

Plot 6 Development at Keppel Island

Environmental Study Report



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Prepared for Keppel Land Pte Ltd
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APPENDICES

- A** **Hydrodynamics Model Setup and Results**
- B** **Sediment Plume Model Setup and Results**
- C** **Laboratory Results**
- D** **Marine Ecology Baseline Survey Results and Literature Review**
- E** **Terrestrial Flora Baseline Survey Results**
- F** **Terrestrial Fauna Baseline Survey Results**
- G** **Soil Investigation Report**

Executive Summary

Keppel Land Pte Ltd intends to develop a residential development in Plot 6 at Keppel Island of Singapore. The proposed development will comprise the demolition of the Keppel Marina Multi-purpose Berth MKPM on the southern part of Keppel Island and the construction of a pile deck and floating boardwalk. The proposed residential development will be a low rise residential development.

Construction activities are not confirmed at this stage but are likely to include demolition, piling, soil excavation and construction of superstructure. As the construction methodology is not yet set, the worst-case scenarios in terms of potential impacts were identified and assessed within the study.

DHI established the baseline conditions in the Project area using baseline surveys and available secondary data. The MIKE by DHI suite of fully calibrated and validated numerical models, as well as expert judgement, quantified the potential impacts associated with the proposed development works in Plot 6 at Keppel Island.

The following changes and impacts were predicted for the construction (process) phase:

- **Hydrodynamics:** The hydrodynamic conditions during the baseline stage were determined using a calibrated and validated MIKE 21 HD model. Details of these baseline characteristics can be found in Section 5.1.1. No modelling for the construction phase was conducted, as no significant impacts on hydrodynamics were expected.
- **Sediment plume:** The MIKE 21 MT model simulated sediment plumes from demolition and piling works based on the client's construction methodology. Worst-case scenarios for receptors on the east and west of Keppel Island were assessed, including the impact during the intermonsoon season with minimal flushing rate as requested by NEA. The model results show sediment plumes being generated from the works, with a larger plume on the eastern side and slight differences between chosen monsoon seasons. Generally, the plumes were localised around the Study Area.
- **Pollutant Release:** In relation to water quality, a study was conducted on the potential release of heavy metals from suspended sediment during piling activities. Calculations based on conservative inputs from baseline sediment and water quality data, along with maximum amounts of suspended sediments generated, showed a minimal increase in heavy metal concentrations. When compared to the ASEAN MWQC for the protection of aquatic life, the analysis indicated that there were no exceedances of the ASEAN MWQC, and the risk of heavy metal contamination in the water due to suspended sediment is very low.
- **Air quality:** Expected construction activities that produce dust, such as Demolition, Earthworks, Construction, and Trackout, were assessed and found to be contributing a "Medium" to "Large" amount of dust emission, based on the Institute of Air Quality Management (IAQM)'s Guidance on the Assessment of Dust from Demolition and Construction.
- **Airborne Noise:** The noise levels in the study area were measured using the SoundPlan 3D noise propagation model in two (2) construction scenarios. The model predicted that noise from the demolition and piling work was mainly concentrated around Keppel Island. Only the Marina at Keppel Bay and the wildlife in the Hillock Area were exposed to excessive noise. It was shown that building a 4.0 m high noise barrier would reduce the noise levels to 61 dBA at the Hillock Area and 62 dBA at the

Marina at Keppel Bay. For all other locations, the predicted noise levels were no more than 64 dBA.

- **Ground Vibration:** The vibratory piling rig employed for the piling work is anticipated to generate significant ground vibrations exclusively on Keppel Island. The predicted levels indicate that the Hillock Area may experience up to 2.86 mm/s of Peak Particle Velocity (PPV), while employees of local businesses and recreational users could be exposed to 2.60 mm/s of PPV. Human responses to these vibrations are expected to be manageable, provided that affected individuals receive prior warnings and explanations, although complaints may still arise. The response of wildlife to the anticipated ground vibrations is likely to be similar to, or even more intense than, that of humans in terms of stress.
- **Underwater Noise:** The construction of the residential development and the floating boardwalk could potentially stress marine life, particularly fish and large marine animals, in the study area. Underwater noise comes from natural, human-made, and tonal sources. Potential effects were assessed using the National Marine Fisheries Service (NMFS) Multi-Species Pile Driving Calculator. The results indicate that sea turtles may change their behaviour up to 10 m away from the piling location, while fish may be impacted up to 464 m away.
- **Marine Ecology and Biodiversity:** The study area contains significant marine habitats, including intertidal zones (coral and seagrass), coral reefs, subtidal seagrass, and notable marine fauna and megafauna. Various impacts on these habitats were evaluated, yielding impact levels ranging from **No Impact** to **Moderate Negative Impact** before mitigation. This assessment utilised a combination of modelling, calculation results, and qualitative evaluations. The most considerable impacts during the construction phase are anticipated to arise from spills/leaks, marine construction activities, and erosion/sedimentation effects, particularly affecting the marine habitats around Keppel Island. Underwater noise is also expected to have significant effects on marine fauna and megafauna. To achieve the Environmental Quality Objectives (EQOs), these impacts should be managed through a Construction Environmental Management and Monitoring Plan (CEMMP), along with measures to prevent accidental spills by implementing appropriate controls. Additionally, mitigation strategies for underwater noise impacts should be established.
- **Terrestrial Ecology and Biodiversity:** Key terrestrial biodiversity receptors include the flora in the Hillock Area and the fauna in the Study Area. The impacts assessed on these terrestrial biodiversity receptors range from **No Impact** to **Minor Negative Impact**. The most significant concerns involve the potential encroachment of construction equipment into the tree canopy of the Hillock Area and the effects of increased airborne noise on terrestrial fauna. It is important to note that no loss of flora in the Hillock Area is expected due to the construction of the residential development and the floating boardwalk. To manage the anticipated impacts on terrestrial flora and fauna, terrestrial Environmental Management and Monitoring Plan (EMMP) measures should be implemented, including designated "No Infringement Zones" in the Hillock Area.
- **Marine Infrastructure and Navigation:** The construction of the residential development and floating boardwalk is anticipated to result in impacts on marine navigation, marine jetties and piers, and marine intake in the Study Area, with effects ranging from No Impact to Slight Negative Impact. Proposed mitigation measures, such as the Formal Safety Assessment (FSA) and close coordination with MPA during works, are intended to address these impacts.
- **Rivers and Canals:** Berlayer Creek is located near the Project and may be subject to potential impacts. The construction of the residential development and floating boardwalk could lead to sedimentation at their outlets, which may impair their ability to

discharge into the sea. However, sediment plume model results indicate no significant sedimentation at the river's outlet, alleviating concerns about the blockage of this water body.

- **Socio-economic:** According to the baseline surveys, most socio-recreational users of the boardwalks surrounding Keppel Island reside in the area and primarily engage in walking as their main recreational activity (from Labrador Park to Keppel Island). The assessment indicated that the construction works would result in impacts ranging from **No Impact to Minor Negative Impact**. The most significant anticipated effects include underwater noise impacting divers and construction-related issues affecting recreational users (such as air pollution, changes in airborne noise, ground vibration, and visual landscape impacts), which may also occasionally affect staff of businesses. To minimise potential negative impacts on the health and safety of recreational users, appropriate mitigation measures are recommended.

During the Post-construction phase, the following changes and impacts were predicted:

- **Hydrodynamics:** The hydrodynamic changes in the Study Area were evaluated using DHI's MIKE 21 HD model. The results indicate alterations in slackwater duration and the 95th percentile BSS (for long-term sedimentation and erosion assessment) primarily in the waters just south of Keppel Island and around the newly constructed boardwalk.
- **Marine Ecology and Biodiversity:** Predicted impact levels range from **No Impact to Moderate Negative Impact**. The loss of habitat within the pile deck and floating boardwalk area is expected to significantly affect the identified marine ecological receptors. To address the anticipated loss of coral reefs, intertidal areas, and subtidal seagrass, relocation efforts for coral and seagrass are proposed within a 100 m buffer around the pile deck footprint and the estimated marine working area.
- **Terrestrial Ecology and Biodiversity:** The Project footprint has minimal spatial overlap with terrestrial habitats, which helps prevent any impact on species in the Hillock area. The expected effects on terrestrial flora and fauna were evaluated as ranging from **No Impact to Minor Negative Impact**, with the primary concern being the effect of the Project footprint on fauna within that area.
- **Marine Infrastructure and Navigation:** The footprint of the residential development and the floating boardwalk is anticipated to result in impacts on marine infrastructure and navigation in the Study Area, ranging from No Impact to Slight Negative Impact.
- **Rivers and Canals:** According to the bed shear stress results, the residential development and the floating boardwalk are unlikely to face sedimentation at the mouth of Berlayer Creek. Therefore, **No Impact** on the rivers and canals is anticipated.
- **Socio-economic:** Potential impacts on socio-economic receptors in the Study Area primarily stem from changes in the landscape, ranging from **No Impact to Minor Negative Impact**. While marine-based recreational users are not anticipated to be affected by current changes, significant impacts may arise from the loss of recreational spaces once the Project is completed.

The Environmental Study has recommended the requirements for a Construction-specific Environmental Monitoring and Management Plan (CEMMP) for the Project, encompassing both marine and terrestrial areas, as well as providing comprehensive mitigation measures within each of the relevant assessments.

Overall, the Project does not pose any significant negative or unacceptable impacts given the suitable application of mitigation, management, and recommendations provided.

1 Introduction

DHI Water & Environment (S) Pte. Ltd. (“DHI”) has been commissioned by Keppel Bay Pte. Ltd. (henceforth termed the “Client”) to conduct an Environmental Study (ES) (henceforth referred to as “Study”) for the construction of a residential development and its associated developments on Keppel Island (henceforth termed the “Project”). These include demolition of the Keppel Marina Multi-purpose Berth MKPM on the southern part of Keppel Island (henceforth termed as the “Wharf”), and construction of a pile deck and floating boardwalk (Figure 1.1).



Figure 1.1 Map of the spatial extents of the residential development and floating boardwalk at Keppel Island (Source: Google Earth image @ 2024 Maxar Technologies)

1.1 Study Objectives

The Study comprises two (2) main components as follows:

- **Environmental Study (ES):** To establish the baseline environmental conditions prior to the proposed development, predict potential environmental impacts due to the proposed development, and assess and document the results.
- **Formulation of an Environmental Monitoring and Management Plan (EMMP) for the Project:** To provide recommendations for mitigating predicted impacts and guidance and input for the implementation of the EMMP during the pre-construction, construction and post-construction stages to monitor and manage potential impacts due to the actual construction works, so that Environmental Quality Objectives (EQOs) for the identified environmental receptors would be met.

The adequacy and relevance of the EMMP framework and its implementation for the construction of the proposed development are hinged on the Environmental Study. The objectives of the Environmental Study are, therefore, to provide information and

assessment on the nature and extent of environmental impacts expected to arise from the construction of the proposed development, to (1) undertake consultation with the TAs and ensure that specific concerns are addressed, and (2) form the basis for a robust EMMP framework for the Construction Phase.

The detailed objectives are as follows:

- To identify and determine the baseline conditions of biodiversity and to formulate a biodiversity inventory and distribution map;
- To assess the extent of potential environmental impacts caused by the construction of the proposed Project based on the detailed development plan; and
- To propose suitable mitigation measures in order to prepare a robust Environmental Monitoring and Management Plan (EMMP) for the Construction and Post-Construction Phases of the Project in preparation for future steps.

This report outlines the objectives and methodologies for the Environmental Study, details the environmental baseline results, describes the development works and discusses the potential impacts predicted to arise from them. It also documents the recommended measures to mitigate the predicted impacts and outlines an Environmental Management and Monitoring Programme (EMMP) for the Project.

1.2 Report Layout

The Environmental Study Report is structured as follows:

- Section 1 – Introduction
- Section 2 – Project Understanding
- Section 3 – Environmental Laws, Standards and Guidelines
- Section 4 – Environmental Study Scope and Approach
- Section 5 – Construction Phase (Short-Term) Impacts
- Section 6 – Post-Construction Phase (Long-Term) Impacts
- Section 7 – RIAM Impact Significance Summary
- Section 8 – Environmental Management Framework
- Section 9 – Conclusion

- Appendix A – Hydrodynamics Model Setup and Results
- Appendix B – Sediment Plume Model Setup and Results
- Appendix C – Laboratory Results
- Appendix D – Marine Ecology Baseline Survey Results and Literature Review
- Appendix E – Terrestrial Flora Baseline Survey Results
- Appendix F – Terrestrial Fauna Baseline Survey Results
- Appendix G – Soil Investigation Report

2 Project Understanding

2.1 Project Location

The proposed Project site is located on Keppel Island (Figure 2.1), west of the southern tip of mainland Singapore. The island is connected by a bridge to the mainland (henceforth termed “Keppel Bridge” or “Keppel Island Vista”), which is linked to the end of a coastal boardwalk from Labrador Nature Reserve. This pathway crosses large private residential areas such as Reflections at Keppel Bay and Caribbean at Keppel Bay. Keppel Island is approximately 5 ha in size. Its southern half comprises manicured fields and small grass pastures, while the northern half comprises approximately 1.5 ha of coastal forest. The proposed Project site is within the southern half of Keppel Island, also designated as “Plot 6” (~2.2 ha in size), while the northern coastal forest is termed the “Hillock Area” herein.



Figure 2.1 Overview of the profile of Keppel Island (source: Client)

Due to its proximity to the coral-rich Southern Islands of Singapore (Ng *et al.*, 2013; Chou *et al.*, 2019; Figure 2.2), Keppel Island and its surroundings (i.e., Marina at Keppel Bay) harbour a high richness of hard and soft coral communities. These communities are well documented by local nature groups such as Wild Singapore and the Blue Water Volunteers (Tan, 2015; Tan, 2021). One of the most well-known coral communities in the area is the Marina at Keppel Bay, which hosts a rich variety of species due to the careful thought put in to ensure that the Marina is well-flushed (Ang, 2022). To the west of Keppel Island is one of Singapore’s four Nature Reserves, the Labrador Nature Reserve and, alongside it, Berlayer Creek. Berlayer Creek is one of the two remaining stands of mangrove forests along the southern shoreline of mainland Singapore (Yang *et al.*, 2011), and seagrass meadows are located at its mouth, with two species, *Halophila ovalis* and *Enhalus acroides*, previously recorded there. Due to the coastal nature of Berlayer Creek and the multifunctional use of the Marina at Keppel Bay, the area serves many recreational functions, such as being a popular coastal track for walking, running, picnicking, and even educational outreach and diving.

