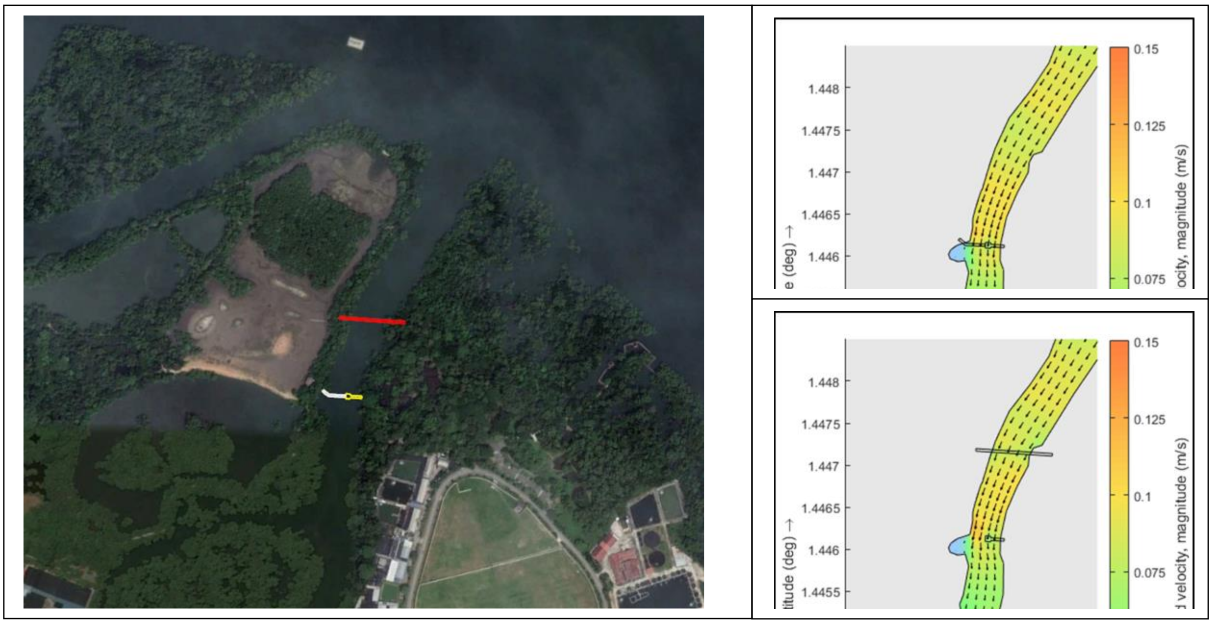
EIS for Existing Main Bridge West Side Access Demolition Work and Construction of Buggy Shelter at Sungei Buloh Wetland Reserve



REPORT
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EXECUTIVE SUMMARY

NParks intends to demolish the west side access of the existing main bridge across Sg Buloh Besar after erection of a new bridge. A new Buggy Shelter is also proposed that is located beside the new bridge on the western riverbank. The proposed work may have the potential impacts on the natural environments that include:

a. Hydraulic conditions change post demolition work
b. Sediment plume during demolition work
c. Ecological receptors

The impact of the proposed work on the coastal hydraulics is modelled. The main objective of this study is to elucidate the potential effects of proposed work on the coastal environment based on the findings of the numerical model and extensive desktop study.

EXISTING CONDITION

A desktop study for hydrology, water quality and ecology have been carried out as part of the baseline studies to understanding the existing site condition and coastal environment in the study area.

The proposed project site is located in the Sungei Buloh Wetland Reserve (SBWR), which is on the northwestern sector of Singapore. SBWR is low-lying and acts as a sink to the surrounding areas. SBWR has primarily brackish water ponds, brackish riverine estuaries and brackish intertidal mudflats. The Kranji Nature Trail includes primarily coastal seawater. The water level at the shore and the riverine estuaries are under the influence of semi-diurnal tides, i.e. two low and high tides a day.

Sg Buloh Besar is the main riverine water body in SBWR. The downstream course runs northerly into the Western Straits of Johor. The proposed bridge is located in the estuarine reach and is located at a distance 200 m from the river mouth. The hydrodynamics of the project site is dominated by tidal currents. In general, the current flow in the river is mild.

A bathymetry survey shows that the river bathymetry around the project site is generally uniform with a depth around 2 m at mean sea level.

The geology of SBWR is typical of the coastal areas of Singapore and comprises a superficial layer of recent alluvium. Soil investigation reveals that the nearby seabed sediments are mostly very soft clay material. The thickness of surface layer marine clay ranges from 1.3 m to 4 m. The bulk density varies from 1360 to 1440 kg/m^3, and the dry density ranges from 670 to 780 kg/m^3.

Scarce data or references are available for SBWR in terms of water quality. According to a reported measurement [7], the water quality in SBWR was either relatively unpolluted or weakly polluted. The measured turbidity ranged from 3 to 36 NTU. Turbidity or total suspended solid is the most relevant water quality parameter as the demolition work may produce sediment plume.

SBWR is a predominantly tropical coastal mangrove wetland. The area is 130 hectares and consists primarily of brackish water ponds, riverine estuaries, intertidal mudflats, mature mangroves and fringing mangroves. The coastal wetland includes natural and man-made wetlands as well as natural mangrove-lined river estuaries.

There are no record of large seagrass meadows within the Western Straits of Johor. Bathymetry survey and soil investigation also indicate that there is no significant seagrass patches in the vicinity of the project site.

Many species of birds are found in SBWR because they feed on the flora and fauna in the area. In particular, SBWR is an important roosting and feeding area for migratory shorebirds in Singapore between August and April.

IMPACT ASSESSMENT

Based on the field surveys, data analysis, modelling results, environmental impact assessment are carried out for the proposed work. The key findings of the impact assessment are as follows:

1. The river flow regime in Sungei Buloh Besar is generally mild. The changes in water level and velocity due to the proposed demolition work are marginal for the river flow. The impact magnitude is in the level of undetectable. Thus, according to **Table 3-2** the hydrodynamic influence can be classified as "**No Impact**".

2. Pile cutting work may lead to sediment plume with the tide flows. The sedimentation of the re-suspended sediment is negligible beyond the vicinity of the project site. The increase in suspended sediment concentration within the extent of 100 m is less than 10%, and sediment plume discharge is temporary (< 6 months). Therefore, according to **Table 3-3** the influence of sediment plume is classified as "**Slight Impact**".

3. The proposed works have no long term influence on the water quality. The envisaged temporary influence on water quality is related to the change in total suspended solid (TSS) due to the sediment plume discharge. TSS increase within the extent of 200 m about 20% and temporary impact (< 6 months), the impact on water quality is classified as "**Slight Impact**".

4. The sediment plume concentration is less than 5 mg/l at the environment sensitive receptors. The sedimentation is ignored beyond the vicinity of the project site. Therefore, sediment plume has "**No Impact**" on the seagrass and mangroves according to **Table 3-4** and **Table 3-5**.

5. The direct benthic habitat disturbance or loss due to bridge pile removing is small as the working area is small (Estimated 22.5 m^2). The affected area is relatively small, fragmentation of the riverbed surface habitat during recovery period is expected to be minimal. Therefore, the impact on benthic species can be classified "Slight Impact" according to **Table 3-6**.

6. Demolition work of the bridge and construction work of the Buggy Shelter would result in temporary increase in vessel traffics and construction noise disturbance to marine water habitats and estuarine birds. The traffic and noise effects is small and unlikely to have any material impact. The recovery is rapid. Therefore, the impact of traffic and noise can be classified “Slight Impact” according to **Table 3-6**.

7. The project site is about 1.3 km away from the nearest international border. The changes in hydraulic condition and sediment plume are ignorable. The demolition and construction disturbance is also expected undetectable. Therefore, the transboundary impact is classified as “**No Impact**”.

RECOMMENDATIONS

The environmental impacts during demolition work shall be controlled by adopting best practice and high working standards as required for all such works in Singapore. The following mitigation measures for the potential impacts are recommended:

SEDIMENT PLUME

i. Cutting off piles during low-tide periods when mudflat is exposed in intertidal areas. This will minimize amount of sediments re-suspended in the water column.
ii. If necessary, cease the works that can produce significant sediment plume at the middle 2 ~ 3 hour of strong tide current;
iii. And, where it is found necessary, silt screen barriers should be deployed.

RIVERBED BENTHIC LOSS

iv. Minimize the disturbed area during installation coffer dam and cutting the piles.

v. Put the riverbed soil back to the hole if substantial amount is removed or extracted during the pile removal.

DEMOLITION WORK NOISE

vi. Limit the amount of hacking, cutting and hammering work during the migration season for the migratory birds.
vii. The use of a ‘soft start’ or ‘ramping up’ process, in which hacking power is gradually increased from low to normal operating levels.
viii. Interrupting, or not even starting, beam hacking, pile cutting and pile driving if sensitive seabirds or other wildlife are present in the vicinity. This requires the presence of a trained observer to search the area before and during demolition work.
ix. To reduce vibration and noise, wire saw machine or circular saw blade machine shall be used to cut the bridge beams.

INCREASED VESSEL TRAFFIC

x. Reduce vessel strike risk by limiting vessel speeds.
xi. Implement educational programmes for vessel operators to increase awareness of wildlife and vessel related issues in wetland reserve.

DEBRIS

xii. Collect debris when hacking beams by mounting trays blow beams
xiii. Collect debris when cutting of pile caps and upper segment of piles by mounting trays on piles.
xiv. Manually collect debris in cofferdam after cutting off lower segment of piles.

1. INTRODUCTION

1.1. OVERVIEW OF THE PROJECT

NParks intends to demolish the west side access of the existing main bridge across Sg Buloh Besar after erection of a new bridge. A new Buggy Shelter is also proposed that is located beside the new bridge on the western riverbank. The location and outline of the existing and proposed main bridges are as shown in **Figure 1-1**.

The proposed work may have the potential impacts on the natural environments that include:

a. Hydraulic condition changes post demolition work

b. Sediment plume during demolition work

c. Ecological receptors

An EIS study is required for the proposed work.

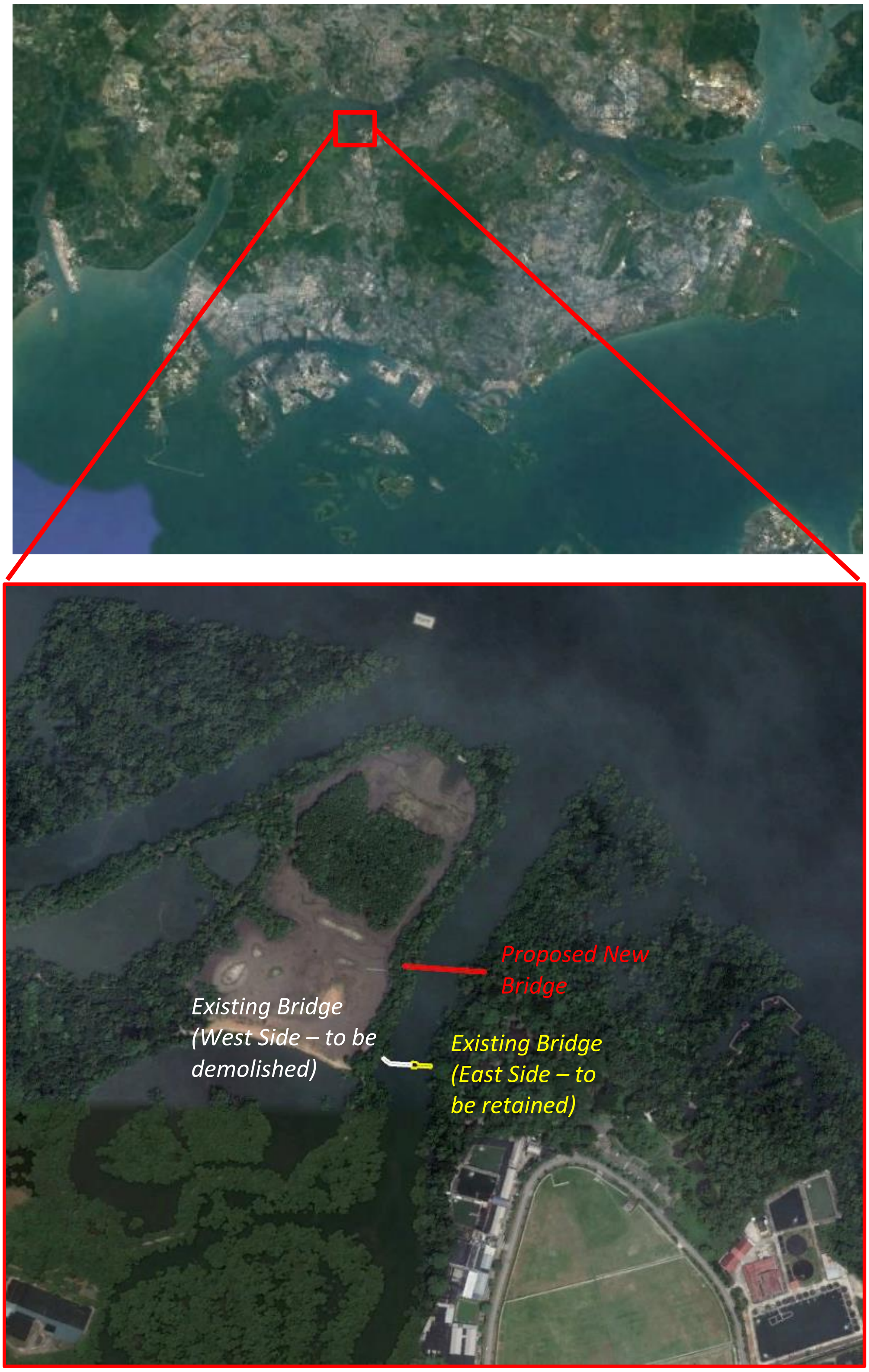

Figure 1-1: Location and outline of the existing and proposed main bridges across Sg Buloh Besar

1.2. OBJECTIVE AND SCOPE

The main objective of this study is to address the potential effects of the proposed demolition and construction work on the coastal environment.

The General EIS include the following scope of work:

(i) Hydrodynamic impact assessment – tide and current condition changes due to erection of the new bridge and demolition of the existing bridge;

(ii) Sediment plume impact assessment – suspended sediment plume during demolition work;

(iii) Water quality assessment – changes in water quality due to the demolition work;

(iv) Environment receptors / environmental review – probability and severity of impacts on the surrounding key marine receptors i.e. mangroves, seagrass, and migratory birds;

(v) Recommendations – mitigation measures for the potential impacts on the environment, where they are deemed necessary.

2. PROJECT DESCRIPTION

The presence of the new bridge with piles will directly modify the flow field in the adjacent region. During the construction phase, pile-driving process may disturb the river bed and re-suspend the bed material. The impact of the proposed new bridge on the hydraulics and environment has been assessed in a separate EIS study [1]. This study focuses on the demolition work of the existing bridge.

The existing main bridge is located at the Visitor Centre of Sungei Buloh Wetland Reserve. An overview of the bridge is shown in **Figure 2-1**. The bridge foundation consists of 23 numbers of 500 mm diameter spun piles and 18 numbers of 150 x 150 mm RC piles. The west side bridge including the piles are proposed to be demolished.

Figure 2-1: Existing Sungei Buloh main bridge

According to the safe work method statement [2], the demolition work includes the following procedures:

1) Termination of service lines
    - Existing service lines will be terminated before commencement of works.
2) Removal of hoarding
    - The hoarding will be removed manually and disposed off-site.
3) Removal of wooden railing

- The railing will be removed by releasing the bolts and plates. Hand tools and circular saw (if required) will be used.

