of the existing drainage capacity.

The validation model result for the Semporna study area is shown below (Figure 5-17), and it indicates a good agreement with the modelled extent of inundation of Taman Miramas. The calibration model shows that a significant proportion of the Taman Miramas housing area is inundated, which matched the observed field survey data.

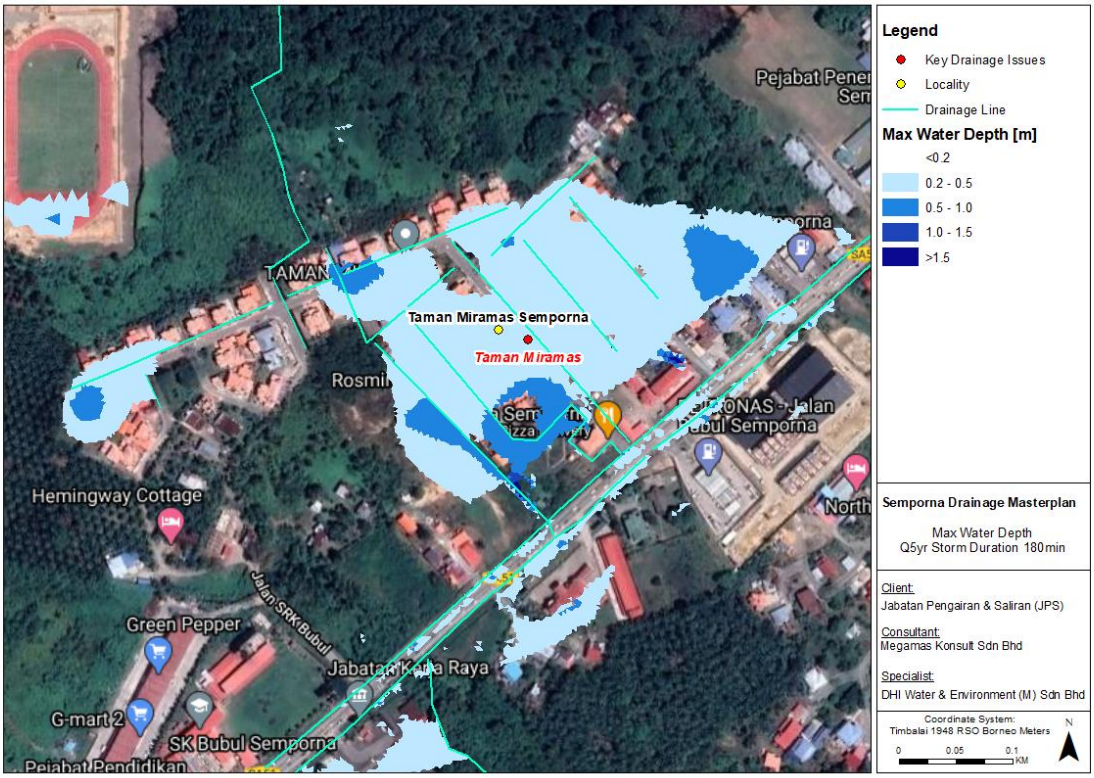

Figure 5-17 MIKE FLOOD model validation results indicating the occurrence of flooding at Taman Miramas for 5-year ARI

6 Drainage Inundation Model Application

6.1 System capacity assessment

6.1.1 Existing drainage capacity assessment

Assessment of the existing drainage assessment was conducted using the developed MIKE 11 model for the study area. Different design return rainfall events (2yrs, 5yrs, 10yrs, etc.) were applied to the rainfall-runoff model and routed in the MIKE 11 hydrodynamic model. The model results were then analysed to determine the ability of the system to cater for the peak flows without overtopping the drainage / riverbanks. The drainage / river capacity was determined as the maximum design event which could be carried without overtopping. Figure 6-1 and Figure 6-2 show the existing drainage system capacity within the study area.