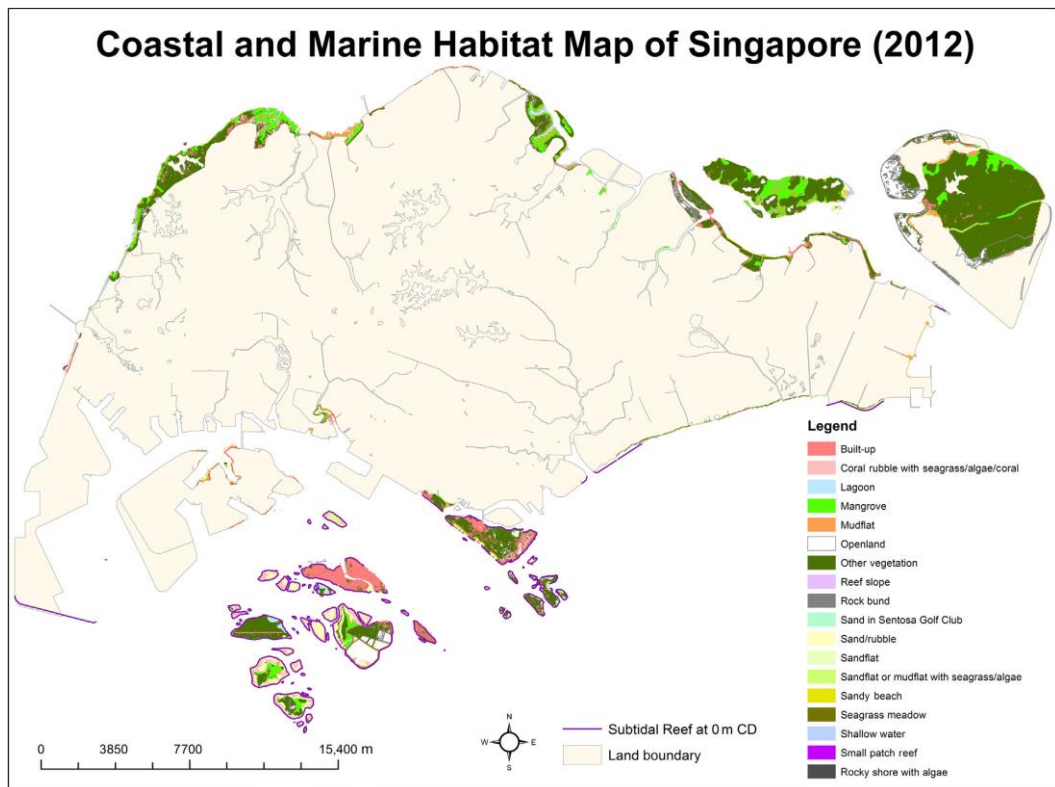


Figure 2.2 Distribution of marine and coastal habitats in Singapore in 2012 (obtained from Chou *et al.*, 2019)

2.2 Project Description

The proposed Project is a low-rise residential development at Keppel Island. With the retention of the Hillock Area in the north, and the construction of a new 5 m wide floating boardwalk in the south, the Project is surrounded by greenery or marine waters.



Figure 2.3 Plan view drawing of proposed residential development, including the existing Hillock Area in the north and floating boardwalk to the south (source: Client)

2.3 Project Background

2.3.1 Summary of Environmental Consultation and Scoping

This section summarises the original environmental consultant and scoping report respectively, including the proposed design as well as comments received from Technical Agencies (TAs).

Environmental Consultation

The environmental consultation was approved on 5th October 2023. The proposed design proposed reclamation within the three (3) existing lagoons south of Keppel Island, the extension of the Wharf on the western end, and the addition of a floating deck to the east (Figure 2.4). In the response, it was noted that works are in close proximity to several sensitive receptors, which would result in airborne and underwater noise emissions, air pollution and sediment plumes. In the long term, loss of corals and intertidal areas is also expected. DHI was requested to consult the Technical Agencies (NParks, MPA, and NEA) to scope the Environmental Study and was expected to have an engagement with the nature group(s) before the Environmental Study report can be accepted by the developer. Finally, the report is expected to be disclosed for public feedback. Results collected for this Study are also required to adhere to the authorities' standardisation guides for data storage.

Scoping Stage

During the scoping stage, the construction design was still undergoing modification as it was still ongoing discussions with authorities. The floating deck was first removed from the works completely. Then different construction design options were listed as three (3) construction designs.

The designs are as follows: 1) reclamation; 2) construction of a pile deck and; 3) floating boardwalk (Figure 2.5). Among the scenarios, reclamation was considered as the “worst-case” due to greater loss of ecological habitat and more pronounced change in hydrodynamics. In the event that one of the other alternative methods (pile deck or floating boardwalk) was chosen instead, the Environmental Study will only assess impacts relevant to the chosen method. One of the major differences in the impact assessment scope is the inclusion of wave modelling only in the worst case (i.e., reclamation) construction method. This is because the creation of new land would require reinforcement using a new vertical sea wall, which could result in the reflection of waves, and potential shipwake impacts and changes to the wave environment. However, because the waves in this area are generally calm due to the sheltered location, wave modelling and assessment was scoped out for the non-worst-case scenarios (i.e., pile deck and floating boardwalk designs).

Scoping was carried out between October 2023 and April 2024. While several designs were proposed, it was clearly stated that only one (1) design will be assessed in the Environmental Study (See Section 2.3.2).



Figure 2.4 Map of the construction design during the submission for the environmental consultation for Plot 6



Figure 2.5 Maps showing the designs proposed for Plot 6. Two designs share the same footprint with one design carrying out reclamation in the Proposed Reclamation Extent (top), and another carrying out pile decking in the same area (bottom). The third design is a combination of piling and the construction of a floating boardwalk.

2.3.2 Chosen Design

After discussions with authorities, the floating boardwalk method was chosen as the construction method and it comprises of a pile deck that provides a foundation to support the residential building, and a 5 m wide floating boardwalk. The floating boardwalk's layout connects the existing breakwater jetty on the west of Keppel Island and the edge of the Keppel Bay Bridge to the East of Keppel Island (Figure 2.6). The floating boardwalk was designed to be accessible in compliance with the Building and Construction Authority's Code on Accessibility in the Built Environment (2019). Therefore, it provides a longer waterfront experience for the public.

The footprint of Plot 6's residential development, construction boundary and extent of the proposed pile deck were provided by the Client. The marine work area was estimated to be 60 m based on the use of towboats which would be required to adjust/secure the floating boardwalk onto the piles.



Figure 2.6 Chosen construction design for Plot 6's residential development and floating boardwalk

The construction scope for the pile deck with floating boardwalk construction method, involves four (4) key aspects (with mentioned features shown in Table 2.1):

1. Demolition of the existing Wharf;
2. Erection of pile deck at the Proposed Pile Deck Area;
3. Installation of floating boardwalk; and,
4. Construction of residential buildings within Plot 6.

For aspect 2 and 3, the two different methodologies are elaborated in Table 2.1 below.

Table 2.1 Construction methodology for floating boardwalk scenario showing the pile deck installation, followed by the floating boardwalk

Pile Deck
• Demolition of existing Wharf structure. • Erection of pile deck, comprising of marine piles, precast beams, slab and walls. • Installation of pile deck to form basement floor and landscape deck.
Floating Boardwalk
• Installation of piles for floating boardwalk into seabed. • Fabrication of floating boardwalk off-site. • Transportation of completed floating boardwalk to launching site. • Launching of completed floating boardwalk into position in water. • Adjusting/securing floating boardwalk onto piles. •

2.4 Project Timeline

Construction is tentatively slated to start in the 2H 2025. Marine works are estimated to take around 37 weeks and the construction works are estimated to take a total of 38 months.

3 Environmental Laws, Standards and Guidelines

In addition to the environmental study Process employed across various environmental studies in Singapore (Section 3.1), there is a selection of laws, regulations, guidelines, conventions, and protocols identified and considered in the process of conducting the Study. These are presented in the sub-sections as follows:

Section 3.2	Relevant Singapore Legislation
Section 3.3	Relevant Singapore Regulations and Guidelines
Section 3.4	Applicable International Guidelines
Section 3.5	Conventions, Treaties and Protocols

3.1 Environmental Impact Assessment (EIA) Process in Singapore

At present, under the Planning Act (1998), statutory permissions and conditions can be imposed for the conduct of environmental studies and investigations into biodiversity. These studies are called Environmental Studies (ES), where potential environmental impacts of development proposals are assessed internally or collectively by relevant government agencies as part of the planning approval process.

The aim of an Environmental Study is to protect the environment by ensuring that a local planning authority, when deciding whether to grant planning permission for a project, does so in full knowledge of the likely significant environmental effects and takes this into account in the decision-making process. The EIA Framework in Singapore comprises a set of screening criteria to identify projects that agencies require more in-depth assessment, and a planning process that allows for environmental study and public disclosure when needed. The process is illustrated in Figure 3.1 and summarised in Table 3.1.

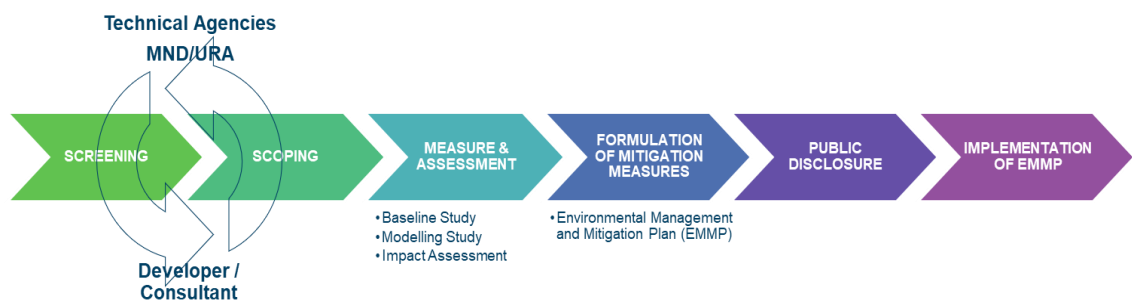


Figure 3.1 An illustration of the EIA Process in Singapore. The relevance and requirement of stakeholder engagement are project-dependent and can take place at various stages of the Study

Table 3.1 Objectives of key EIA stages in Singapore

EIA Stage	Objectives
Screen	To identify and recommend whether or not an Environmental Study is required and propose a stakeholder engagement plan for the Project.
Scope	To identify environmental pressures/changes arising from the Project and environmental sensitive receptors (ESRs) that may be affected by them and on that basis, determine assessment scope (spatial and temporal boundaries, impacts to be assessed) and formulate environmental study approach and methodology.
Measure	To describe the baseline conditions and the identified ESRs in potential impact zone of the Project, either through field surveys or desktop literature searches and data analysis.
Assess	To classify significance of impacts through assessment of magnitude and duration of environmental pressures in relation to tolerance limits of the ESRs, taking into account the importance of the receptors and their recoverability from the impacts.
Manage & Mitigate	To outline management and engineering measures which are required to mitigate the impacts to an as-low-as-reasonably-practicable level (ALARP) and monitoring regime for the Construction Phase to ensure that impacts are managed accordingly.
Engage	To engage relevant stakeholders (socio-economic receptors, interest groups, etc.) to obtain feedback on scoping, impact findings and monitoring requirements – stakeholder engagement requirement varies depending on scale of development, sensitivity of the Project area, among other factors.
Public Disclosure	After incorporation of relevant agencies' views, environmental study reports should be made available for public feedback. Public feedback received should be incorporated into the final environmental study report.
Implementation of the EMMP	Relevant agencies to implement and monitor the approved EMMP.

3.2 Relevant Singapore Legislation

Several Singaporean Acts are applicable to this Project. These include, but are not limited to, the following:

- Environmental Protection & Management Act 1999 (revised 2002). Covers pollution control including noise, hazardous substances, trade effluent & air quality (including ozone depleting substances, or ODS). Implemented by NEA (Pollution Control Department - PCD).
- Environmental Public Health Act 1987 (revised 2002). Covers general waste, dangerous substances, and hazardous wastes. Implemented by NEA.
- Maritime and Port Authority of Singapore Act 1996 (revised 1997). Establishes the Marine and Port Authority (MPA) of Singapore to provide for its functions and powers.

Also covers regulation and control navigation within the limits of the port and the approaches to the port. Implemented by MPA.

- Merchant Shipping (Civil Liability and Compensation for Oil Pollution) Act 2008 (revised 2010). Covers penalties for oil spills from any vessel. Implemented by MPA.
- Planning Act (revised 1998). An act to provide for the planning and improvement of Singapore and for the imposition of development charges on the development of land and for purposes connected therewith.
- Prevention of Pollution of the Sea Act 1990 (revised 1999). An act to put into effect the International Convention for the Prevention of Pollution from Ships 1973, as modified by the Protocol of 1978, and to other international agreements relation to the prevention, reduction and control of pollution of the sea and pollution from ships, and generally for the prevention reduction and control of pollution to the sea (MARPOL). Implemented by MPA.
- Sewerage and Drainage Act 1999 (revised 2001). An Act to provide for and regulate the construction, maintenance, improvement, operation and use of sewerage and land drainage systems, and to regulate the discharge of sewage and trade effluent. Implemented by PUB.
- Parks and Trees Act 2005. For the planting, maintenance and conservation of trees and plants within national parks, nature reserves, tree conservation areas, heritage road green buffers and other specified areas.
- Wildlife Act 1965 (revised 2021). For the protection, preservation and management of wildlife for the purposes of maintaining a healthy ecosystem and safeguarding public safety and health.

3.3 Relevant Singapore Regulations and Guidelines

Regulations and guidelines of relevance to the Project include, but are not limited to, the following:

- MPA General Guidelines on Requirements for Application on Dredging and Dumping Works (2014);
- JTC Guideline on Environmental Baseline Study (EBS) (2019);
- SLA Guideline on Environmental Site Assessment (ESA);
- NEA Hazardous Waste (Control of Export, Import and Transit) Regulations 1998 (revised 2000). Covers transport of hazardous waste (BASEL permits);
- NEA Environmental Public Health (Toxic Industrial Waste) Regulations 1988 (revised 2000);
- NEA Environmental Protection and Management (Hazardous Substances) Regulations 1999 (revised 2008);
- NEA Code of Practice on Pollution Control (2013);
- NEA Guidebook on Waste Minimisation for Industries (2002);
- NEA Code of Practice on Environmental Health (2017);

- NEA Environmental Protection and Management (Control of Noise at Construction Sites) Regulations 1999 (revised 2008) that include Maximum Permissible Noise Levels for Construction Work Commenced on or after 1st October 2007;
- NEA Singapore Ambient Air Quality Targets (2011);
- NParks Biodiversity Impact Assessment (BIA) Guidelines of Singapore (2020);
- PUB Code of Practice on Surface Water Drainage (2011);
- PUB Sewerage and Drainage (Trade Effluent) Regulations 1999 (revised 2007)
- PUB Requirements for Discharge of Trade Effluent into the Public Sewers 2016.

3.4 Applicable International Guidelines

Some aspects of the Project are not covered by existing Singapore regulations. For example, the Singapore guidelines do not specify certain water quality standards or guidelines. In accordance with usual environmental study practices, where National standards are not available, relevant international standards such as the World Bank (which includes the International Finance Corporation, or IFC) guidelines will be applied. DHI will also apply other relevant international benchmarks and our own well-established port and marine ecology related tolerance limits as appropriate. The standards and guidelines used within the assessment process will be further detailed within the environmental study Report.

3.4.1 World Bank / IFC

In general, the environmental study will reference where IFC Performance Standard 1: Assessment and Management of Environmental and Social Risks are relevant. More specifically, the environmental study may reference IFC Performance Standards, including:

- Performance Standard 3: Pollution Prevention and Abatement;
- Performance Standard 4: Community Health, Safety and Security;
- Performance Standard 6: Biodiversity Conservation and Sustainable Natural Resource Management; and
- Performance Standard 8: Cultural Heritage.

The IFC Performance Standards are strengthened by a set of Environmental Health and Safety (EHS) Guidelines which provide additional supporting material to assist with improving compliance with the standards and improving project performance. Those which may apply for this Project include:

- Air emissions and ambient air quality;
- Wastewater and ambient water quality;
- Hazardous materials management; and
- Waste management.