4) Removal of timber deck

- The railing, the timber deck and its sub-structure will be removed concurrently. All timbers will be manually carried to the west bank where they will be subsequently loaded in lorry and sent off site.

5) Hacking of RC beams on the 1st section

- A small excavator fitted with hydraulic breaker will be used to start hacking the RC beams from the West Bank. Once the 1st section is removed, the excavator will be driven down the slope and moved forward as the bridge will be removed next. Appropriate measures will be taken to ensure that there will be no damage to existing trees/roots. The survey of the proposed path shows that only one location requires protection of tree roots. Sand bags will be laid to protect the roots and the area around them.
- The beams will be cut off in 2 or 3 sections and sent off site.
- The excavator will proceed towards the centre of the river up to row 4 of piles.

6) Cut off piles on the 1st section

- Riprap protection layer will be opened around the pile. The excavator will then excavate. The pile will be cut off using a diamond cutter.
- The pile will be lifted by the excavator and loaded on a pontoon for subsequent disposal.

7) Hacking of RC beams on the 2nd section

- The 2nd section of bridge is not accessible from land and therefore an excavator (with breaker) will be mounted on a steel pontoon. The pontoon will be located on the upstream side of the bridge
- The beams will be hacked at both connecting points to the pile caps.
- Before cutting off the steel reinforcement, a working pontoon will be positioned under the beam at low tide. When the tide rise, the pontoon will

be floated upwards and come into contact with the soffit of the beam. The reinforcement will then be cut off the beams, and the beams will be lifted by virtue of the buoyancy uplift of the pontoon.

- The upstream beam will be removed first and followed by the beam downstream.

8) Cutting off pile caps on the 2nd section

- The pile caps on the 2nd section will be hacked off in between each of the 3 piles. Debris will be collected and loaded in a work pontoon for subsequent disposal.

9) Cutting off piles on the 2nd section

- The piles on the 2nd section will be cut off above water (approximately at 1.5 m CD) using a diamond cutter. The workers will work from the working pontoon.
- The last section of pile (approximately 2.5 m long) will be cut below seabed. In order to do that, a cofferdam will be placed over the pile with the excavator to form an outer wall. The top of the cofferdam will be set at approximately 1.5 m CD. When the water fall below that level, the water within the cofferdam will be pumped out. This will allow a worker to enter the cofferdam and excavate around the pile.
- The pile will then be cut off with the diamond cutter and taken out using the excavator. The coffer dam will then be placed onto another pile and the operation is repeated.

The proposed new bridge is located about 110 m downstream from the existing bridge. The site and bridge plan are shown in **Figure 2-2**. The proposed bridge is 3.5 m wide and 103 m long. Timber and mild steel handrails will be erected at the sides of the bridge. A stone revetment will be installed at one end of the bridge to best match the existing condition on site. The viewing shelter is located on the west side of the bridge and consists of a lightweight aluminum composite roof supported on steel columns. The shelter area is approximately 50 m² in size.

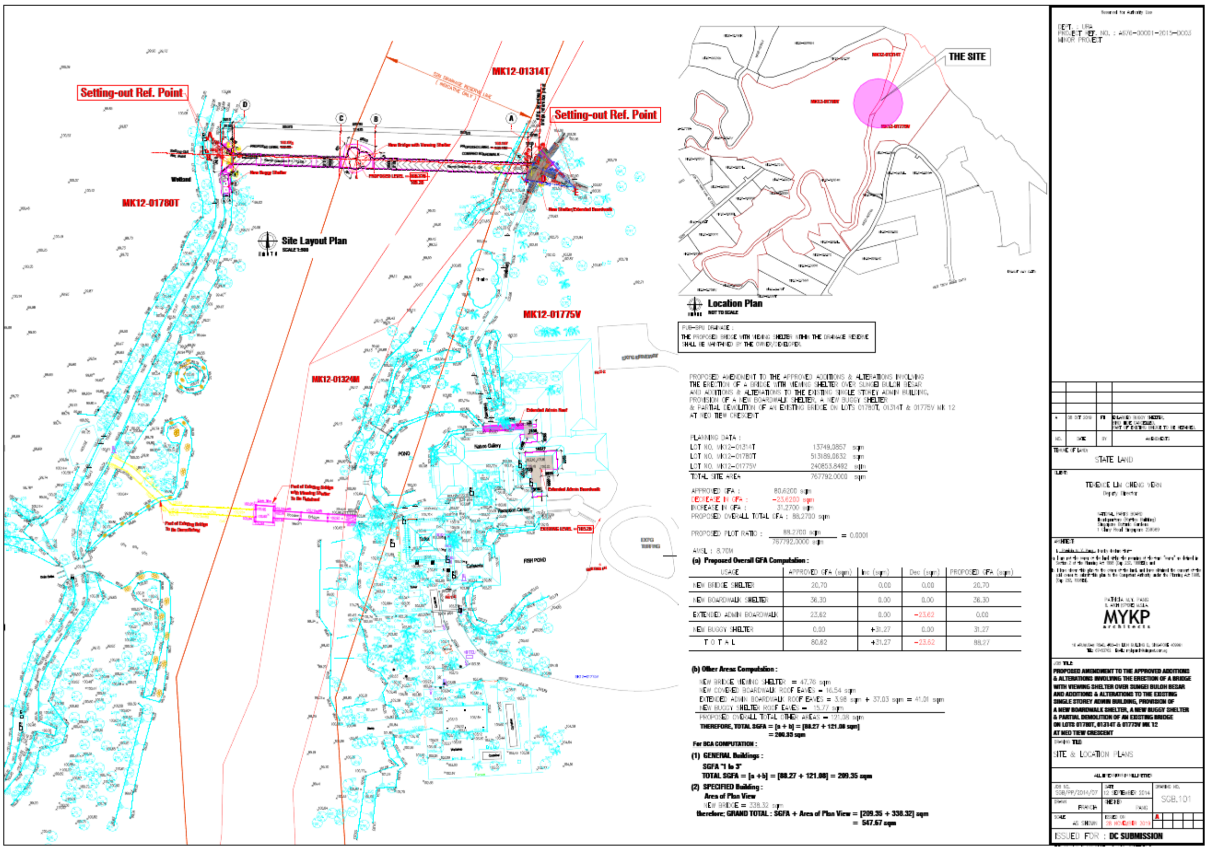

Figure 2-2: Site plan for the existing main bridge and the proposed new bridge

The proposed bridge is a fifteen-span structure with RC beams supported on driven piles. The bridge layout plan and elevation drawing are shown in **Figure 2-3**. There will be 23 nos. of 500 mm diameter RC Spun piles with 21 m embedded into the riverbed, and 18 nos. of 150 x 150 mm RC piles with 19 m embedded into the riverbed. Beam B1 to B12 will be 400 x 600 (H) mm precast RC beam, and B13 to B15 will be 300 x 400 (H) mm cast-in-situ RC beam. The bridge deck will be composed of 125 mm thick precast RC plank and cast-in-situ 75 mm thick topping concrete. The proposed deck surface level is 104.5 m.

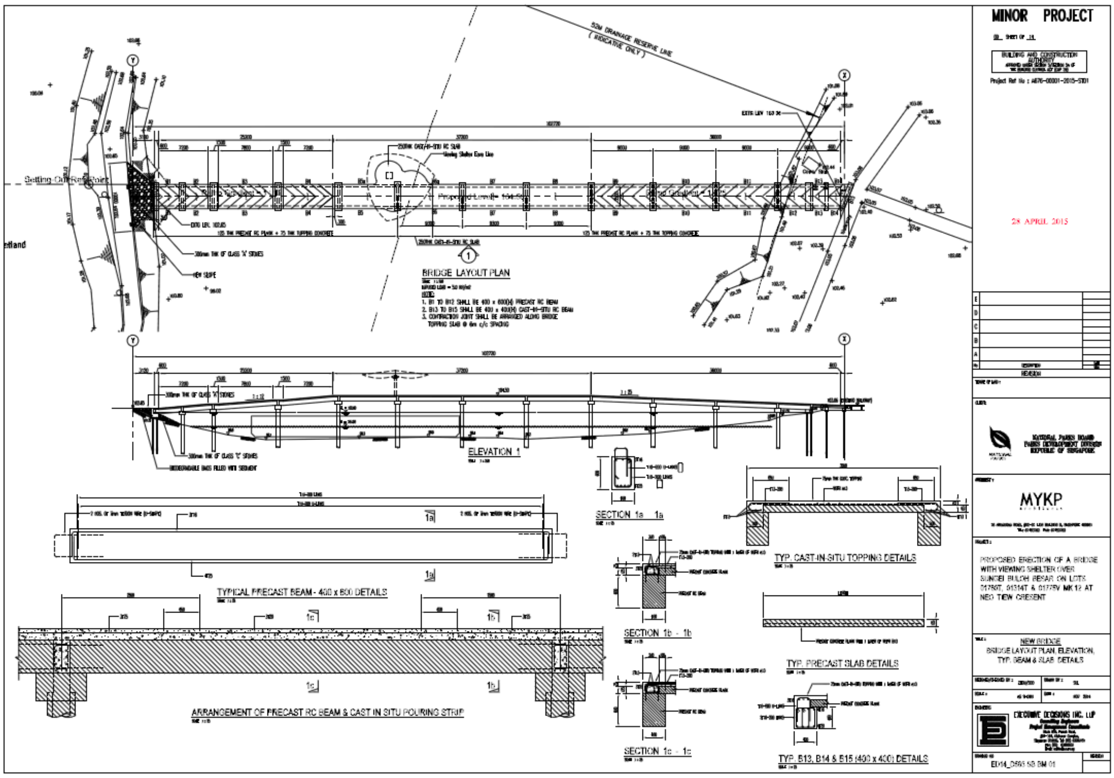

Figure 2-3: Bridge layout plan and elevation drawing

A new Buggy Shelter is also proposed that is located beside the new bridge on the western riverbank. The layout plan of the proposed Buggy Shelter is shown in **Figure 2-4**. The Buggy Shelter structure consists of 8 nos RC piles, 8 RC pile cap, steel structures, LCP roof, FRP floor, welded mesh fence, 3 panels sliding gate. The overall dimensions of the Buggy Shelter is about 10 m (L) × 3 m (W) × 3.6 m (H).

According to the safe work method statement for Buggy Shelter [3], the construction work includes the following procedures:

1) Mobilization

- Piling rig, RC piles, ready mix concrete, and steel structure will be delivered from Lim Chu Kang Lane 6F to site through Route 1.

2) Site land survey

3) Driving RC piles

4) RC piles cap work

5) Steel Structure and roof installation

6) Architecture works

7) Quality control

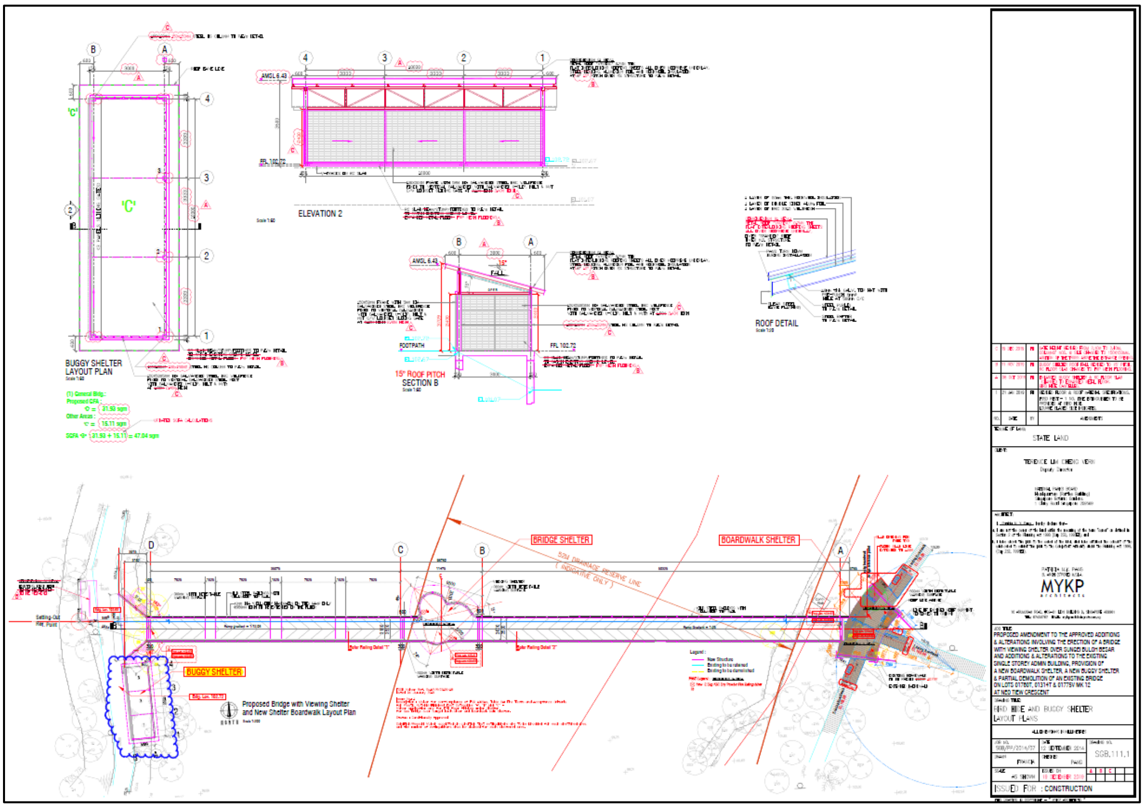

Figure 2-4: Buggy Shelter layout plan (indicated by blue cloud lines)

3. ENVIRONMENTAL IMPACT ASSESSMENT PROCESS

3.1. BASELINE STUDY

Relevant baseline data and information have been collated to provide a reliable basis upon which one could identify the key marine receptor and predict the likely influence of the proposed works. Data have been collated from the existing available sources and supplemented with the data obtained through field surveys. The task and data set include the followings:

a. A desktop review of the available data for the Sungei Buloh Wetland Reserve

b. Bathymetry Survey

c. Soil Investigation

3.2. IMPACT ANALYSIS

Potential impacts to coastal environment and identified sources from construction activities are limited to the proposed demolition work and new Buggy Shelter. The proposed works may impact the natural environment of SBWR in the following aspects:

- Coastal Hydraulics
- Water quality
- Ecological receptors

The impact analysis on the hydraulics and water quality is based on the findings of numerical modelling results and coastal hydraulics. The effects of the proposed demolition work on the hydrodynamics and sediment plume dispersion are modelled. Appendix A shows the details of the model setup using Deflt3D [4]. The water quality is analyzed based on the sediment plume as this is the only relevant potential pollution arisen from the demolition work. The bridge pile surface is concrete and is understood to have no direct influence on the river water quality.

The hydrodynamic modelling is carried out for a simulation period of 14 days to cover a typical full spring-neap tidal cycle. The amplitude of the spring-neap tide cycles varies in time, and the sediment plume and its dispersal during the high and low water are included in the study. The baseline condition refers to that before the construction of the new bridge and demolition of the existing bridge. As the demolition work will be carried out after the erection of the new bridge, the post condition also includes the new bridge. The model runs for this study are listed in **Table 3-1**.