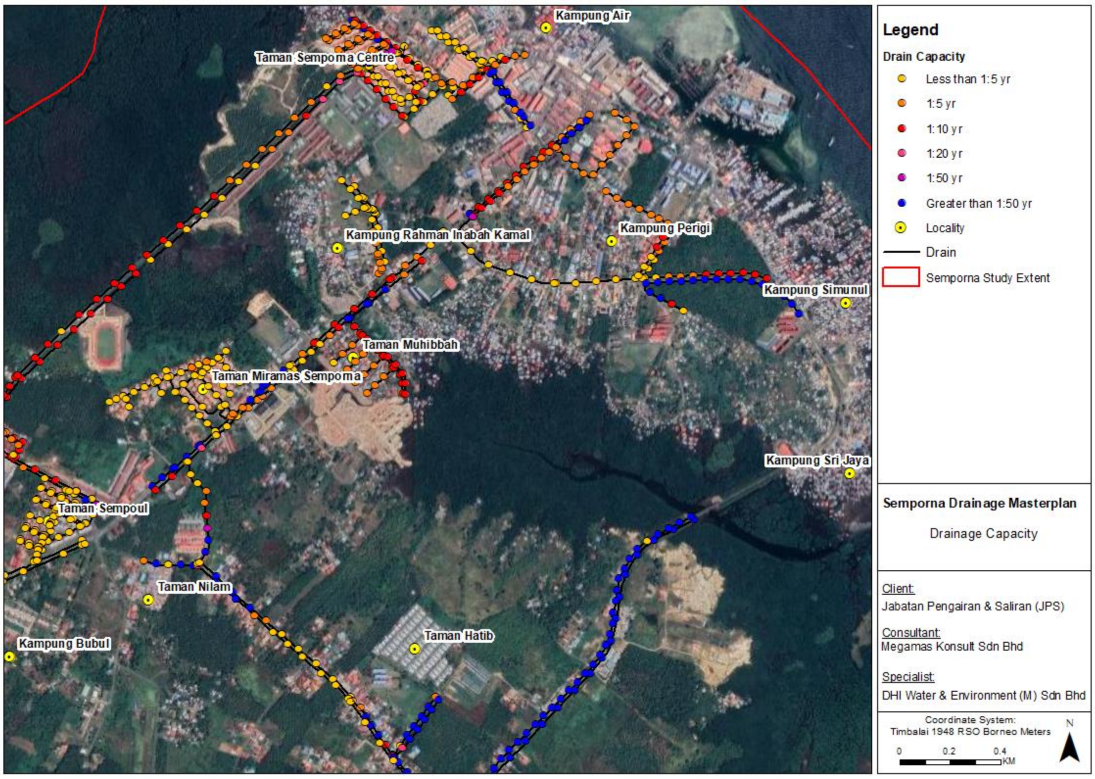

Figure 6-1 Existing drainage system capacity – eastern section of the study extent

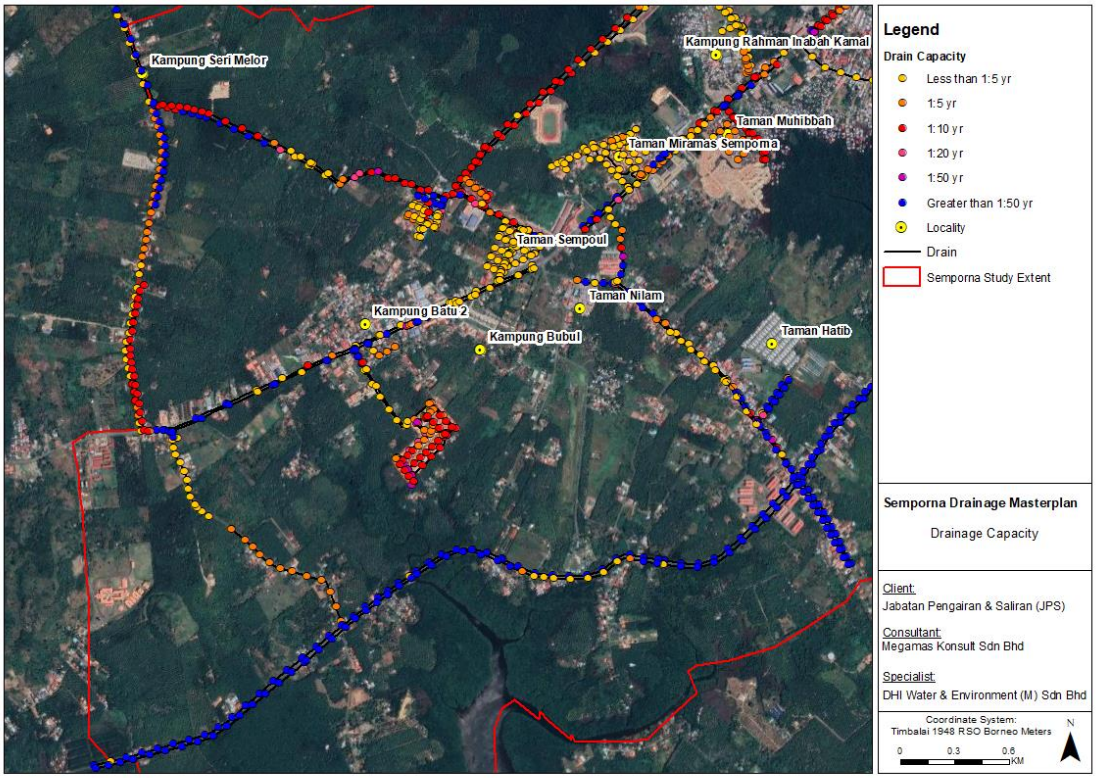

Figure 6-2 Existing drainage system capacity – western section of the study extent

6.1.2 Existing tidal influence

Assessment of the existing tidal influence on the drainage system was also conducted using the developed MIKE 11 model for the study area. Different design tidal events (2yrs, 5yrs, 10yrs, etc.) were applied and routed in the MIKE 11 hydrodynamic model. The model results were then analysed to determine the extent of the tidal influence along the drainage / riverbanks. Figure 6-3 show the existing tidal influence along the drainage / riverbanks within the study area.