3.4.2 Other International Guidelines

Other internationally accepted policies and guidelines may be referenced and applied as a basis for assessing impacts. The following, amongst others, have been identified for this Project:

- British Standard 5228 Code of Practice for Noise and Vibration Control on Construction and Open Sites (BS 5228-2, 2009);
- British Standard BS 6472 Guide to Evaluation of Human Exposure to Vibration in Buildings – Part 1: Vibration Sources other than Blasting;
- German Standard DIN 4150: Part 3 (1999) “Structural Vibration Part 3 – Effects of Vibration on Structures”;
- Federal Transit Administration (FTA) Transit Noise and Vibration Impact Assessment Manual (Quagliata *et al.*, 2018);
- European Union Guidance on ES (European Commission 2001);
- The European Commission’s Integrated Pollution, Prevention and Control (IPPC) General Principles of Monitoring, 2003;
- Association of Southeast Asian Nations Marine Water Quality Criteria (ASEAN 2008) for assessing water quality;
- Hong Kong Sediment Quality Criteria for Management of Dredged/Excavated Sediment (ETWB, 2002);
- International Panel on Climate Change (IPCC), 2013: Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5 WG1 2013);
- IUCN Red List of Threatened Species for assessing the vulnerability of species. Under this classification scheme, globally threatened species have been categorised as Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened or Least Concern;
- Singapore Red Data Book version 3 (NParks, 2024a) for assessing the vulnerability of species in Singapore. Under this classification scheme, locally threatened species have been categorised as Globally Extinct, Presumed Nationally Extinct, Critically Endangered, Endangered, Vulnerable, Near Threatened or Least Concern;
- The Netherlands Ministry of Housing, Spatial Planning and Environment Target Values and Intervention Values for Soil Remediation (VROM, 2000) for assessing soil toxicity; and
- USEPA Guidelines for Assessing Air Quality.

It should be noted that this list is not exhaustive, and specific standards and guidelines may be referenced throughout the relevant sections of this Environmental Study Report.

3.5 Conventions, Treaties and Protocols

Singapore has ratified or acceded to the following key international conventions, treaties and protocols of relevance to this Environmental Study:

- ASEAN Agreement on Transboundary Haze Pollution 2002;
- BASEL Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal 1989;
- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, the "London Convention" in short;
- International Convention on Civil Liability for Oil Pollution Damage, 1969, renewed in 1992 and often referred to as the CLC Convention;
- International Regulations for Preventing Collisions at Sea 1972 (Colregs) are published by the International Maritime Organization (IMO);
- International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC) 1990;
- International Convention for the Safety of Life at Sea (SOLAS), most recent amendment dates from May 2011;
- Kyoto Protocol to the UNFCCC 1997;
- MARPOL 73/78: International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978. ("MARPOL" is short for marine pollution and 73/78 short for the years 1973 and 1978.);
- Montreal Protocol on Substances that Deplete the Ozone Layer 1987 and its Amendments;
- Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade 1998;
- Stockholm Convention on Persistent Organic Pollutants 2001;
- UN Convention on Biological Diversity 1992;
- UN Framework Convention on Climate Change (UNFCCC) 1992;
- United Nations Convention on the Law of the Sea (UNCLOS) 1982, also called the Law of the Sea Convention or the Law of the Sea treaty; and
- Vienna Convention for the Protection of the Ozone Layer 1988.

4 Environmental Study Scope and Approach

4.1.1 Study Scope

DHI identified potential impacts from the Project using a Scoping Matrix. This process requires a clear understanding of impact processes, including ecosystem processes and linkages. An impact process describes how a specific receptor is affected by a specific type of impact, i.e., from Pressure via Pathway to Receptor. All three elements are required for there to be an impact. For example, if there is no pathway from the source of the pressure to the receptor, then no impact will eventuate, and if there is a pressure source but no receptor, there will also be no impact.

Environmental pressure is defined as a change in environmental conditions (such as currents, waves, and water quality) resulting from a development project. A sensitive receptor is a social, economic or ecological feature that may be affected by a pressure or a group of pressures. The following subsections discuss the pressures and receptors relevant to the Project in detail.

4.1.2 Temporal Scope of Assessment

There is a general need to set a timescale for environmental studies to establish the period to assess impacts. This Environmental Study covers the demolition of the existing Wharf, construction of the pile deck, installation of the floating boardwalk, and construction of the residential buildings. These are the short-term impacts of the “Construction” Phase assessed in this Environmental Study. The long-term impacts of the Project will be assessed against a reasonably foreseeable future, i.e., after all the proposed works have been completed and the Project moves into the operational phase, which is the “Post-Construction” Phase assessed in this Environmental Study. The specific assessments DHI will carry out for each phase are detailed in Table 4.1.

Table 4.1 Summary of the relevant assessments that will be carried out in this Environmental Study for the identified phases (construction and post-construction)

Construction Phase	Post-Construction Phase
Sediment plume and sedimentation	Direct impact (habitat footprint and landscape change)
Air quality	Currents
Airborne noise	Long-term erosion/sedimentation
Underwater noise	Marine navigation
Vibration	
Marine navigation	
Construction site visual impact	

4.1.3 Environmental Scope

Expert scoping for the Project was conducted between October 2023 and April 2024, including consultation with URA and Technical Agencies. The exercise identified relevant environmental pressures listed in Section 4.1.3.1, sensitive receptors in Table 4.2, and the Scoping Matrix in Table 4.3.

4.1.3.1 Environmental Pressures

Based on the understanding of the proposed Project described in Section 2, which includes the planned construction activities, and features and footprint of the final development, the environmental pressures which are expected to arise from the Project have been identified as follows:

Construction Phase

- Visual impact due to construction site;
- Physical disturbances due to construction activities;
- Construction vessel traffic;
- Suspended sediments and sediment plume in the marine environment due to the demolition and piling works, and/or runoff from the construction site;
- Sedimentation of the suspended sediments;
- Water quality changes (i.e., pollution release);
- Spills and leaks;
- Underwater noise emission from piling works;
- Airborne noise emission from demolition, piling and residential building construction works; and,
- Air pollution (dust) from demolition, piling, building construction works and vegetation clearance.

Post-Construction Phase

- Project footprint and landscape changes due to the Project's development;
- Hydrodynamic changes in currents due to the Project's development; and,
- Long-term seabed erosion and sedimentation due to the Project's development.

4.1.3.2 Sensitive Receptors

The spatial scope for identification of sensitive receptors varies for each pressure, depending on the likely spatial scale of change, as well as any distances of concern from existing guidelines. For example, the Institute of Air Quality Management (IAQM) Guidance on the assessment of dust from demolition and construction (Stoaling *et al.*, 2023) recommends the consideration of receptors within 250 m from the project boundary, so this boundary will be used for scoping for this Environmental Study.

Based on the literature review and DHI's in-house knowledge, Figure 4.1 shows the key known environmental features within the Study Area. In contrast, Figure 4.2 shows the specific sensitive environmental receptors that will be assessed as part of the Environmental Study (listed in Table 4.2). Note that the sensitive receptors are a subset of

the known environmental features, as informed by guidelines, literature review and site understanding.

For maritime navigation, Keppel Harbour and Selat Sengkir, north and south of Brani Island to the east of the Singapore-Sentosa link bridge, were scoped out due to distance or lack of navigational connectivity. For coral habitats, areas immediately around the works, i.e., Keppel Island coastline, Keppel Marina and southern coastline of the condominiums, will be the first to get impacted and thus were scoped in, while further out areas such as corals along the northern coast of Sentosa were scoped out. Similarly, for socio-economic receptors, the main users targeted are people whose activities are centred around Keppel Island, receptors that will be immediately affected by the works. Additionally, the client has confirmed that there will be no construction works carried out at night, hence impacts from the construction on the receptors are limited to daylight hours only (i.e., 0700hrs – 1800hrs).

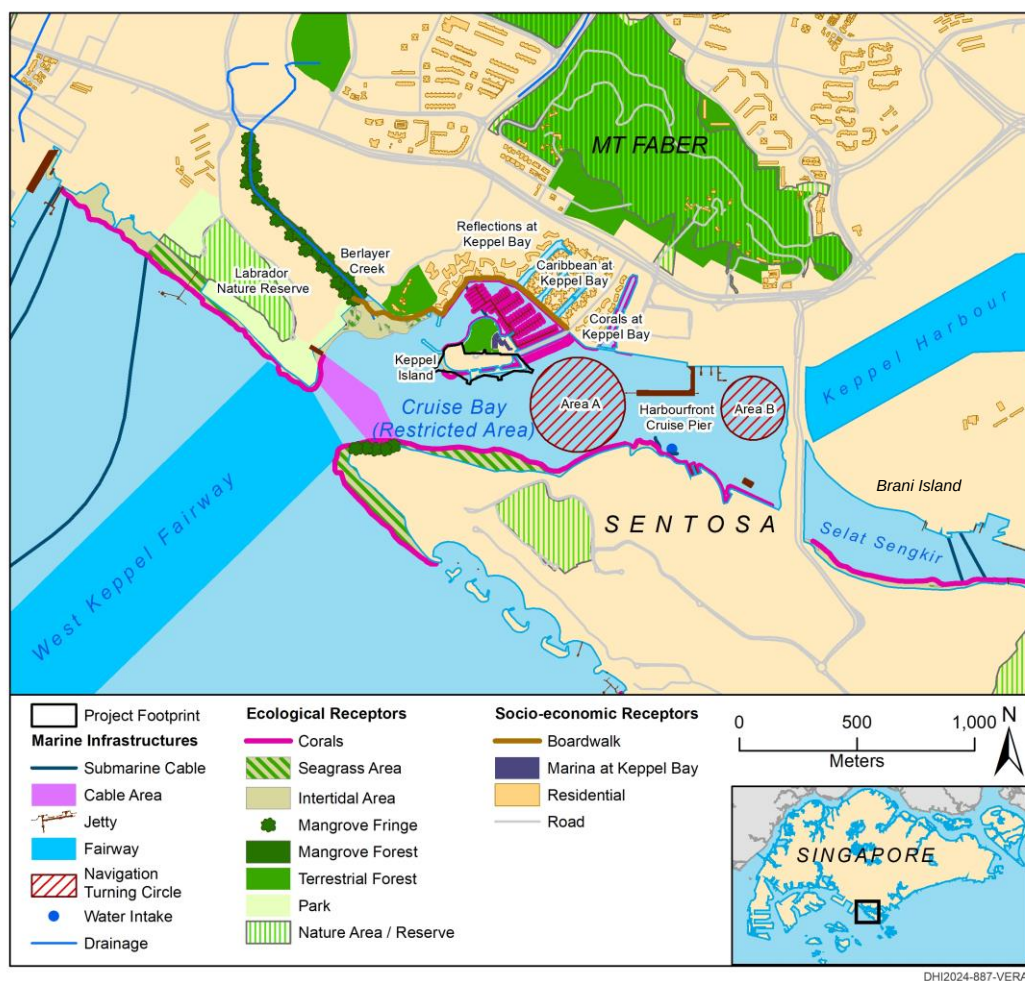


Figure 4.1 Broad overview of the Project area and existing environmental features in the vicinity of the Project works

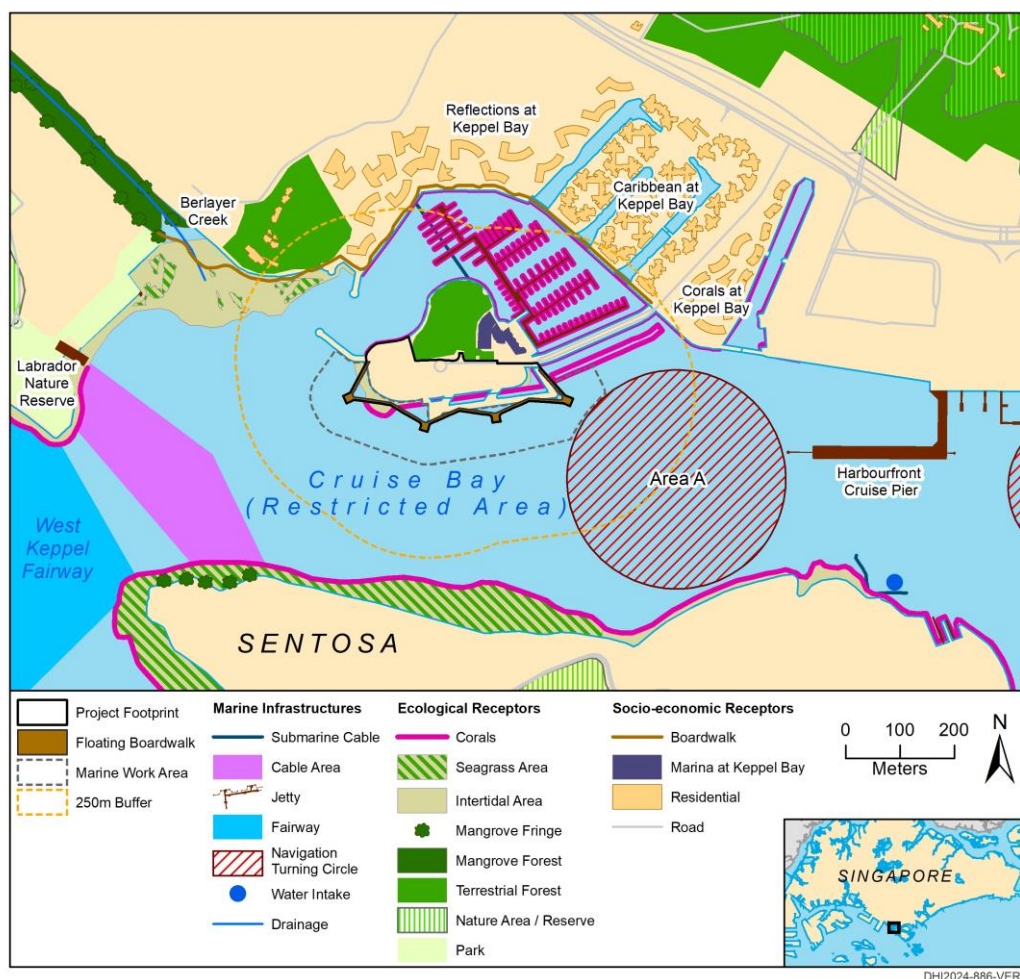


Figure 4.2 Existing environmental receptors in the vicinity of the Project works that will be assessed in this Environmental Study

Table 4.2 List of key sensitive environmental receptors within and near to the proposed development

Receptor groups	Sensitive Environmental Receptors (estimated distance from works)
Maritime infrastructure and navigation	- HarbourFront Cruise Pier (~500 m) - Marina at Keppel Bay (~100 m) - Marine navigation space south of Keppel Island, and West Keppel Fairway (<100 m). Within these areas are navigational turning circles and restricted areas for navigation. Keppel Harbour and Selat Sengkir are assessed to be outside of potential impact zone.
Submarine infrastructure	- Submarine cables and pipeline between Keppel Island and Singapore mainland (~150 m) - Submarine cables between Sentosa and Labrador Park (~1 km) - Submarine pipeline at Resorts World Sentosa (~700 m)
Marine intake	Marine intake at Resorts World Sentosa (~700 m)
River	Berlayer Creek (~500 m)
Ecology and biodiversity	- Terrestrial flora and fauna in the Project footprint (i.e., Plot 6) and the Hillock Area (<50 m) - Intertidal areas around Keppel Island and at the mouth of Berlayer Creek (~150 m) - Seagrass at the mouth of Berlayer Creek and at the coastal edge of Bukit Chermin (~150 m) - Mangroves at Berlayer Creek (~500 m) - Corals within and around the Project footprint, including the existing lagoons, the coastal areas of Keppel Island, under Keppel Island Vista (the connecting bridge between Keppel Island and the mainland), the caissons south of Keppel Island Vista and at Marina at Keppel Bay (<50 m) - Marine fauna in the waters around Keppel Island - Macrobenthos within and around the Project footprint (<50 m)
Socio-economic receptors	- Residents within 250 m boundary from the Project (Reflections at Keppel Bay, Caribbean at Keppel Bay, and Corals at Keppel Bay) - Staff of businesses within 250 m boundary from the Project - Recreational users: - At Keppel Island (Lawn area, Keppel Island Viewpoint, Keppel Island Plaza, etc.), Marina at Keppel Bay (businesses, administrative office, berthing dock for luxury yachts) (<50 m), and Keppel Bay Promenade (from Corals at Keppel Bay to Reflections at Keppel Bay) (~200 m) - Passengers in cruise ships passing through the Project area - Carrying out water sports (i.e., scuba diving and snorkelling) and boaters around Keppel Marina (~100 m)

4.1.3.3 Key Environmental Issues

All interactions presented in Table 4.3 will be explored in this Environmental Study. However, the following key environmental issues are useful in helping to focus on the effects of the Study:

- Direct loss of habitats and biodiversity within the Project footprint (including intertidal and coral reef habitats);
- Sediment plume impacts from piling works on marine ecology and biodiversity, rivers and marine intakes, and resulting inaesthetic appearance of the water for human users (both land and marine);
- Construction works impacting marine navigation of a major route for boats arriving and departing HarbourFront Cruise Pier;
- Construction noise (airborne and underwater) and ground vibration impacts from sound-intensive piling works, and air quality impacts from general construction work on nearby residential areas, recreational locations (e.g., Marina at Keppel Bay, the Keppel Bay Promenade), and fauna (e.g., avifauna, marine and terrestrial) within the Project's vicinity;
- Indirect construction impacts and potential edge effect impacts on the coastal forest in the Hillock Area;
- Potential impact on avifauna moving through and using the site during and following development;
- Indirect construction impacts and potential edge effect impacts on the coastal forest in the Hillock Area;
- Potential impact on ecological connectivity of marine receptors from the Project footprint; and
- Long-term erosion/sedimentation changes in the seabed as a result of the development.