Table 3-1: Numerical modelling Runs

No.	Numerical Model	Layout	Operation/Process
1	Hydrodynamic (HD)	Baseline	Tide / current
2	Hydrodynamic (HD)	Post demolition	Tide / current
3	HD + Sediment plume Dispersion	during demolition	Tide / current + Sediment plume from discharge Point 1 – River Centre
4	HD + Sediment Plume Dispersion	during demolition	Tide current + Sediment plume from discharge Point 2 – West Bank

The ecological receptors within the tidal wetland mainly include mangroves, seagrass, sea fish and birds. The potential impacts on the ecological receptors include those results from the changes to water quality, construction noise and vessel traffic. The water quality is based on the modelling results as mentioned above. The impact assessments associated with noise and vessel traffic are based on the desktop study.

3.3. IMPACT MAGNITUDE AND SIGNIFICANCE

Environmental impact significance is presented in the form of a matrix in which value or sensitivity of environment receptor and magnitude of impact are combined into a significance score. The value or sensitivity of the environmental receptor that may be impacted is determined from the baseline information and classified into categories.

Sungei Buloh Wetland Reserve is a national reserve park and thus the value of the environmental receptors is considered high.

The specific criteria for river flow and hydraulic conditions are set out in **Table 3-2**. Demolition work may lead to sediment plume discharge in the river. Sediment plume affects the total suspended solid (TSS) in the water, that is a key parameter for water quality. Therefore, the same assessment criteria for sediment plume and water quality is set out in **Table 3-3**.

Table 3-2: Impact magnitude and significance: river flow

No.	Description of Impact magnitude	Impact Significance
1	Greater than 50% of the predisturbance range.	Major
2	Between 25% and 50% of the predisturbance range.	Moderate
3	Between 10% and 25% of the predisturbance range.	Minor
4	Less than 10% of the predisturbance range.	Slight
5	Basically indistinguishable from the predisturbance range.	No Impact

Table 3-3: Impact magnitude and significance: sediment plume and water quality

No.	Description of Impact magnitude	Impact Significance
1	A long-term (greater than 12 months) or irreversible change in water quality and/or sediment quality greater than 70% of existing conditions over an area spanning more than 10 km.	Major
2	A long-term (greater than 12 months) change in water quality and/or sediment quality greater than 50% of existing conditions over an area spanning more than 1 km.	Moderate
3	A medium-term (between 6 and 12 months) change in water quality and/or sediment quality greater than 30% of existing conditions over an area spanning more than 100 m.	Minor
4	A short-term (less than 6 months) change in water quality and/or sediment quality greater than 10% of existing conditions over an area spanning more than 100 m.	Slight
5	Undetectable or insignificant changes to water quality and/or sediment quality.	No Impact

The tolerance limits of seagrass and mangrove to the influence of increased suspended sediments and sedimentation are set based on extensive desktop review as well as experience in marine projects in the region.

Productivity of seagrass may be limited as a result of reduced light penetration following algal blooms (not applicable in this study) and suspended sediments. Seagrass requirements for light penetration have been well described by many authors, and the habitat is typically confined to water depths where light levels are above 10% to 15% of surface irradiance. At low tide, many seagrass beds in the Singapore nearshore area are exposed, indicating a possible adaptation to, and higher tolerance to a high level of excess suspended sediments. For deeper beds, the tolerance is lower, but given the natural background variability in suspended sediment loads in Singapore coastal area, it is reasonable to assume that the outer limits of the seagrass are well adapted (in terms of water depth) to short-term fluctuations in the background suspended sediment concentration of 5 to 10 mg/l, such that only excess loadings higher than 5 mg/l will stimulate a noticeable habitat change. With these findings Goorn-Groen [5] proposed the impact severity matrix as presented in **Table 3.2**. The short-term survival of seagrass beds, which depends on anaerobic performance, will only be affected significantly in the case of very high sedimentation rates. Such critical sedimentation rates will normally be observed very close to a construction site. Based on the experience in the Southeast Asia, the following impact severity matrix is presented for sedimentation impact on seagrass (see **Table 3.3**).

Table 3-4: Impact severity matrix for suspended sediment impact on Seagrass

Severity	Definition (excess concentrations)
No Impact	Excess Suspended Sediment Concentration > 5 mg/l for less than 20% of the time
Slight Impact	Excess Suspended Sediment Concentration > 5 mg/l for more than 20% of the time Excess Suspended Sediment Concentration > 10 mg/l for less than 20% of the time
Minor Impact	Excess Suspended Sediment Concentration > 25 mg/l for less than 5% of the time
Moderate Impact	Excess Suspended Sediment Concentration > 25 mg/l for more than 20% of the time Excess Suspended Sediment Concentration > 75 mg/l for less than 1% of the time
Major Impact	Excess Suspended Sediment Concentration > 75mg/l for more than 20% of the time

Table 3-5: Impact severity matrix for sedimentation impact on Seagrass

Severity	Definition (Excess sedimentation)
No Impact	Sedimentation < 0.1 kg/m²/day (<0.25 mm/day)
Slight Impact	Sedimentation < 0.25 kg/m²/day (<0.63 mm/day)
Minor Impact	Sedimentation < 0.5 kg/m²/day (<1.25 mm/day)
Moderate Impact	Sedimentation < 1.0 kg/m²/day (<2.5 mm/day)
Major Impact	Sedimentation > 1.0 kg/m²/day (>2.5 mm/day)

Mangroves can be considered to be very tolerant to a wide range of suspended sediment loads that may be generated from dredging and reclamation activities. Of the various mangrove species, those with pneumatophore root systems are the most sensitive to sedimentation, but even mangroves with pneumatophore root systems are only likely to be stressed when prolonged sedimentation reach levels from 10 cm up to 30 cm. This level of sedimentation is unlikely to occur outside the work area, and mangroves are thus not considered as sensitive receptors.

Despite suspended solids being an important water quality parameter with regards to aquaculture facilities, very little is known about the risks of prolonged exposure to high concentrations of suspended solids in fish, especially marine aquaculture species. Based on the tolerance limits reviewed by DHI [6], the absolute value for negative impacts on aquaculture species is given as that value of suspended sediment concentrations above 1,200 mg/l and for incremental changes of less than 100 mg/l. DHI has successfully applied a conservative limit of no increase of more than 1 to 3 mg/l in Total Suspended Solids (TSS) at aquaculture facilities for past projects in Singapore. This range of TSS corresponds to a statistical flag of “No Change”, depending on the specific location of the aquaculture farm.

Demolition and construction works would result in a temporary increase in disturbance (direct loss, vessel traffic and noise) to the ecological receptors. The overall characterisation of impacts on the ecology receptors includes:

- Scale/extent;
- Direct or indirect impact;
- Reversibility of impact;
- Frequency of impact (single event, recurring or constant);

- Duration of impact (short term, medium term, long term or permanent); and
- Likelihood of occurrence (certain/near certain, probable, unlikely or extremely unlikely).

It is not possible to quantify the magnitude of effect from the available literature. The impact magnitude translated from the characterisation and the impact significance are as shown in **Table 3-6**.

Table 3-6: Impact magnitude and significance: construction work disturbance

No.	Description of Impact magnitude	Impact Significance
1	Effect likely to have large impact on population, community or ecosystem survival and health, possibly even leading to local extinction or system collapse. Impact is widespread, affecting 10 to 25% of a regional population. Recovery, if possible, is likely to take more than 10 years.	Major
2	Effect likely to have severe negative impact on population, community or ecosystem survival or health. Impact is regional, affecting up to 10% of a regional population. Recovery, if possible, is likely to take from 5 to 10 years.	Major
3	Effect will be detectable but not severe; populations or the areal extent of communities may be reduced but unlikely to lead to major changes to population, community or ecosystem survival or health. Impact is local, generally occurring up to 2 km from impact site. Recovery is likely to take from 2 to 5 years.	Moderate
4	Effect may be detectable but is small and unlikely to have any material impact. Impact affects immediate surrounds of area of activity and extends for less than 1 km radius. Recovery is rapid - up to 2 years.	Slight
5	A short-term reversible effect on the distribution and/or abundance of a habitat, species assemblage/community or population. Effect unlikely to be detectable by monitoring.	No Impact

4. EXISTING SITE CONDITION AND COASTAL ENVIRONMENT

A desktop study for hydrology, water quality and ecology has been carried out as part of the baseline studies to understanding the existing site condition and coastal environment in the study area.

4.1. OCEANOGRAPHY AND HYDRODYNAMICS

The proposed project site is located in the Sungei Buloh Wetland Reserve (SBWR), which is on the northwestern sector of Singapore. SBWR is low-lying and acts as a sink to the surrounding areas. As shown in **Figure 4-1**, SBWR has primarily brackish water ponds, brackish riverine estuaries and brackish intertidal mudflats, and the Kranji Nature Trail includes primarily coastal seawater. The water level at the shore and the riverine estuaries follow the semi-diurnal tides with two low and high tides. SBWR is a special area, and despite being only 130 hectares in land area, one can find within the reserve the three different categories of water: seawater, brackish water and fresh water.

Figure 4-1: Sungei Buloh Wetland Reserve and Wetland Park

Sg Buloh Besar is the main riverine water body in SBWR. The downstream watercourse runs northerly into the Western Straits of Johor. An aerial view of the river is shown in **Figure 4-2**. The proposed bridge is located in the estuarine reach and is 200 m from the river mouth. The hydrodynamics of the project site is dominated by tidal currents. In general, the current flow in the river is mild (magnitude in the order of 0.5m/s).

Figure 4-2: An aerial view of the Sungei Buloh Besar

A bathymetry survey has been carried out for construction of the proposed bridge. As shown in **Figure 4-3**, the river bathymetry around the project site is generally uniform with a depth of around 2 m at mean sea level.

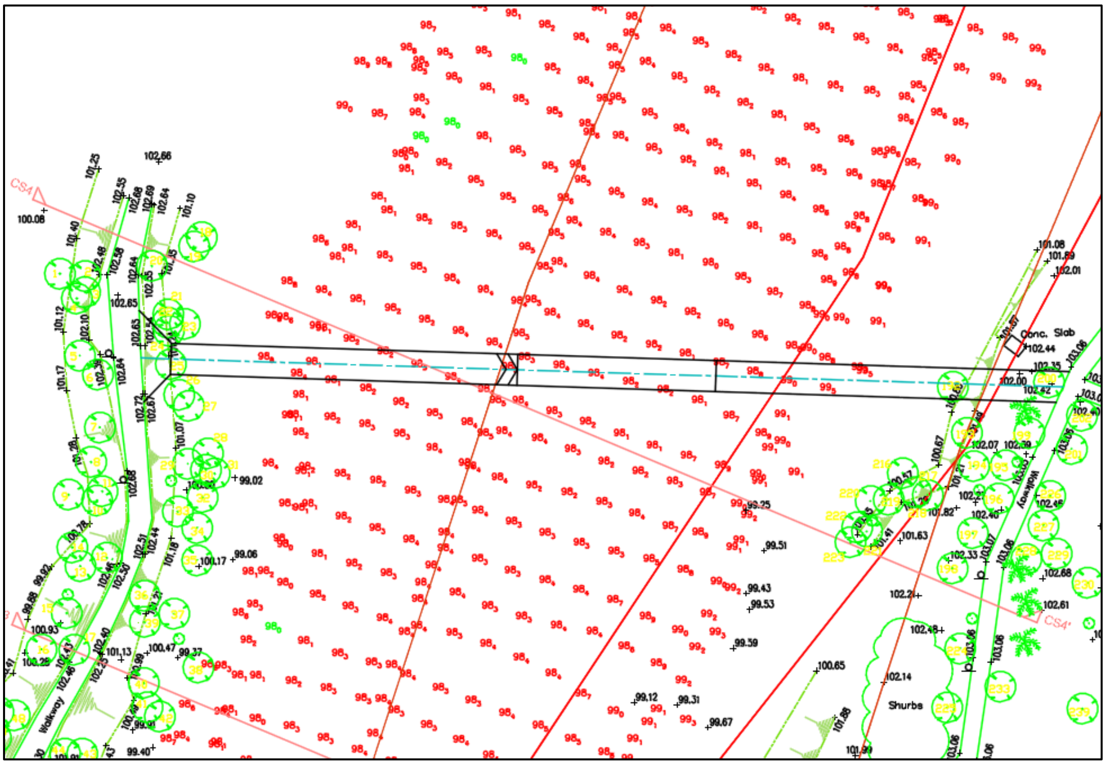

Figure 4-3: Bathymetry survey map

4.2. GEOLOGY AND SOIL CONDITIONS

The geology of SBWR is typical of the coastal areas of Singapore and comprises a superficial layer of recent alluvium. Soil investigation of bore holes drilled to depths of about 25 meters in 1991 and 1999 revealed the presence of soft clay with decayed vegetation. Higher proportions of hard clayey silts with sand were noted at the lower levels.

Soil investigation carried out at the adjacent coastal area with four bore holes (RYOBI Geotechnique, 2011) revealed that the seabed sediments comprise mostly very soft clay material. The thickness of surface layer marine clay is 1.3 m to 4 m. The bulk density is from 1360 to 1444 kg/m^3, and the dry density is from 670 to 780 kg/m^3.

4.3. WATER QUALITY

There are few data or references of water quality for SBWR. According to a previous measurement [7], the water quality in SBWR was either relatively unpolluted or weakly polluted. The water temperature was 25 – 31°C, and was consistent with the ambient temperature range in Singapore water. The pH in SBWR was marginally alkaline, ranging from 7.2 to 8.4 because seawater exerts a significant influence.

Turbidity or total suspended solid is the most concerned water quality parameter as the demolition work may produce sediment plume. The measured turbidity ranged from 3 to 36 NTU.

4.4. MANGROVE

SBWR is a predominantly tropical coastal mangrove wetland of 130 hectares consisting primarily of brackish water ponds, riverine estuaries, intertidal mudflats, mature mangroves and fringing mangroves. The wetland is a coastal wetland with natural and man-made wetlands as well as natural mangrove-lined river estuaries.

The wetland is gazetted as a nature reserve and contains remnants of the original forest. The mangroves are ecologically complete, patches of which are pristine (see **Figure 4-4**). They represent the largest complete block of mangroves on the main island of Singapore.

Figure 4-4: Photographs of mangroves along the Sg. Buloh Besar

4.5. SEAGRASS

There are no large seagrass meadows recorded within the Western Straits of Johor. Bathymetry survey and soil investigation also indicate that there is no significant seagrass patches around the project site.

4.6. AQUACULTURE

The fish in the Sungei Buloh Wetland Reserve have increased since the park received nature reserve status in 2001 and since then fishing is no longer allowed. There are Archer Fish, Halfbeak, and Mullet. The high and low tides affect the crabs, mudskippers, and mud lobsters that can be observed close to the shore. Outside the river mouth there are some aquaculture farms in the Western Straits of Johor (see **Figure 4-5:** Aquaculture farms in the Western Straits of Johor).