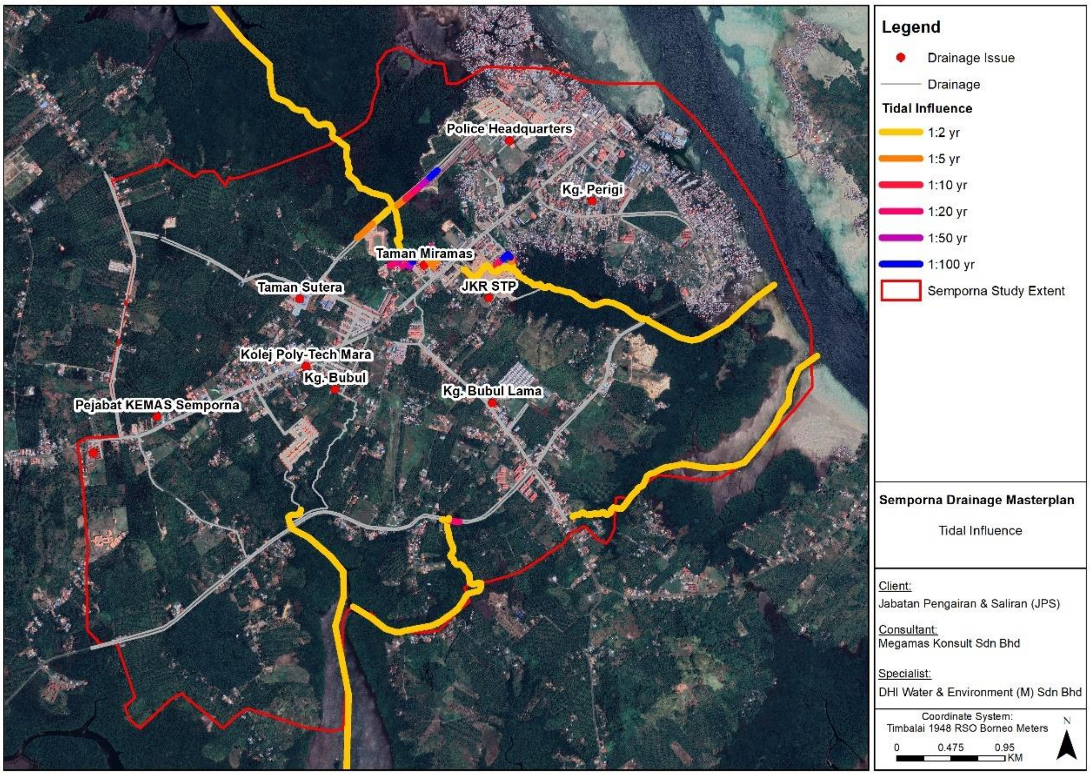

Figure 6-3 Existing tidal influence – within the study extent

6.2 Drainage options modelling

6.2.1 General approach

The assessment of flood mitigation options was carried out using the developed MIKE 11 model. The MIKE 11 model was used to develop and test a number of mitigation scenarios for each problem area. The model was developed so that constrictions in channel or pump capacities would result in water levels rising above bank full which could be easily identified and therefore the effectiveness of flood mitigation options could be assessed.

The mitigation options tested comprised a combination of approaches including:

- Channel widening and deepening
- Upgrading of earth channels to concrete
- Diversions to less congested parts of the drainage network

The range of final options has then been finally assessed in the MIKE FLOOD model to indicate the reduction in flood extent and levels that can be expected as a result of the mitigation works. The following subsection will discuss some drainage options modelled for the present study.

Drainage options for each area of interest are summarised in Volume 1 Section 10.2.2.

7 Flood mapping

7.1 Modelling assumptions

The flood maps have been processed to indicate the maximum flood depth and extent from the various combinations of storm duration and tide level. The indicated flood depths and extents are very much influenced by the land levels (LIDAR / IFSAR). Areas of very shallow flooding (less than 20cm deep) have been excluded from the maps.

7.2 Flood maps

Flood maps have been generated from the MIKE FLOOD drainage and inundation model for the existing condition and are presented in the following maps. The map extents cover the study area, from Sg. Gagoyan in the north to the natural outlet located next to Kpg. Bubul in the south. Maps have been generated for 2, 5, 10, 20, 50- and 100-year ARI events. Storms of 180 minutes duration have been shown to be critical for different parts of the catchment. Models have also been run for events with durations ranging from 15 minutes to 240 minutes.