There are no known autonomous developments in the vicinity of this Project. Even though MPA Port Marine Notice (PMN) No. 54 of 2023 indicates the channel next to Caribbean at Keppel Bay to be a working area until 30 December 2023 for the installation of a floating deck, construction works for the floating deck are off-site, and the marine works for the installation have been completed, hence no cumulative impact is expected.

Table 4.3 Scoping Matrix for the proposed Project. “S” refers to Short-term, Construction Phase impacts; “L” refers to Long-term, Post-Construction Phase impacts.

Environmental Pressures	Marine infrastructure and navigation					Ecology and biodiversity								Socio-economic		
	Jetties	Marine navigation	Submarine cables	Marine intakes	Rivers and canals	Terrestrial flora	Terrestrial fauna	Intertidal area	Seagrass	Mangroves	Corals	Marine fauna (including megafauna)	Macrobenthos	Residents	Staff of Businesses	Recreational Users
Project footprint and landscape		L				L	L	L	L*		L		L	SL	SL	SL
Currents	L	L														L
Physical disturbance due to construction activities						S	S	S			S	S		S	S	S
Construction vessel traffic		S														S
Suspended sediments				S				S	S		S	S		S	S	S
Erosion/sedimentation	SL	SL	L		SL			SL	SL	L	SL		SL			
Pollution release				S				S	S	S	S	S				S
Spills and leaks				S		S	S	S	S	S	S	S		S	S	S
Underwater noise												S				S
Airborne noise and ground vibration							S							S	S	S
Air quality							S							S	S	S

*Subtidal Seagrass

4.2 Study Approach

DHI's overall workflow for environmental studies is illustrated in Figure 4.3. This section elaborates on the approach for the Measure, Assess and Manage stages.

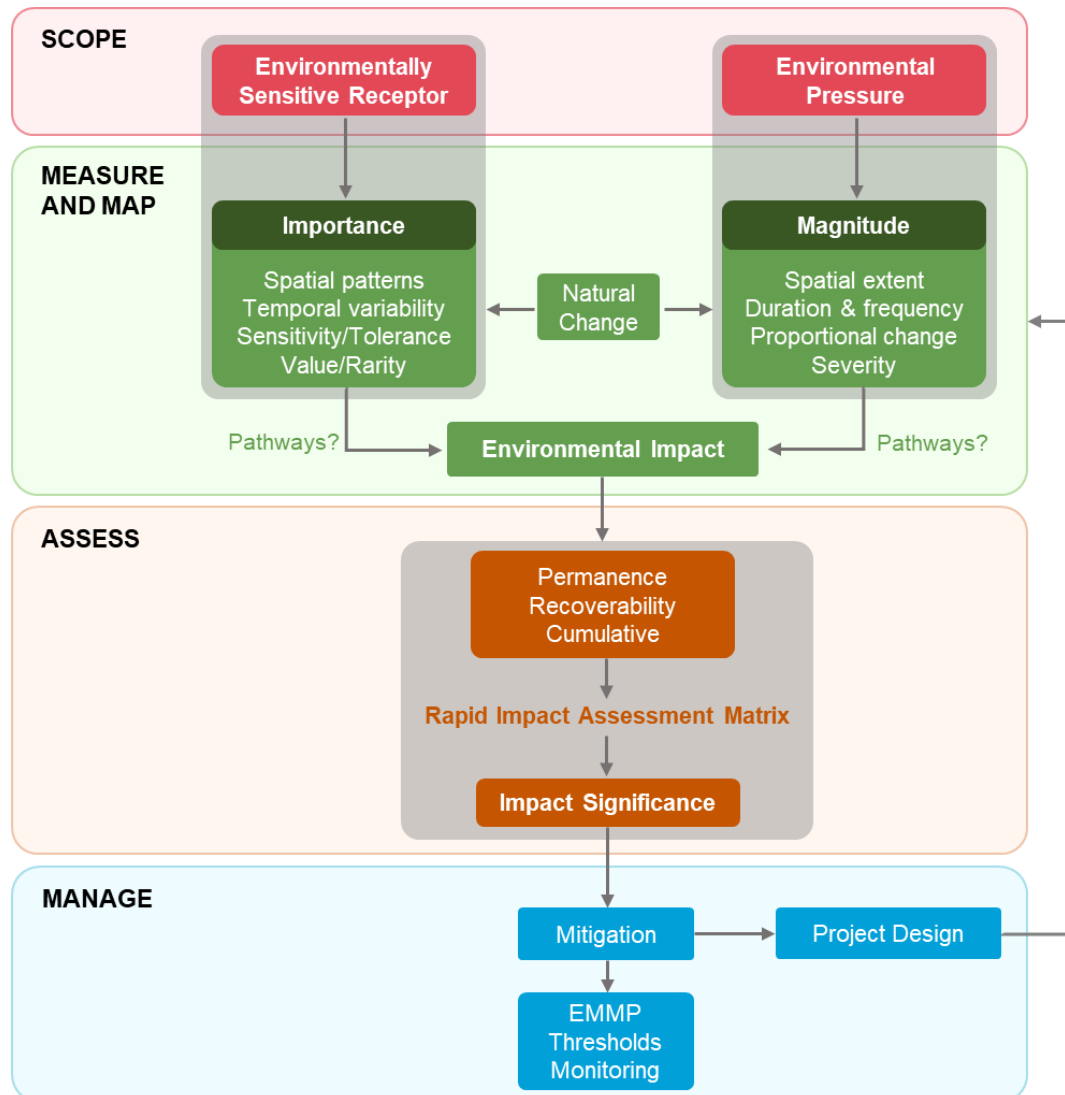


Figure 4.3 DHI's approach to environmental scoping, impact assessments and environmental management

4.2.1 Measurement

4.2.1.1 Baseline Conditions

The baseline conditions were established through a combination of physical surveys and thorough desktop review of other data and information available or to be made available to DHI. Such information can be in-house data held by DHI from internally funded research projects (e.g., AIS data) or other projects or agencies associated with other environmental studies (e.g., the previous Biodiversity Cultivation and Enhancement at Keppel Bay, Plot 4 (King's Dock) (Keppel Corporation, 2020)).

DHI also undertook an extensive review of available satellite imagery, which, in combination with the collated secondary data, will allow DHI to update our GIS database with the latest details of:

- Ecological receptors (protected and key species, mangroves, seagrass, etc.);
- Marine infrastructure (ports/jetties, navigation areas, anchorages, etc.);
- Coastal features (breakwaters, revetments, sandy shorelines, mudflats, etc.); and
- Land use (cleared land, residential land, industrial areas, natural vegetation, etc.).

Table 4.4 Field surveys conducted in this Project, presented in the order of mention in Section 5

Environmental Aspects	No. of Stations/Transects	Survey Dates
Marine Water Quality	3 points	23 February 2024 (spring-tide) 05 March 2024 (neap-tide)
Seabed Sediment Quality	3 points	20 February 2024 05 March 2024
Air Quality	3 stations	07 – 13, 15 – 21 June 2024
Airborne Noise Quality	2 stations	23 February – 08 March 2024
Underwater Noise Quality	1 location	16 March – 19 March 2024
Intertidal surveys	2 locations	13 March 2024 28 May 2024
Coral surveys	3 stations	21, 22 April 2024
Macrobenthos	3 points	20 February 2024 05 March 2024
Terrestrial Flora	Keppel Island	12, 18, 27 March 2024 03 April 2024
Terrestrial Fauna	1 transect 2 rapid survey points	26 February, 16 April 2024 (diurnal) 07 March, 30 April 2024 (evening)
Camera Trap	1 location	26 February – 30 April 2024
Socio-Recreational Survey	Around Keppel Island and along Berlayer Creek Boardwalk	14 March 2024 (morning & evening) 16 March 2024 (morning & evening)

Findings from the above surveys and secondary data research are discussed in Sections 5 (for Construction Phase impacts) and 6 (for Post-Construction Phase impacts) of this report and integrated into the relevant impact assessments for each phase. Flora and fauna surveys were conducted in compliance with the local Biodiversity Impact Assessment (BIA) Guidelines (NParks, 2020) at the time of scoping.

Biological Classifications: Flora and Fauna

Habitat Type Classifications

Table 4.5 Habitat types found within Singapore and general description of each habitat, modified from the Biodiversity Impact Assessment (BIA) Guidelines (National Parks Board, 2020) and Yee et al. (2016)

Habitat	Description	Source(s)
Primary forest	Contains an emergent layer that has dipterocarp trees such as <i>Shorea</i> and <i>Dipterocarpus</i> . Has a continuous layer of tall native trees, a sub-canopy consisting of smaller trees, and an understorey dominated by saplings of big tree species interspersed with other shrubs and treelets.	Tan <i>et al.</i> (2007)
Native-dominated young secondary forest	Naturally-regenerated vegetation on land cleared not long before the 1960s, or on degraded soils and not near other native-dominated forests. Dominated by native pioneer trees such as <i>Adinandra</i> , <i>Macaranga</i> , <i>Mallotus</i> and <i>Trema</i> .	Yee <i>et al.</i> (2016)
Native-dominated old secondary forest	Naturally-regenerated vegetation on land cleared much earlier than the 1950s, often on less degraded soil and with higher species richness than early successional native dominated secondary forest. Common species found in the canopy layer include <i>Alstonia</i> spp., <i>Calophyllum</i> spp., <i>Camposperma</i> spp., <i>Elaeocarpus</i> spp., <i>Garcinia</i> spp., <i>Litsea</i> spp., <i>Rhodamnia</i> spp. and <i>Syzygium</i> spp. Common understorey plants include <i>Anisophyllea disticha</i> and <i>Agrostistachys borneensis</i> .	Yee <i>et al.</i> (2016)
Exotic-dominated secondary forest	Regrown on land that was recently cleared, usually after the 1960s. Typically dominated by <i>Acacia auriculiformis</i> and <i>Falcataia moluccana</i> , and in recent years, <i>Cecropia pachystachya</i> and <i>Leucaena leucocephala</i> , depending on the seed sources available from the surroundings during the time of clearance and succession.	National Parks Board (2020)
Abandoned kampong	Naturally-regenerated vegetation on an abandoned kampong or orchard, usually dominated by fruit trees such as Durian (<i>Durio zibethinus</i>) or Rambutan (<i>Nephelium lappaceum</i>), or ornamental plants such as <i>Spathodea campanulata</i> , <i>Aglaonema commutatum</i> , <i>Dieffenbachia seguine</i> and <i>Heliconia</i> spp..	Yee <i>et al.</i> (2016)
Abandoned plantation	Naturally-regenerated vegetation on an abandoned plantation, usually dominated by Para Rubber (<i>Hevea brasiliensis</i>).	Yee <i>et al.</i> (2016)
Scrubland/ grassland	Exposed areas with very little tree cover, typically dominated by grasses, shrubs and herbs.	Yee <i>et al.</i> (2011); Lee Kong Chian Natural History Museum (2017a)

Habitat	Description	Source(s)
Freshwater swamp forest	Formed where slow-flowing streams drain into shallow valleys. The swamp is flooded periodically or semi-permanently, resulting in waterlogged soils that are anaerobic and unstable. Dominated by plants with special adaptations such as stilt roots, plank-like buttresses and pneumatophores. Examples include <i>Xylocarpus fusca</i> and <i>Palaquium xanthochyllum</i> .	Tan <i>et al.</i> (2007)
Freshwater marsh or pond	A wetland which is covered by water and typically dominated by grasses, sedges and other herbaceous plants or hydrophytes that are able to tolerate flooding.	Lee Kong Chian Natural History Museum (2017b)
Natural stream	A well-shaded stream which is shallow, cool, and typically has mildly acidic waters (pH 6-7). Typically flows along natural topographical gradients over sand, clay or mud substrate with accumulations of leaf litter and woody debris.	Yeo <i>et al.</i> (2010)
Naturalised stream	A stream which is warm and typically has less acidic water than natural streams (slightly less than pH 7). Typically modified from pre-existing natural streams and is often linear. Flows through natural earth or open grassy banks, lacking leaf litter and woody debris.	Yeo <i>et al.</i> (2010)
Mangrove forest	A tidal habitat consisting of flora that normally grows above mean sea level in the intertidal zone of marine environments and estuarine margins. Common species include Rhizophore, <i>Bruguiera</i> spp., <i>Avicennia</i> spp., and <i>Sonneratia</i> spp. trees which have roots that provide structural and respiratory support in the soft anaerobic sediments of the habitat.	Ng <i>et al.</i> (2011)
Coastal vegetation	Found along un-reclaimed coasts where the forest is on sandy or rocky substrate. Dominated by hardy plants which can withstand higher temperatures, strong winds and salt sprays. Common species include <i>Casuarina equisetifolia</i> , <i>Cerbera</i> spp., and <i>Barringtonia</i> spp..	Tan <i>et al.</i> (2007)
Reclaimed land vegetation	Developed on reclaimed land. Can be similar to exotic-dominated secondary forests (waste-woodlands) or dominated by <i>Casuarina equisetifolia</i> .	Yee <i>et al.</i> (2016)
Urban vegetation	Consists of turf, shrubs or trees (often mostly non-native) which are planted by humans. This type of vegetation is typically managed for aesthetic purposes.	National Parks Board (2020)

Species Status

The species status for flora and fauna is categorised as native, non-native or cryptogenic (Table 4.6). In addition, non-native flora species are further classified into casual, naturalised, and cultivated species (Table 4.7).