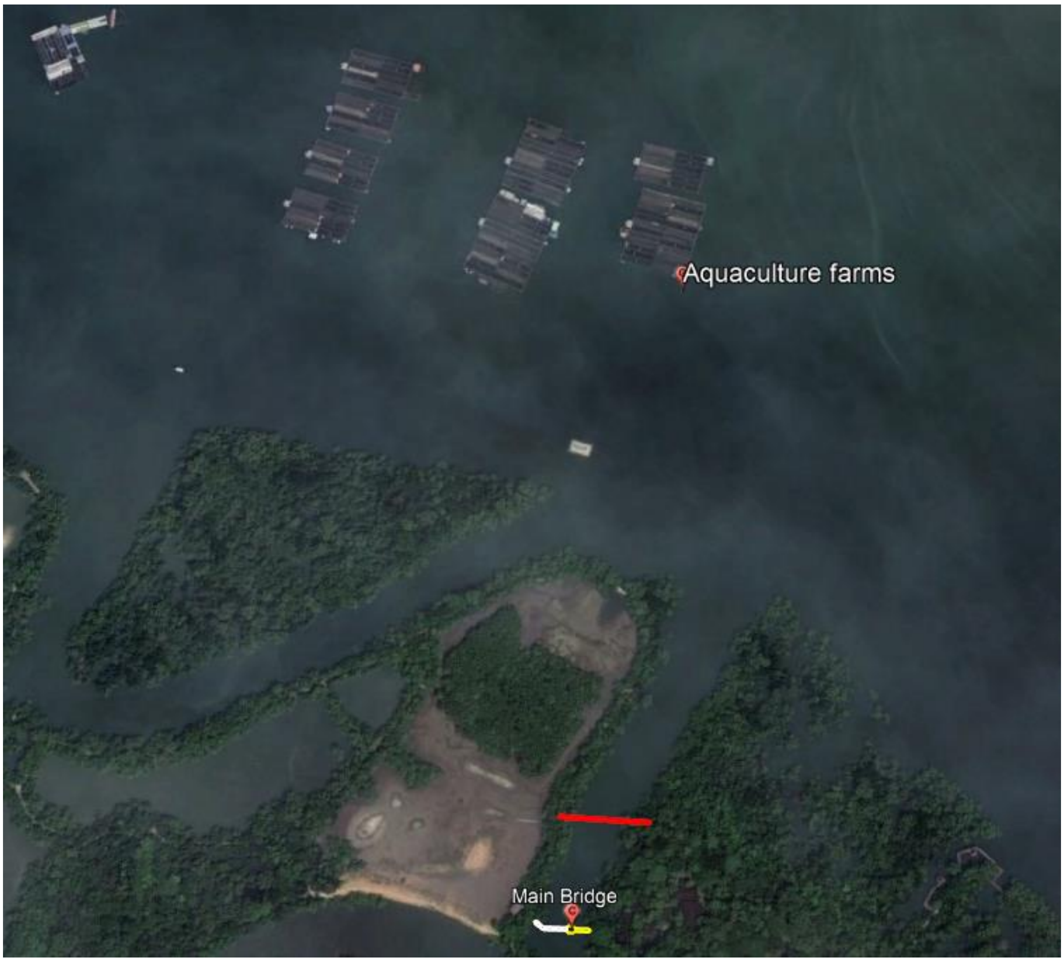

Figure 4-5: Aquaculture farms in the Western Straits of Johor

4.7. BIRDS

Many species of birds can also be found in SBWR because they feed on the flora and fauna in the surrounding area. Some of the birds that can be seen are Marsh Sandpiper, Mongolian Plover, Pacific Golden Plover, Common Greenshank, Whimbrel, and others (see **Figure 4-6:** Birds observed in SBWR). More than 212 local and migratory bird species have been recorded in SBWR, which are more than 60 percent of Singapore's bird species, and some of them are nationally and internationally endangered.

In particular, SBWR is an important roosting and feeding area for migratory shorebirds in Singapore between August and April. Birds on the East Asian-Australasian FLYWAY (see **Figure 4-7:** Birds on the East Asian-Australasian FLYWAY) use the mangroves as an important refueling stop, on their travels from Australia all the way up north to Russia. The smooth otter is regularly sighted, as is the palm civet. Long-tongued nectar bats and cave fruit bats are common and feed on the nectar of the flowers from Sonneratia in the wetland.

Figure 4-6: Birds observed in SBWR

Figure 4-7: Birds on the East Asian-Australasian FLYWAY

5. HYDRODYNAMIC IMPACTS

Hydrodynamic modelling was carried out to simulate the water level variations and current flows. This chapter shows the comparison between the pre- and post-demolition work conditions to assess the impacts on the hydrodynamics of the water.

The typical water level distributions during high tide (Spring-Flood), low tide (Spring-Ebb) and mean tide (over a Spring-Neap cycle) for both existing condition and post-demolition are shown in **Figure 5-1** to **Figure 5-3**, respectively. Their difference are also plotted to illustrate the impact of the demolition of the existing bridge and the proposed new bridge. The results show that the water level gradient is generally very mild in this tidal river. The existing bridge piles can affect the river flow and water level gradient around the piles is also affected. After the demolition work, the west side piles of the existing bridge are removed and blockage to the flow is also reduced. During the flood tide when the seawater flow into the river, the water level upstream of the new bridge is slightly lower compared to that of the existing condition, and vice versa during the ebb tide. However, such change may be ignored in practice. On average, the water level difference is marginal with a magnitude less than 0.2 mm.

Typical current flow patterns during different tide phases are shown in **Figure 5-4** and **Figure 5-5**. The water flow is directed upstream during the Spring-Flood tide but downstream during the Spring-Ebb tide. The current flow speed is in the order of 0.1 m/s. The demolition and new bridge has certain impact on the current flows but the significant difference is only observed locally around the existing piles to be removed and the new bridge piles. In order to provide an overview of the spatial distribution of impacts, the mean and maximum current conditions are plotted in **Figure 5-6** and **Figure 5-7**, respectively, and note that:

- The mean flow velocity is the vector average of the current flow over the spring-neap tide cycle; and
- The maximum flow velocity is the highest current flow at each point during spring-neap tide cycle.

The change of flow velocity in the river is generally negligible (< 0.01m/s) for either mean or maximum flows. The results show that the key environmental receptors as identified in Chapter 7 are not likely to be impacted by the demolition work as the overall hydraulic conditions remain the same with that of the baseline. The impact magnitude is in the level of undetectable. Therefore, the impact is classified as “No Impact” according to **Table 3-2**.

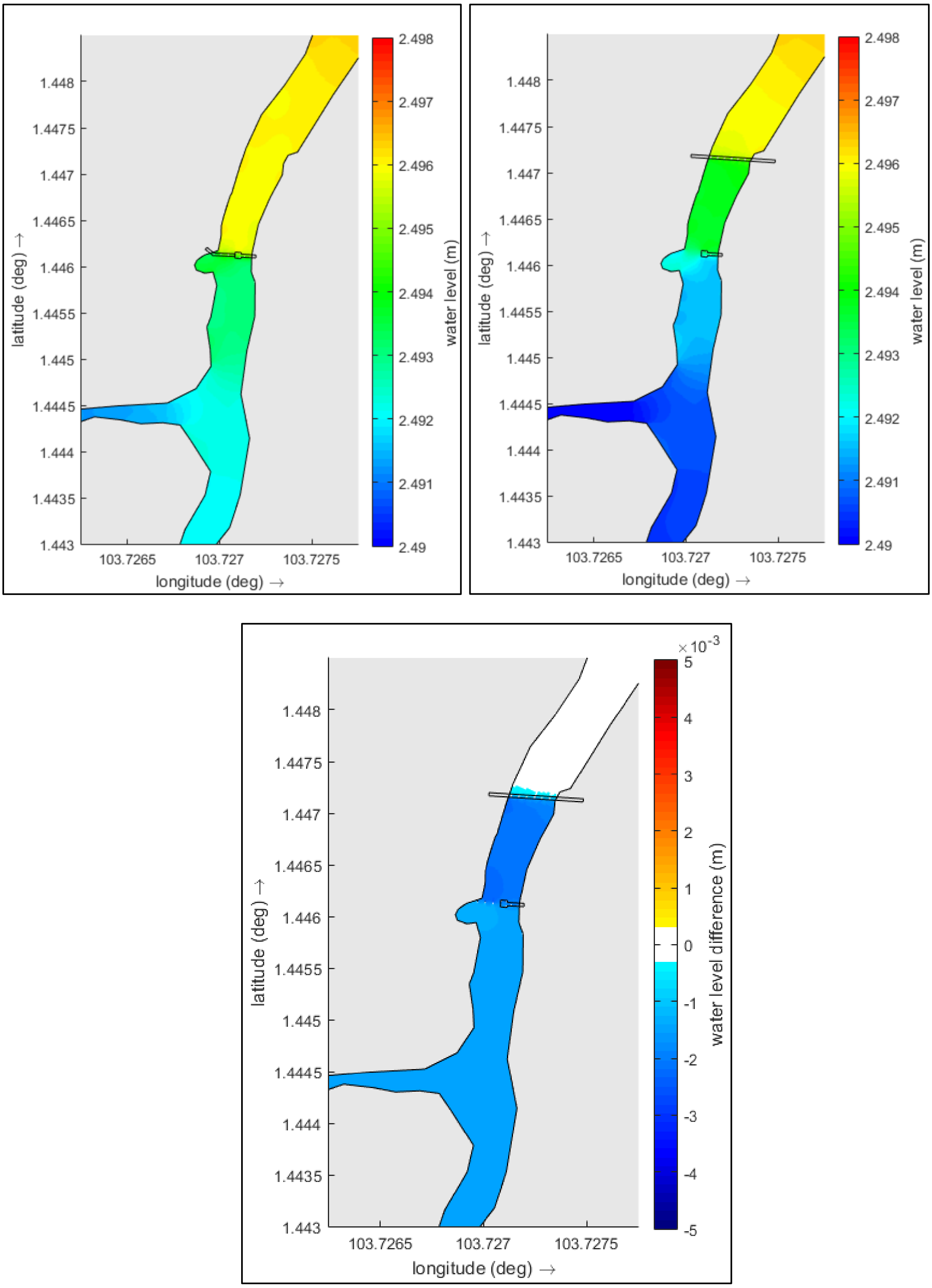

Figure 5-1: Typical water level distribution during Spring-Flood Tide for a) existing condition (upper left), b) post-demolition (upper right), and c) their difference (lower)

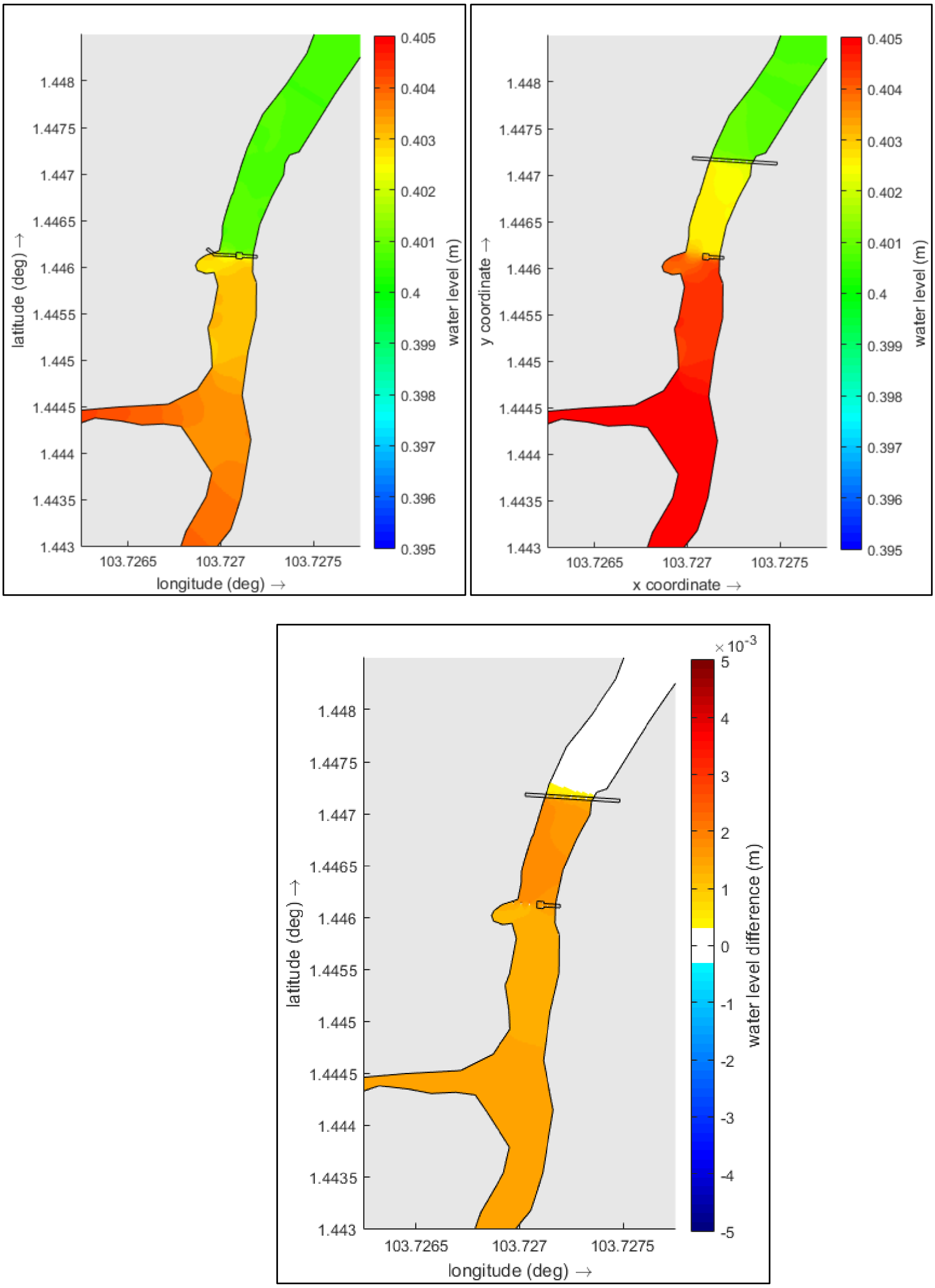

Figure 5-2: Typical water level during Spring-Ebb Tide for a) existing condition (upper left), b) post-demolition (upper right), and c) their difference (lower)

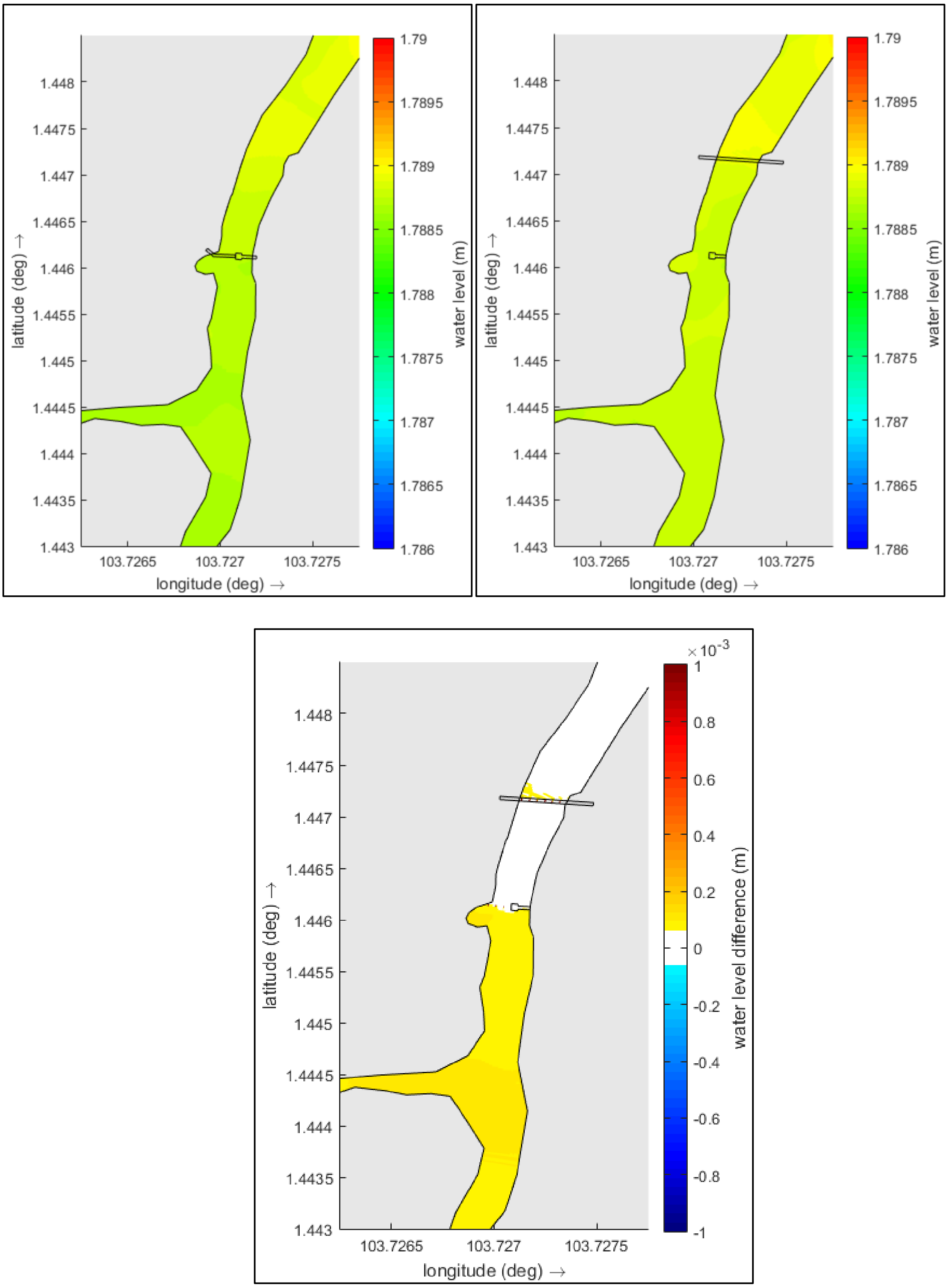

Figure 5-3: Mean water level over a typical spring-neap tide cycle for a) existing condition (upper left), b) post-demolition (upper right), and c) their difference (lower)