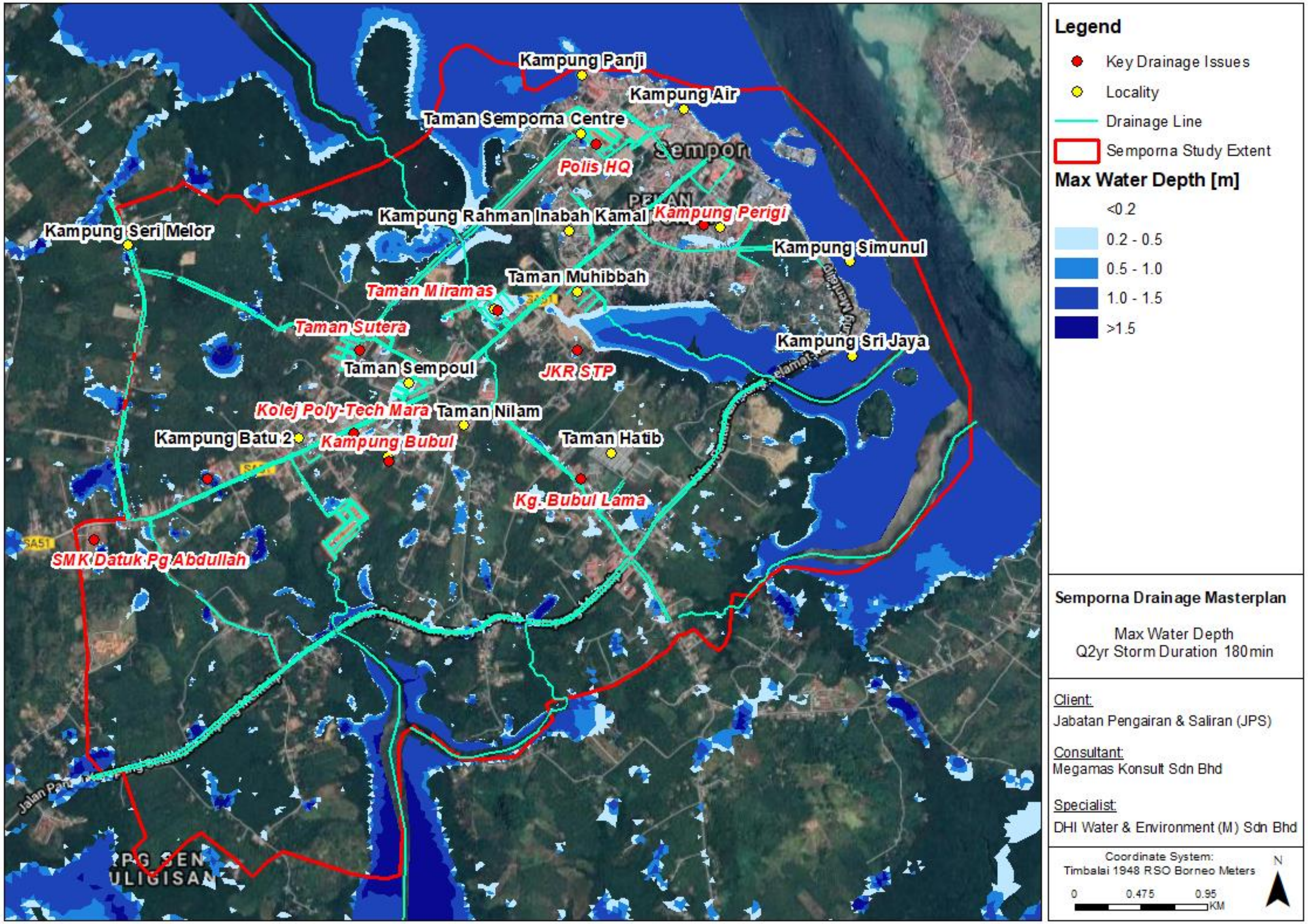

Figure 7-1 Flood map – 2-year ARI