Table 4.6 List and definitions of native status terms for flora and fauna used in this report

Native Status	Definition (adapted from Lindsay <i>et al.</i> , 2022)
Native	Originated or arrived in Singapore without intentional or unintentional involvement of human activities
Non-native	Presence in Singapore is because of intentional or unintentional involvement of human activities
Cryptogenic	Uncertain whether presence in Singapore is from natural dispersal or as a result of human activities

Table 4.7 List and definitions of non-native status terms for flora used in this report

Non-native Species Categories for Flora (adapted from Chong <i>et al.</i> , 2009 and Lindsay <i>et al.</i> , 2022)	
Casual	Non-native species that do not maintain self-sustaining populations
Naturalised	Non-native species that maintain self-sustaining populations
Cultivated-Only	Species not naturally found in the wild that is produced and maintained by horticultural techniques

Species of Conservation Significance

The classification of species of conservation significance is presented in Table 4.8, based on the Singapore Red Data Book version 3 (NParks, 2024a).

Table 4.8 List of global and local conservation statuses used to regard a species as 'conservation-significant (CS)'

Conservation Status	Definition
Local - Singapore Red Data Book version 3 (NParks, 2024a)	
Vulnerable (VU)	Species with <1,000 mature individuals and >250 total individuals
Endangered (EN)	Species with <250 mature individuals
Critically Endangered (CR)	Species with <50 mature individuals or <250 total individuals
Presumed Nationally Extinct (NEx)	Flora and fauna not recorded within the last 30 and 50 years, respectively
Globally Extinct (EX)	Globally extinct, including in captivity or through cultivation
Local (Flora) – Lindsay <i>et al.</i> , 2022	
Vulnerable (VU)	Between 250 to 1000 mature individuals estimated in Singapore

Conservation Status	Definition
Endangered (EN)	Between 50 and 250 mature individuals estimated to be in Singapore, with no evidence of decline or fragmentation of populations
Critically Endangered (CR)	Fewer than 50 mature individuals estimated to be in Singapore; or if more than 50 but fewer than 250 mature individuals, with evidence of rapid decline or decline and fragmentation of populations
Presumed Nationally Extinct (NEx)	Not recorded in Singapore within the last 30 years. Endemic species that are presumed nationally extinct will consequently also be presumed to be globally extinct
Globally Extinct (EX)	Globally extinct
Data Deficient (DD)	Not enough information available to assess the risk of extinction
Global - IUCN Red List	
Vulnerable (VU)	Species facing a high risk of extinction in the wild
Endangered (EN)	Species facing a very high risk of extinction in the wild
Critically Endangered (CR)	Species facing an extremely high risk of extinction in the wild
Extinct in the Wild (NW)	Species that only survives through cultivation, captivity or as a naturalised population(s) outside its natural range
Extinct (EX)	Globally extinct, including in captivity or through cultivation

4.2.1.2 Impact Prediction

Prioritisation of key impacts and applicable assessment methodologies have been agreed upon at the scoping stage and presented in the Inception Report (ref. 61803576-RPT-Scoping-04.1). In this Project, DHI adopts a selection of qualitative (e.g., review of existing survey data/consultation data), semi-quantitative and modelling analyses to predict changes arising from the Project, as presented in Table 4.9.

Table 4.9 Summary of potential impacts and corresponding assessment methods

Receptors	Potential Short-term Impacts	Potential Long-term Impacts
Marine Infrastructure and Navigation		
Marine Facilities (i.e., Berths, Jetties)	Short-term sedimentation of suspended sediments arising from construction works affecting available under keel clearance at these marine facilities. Tool: DHI's MIKE 21 MT model	Long-term changes in sedimentation may affect available under keel clearance at berthing facilities. Tool: DHI's MIKE 21 HD model
Marine Navigation	Sedimentation of suspended sediments arising from construction works may reduce under keel clearance at the navigational space. Tool: DHI's MIKE 21 MT model	Potential changes to current speeds may affect manoeuvrability. Tool: DHI's MIKE 21 HD model
	Construction vessel traffic and marine work area occupying navigational space, adversely affecting the existing traffic. Tool: Qualitative assessment	The hydrodynamic changes may lead to long-term erosion/sedimentation in navigation channels. Tool: DHI's MIKE 21 HD model
Submarine Cable		Long-term changes in erosion may potentially expose the submarine cables. Tool: DHI's MIKE 21 HD model
Marine Intake	Suspended sediments arising from construction works potentially adversely affect the intake filtration system. Tool: DHI's MIKE 21 MT model	

Receptors	Potential Short-term Impacts	Potential Long-term Impacts
	Water pollution due to pollution release from suspended sediments, and spills and leaks from the construction works may negatively affect the marine intake. Tool: Suspended sediments derived from DHI's MIKE 21 MT model, pollution release, qualitative assessment of spills/leaks	
Rivers and Canals		
Berlayer Creek	Short-term sedimentation at the river mouth causing blockage. Tool: DHI's MIKE 21 MT model	Long-term sedimentation changes at the river mouth may lead to blockage. Tool: DHI's MIKE 21 HD model
Ecology and Biodiversity		
Terrestrial Flora	Construction activities disturbing root system of terrestrial flora adjacent to the site, encroachment of machinery or equipment into the tree canopy. Tool: Qualitative assessment of Construction Phase physical disturbances	Direct loss of terrestrial flora due to clearance and excavation within with Project footprint. Tool: Qualitative assessment of Post-Construction Phase physical disturbances
		Reduced photosynthetic activity due to edge effects (i.e., reduced growth due to creation of shade). Tool: Qualitative Assessment
Terrestrial Fauna	Potential effects on terrestrial fauna in the event of spills/leaks into the Hillock Area. Tool: Qualitative Assessment	Potential occurrences of wildlife strike due to glass facades of buildings. Tool: Qualitative Assessment
	Construction noise may adversely affect the normal activities of terrestrial fauna in vicinity. Tool: SoundPLAN modelling software and qualitative assessment of airborne noise disturbances	Potential impact to connectivity between forested areas due to the new building development. Tool: Qualitative Assessment

Receptors	Potential Short-term Impacts	Potential Long-term Impacts
	Construction ground vibration, atmospheric emissions and light pollution may adversely affect the normal activities of terrestrial fauna in vicinity. Tool: Quantification of air pollutant emissions from Construction Phase, and qualitative assessment of Construction Phase physical disturbances	Loss of vegetation/habitat within Plot 6, that is used by terrestrial fauna (e.g., Avifauna). Tool: Qualitative assessment of Post-Construction Phase physical disturbances
	Potential change in behaviour of terrestrial fauna due to the presence of the construction site (e.g., potential human-wildlife interactions with construction personnel). Tool: Qualitative Assessment and Documenting of fauna in the Study Area during baseline surveys	Potential change in behaviour of terrestrial fauna due to the presence of new buildings and land area occupants (e.g., potential human-wildlife interactions with residents). Tool: Qualitative Assessment and Documenting of fauna in the Study Area during baseline surveys
Mangroves	Water pollution at mangroves due to pollution release from suspended sediments, spills and leaks from construction site. Tool: DHI's MIKE 21 MT model for pollution release and qualitative assessment for spills/leaks	Planned works resulting in long-term morphological changes, affecting erosion or sedimentation of mangrove habitats nearby. Tool: DHI's MIKE 21 HD model
Intertidal Areas	Movement of construction barges may disturb intertidal habitat along Keppel Island's southern shoreline. Tool: Qualitative assessment of Construction Phase physical disturbances	Loss of intertidal areas around Keppel Island (under the pile deck). Tool: GIS-supported assessment of extent of lost intertidal areas
	Potential increase in suspended sediments arising from piling works affecting intertidal habitat and fauna living within. Tool: DHI's MIKE 21 MT model	Long-term changes in erosion/sedimentation may occur at intertidal areas. Tool: DHI's MIKE 21 HD model
	Water pollution at intertidal area due to pollution release from suspended sediments, spills and leaks from construction site. Tool: DHI's MIKE 21 MT model for pollution release and Qualitative Assessment for spills/leaks	Potential impact to connectivity due to loss of intertidal areas around Keppel Island (under the pile deck and at the entrances of the floating boardwalk). Tool: Qualitative assessment based on MIKE 21 HD and MT model results.

Receptors	Potential Short-term Impacts	Potential Long-term Impacts
Seagrass	Potential increase in suspended sediments arising from marine works affecting light availability in the seagrass habitat and smothering fauna and seagrass Tool: DHI's MIKE 21 MT model	Long-term changes in erosion/sedimentation may occur at seagrass areas Tool: DHI's MIKE 21 HD model
	Changes in light availability due to sediment plumes generated by piling, affecting the seagrass habitats and organisms living within. Tool: DHI's MIKE 21 MT model	
	Water pollution at seagrass area due to pollution release from suspended sediments, spills and leaks from construction site Tool: DHI's MIKE 21 MT model for pollution release and qualitative assessment for spills/leaks	
Corals	Movement of construction barges may disturb and damage corals within and around the construction area Tool: Qualitative assessment of Construction Phase physical disturbances	Loss of coral habitat within the Project footprint (i.e., pile deck and floating boardwalk footprint). Tool: GIS-supported assessment of extent of lost coral areas
	Changes in light availability and smothering effects, due to sediment plumes generated pile deck due to piling works and being deposited at nearby coral habitats. Affecting the coral reefs and organisms living within. Tool: DHI's MIKE 21 MT model	Potential impact to connectivity due to loss of coral habitat around Keppel Island (under the pile deck and at the entrances of the floating boardwalk) Tool: Qualitative assessment based on MIKE 21 HD and MT model results
	Water pollution at coral habitat due to pollution release from suspended sediments, spills and leaks from construction site. Tool: DHI's MIKE 21 MT model for pollution release and qualitative assessment for spills/leaks	Long-term changes in erosion/sedimentation may occur at coral areas. Tool: DHI's MIKE 21 HD model

Receptors	Potential Short-term Impacts	Potential Long-term Impacts
Marine fauna in vicinity of development area	Presence construction activities may cause physical disturbances to marine fauna that may otherwise utilise the area (including otters and fishes). Potential human-wildlife conflict is a possibility. Tool: Qualitative assessment of Construction Phase physical disturbances	
	Impact from underwater noise generated by marine piling and excavation works Tool: Underwater noise calculation	
	Increase in suspended sediment concentration potentially adversely affect fauna (e.g., clogging fish gills) Tool: DHI's MIKE 21 MT model	
	Altered water quality due to pollution release from suspended sediments, spills and leaks from work areas. Tool: DHI's MIKE 21 MT model for pollution release and qualitative assessment for spills/leaks	
Macrobenthos		Loss of subtidal benthic community within Project footprint (i.e., pile deck and floating boardwalk footprint). Tool: GIS-supported assessment of extent of lost macrobenthos habitat
		Potential impact to connectivity due to loss of macrobenthic areas around Keppel Island (under the pile deck and at the entrances of the floating boardwalk) Tool: Qualitative assessment based on MIKE 21 HD and MT model results

Receptors	Potential Short-term Impacts	Potential Long-term Impacts
		Long-term changes in erosion/sedimentation may occur at some areas, resulting in loss and/or smothering effect to benthic community. Tool: DHI's MIKE 21 HD model
Socio-economic		
Residents	Visual effect of the construction site, spills and leaks, and suspended sediment plumes generated by the works. Tool: Qualitative assessment	Presence of newly constructed mid-rise residential buildings may have visual effect. Tool: Qualitative assessment
	Increase in noise due to construction activities may negatively affect human health at nearby premises Tool: SoundPLAN modelling software	
	Reduction in air quality (e.g., due to construction dust), increase in ground vibration due to construction activities may negatively affect human health at nearby premises Tool: Quantification of air pollutant emissions and ground vibrations from Construction Phase and qualitative assessment of Construction Phase physical disturbances	
Staff of Businesses	Visual effect of the construction site, spills/leaks and suspended sediments generated by the works. Tool: Qualitative assessment	Presence of newly constructed mid-rise residential buildings may have visual effect. Tool: Qualitative assessment
	Increase in noise and vibration due to construction activities may negatively affect human health at nearby premises. Tool: SoundPLAN modelling software for noise and quantification of ground vibration.	

Receptors	Potential Short-term Impacts	Potential Long-term Impacts
	Reduction in air quality (e.g., due to construction dust) due to construction activities may negatively affect human health at nearby premises. Tool: Semi-quantification assessment based on Institute of Air Quality Management (IAQM)	
Recreational Users (Land and/or Water Sports)	Visual effect of the construction site, spills/leaks and suspended sediments generated by the works. Tool: Qualitative assessment	Presence of newly constructed mid-rise residential buildings may have visual effect. Tool: Qualitative assessment
	Marine water quality changes due to accidental spills and leaks on human health (water sports recreational users only). Tool: Qualitative assessment	Potential changes to current speeds may affect manoeuvrability of leisure yachts. Tool: DHI's MIKE 21 HD model
	Increase in airborne / underwater noise and ground vibration due to construction activities may cause nuisance to the nearby recreational users. Tool: SoundPLAN modelling software for airborne noise; underwater noise calculation; ground vibration calculation.	Loss of recreational space due to presence of newly constructed mid-rise residential buildings. Tool: Qualitative assessment supported by impact definitions in RIAM framework.
	Reduction in air quality (e.g., due to construction dust) cause nuisance to participants of recreational water sports in Keppel Marina. Tool: Semi-quantification assessment based on Institute of Air Quality Management (IAQM)	
	Reduction in navigational space potentially causing disruption to cruise ships and movement of leisure yachts in and out of the marina. Tool: Qualitative assessment supported by existing traffic information extracted from AIS.	

4.2.2 Assessment

4.2.2.1 Methodology

The well-recognised Rapid Impact Assessment Matrix (RIAM) developed by Pastakia and Jensen (1998) is applied in this Environmental Study. RIAM allows for a holistic and rapid comparable presentation and summary of the overall project impacts. The method provides a transparent presentation and summary of overall Project impacts within a common framework and ultimately aids in pinpointing which impacts are most significant. RIAM also accounts for the presence of impacts that may be cumulative in nature. The RIAM method is also consistent with the Biodiversity Impact Assessment (BIA) Guidelines of Singapore (National Parks Board, 2020) recommendation as being one of three approved methods for assessing and summarising the overall significance of impacts. The definitions applied in the ranking of impacts are provided in Table 4.10 below.

Table 4.10 Broad definitions for each level of predicted impact significance. Impacts can be either negative or positive

Impact Significance	Broad Definition
No Impact	Changes are significantly below physical detection level and below the reliability of numerical models, so that no change to the quality or functionality of the receptor will occur.
Slight Negative or Positive	Changes can be resolved by numerical models and are unlikely to be detectable in the field, which may cause slight and localised nuisance or disruption of daily activities.
Minor Negative or Positive	Changes can be resolved by numerical models and are likely to be detected in the field, which may cause stress to a portion of the population at endurable levels, but at a spatial scale that is unlikely to have any secondary consequences.
Moderate Negative or Positive	Changes can be resolved by numerical models and are obviously detectable in the field, which may cause significant stress to a large portion of population and would likely disrupt the quality and functionality of the receptor.
Major Negative or Positive	Changes are highly detectable in the field and are likely to be related to significant habitat loss. Major impacts are likely to have secondary influences beyond the area of assessment.

RIAM translates qualitative standard definitions of evaluation criteria into semi-quantitative ordinal scores, which are then used to calculate the Environmental Score (ES) via the formula:

$$\text{Environmental Score (ES)} = I \times M \times (P + R + C)$$

The five evaluation criteria (variables) used in the formula are defined:

(I) Importance – This defines the importance of the sensitive receptor identified and assessed against spatial or political boundaries, socio-economic value, intrinsic quality, or the degree of rarity.