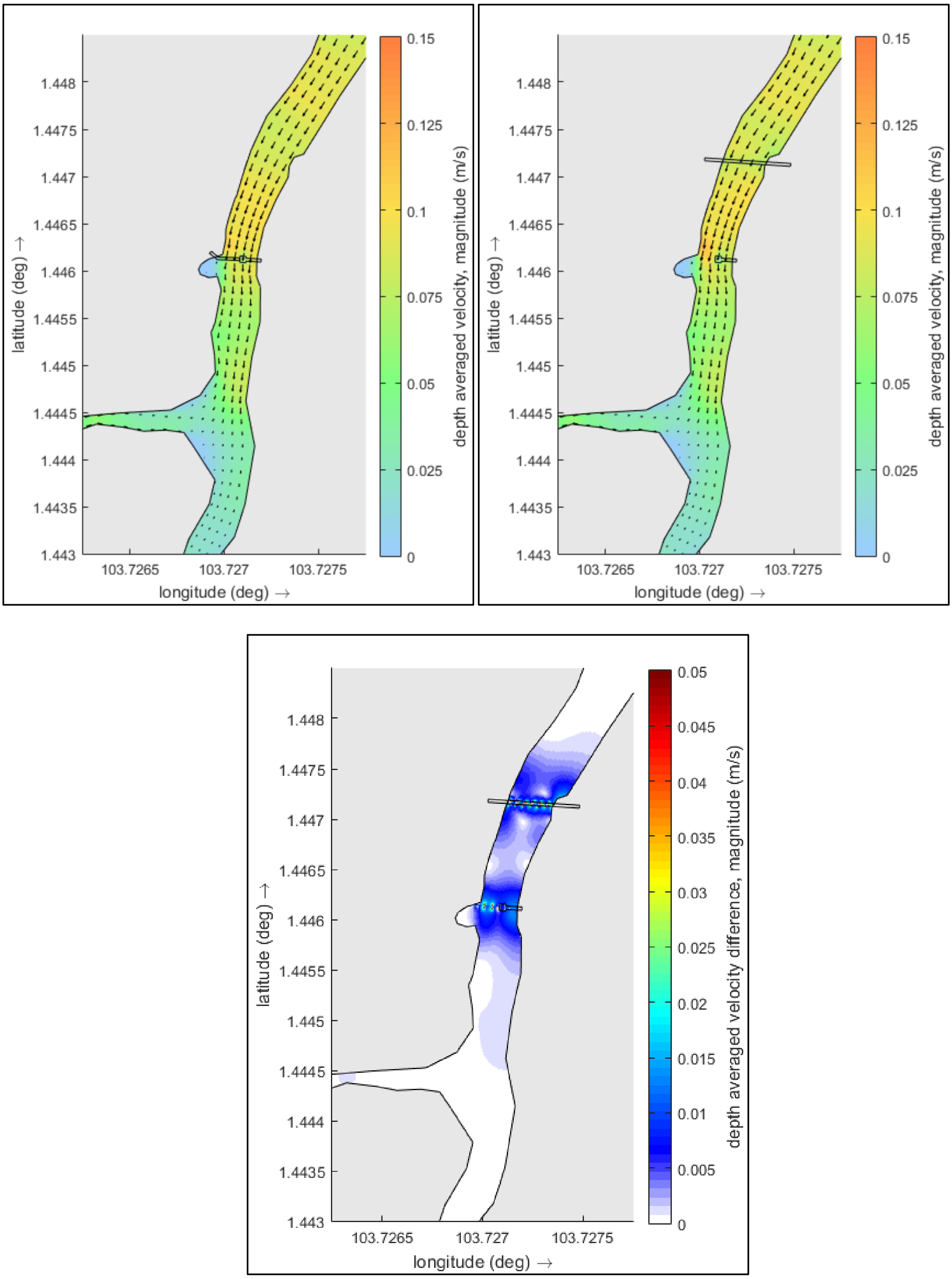

Figure 5-4: Typical tidal current during Spring-Flood Tide for a) existing condition (upper left), b) post-demolition (upper right), and c) their difference (lower)

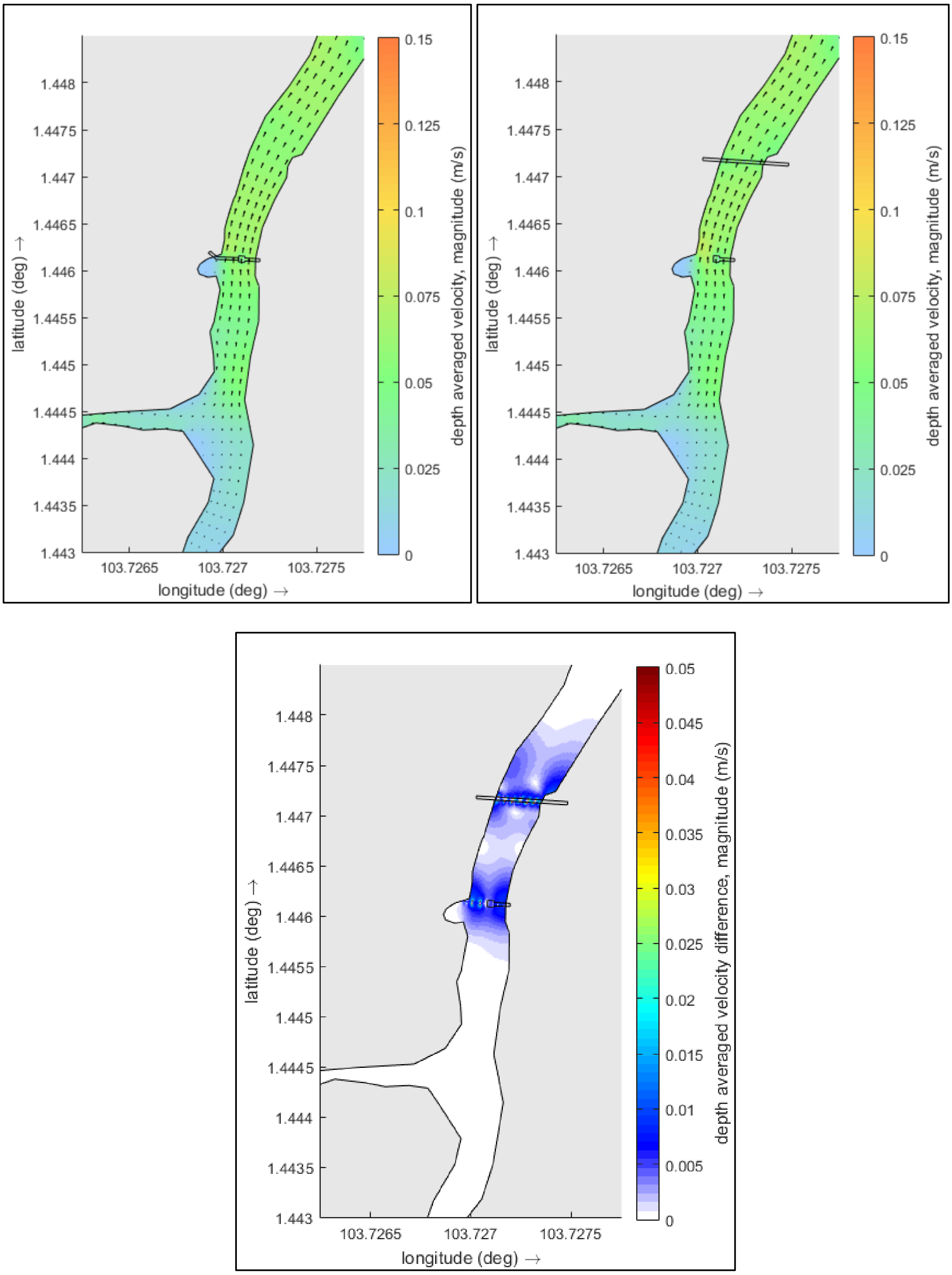

Figure 5-5: Typical tidal current during Spring-Ebb Tide for a) existing condition (upper left), b) post-demolition (upper right), and c) their difference (lower)

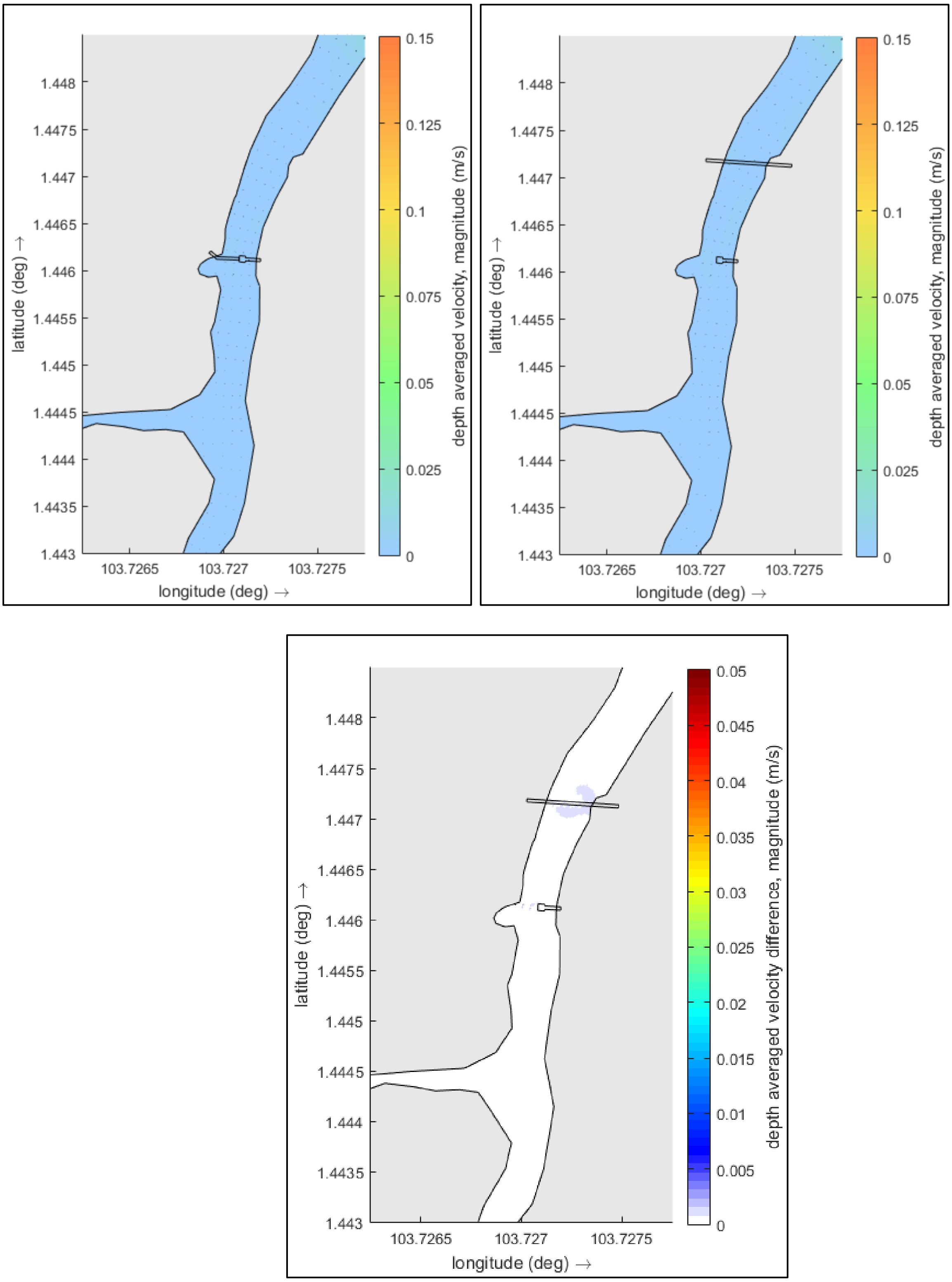

Figure 5-6: Mean tidal current over a typical spring-neap tide cycle for a) existing condition (upper left), b) post-demolition (upper right), and c) their difference (lower)