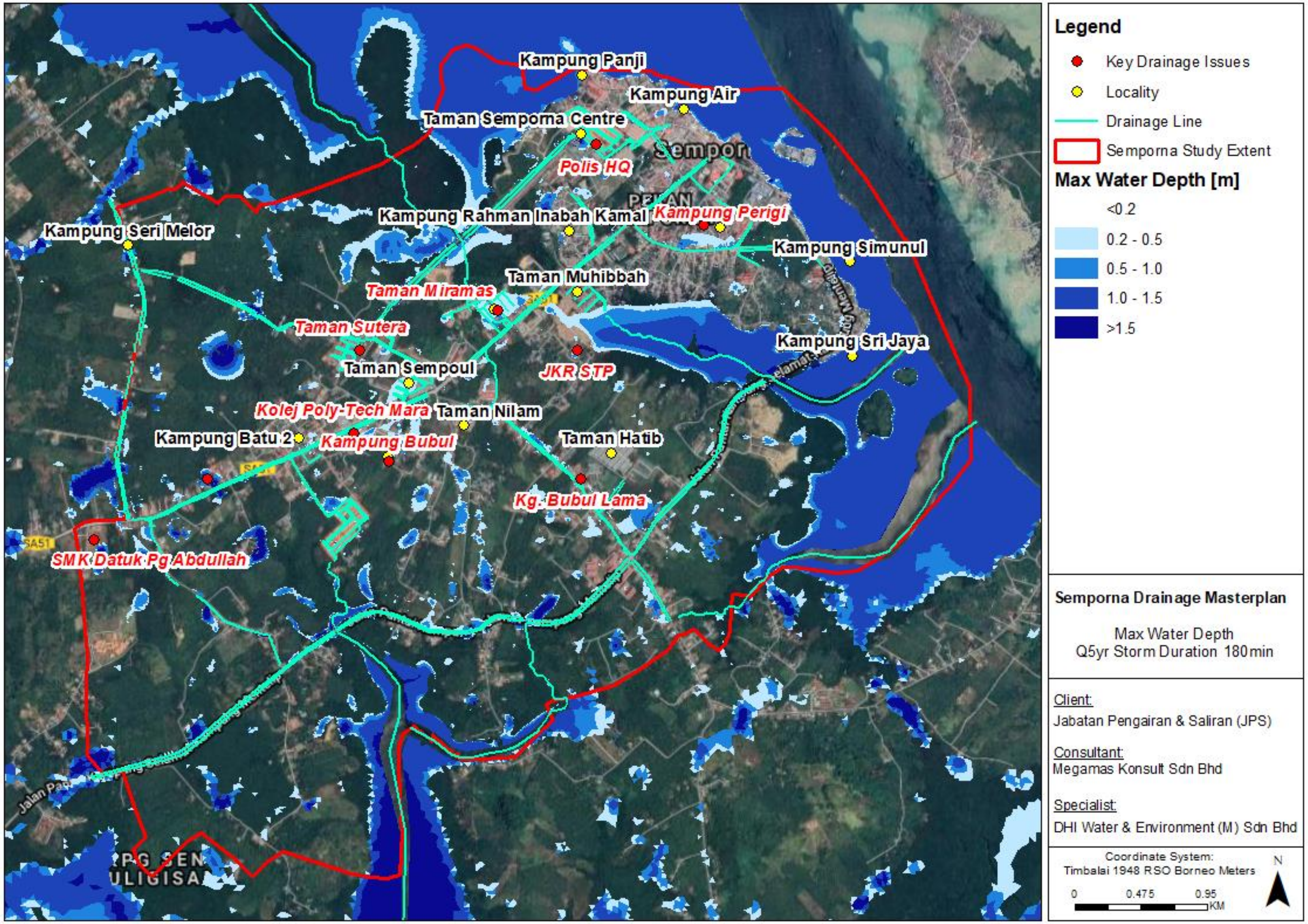

Figure 7-2 Flood map – 5-year ARI

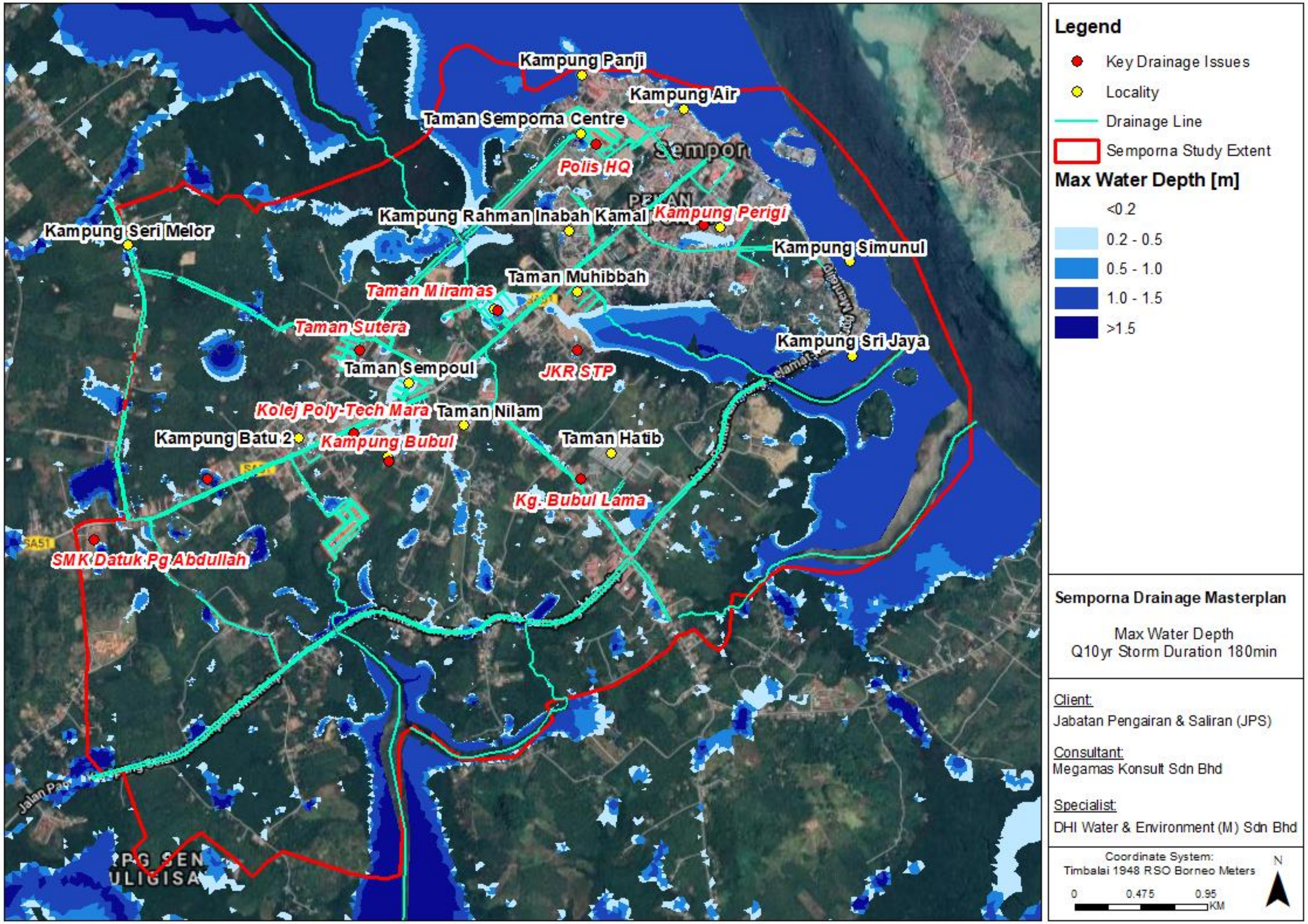