(M) Magnitude – Impact Magnitude or Magnitude of Change is based on the relationship between the analysed physical-chemical, biological, or socio-economic deviation from

baseline conditions and the relevant environmental standards, benchmarks, guidelines, or tolerance limits. Notably, the Magnitude value should reflect the Magnitude of Change experienced at a particular sensitive receptor. In this way, the impact pathway is considered, i.e., whether there is a spatial and temporal overlap between the environmental change and receptor. Positive or negative impacts are represented through positive or negative ordinal scores for Magnitude, respectively.

(P) Permanence – This defines whether an impact is temporary or permanent, i.e., a measure of the temporal status of the loss/change. For example, slope stabilisation with gabion walls will have a permanent impact, while slope stabilisation with sheet piles will have a temporary impact, given their eventual removal.

(R) Reversibility – The score expresses whether the receptor can recover from the impact, either unassisted or via mitigation measures. Reversibility is also a measure of control over the effect of the condition. It is not equated with permanence. For example, the loss of streetscape trees is recoverable with replacement plantings, while the loss of an endemic species is irrecoverable.

(C) Cumulative Impact – This measures whether the effect will have a single direct impact, a cumulative effect over time or a synergistic effect with other conditions. For example, the loss of flora and fauna species is cumulative and associated with other impacts, such as the loss of ecosystem functioning and ecological connectivity.

Therefore, the approach of RIAM is to couple the potential impact Magnitude experienced at the sensitive receptor(s) of interest with a concurrent assessment of receptor Importance, impact Permanence, Reversibility, and Cumulative potential.

The multiplication of Magnitude and Importance in the formula ensures that each evaluation criterion's weight is expressed and can significantly influence the resultant ES. The summation of Permanence, Importance, and Cumulative ensures that these criteria are represented collectively but do not have a large influence on the resultant ES individually.

The standard (generic) definitions of each evaluation criterion and the associated ordinal scores used to calculate ES are shown in Table 4.11. To account for the wide variability and context-specificity of sensitive receptors and predicted environmental impacts (pressures), the generic definitions of Importance and Magnitude in Table 4.11 will be customised and made specific for sensitive receptors and predicted environmental impacts, respectively, with justifications elaborated in each assessment in Sections 5 and 6.

Table 4.11 Evaluation criteria and the associated standard definitions and ordinal scores used in the calculation of Environmental Scores

Evaluation Criteria	Standard Definitions	Ordinal Score
Importance*	Important to national/international interests	5
	Important to regional/national interests	4
	Important to areas immediately outside the local condition	3
	Important to the local conditions (within a large direct impact area)	2
	Important only to the local condition (within a small direct impact area)	1
Magnitude*	Major positive benefit or change	+4

Evaluation Criteria	Standard Definitions	Ordinal Score
	Moderate positive benefit or change	+3
	Minor positive benefit or change	+2
	Slight positive benefit or change	+1
	No change/status quo	0
	Slight negative disadvantage or change	-1
	Minor negative disadvantage or change	-2
	Moderate negative disadvantage or change	-3
	Major negative disadvantage or change	-4
Permanence	Temporary or short-term change.	2
	Permanent change or long-term; value and/or function unlikely to return.	3
Reversibility	Reversible or controllable through EMMP/mitigation measures	2
	Irreversible	3
Cumulativity	Impact can be defined as non-cumulative/single (no interaction with other impacts or knock off impacts).	2
	Presence of obvious cumulative/cascading effect that will affect other projects or activities or trigger secondary impacts.	3

* Definitions and scorings of Importance and Magnitude will be customised for all identified sensitive receptors and environmental impacts respectively in Sections 5 and 6

An ES will be calculated for each identified environmental impact affecting a sensitive receptor. The ES is then banded together and ranked in range bands as presented in Table 4.12, which are then translated to Impact Significance – the reported output of the impact assessment process.

Table 4.12 Range bands of ES and the associated Impact Significance used in RIAM

Environmental Scores (Range Bands)	Impact Significance Translated from Environmental Scores
116 to 180	Major positive change/impact
81 to 115	Moderate positive change/impact
37 to 80	Minor positive change/impact
7 to 36	Slight positive impact
-6 to +6	No impact/Status quo/Not applicable
-7 to -36	Slight negative change/impact
-37 to -80	Minor negative change/impact
-81 to -115	Moderate negative change/impact
-116 to -180	Major negative change/impact

4.2.2.2 Assessment Criteria

Ranking Magnitude of Change requires knowledge of relevant environmental standards, benchmarks, guidelines, or tolerance limits of the sensitive receptors – the assessment criteria, also found within the evaluation framework sections within this report. This Environmental Study adopts various assessment criteria from the laws, standards, and guidelines mentioned above.

For other environmental aspects which do not have a definite limit of impact (e.g., ecological and biodiversity receptors), DHI will assess qualitatively based on knowledge from international literature, standards, guidelines, expert opinion, and past project experiences such as standards which have been adopted for previous environmental studies in Singapore and validated against long-term environmental monitoring and management projects undertaken for multiple Singapore government agencies. The identified tolerance limits allow for a level of detail that will enable the results of the short- and long-term impact assessments to be quantified in terms of magnitude and scale of impact on each receptor.

The criteria adopted in this Project are described in each impact assessment section of Sections 5 and 6.

4.2.3 Management and Mitigation

A core aspect of the environmental study is providing appropriate mitigation measures to address any significant predicted impacts, particularly those classified as 'Moderate' or 'Major' negative. Mitigation measures are recommended and designed to reduce the impact to an as-low-as-practicable level. Slight or Minor impacts may also require mitigation actions, but these are often in the form of best environmental management procedures and operational controls.

Mitigation measures are often established through industry standards and may include:

- Changes to the design of the Project during the design process;
- Engineering controls and other physical measures applied (e.g., noise barrier);
- Operational plans and procedures (e.g., noise pollution control management plan);
- Provision of like-for-like replacement, restoration, or compensation;
- Pollution control measures during the preparation and construction stages for the contractor to implement accordingly.

Figure 4.4 presents the mitigation hierarchy concept. In developing mitigation measures, the primary focus is to avoid or minimise impacts through design modification or optimisation and project management, e.g., by applying appropriate abatement measures. Where impacts cannot be avoided, offsets and compensation could be considered.

It is important to note that not all impacts are necessarily negative. Some actions can be recommended to create net positive gains. Avoidance, minimisation and restoration alone are generally insufficient to achieve a net gain, and some form of offset is also necessary.

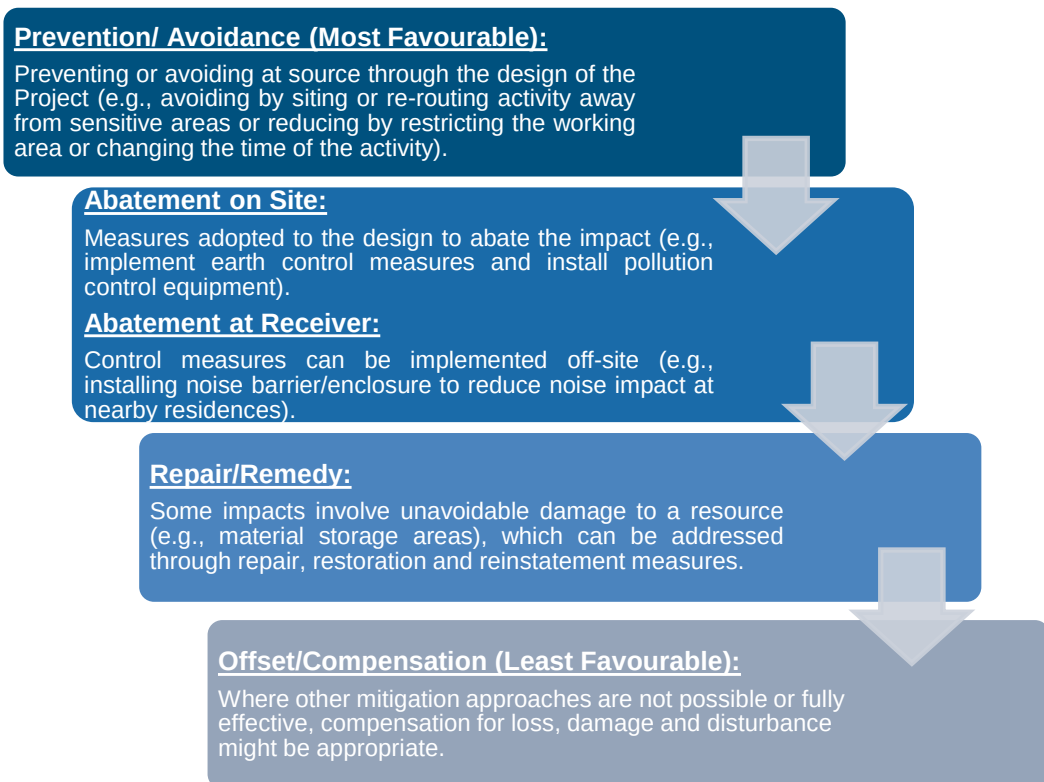


Figure 4.4 Hierarchy of mitigation strategy adopted in this Environmental Study

DHI will also identify, predict, and evaluate potential residual impacts associated with the Project's construction. A residual impact is an impact that is expected to remain after mitigation measures have been designed into the intended activity.

4.3 Reporting Flow

The impact assessment sections for the Construction Phase (Section 5) and Post-Construction Phase (Section 6) are carefully structured to describe the key components involved in analysing environmental impacts, namely:

- Identification of relevant baseline features and sensitive receptors;
- Description of an evaluation framework for measuring, defining and scoring the Magnitude of environmental change. This would include modelling methodologies and scenarios, and reference standards, guidelines or tolerance limits, if any;
- Prediction of Impact Significance for specific receptor groups;
- Recommendation of mitigation measures; and,
- Evaluation of Residual Impact Significance (if necessary).

After mitigation measures are recommended, the Impact Significance is re-evaluated to derive the Residual Impact Significance. Mitigation measures are expected only to affect the RIAM variable of Magnitude; hence, only the change in Magnitude is shown for the evaluation of Residual Impact Significance.

5 Construction Phase (Short-Term) Impacts

The assessment of impacts for the Construction Phase is aimed at predicting and analysing the level of environmental changes in the surrounding marine and terrestrial areas receptors due to the construction activities and highlighting if any of these changes can be expected to have secondary consequences, for example, to ecology and biodiversity or marine navigation. The assessment comprises the quantification of relevant deviations from baseline conditions, including changes in currents, suspended sediments, water quality, air quality, and airborne and underwater noise quality associated with the Construction Phase of the Project. The impacts that could result from these changes are expected to be short-term and assessed for ecology and biodiversity, and other sensitive receptors previously identified in Section 4.1.3.2.

5.1 Hydrodynamics

No Construction Phase impacts to the hydrodynamics within the Study Area is expected (Table 4.1) and were scoped out of this Environmental Study. Instead, this section presents the baseline hydrodynamic conditions in the Study Area. This is to allow for the reader to have an understanding of the site conditions so that they may understanding other relevant sections of this impacts assessed in the construction stage.

5.1.1 Baseline Conditions

While no current measurements are available within the vicinity of the Study Area, hydrodynamic modelling has been conducted as part of the baseline study to provide current patterns and understanding of the Study Area. An analysis of the current speed at a single location (P1) near Keppel Island was carried out (Figure 5.1). Overall, the current speed at P1 has maximum and minimum speeds of up to 0.55 m/s and 0.01 m/s, respectively, with an average speed of 0.26 m/s. The rose plot for current speed at P1 is presented in Figure 5.2, while the directional occurrence percentages are shown in Table 5.1. The directionality indicates a strong tidal current consisting of two main current directions: westerly and easterly going currents.

The typical current field around Keppel Island flows predominantly in the eastward and westward directions, with speeds reaching up to 0.8 m/s in both directions. Figure 5.3 and Figure 5.4 show the snapshot of the current field around the Keppel Bay area. Currents flow westward during flood tide and eastward during ebb tide. The strong current speed exists mainly in the Cruise Bay area compared to the northern part of Keppel Island, which is surrounded by jetties. Low current speeds of up to 0.3 m/s were predicted at Marina at Keppel Bay and Berlayer Creek's intertidal area during both flood and ebb tidal conditions.

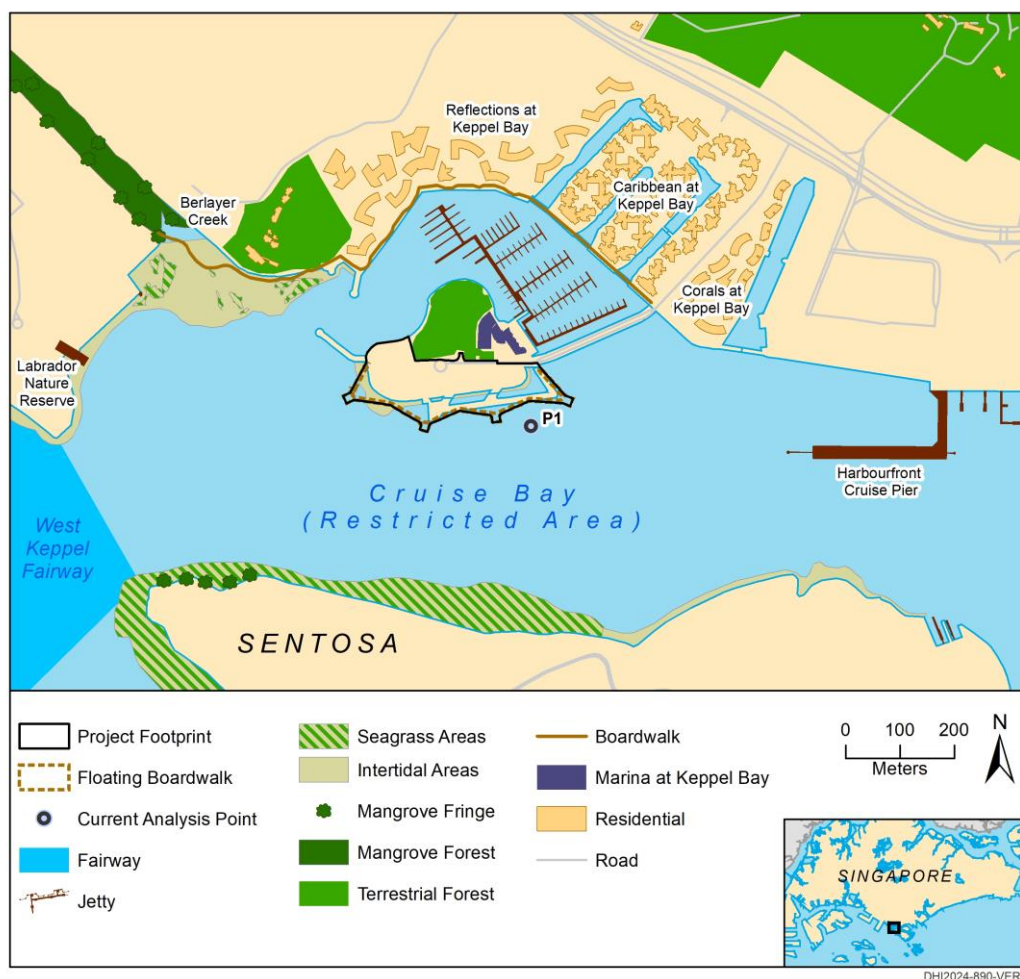


Figure 5.1 Location of the current analysis point (P1) for baseline conditions. Please note that the floating boardwalk was added in for visualisation purpose but was not included in the model setup.