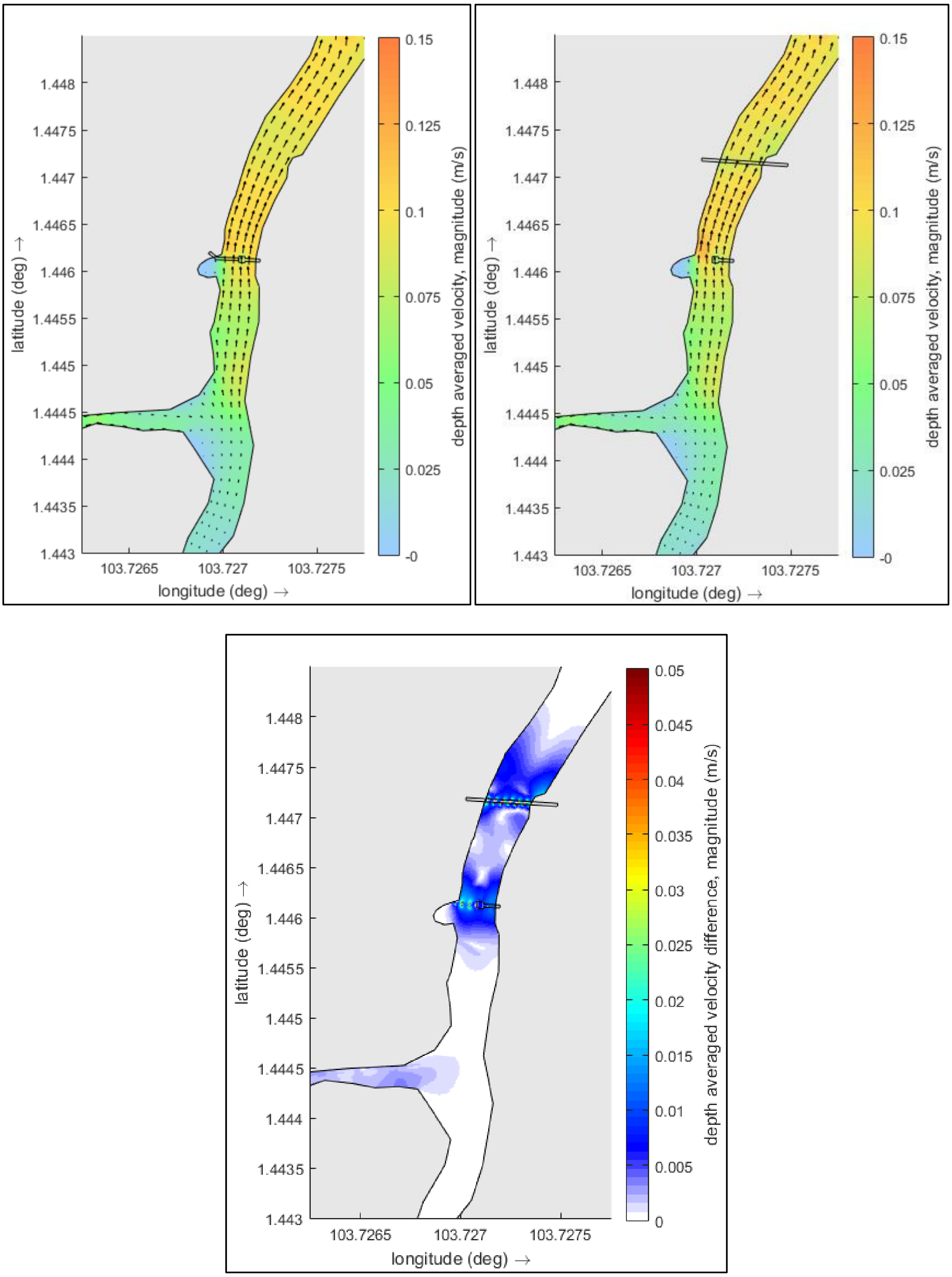

Figure 5-7: Max tidal current over a typical spring-neap tide cycle for a) existing condition (upper left), b) post-demolition (upper right), and c) their difference (lower)

6. SEDIMENT PLUME DISPERSION

The lower section of the piles in the main channel of river will be cut below seabed. A cofferdam will be first placed around the pile to be cut. The top of the cofferdam will be set at approximately 1.5 mCD. When the tide recedes to below that level, the water within the cofferdam will be pumped out. This will allow a worker to enter the cofferdam and excavate around the pile.

The process of cofferdam installation, water pumping and cofferdam removal may lead to the bed sediment resuspension into the water column. It is not easy to predict the sediment loss rate during the process. It errs on being conservative to assume that there is continuous discharge of suspended sediment (fine particles) with a loss rate of 10000 mg/s during the simulation period. This is almost analogous to assume that the clay and fine silt contents in the surface bed layer within the mechanically disturbed zone are effectively entrained into the water column and continuously dispersed with the flow during the cutting of piles.

Two locations are selected as the sediment plume discharge points for simulation, the first is located at the river centre and the second is located close to the west bank, as shown in **Figure 6-1**. The two scenarios (3 and 4) were simulated with continuous and constant discharge of sediment plume for a full spring-neap tide cycle. No containment measures, such as settlement ponds or silt curtains, are applied at the site such that the sediment plume dispersion is not constrained or trapped in the modelling exercise. The simulated cases are thus considered as the conservative scenarios of sediment plume dispersion.

Figure 6-1: Selected discharge points of sediment plume for numerical modelling: P1 – at the river centre, P2 – close to the west bank.

The distribution patterns of sediment plume for two sediment discharge scenarios are illustrated in **Figure 6-2** and **Figure 6-3**, respectively. The figures display the typical sediment plume distribution pattern during flood and ebb tides, as well as the time mean and maximum concentration distributions.

It is observed that the sediment plume spreads upstream during flood tide while it spreads downstream during ebb tide. The plume is more easily diluted during the flood tide as the flow depth is higher. The mean concentration contours of 5 mg/l are limited to an extent about 10 m from the discharge point. The maximum concentration contour of 5 mg/l is within the extent of 300 m while 10 mg/l maximum value contour is within the extent of 50 m.

The sediment plume is observed within a site scale distance (1 km upstream and downstream). In Sungei Buloh Wetland Reserve, the mean TSS is approximately 10 mg/L (average turbidity 12 NTU). A 20% increase in TSS is observed within 200 m extent. Furthermore, the sediment plume is only a temporary impact (< 6 months) that is only caused during the removal of bridge piles. Therefore, the impact of sediment plume is classified as “Slight Impact”, according to **Table 3-3**.

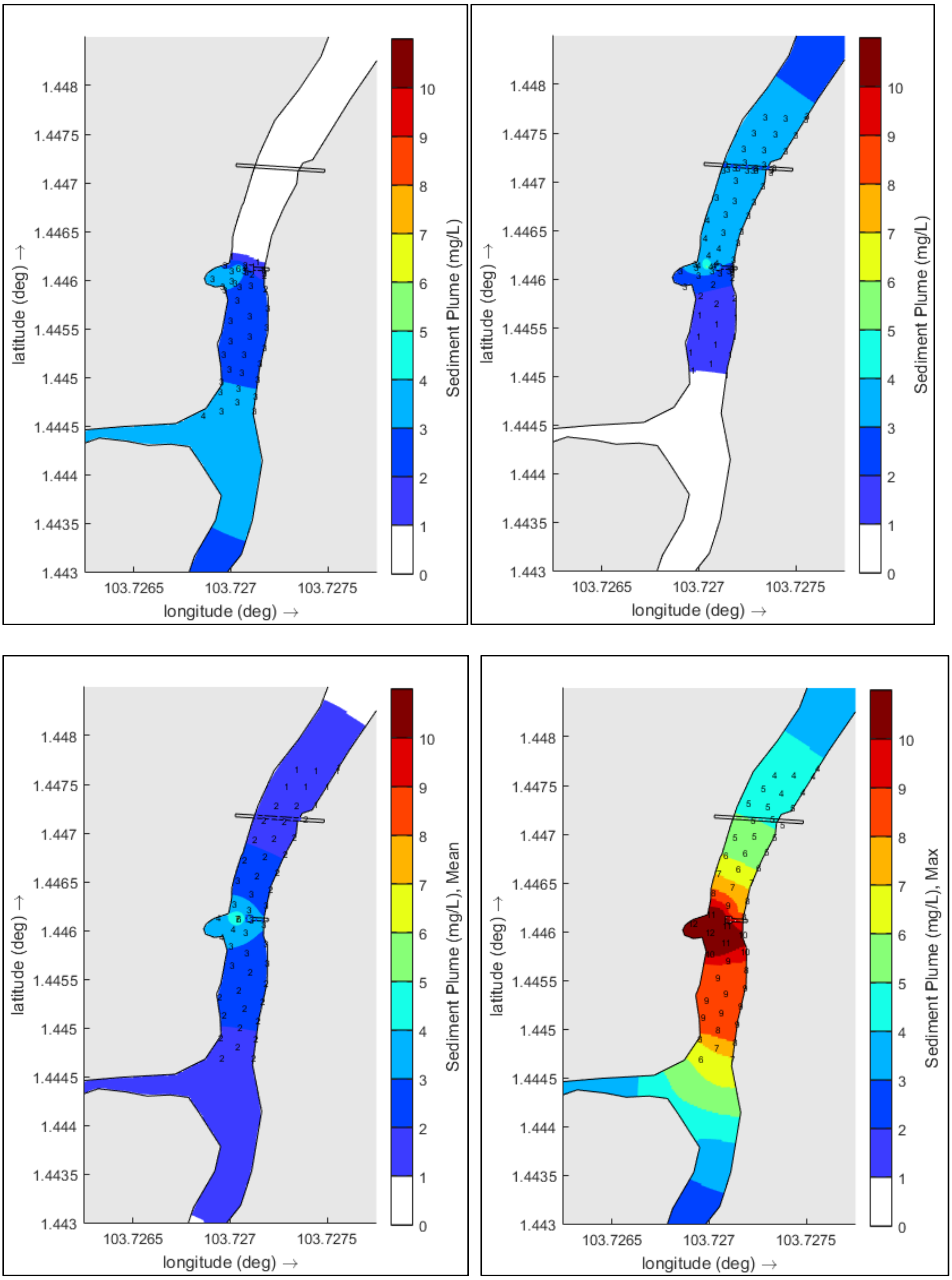

Figure 6-2: Sediment plume distribution for the discharge point at the river centre: upper left: spring-flood tide; upper right: spring-ebb tide; lower left: mean; lower right: maximum.

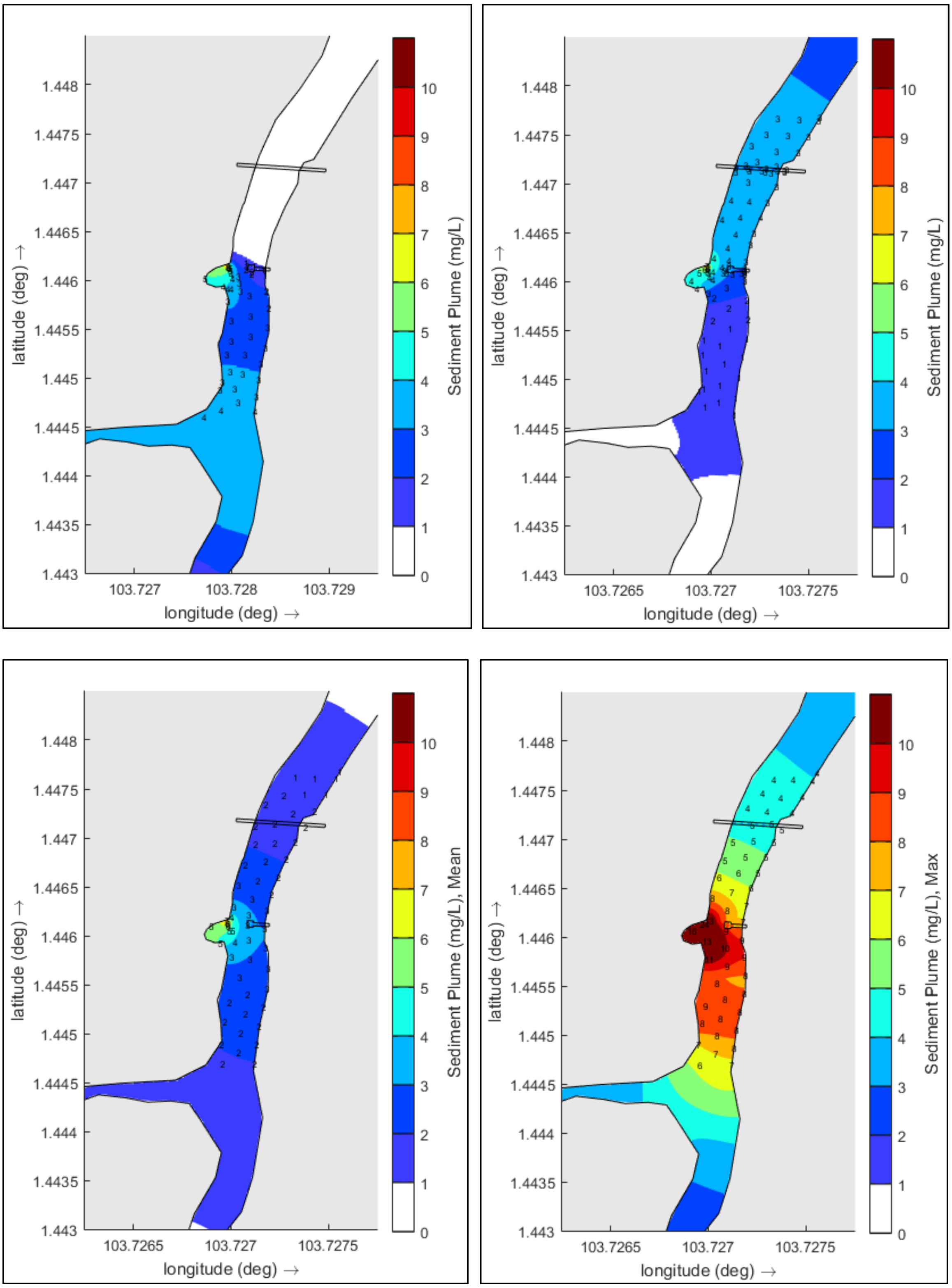

Figure 6-3: Sediment plume distribution for the discharge point close to the west river bank: upper left: spring-flood tide; upper right: spring-ebb tide; lower left: mean; lower right: maximum.

7. EFFECTS ON WATER QUALITY

The post-work hydraulic conditions of the river are almost the same as that of the existing conditions. Therefore, the transport dynamics and overall distribution patterns of the nutrients or pollutants in the water will remain the same in the long term.

The removal of the west portion of the existing main bridge may have a temporary impact on the water quality. The envisaged influence on water quality is related to the TSS change due to the sediment plume discharge. The environment-sensitive receptors around the project site include the river mouth, aquaculture farms, and the international border. Nine (9) typical locations, including the environment-sensitive receptors, are selected as the observation points, as shown in **Figure 7-1:**

- A: the proposed new bridge
- B: drain outlet of the tidal ponds
- C: upstream river junction
- D: river mouth of Sg. Buloh Besar
- E: Aquaculture farm outside the SBWR
- F: Sg. Bilabong Buloh
- G: The international border between Singapore and Malaysia

Mean and maximum sediment plume concentrations are extracted from the modelling results and are listed in **Table 7-1**. It can be seen that the mean concentration of suspended sediment (plume) at all observation locations is not larger than 5 mg/l and some are even undetectable.

As mentioned in Chapter 6, the TSS increase within the extent of 200 m about 20% and temporary impact (< 6 months), the impact on water quality is classified as “Slight Impact”.

Figure 7-1: Identified environmental sensitive areas in the vicinity of the project site

Table 7-1: Mean and maximum concentration of sediment plume concentration at the assessment locations

ESA		Sediment Plume Concentration (mg/l)	
Locations		Mean	Maximum
A	New bridge	2	6
B	Drain outlet	5	12
C	Upstream river junction	1.5	5.5
D	River mouth	0.2	1
E	Aquaculture farms	0	0.1
F	Sg Bilabong Buloh	0	0.1
G	Sampling point near International border	0	0

8. EFFECTS ON ECOLOGY

This chapter addresses the potential effects on the existing ecological receptors within the estuarine environment.

Before cutting a bridge pile, a cofferdam will be placed around the pile. The excavation and cutting will be carried out manually. The area of riverbed habitat affected depends on the cofferdam caisson diameter (1.5 m) and the longitudinal extent for installation of 3 such cofferdams in a row (approximately 5m). An estimate of the footprint area of the directly disturbed riverbed for removing 3 rows of RC piles:

- Footprint area: 3 (rows) x 1.5 m (W) x 5 m (L) = 22.5 m^2

Benthic species located around the piles are likely to be disturbed and some may be lost during pile cutting. However, with the protection of cofferdam, bed material loss from the riverbed will be minimal. It is highly likely the benthic community will recover within one or two years without any significant impact. Furthermore, as the affected area is relatively small (within 10 m), fragmentation of the riverbed surface habitat during recovery period is expected to be minimal. Therefore, the impact on benthic species can be classified “Slight Impact” according to **Table 3-6**.