Figure 7-3 Flood map – 10-year ARI

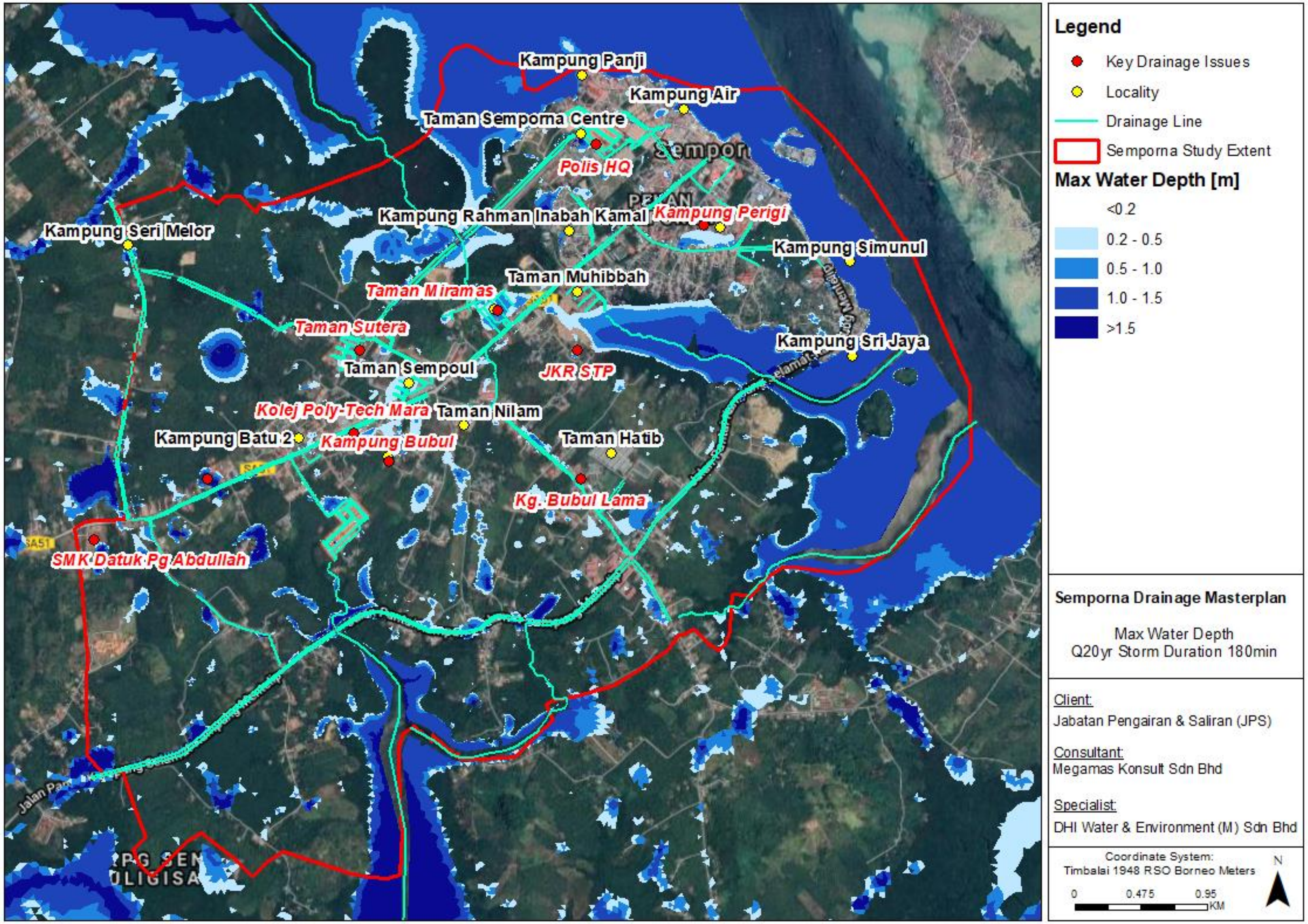