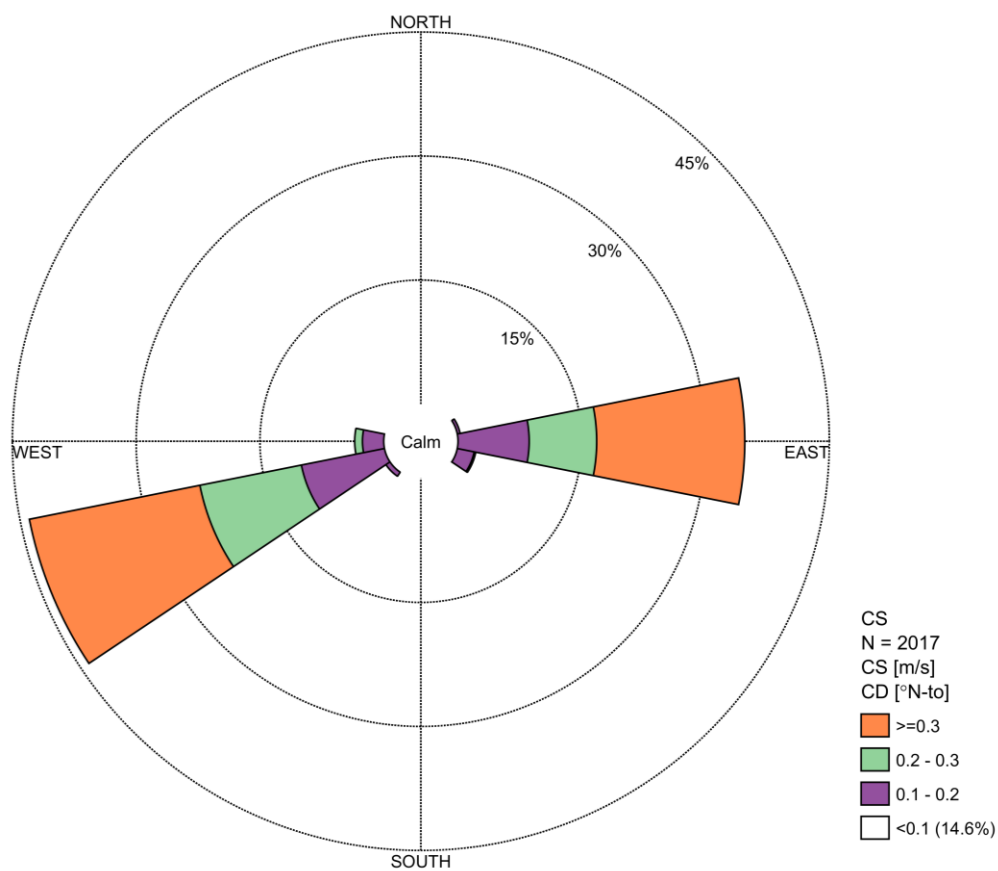


Figure 5.2 Rose plot of current speed and direction within the Study Area

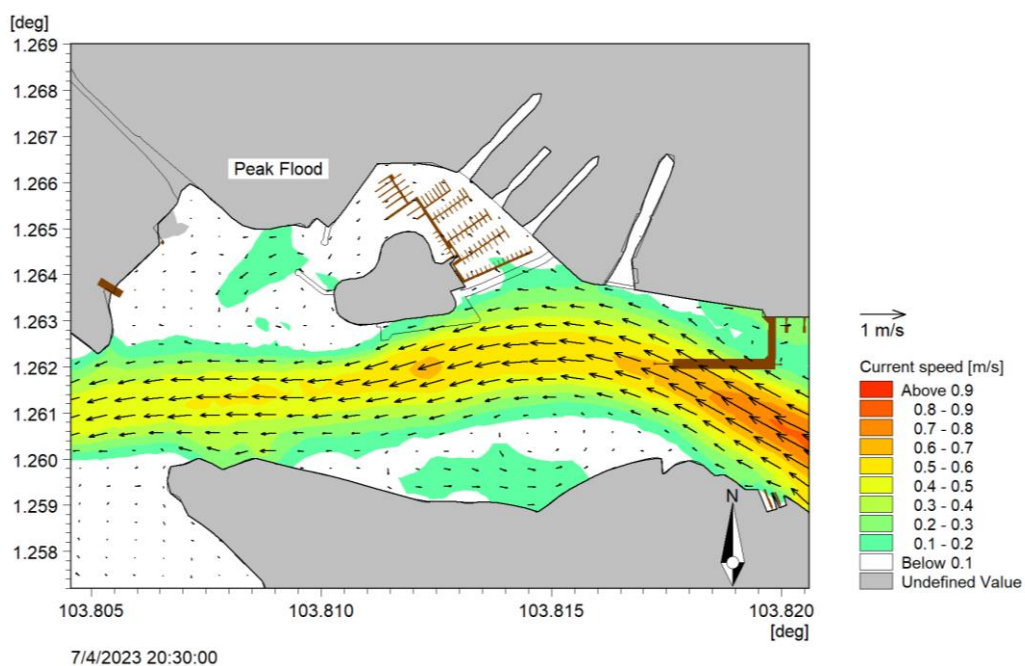


Figure 5.3 Snapshot of current vectors around the Study Area during peak flood condition

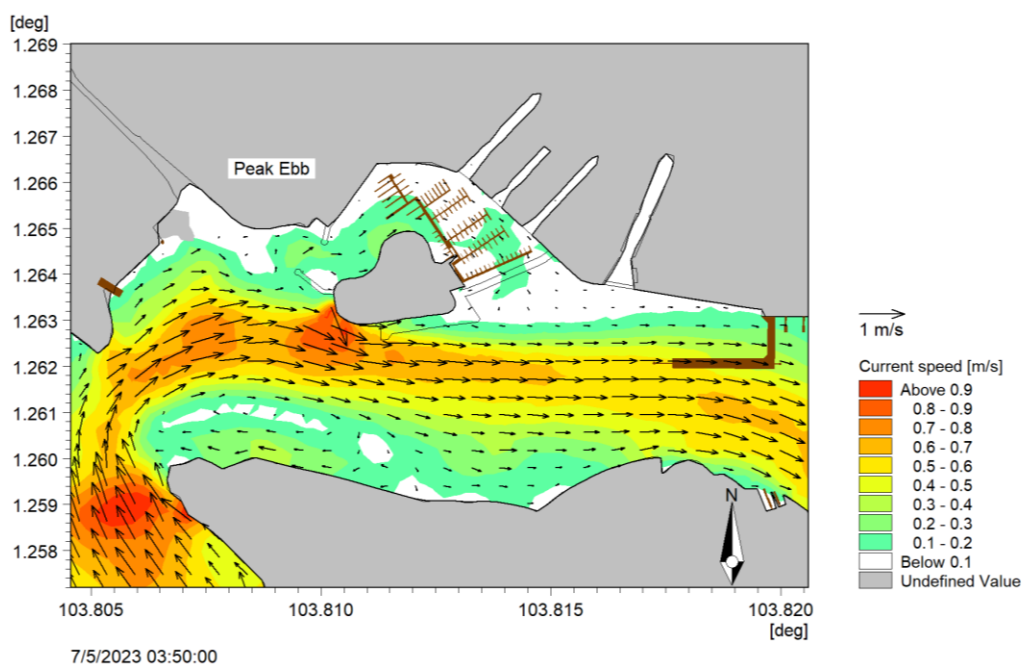


Figure 5.4 Snapshot of current vectors around the Study Area during peak ebb condition

Table 5.1 Frequency of occurrence of current speeds and current directions in the Study Area

Frequency of Occurrence [%] (2023-06-28 - 2023-07-12; 10min) All

CS [m/s] - CS

CD [°N-tg] - CD	CS [m/s] - CS						Total	Accum
	[0-0.1]	[0.1-0.2]	[0.2-0.3]	[0.3-0.4]	[0.4-0.5]	[0.5-0.6]		
[326.25-348.75]	-	-	-	-	-	-	-	100.000
[303.75-326.25]	-	-	-	-	-	-	-	100.000
[281.25-303.75]	-	-	-	-	-	-	-	100.000
[258.75-281.25]	0.694	2.578	0.942	-	-	-	4.214	100.000
[236.25-258.75]	3.371	10.263	12.543	10.808	8.627	1.636	47.248	95.786
[213.75-236.25]	1.983	0.595	-	-	-	-	2.578	48.537
[191.25-213.75]	1.289	-	-	-	-	-	1.289	45.959
[168.75-191.25]	0.694	-	-	-	-	-	0.694	44.670
[146.25-168.75]	0.446	-	-	-	-	-	0.446	43.976
[123.75-146.25]	1.041	-	-	-	-	-	1.041	43.530
[101.25-123.75]	2.082	2.082	0.198	-	-	-	4.363	42.489
[78.75-101.25]	2.727	8.627	8.180	9.817	7.139	0.992	37.481	38.126
[56.25-78.75]	0.297	0.347	-	-	-	-	0.645	0.645
[33.75-56.25]	-	-	-	-	-	-	-	-
[11.25-33.75]	-	-	-	-	-	-	-	-
[-11.25-11.25]	-	-	-	-	-	-	-	-
Total	14.626	24.492	21.884	20.625	15.766	2.628	100.000	-
Accum	14.626	39.118	60.982	81.608	97.372	100.000	-	-

These results inform the hydrodynamics modelling for post-construction impact assessment, which is found in Section 6.1. Additional details for the hydrodynamics modelling are found in **Appendix A**.

5.1.2 Hydrodynamics Summary

Overall, the current conditions near the Project site were low, ranging from 0.01 m/s to 0.55 m/s, with an average of 0.26 m/s. During flood and ebb tides, the currents predominantly flow westward and eastward, respectively, with speeds reaching up to 0.8 m/s. The strongest currents were found in the Cruise Bay area, while the northern part of Keppel Island experiences lower speeds due to surrounding jetties.

5.2 Sediment Plume

Due to the scale of the works and the presence of key recreational sites and ecological receptors, sediment plume impacts are considered a significant potential environmental impact.

This section identifies relevant receptor groups that sediment plumes will impact, documents the baseline water and seabed sediment conditions in the Study Area and presents the methodology for analysing sediment plumes from construction activities. It then describes the evaluation framework related to changes in suspended sediment concentration (SSC) and sedimentation and discusses the outcomes of the analyses.

5.2.1 Relevant Receptors

Sediment plumes piling works could induce high amounts of suspended sediment concentration in the water column, resulting in sedimentation over time as suspended sediments settle in nearby areas.

The following groups of receptors are relevant to the assessment of the impact of sediment plumes:

- Marine ecology and biodiversity (i.e., intertidal area, seagrass, mangroves, corals, marine fauna);
- Marine infrastructure and navigation (i.e., jetties, marine intakes);
- Rivers and canals; and
- Socio-economic (i.e., residents, staff of businesses, and recreational users).

This section only discusses the pressures or stressors related to sediment plumes, including the presence of suspended sediments in the water column, and erosion and/or sedimentation effects. The corresponding receptor chapters will assess and discuss the resulting impacts of sediment plumes on their respective receptors (Sections 5.8, 5.10, 5.11 and 5.12).

5.2.2 Baseline Conditions

The assessment of increased suspended sediments on receptors in the Study Area requires an understanding of the conditions that the receptors are currently exposed to (i.e., baseline water and sediment conditions). These pre-construction conditions for the assessment are therefore collected via in-situ turbidity measurements and ex-situ water samples from water quality surveys for total suspended solids (TSS), and seabed sediment samples collected from sediment quality surveys for sediment grading.

Marine water measurements and sampling was carried out on 23 February 2024 and 05 March 2024 to investigate the baseline water quality conditions in the Study Area. Sampling was carried out at three (3) locations (Figure 5.5), covering spring and neap tides during the flood and ebb tides. In-situ turbidity measurements were conducted at 1 m intervals over the entire water column and water sample collection was carried out at surface depth only (1 m below surface). The laboratory results are presented in the following subsections; with the method detection limit (MDL) and ASEAN Marine Water Quality Criteria (MWQC) shown in the results plots where relevant. Where no bar is plotted for a given sample, it indicates that the concentration for the particular sample is below the MDL. This section focuses on relevant parameters (i.e., TSS and turbidity) from the water

quality surveys due to their relevance to the sediment plume pressure. Other water quality survey results (e.g., nutrients, heavy metals and bacteria) are presented in Section 5.3.2.

Sediment quality and grading surveys were conducted on 23 February 2024 and 05 March 2024 to investigate the baseline sediment quality conditions in the Study Area. Sampling was conducted at three (3) locations (Figure 5.6). Similar to water quality, this section only presents the sediment grading results due to their relevance to the sediment plume pressure. More sediment quality survey results (e.g., nutrients and heavy metals) are presented in Section 5.3.2.

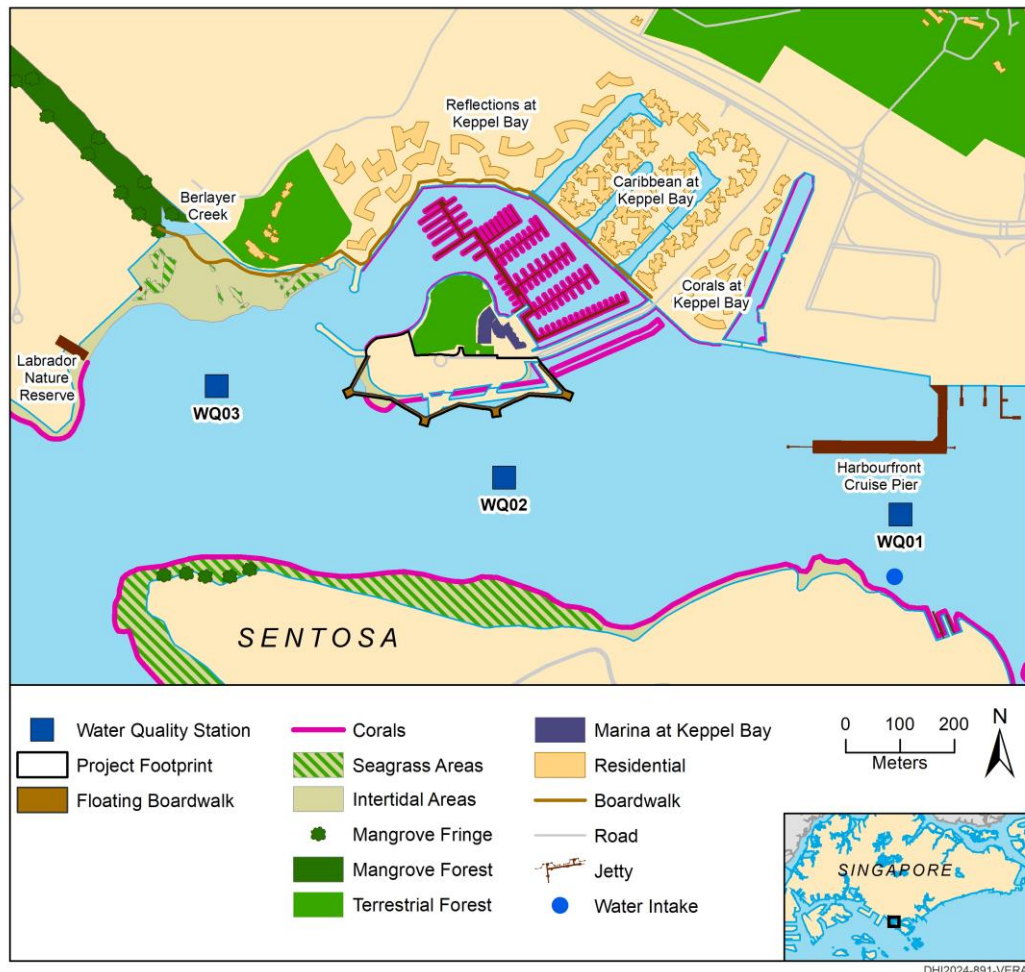


Figure 5.5 Locations of three (3) marine water quality stations within the Study Area