Sediment plume could have potential impacts on the filter-feeding apparatus of benthic organisms or gills of fish. Increased turbidity also decreases the amount of light penetration through the water column resulting in decreased photosynthesis for seagrass and macroalgae. Other impacts include potential eutrophication due to remobilization of nutrients, potential ingestion and accumulation of contaminated sediments or secondary effects associated with resettling sediment which may bury benthic organisms or fish spawn. However, as the modelling results show that sediment plume only spreads within a limited extent and with low concentration. The concentration at the environment sensitive receptors is less than 5 mg/l. The sedimentation of the re-suspended sediment may be ignored beyond the vicinity of the project site. Therefore, sediment plume has “No Impact” on the seagrass according to **Table 3-4** and **Table 3-5**.

Mangroves are known to be very tolerant to changes in suspended sediment and sedimentation. There are also no significant seagrass patches in the immediate vicinity of the project site. It is very likely that the wild fish or higher marine life forms will actively avoid the demolition site where the sediment concentration is higher. Therefore, sediment plume on marine life is anticipated to have “No impact”.

Demolition and construction work would result in a temporary increase in vessel traffic in Sg Buloh Besar as the work requires transport of equipment and disposals. Any increase in vessel traffic associated with the work will increase the risk of ‘ship strike’ and may cause behavioural changes (including movements, acoustic behaviour and other behaviours) to the marine organisms and habitats.

The most likely impacts on the habitats would be those associated with noise. Hacking beams and cutting piles are likely to result in increased noise and vibration. Increased work noise can cause physical injury to marine mammals if they are within certain distance from the work site. The noise may also cause masking of important sounds used for habitat communication and echolocation. Behavioural modification and changes in habitat are a likely effect of hacking and cutting noise.

Studies showed that fish show active avoidance of sound sources within their hearing range. No observation of marine mammals (e.g. seal, dolphin) has been recorded in Sg. Buloh Besar. Given the small scale and short term work, localised nature of demolition work, no significant effects of underwater noise and vibration on marine organisms are anticipated.

However, in the absence of appropriate operation procedures, noise and vibration generated during demolition and construction work have the potential effect which may result in disturbance to estuarine birds and could displace bird species that use areas close to the project site. SBWR is an important roosting and feeding area for migratory shorebirds in Singapore between August and April. Birds on the East Asian-Australasian FLYWAY use the mangroves as an important refuelling stop, on their travels from Australia all the way up north to Russia.

In general, the traffic or noise effects on the ecological receptors may be detectable but is small and unlikely to have any material impact. The recovery is rapid. Therefore, the impact of traffic and noise can be classified “Slight Impact” according to **Table 3-6**.

9. CONCLUSIONS

Based on the field surveys, data analysis, modelling results, environmental impact assessment is carried out for the proposed work. The key findings of the impact assessment are as follows:

1. The river flow regime in Sungei Buloh Besar is generally mild. The changes in water level and velocity due to the proposed demolition work are marginal for the river flow. The impact magnitude is in the level of undetectable. Thus, according to **Table 3-2** the hydrodynamic influence can be classified as "**No Impact**".

2. Pile cutting work may lead to sediment plume with the tide flows. The sedimentation of the re-suspended sediment is negligible beyond the vicinity of the project site. The increase in suspended sediment concentration within the extent of 100 m is less than 10%, and sediment plume discharge is temporary (< 6 months). Therefore, according to **Table 3-3** the influence of sediment plume is classified as "**Slight Impact**".

3. The proposed works have no long term influence on the water quality. The envisaged temporary influence on water quality is related to the change in total suspended solid (TSS) due to the sediment plume discharge. TSS increase within the extent of 200 m about 20% and temporary impact (< 6 months), the impact on water quality is classified as "**Slight Impact**".

4. The sediment plume concentration is less than 5 mg/l at the environment sensitive receptors. The sedimentation is ignored beyond the vicinity of the project site. Therefore, sediment plume has "**No Impact**" on the seagrass and mangroves according to **Table 3-4** and **Table 3-5**.

5. The direct benthic habitat disturbance or loss due to bridge pile removing is small as the working area is small (Estimated 22.5 m^2). The affected area is relatively small (within 10 m), fragmentation of the riverbed surface habitat during recovery period is expected to be minimal. Therefore, the impact on benthic species can be classified "**Slight Impact**" according to **Table 3-6**.

6. Demolition work of the bridge and construction work of the Buggy Shelter would result in temporary increase in vessel traffics and construction noise disturbance to marine water habitats and estuarine birds. The traffic and noise effects is small and unlikely to have any material impact. The recovery is rapid. Therefore, the impact of traffic and noise on the marine fish and wildlife can be classified "**Slight Impact**" according to **Table 3-6**.

7. The project site is about 1.3 km away from the nearest international border. The changes in hydraulic condition and sediment plume are ignorable. The demolition and construction disturbance is also expected undetectable. Therefore, the transboundary impact is classified as "**No Impact**".

10. MITIGATION MEASURES

The environmental impacts during demolition work shall be controlled through adopting "best practice" and high working standards as required for all such works in Singapore. The following mitigation measures for the potential impacts are recommended:

10.1. SEDIMENT PLUME

1. Cutting off piles during low-tide periods when mudflat is exposed in intertidal areas. This will minimize amount of sediments re-suspended in the water column.
2. If necessary, cease the works that can produce significant sediment plume at the middle 2 ~ 3 hour of strong tide current;
3. And, where it is found necessary, silt screen barriers should be deployed.

10.2. RIVERBED BENTHIC LOSS

1. Minimize the disturbed area during installation coffer dam and cutting the piles.
2. Put the riverbed soil back to the hole if substantial amount is removed or extracted during the pile removal.

10.3. DEMOLITION AND CONSTUCTION WORK NOISE

1. Limit the amount of hacking, cutting and hammering work during the migration season for the migratory birds.
2. The use of a 'soft start' or 'ramping up' process, in which hacking power is gradually increased from low to normal operating levels.
3. Interrupting, or not even starting, beam hacking, pile cutting and pile driving if sensitive seabirds or other wildlife are present in the vicinity. This requires the presence of a trained observer to search the area before and during demolition work.
4. To reduce vibration and noise, wire saw machine or circular saw blade machine shall be used to cut the bridge beams.

10.4. INCREASED VESSEL TRAFFIC

1. Reduce vessel strike risk by limiting vessel speeds.
2. Implement educational programmes for vessel operators to increase awareness of wildlife and vessel related issues in wetland reserve.

10.5. DEBRIS

1. Collect debris when hacking beams by mounting trays blow beams
2. Collect debris when cutting of pile caps and upper segment of piles by mounting trays on piles.
3. Manually collect debris in cofferdam after cutting off lower segment of piles.

10.6. Residual Impacts

The impacts before and after implementation of mitigation measures are shown in **Table 10-1**.

Table 10-1: The Impact before and after implementation of mitigation measures.

Issue	Before	After
Sediment Plume/ Water Quality	A short-term (during bridge pile removal) change in suspended sediment concentration and water quality about 20% of existing conditions in an area spanning about 200 m.	Undetectable or insignificant changes to suspended sediment concentration and water quality.
Direct Benthic Loss	The direct benthic habitat disturbance or loss due to bridge pile removing in a small working area about 22.5 m2. Fragmentation of the riverbed surface habitat during recovery period is expected to be minimal.	A short-term reversible effect on the distribution and abundance of a local benthic habitat.
Traffic/Noise Disturbance	Effect on the marine fish and wildlife may be detectable but is small and unlikely to have any material impact. Impact affects immediate surrounds of area of activity and extends for less than 1 km radius. Recovery is rapid.	Impact on the marine fish and wildlife unlikely to be detectable by monitoring.

11. REFERENCES

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12. APPENDIX LIST

APPENDIX A – NUMERICAL MODELLING

APPENDIX A

NUMERICAL MODELLING

This section describes the approach of the assessment of environmental impacts which might be caused by the proposed project and reclamation work. Numerical models are established to simulate the complex coastal response to the proposed engineering work. Delft3D is used as the numerical modelling tool. Delft3D is a world leading 2D/3D modelling system to investigate hydrodynamics, sediment transport and morphology, water quality for fluvial, estuarine and coastal environments.

A hydrodynamic model is set up for the Johor Strait and Sg Buloh Besar. This model is calibrated against data from tidal ports and a dedicated tide and current velocity measurement operation. This model is able to reproduce and predict the complex hydrodynamic flow conditions of the Johor Strait well and is a suitable model for the sediment transport and sediment plume dispersion modelling.

The general steps and procedures of the modelling work included:

1) Define model area according to the project site condition and problems to solve
2) Collect and analyse the relevant Data
3) Define and establish a suitable numerical model
4) Setting up the Model
5) Calibrate and verify the hydrodynamic model
6) Adapt the same hydrodynamic model to simulate sediment dispersion for the proposed reclamation works
7) Adapt the same hydrodynamic model to simulate sediment transport for the erosion and siltation study
8) Analyze the simulation results.

12.1. NUMERICAL TOOLS

The numerical hydrodynamic modelling system Delft3D simulates two-dimensional (2D, depth-averaged) or three-dimensional (3D) unsteady flow and transport phenomena resulting from tidal and/or meteorological forcing, including the effect of density differences due to a non-uniform temperature and salinity distribution (density-driven flow). The flow model can be used to predict the flow in shallow seas, coastal areas, estuaries, lagoons, rivers and lakes. It aims to model flow phenomena of which the horizontal length and time scales are significantly larger than the vertical scales.

If the fluid is vertically homogeneous, a depth-averaged approach is appropriate. Delft3D-Flow module is able to run in 2D mode (one computational layer), which corresponds to solving the depth-averaged equations. Examples in which the 2D, depth-averaged flow equations can be applied are tidal waves, storm surges, tsunamis, harbour oscillations (seiches) and transport of pollutants in vertically well-mixed flow regimes.

Delft3D-Flow solves the unsteady shallow water equations in two (depth-averaged) or in three dimensions. The system of equations consists of the horizontal equations of motion, the continuity equation, and the transport equations for conservative constituents. The equations are formulated in orthogonal curvilinear co-ordinates or in spherical co-ordinates on the globe. In Delft3D-Flow models with a rectangular grid (Cartesian frame of reference) are considered as a simplified form of a curvilinear grid. In curvilinear co-ordinates, the free surface level and bathymetry are related to a horizontal plane of reference, whereas in spherical co-ordinates the reference plane follows the Earth's curvature. The flow is forced by tide at the open boundaries, wind stress at the free surface, pressure gradients due to free surface gradients (barotropic) or density gradients (baroclinic). Source and sink terms are included in the equations to model the discharge and withdrawal of water.

Delft3D-Flow solves the Navier-Stokes equations for an incompressible fluid, under the shallow water and the Boussinesq assumptions. In the vertical momentum equation the vertical accelerations are neglected, which leads to the hydrostatic pressure equation. In 3D models the vertical velocities are computed from the continuity equation. The set of partial differential equations in combination with an appropriate set of initial and boundary conditions is solved on a finite difference grid.

The depth-averaged continuity equation is given by:

$$\frac{\partial \zeta}{\partial t}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\left[(d+\zeta)U\sqrt{G_{\eta\eta}}\right]}{\partial \xi}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\left[(d+\zeta)V\sqrt{G_{\xi\xi}}\right]}{\partial \eta}=Q$$

with *U*, *V* depth average velocity in ξ and η directions; *ζ* water level above some horizontal plane of reference; *d* depth below some horizontal plane of reference; $\sqrt{G_{\xi\xi}}$, $\sqrt{G_{\eta\eta}}$ coefficients used to transform curvilinear to rectangular ordinates; *Q* representing the contributions per unit area due to the discharge or withdrawal of water, precipitation and evaporation:

$$Q=H\int_{-1}^{0}(q_{in}-q_{out})\,d\sigma+P-E$$

with q_{in} and q_{out} the local sources and sinks of water per unit of volume [1/s], respectively, *P* the non-local source term of precipitation and *E* non-local sink term due to evaporation. We remark that the intake of, for example, a power plant is a withdrawal of water and should be modelled as a sink. At the free surface there may be a source due to precipitation or a sink due to evaporation.

The momentum equations in ξ- and η-direction are given by:

$$\frac{\partial u}{\partial t}+\frac{u}{\sqrt{G_{\xi\xi}}}\frac{\partial u}{\partial \xi}+\frac{v}{\sqrt{G_{\eta\eta}}}\frac{\partial u}{\partial \eta}+\frac{\omega}{d+\zeta}\frac{\partial u}{\partial \sigma}-\frac{v^2}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\eta\eta}}}{\partial \xi}+ \\ +\frac{uv}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\xi\xi}}}{\partial \eta}-fv=-\frac{1}{\rho_0\sqrt{G_{\xi\xi}}}P_\xi+F_\xi+ \\ +\frac{1}{(d+\zeta)^2}\frac{\partial}{\partial \sigma}\left(\nu_V\frac{\partial u}{\partial \sigma}\right)+M_\xi$$

and

$$\frac{\partial v}{\partial t}+\frac{u}{\sqrt{G_{\xi\xi}}}\frac{\partial v}{\partial \xi}+\frac{v}{\sqrt{G_{\eta\eta}}}\frac{\partial v}{\partial \eta}+\frac{\omega}{d+\zeta}\frac{\partial v}{\partial \sigma}+\frac{uv}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\eta\eta}}}{\partial \xi}+ \\ -\frac{u^2}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\xi\xi}}}{\partial \eta}+fu=-\frac{1}{\rho_0\sqrt{G_{\eta\eta}}}P_\eta+F_\eta+ \\ +\frac{1}{(d+\zeta)^2}\frac{\partial}{\partial \sigma}\left(\nu_V\frac{\partial v}{\partial \sigma}\right)+M_\eta$$

ν_v is the vertical eddy viscosity coefficient. Density variations are neglected, except in the baroclinic pressure terms, P_ξ and P_η represent the pressure gradients. The forces F_ξ and F_η in the momentum equations represent the unbalance of horizontal Reynold's stresses. M_ξ

and M_η represent the contributions due to external sources or sinks of momentum (external forces by hydraulic structures, discharge or withdrawal of water, wave stresses, etc.).

To solve the partial differential equations the equations should be transformed to the discrete space. For the choice of the numerical methods, robustness has high priority. The numerical method of Delft3D-FLOW is based on finite differences. To discretize the 3D shallow water equations in space, the model area is covered by a curvilinear grid. It is assumed that the grid is orthogonal and well-structured. The grid co-ordinates can be defined either in a Cartesian or in a spherical co-ordinate system. In both cases a curvilinear grid, a file with curvilinear grid co-ordinates in the physical space, has to be provided. The numerical grid transformation is implicitly known by the mapping of the co-ordinates of the grid vertices from the physical to the computational space. Such a file is generated by a grid generator Delft3D-RGFGRID.

To ensure that the total mass is conserved the transport equation in Delft3D-Flow is discretized with a mass conserving Finite Volume approach (flux form). For the spatial discretization of the horizontal advection terms, two options are available in Delft3D-low. The first (and default) option is a finite difference scheme that conserves large gradients without generating spurious oscillations and is based on the ADI-method. This scheme is denoted as the Cyclic method. The Cyclic method is based on an implicit time integration of both advection and diffusion and does not impose a time step restriction.

12.2. HYDRODYNAMIC MODEL SETUP

Model set-up means the bathymetry, boundary conditions, bed roughness and eddy viscosity are selected and set for the area to be modelled.