Figure 7-4 Flood map – 20-year ARI

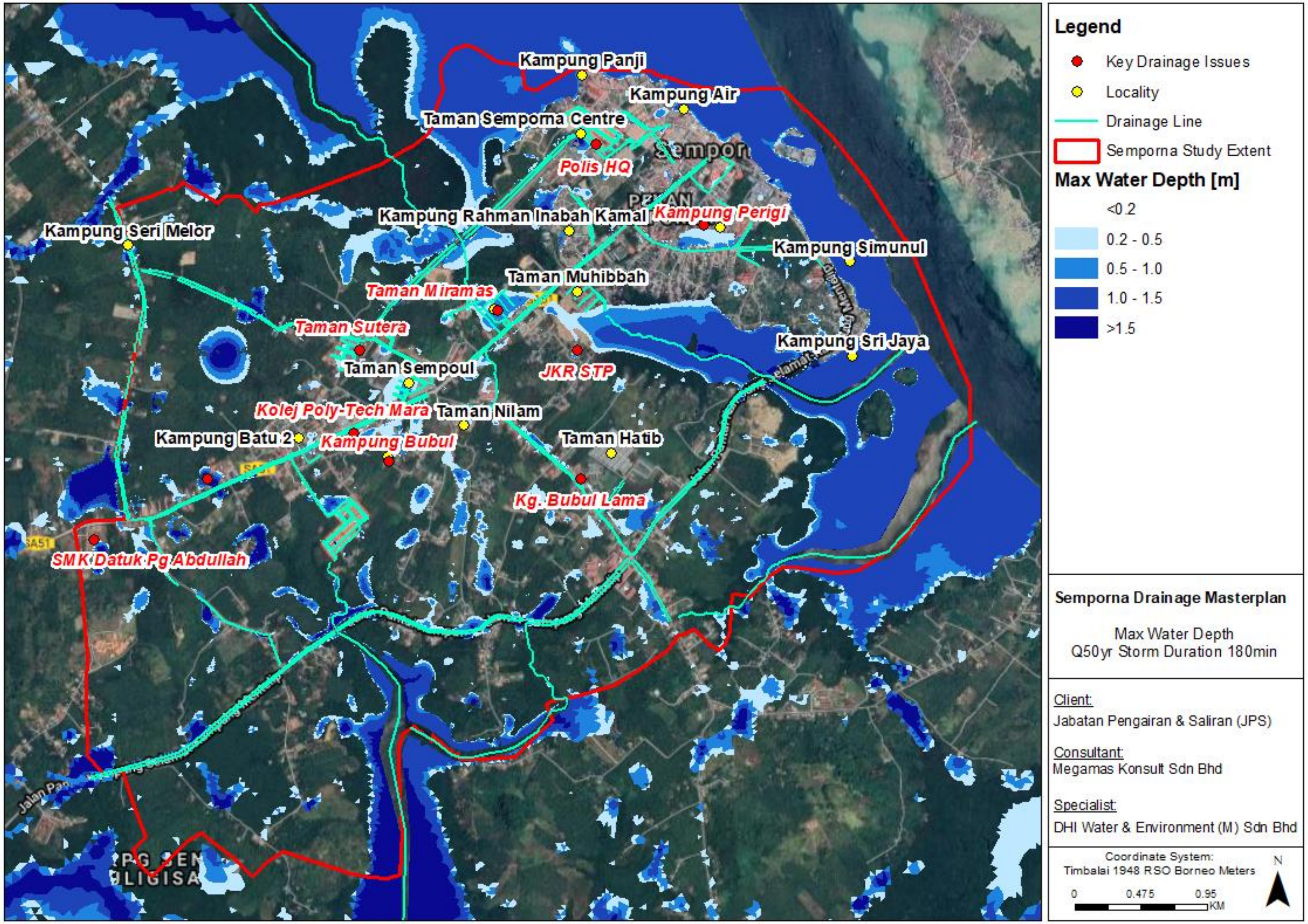

Figure 7-5 Flood map – 50-year ARI

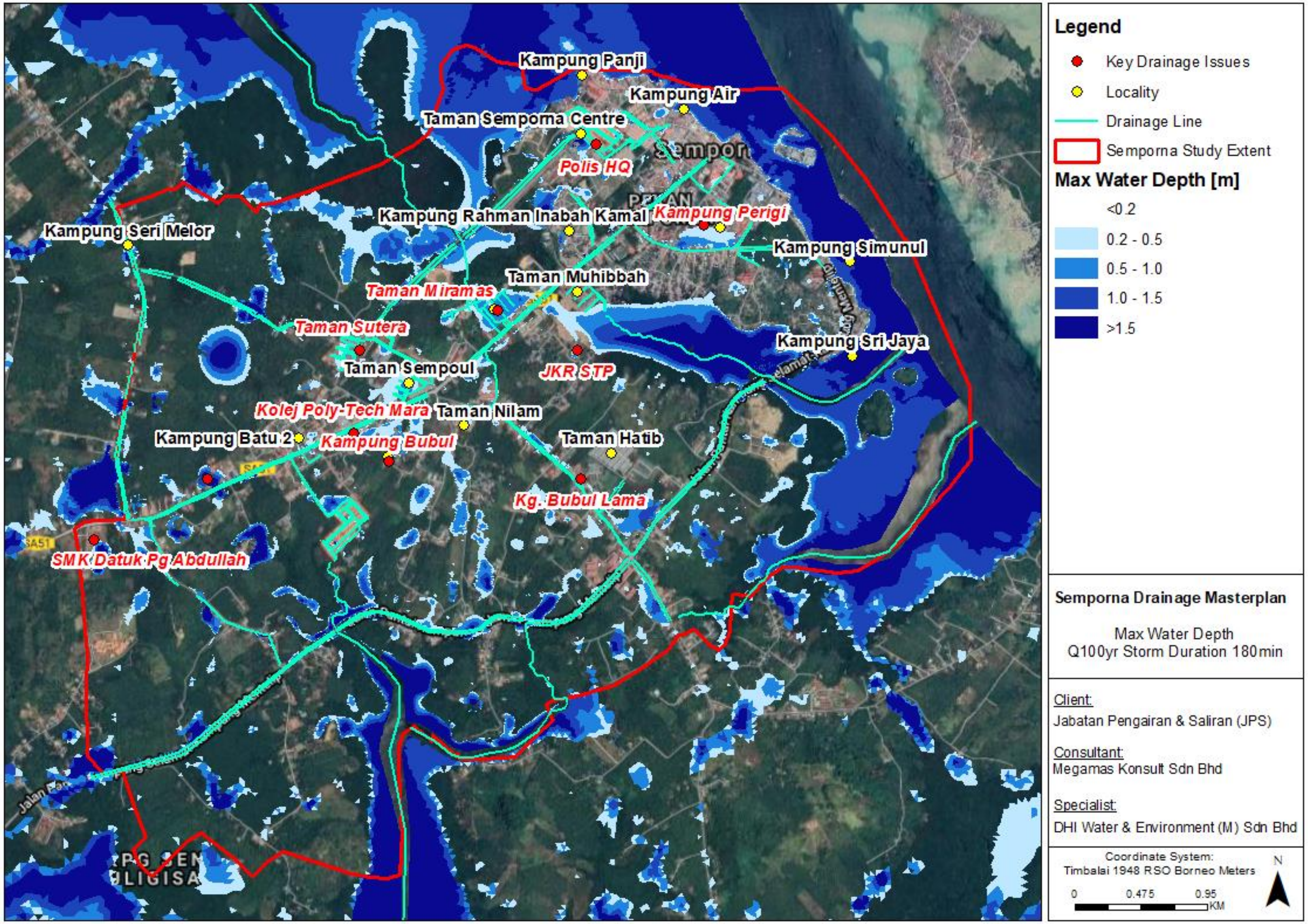

Figure 7-6 Flood map – 100-year ARI