A numerical grid is first established for the hydrodynamic modelling. As illustrated in **Figure A.1**, the modelling extent covers about 19 km of the strait at the western side of Johor-Singapore Causeway Link, in which the west boundary is open boundary that located near Pendas and the east is closed boundary located at Johor Causeway link. The project site is about 1.1 km away from the east boundary and 18 km from the west boundary. The horizontal model resolution ranges from 5 to 20 m which is adequate for accurately simulating the physical processes in the immediate vicinity of the project site.

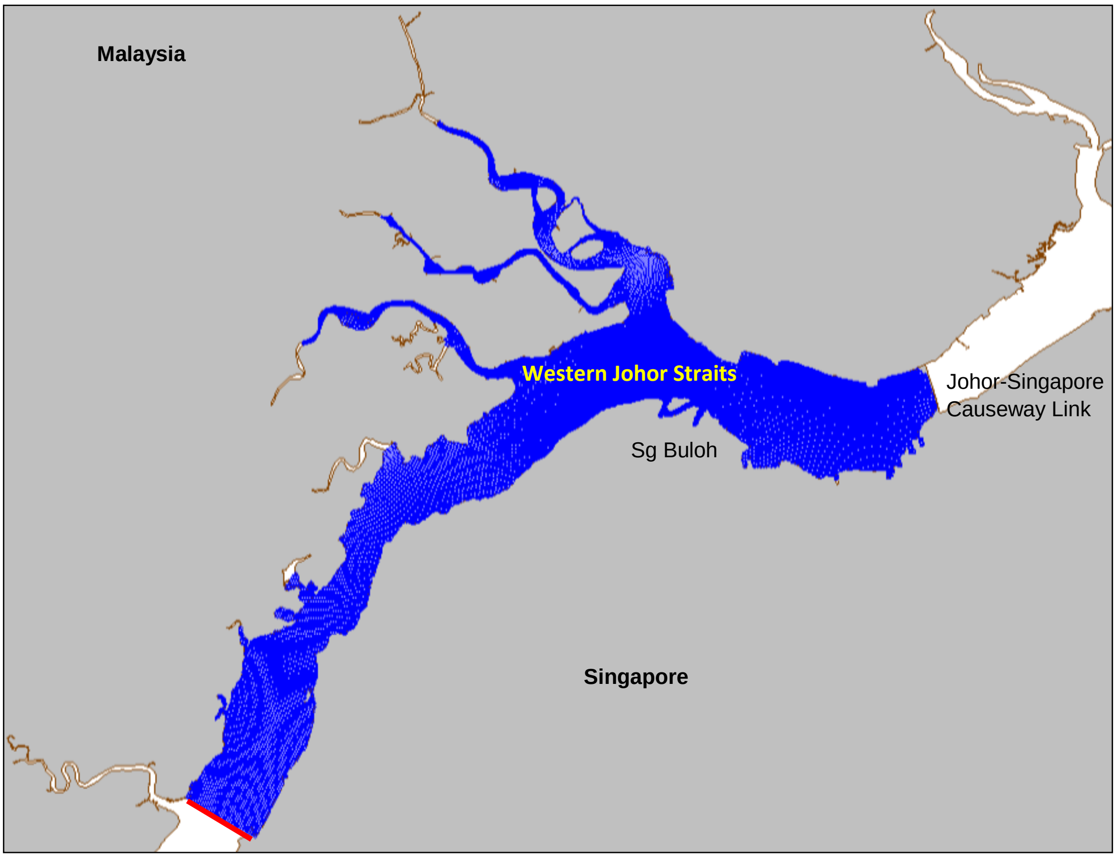

Figure A.1: Grid mesh for hydrodynamic modelling.

The bathymetry of the Johor Strait is digitized based on Admiralty Charts where corrections have been made to the chart until 2014. Detailed bathymetry covering the site is essential for the performance and reliability of the model. The surveyed bathymetry from the Client was also used.

The grid depth was interpolated from the available bathymetry data. **Figure A.2** shows the depth of the model domain with reference to the ACD. The bathymetry varies gently along the strait. The maximum depth in the model domain is about 25 m and the maximum depth at project site is about 10 m.

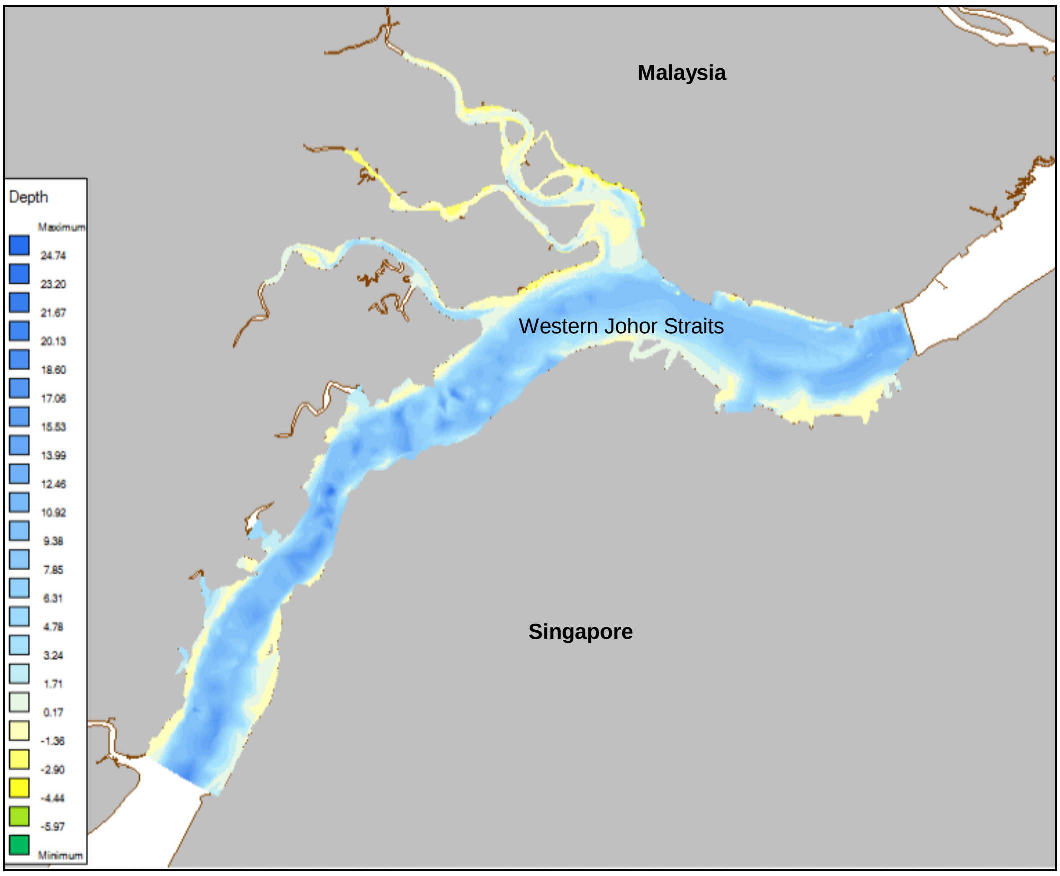

Figure A.2: The depth of the model domain

The boundary conditions for the numerical model setup are established based on the information gathered from tidal station in the Johor Strait. One open boundary and one close boundary have been used for the model setup as illustrated in **Figure A.3**. The boundaries are set to cover larger portion of the western side of Johor Strait to ensure that the tide and current are captured to represent the conditions of the site of interests. The calibration and verification of the hydrodynamic model are carried out using the in-house database.

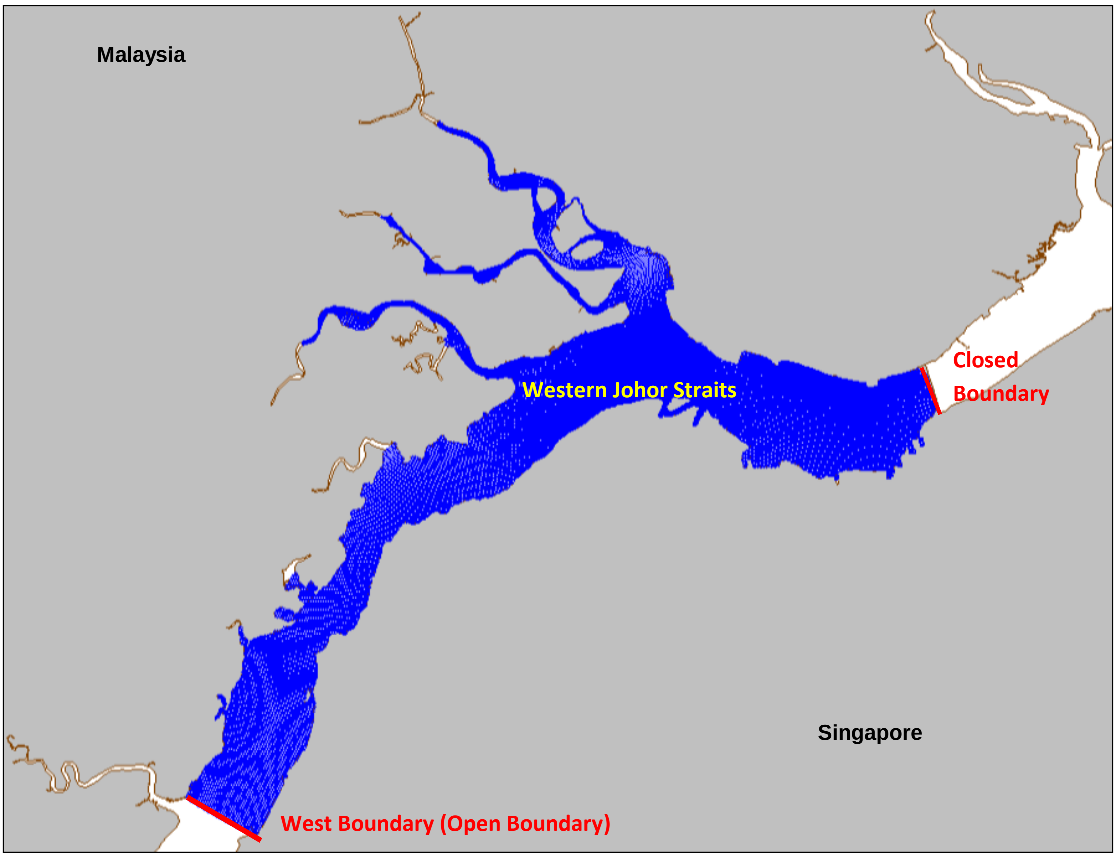

Figure A.3: One open and one close boundaries of the model

12.3. TYPICAL FLOW PATTERNS

This section illustrates 2 selected results from the hydrodynamic modelling. **Figure A.4** show the typical flow patterns during the flood and ebb tide phases in the Johor Strait. It can be seen that the tidal currents are directed from west to east during the flood tide and vice versa during the ebb tide. The maximum flow magnitude in Johor Strait is about 0.5 m/s at the narrowest stretch and gradually decreased towards east. The flow is nearly stagnant close to the Johor Causeway.

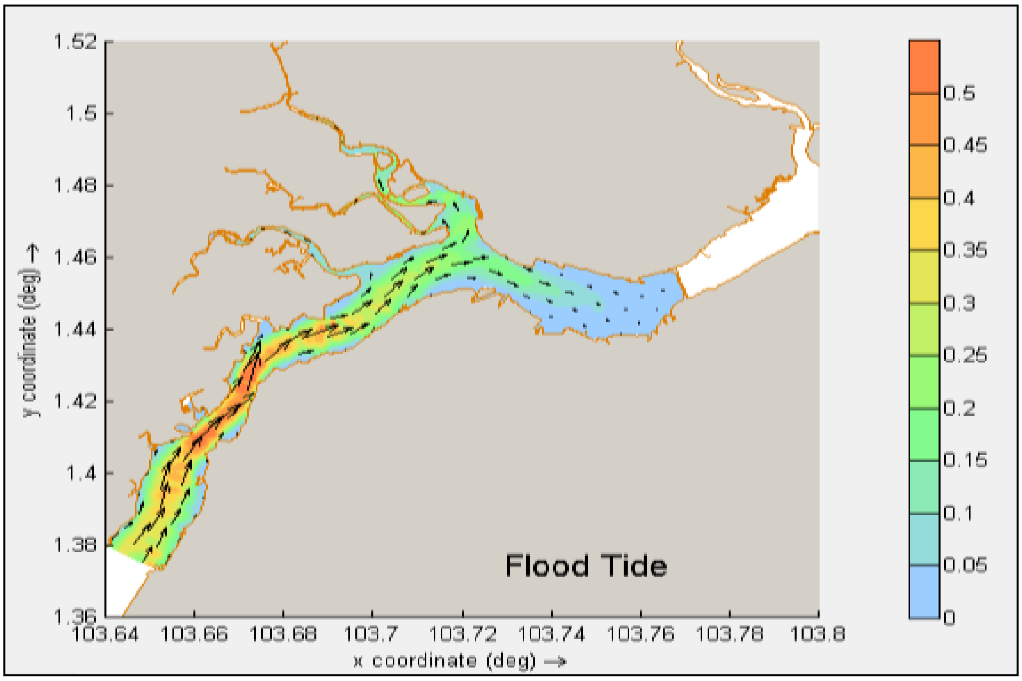

Figure A.4 (a): Typical current flow (m/s) at flood tide in the Johor Strait.

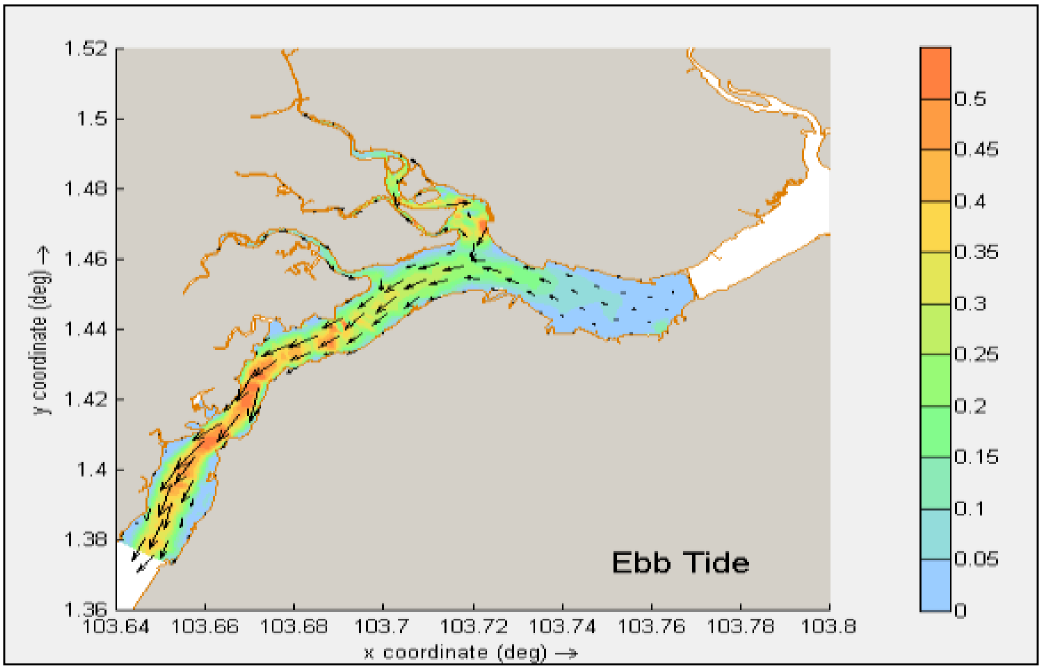

Figure A.4 (b): Typical current flow (m/s) at ebb tide in the Johor Strait.