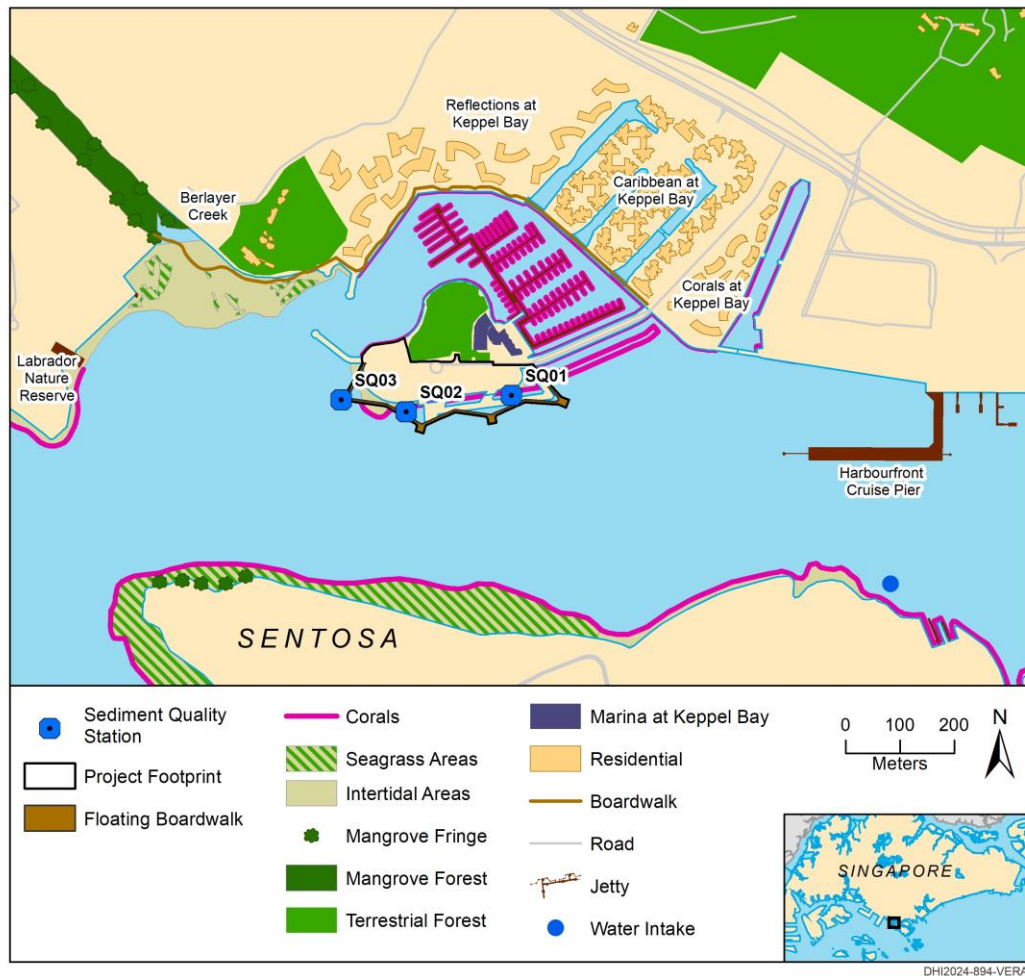


Figure 5.6 Locations of three (3) sediment quality stations within the Study Area

5.2.2.1 Water Clarity

Turbidity

Turbidity levels indicate the volume of suspended materials present in the water column. Higher turbidity levels can reduce light penetration and affect the ecology of a system but may also disrupt marine intake and usage for industrial purposes.

Results of median depth-averaged turbidity levels across all three (3) sampling stations ranged from 1.27 NTU to 2.51 NTU (Table 5.6). Turbidity showed slight tidal variation across all stations, with minor temporal variation at each station. Additionally, turbidity increased slightly with increasing water depth across all stations and tides (Figure 5.7).

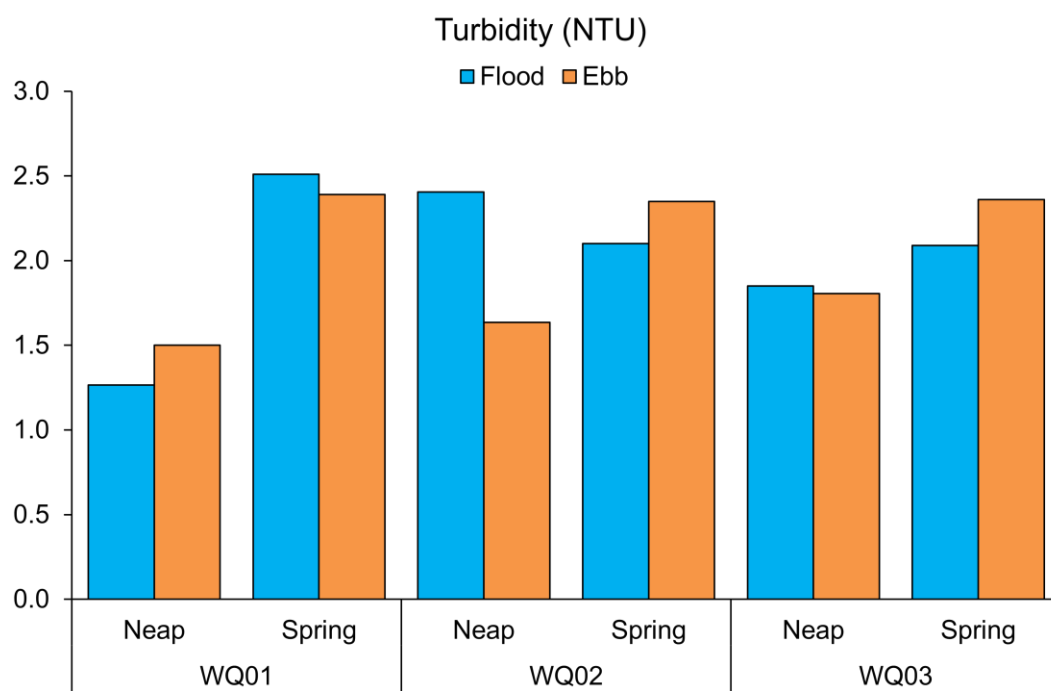


Figure 5.7 Median turbidity results across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

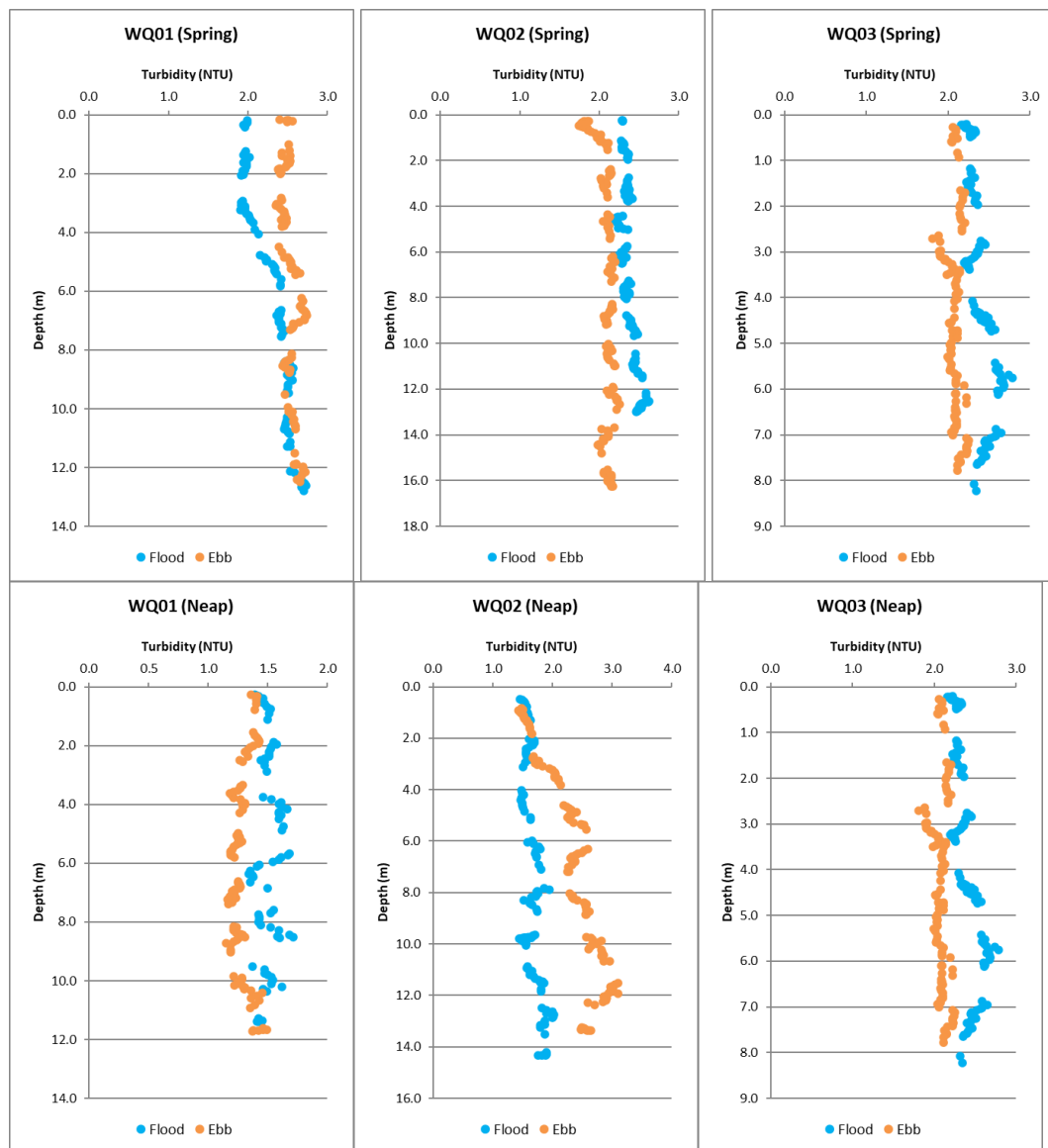


Figure 5.8 Turbidity profiles across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides (note that the x- and y- axes ranges vary for each plot)

Total Suspended Solids (TSS)

TSS are particulate solid materials, including organic and inorganic solids suspended in the water column. Although similar to turbidity, TSS is a separate measurement that provides the actual weight of particulate material present in the sample. TSS occurs through a few factors, such as bottom sedimentation disturbance, discharge from a nearby stream or river channel, or natural environmental impacts. The amount of TSS in a water column affects turbidity readings, light penetration into the water column and even, the behaviour and ecology of aquatic species such as filter feeders.

TSS readings at WQ01 to WQ03 (Table 5.7) during the baseline surveys ranged between 5.5 mg/l to 8.9 mg/l during spring tide. It fluctuated within a smaller window of 4.0 mg/l and 5.3 mg/l during neap tide.

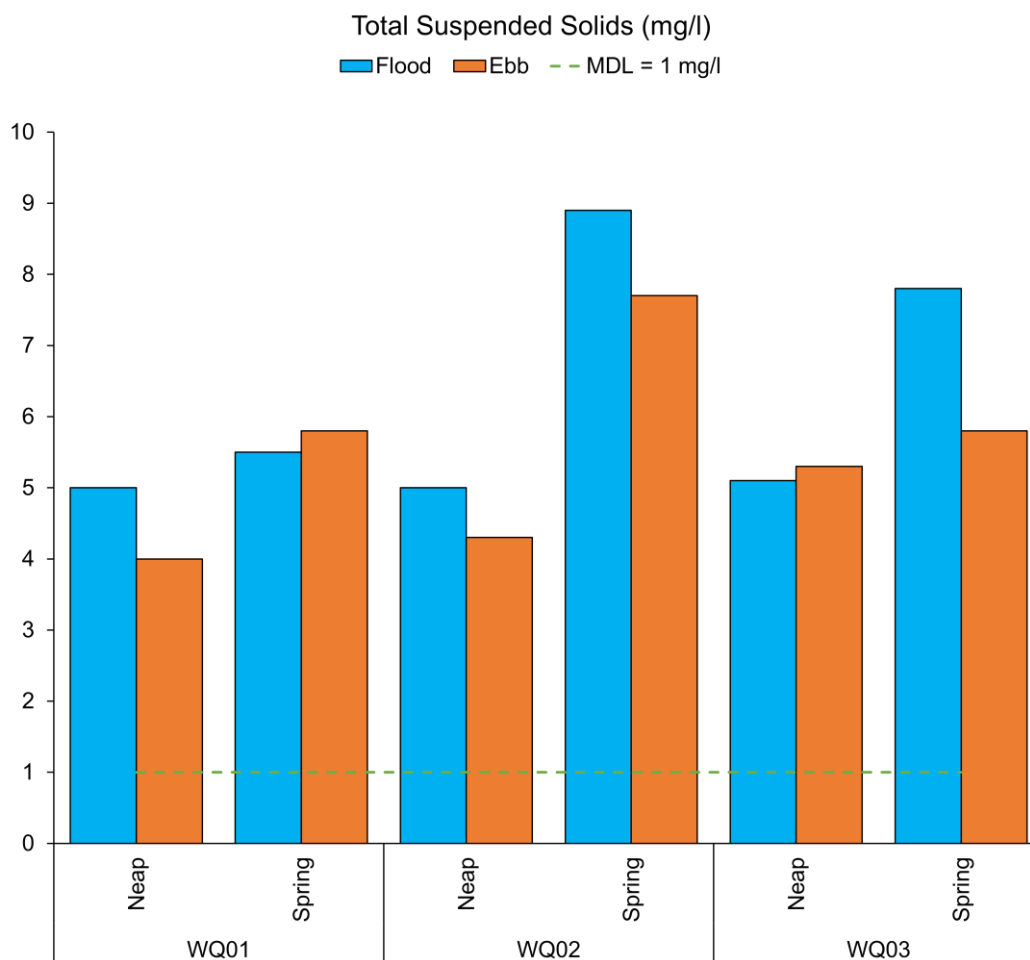


Figure 5.9 TSS concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides. MDL refers to the method detection limit.

5.2.2.2 Sediment Grading

Characteristics of the seabed sediment in the Study Area has a bearing on the suspended sediment levels potentially generated by marine works. Finer seabed material tends to result in higher suspended sediment concentration (SSC) when disturbed, and vice versa. Sediment quality across sampling locations SQ01 to SQ03 was mostly dominated by clay and silt type substrate. This information is used as an input to the sediment plume simulations of piling operations. Sediment composition values are presented in Table 5.2. The sediment grading laboratory results is provided in **Appendix C**.

Table 5.2 Results of the sediment grading for stations SQ1 to SQ03

Station	Clay	Silt	Sand	Gravel
	(< 2 µm) (%)	(2 – 60 µm) (%)	(60 – 2000 µm) (%)	(> 2000 µm) (%)
SQ01	35	64	1	0
SQ02	48	45	7	0
SQ03	48	46	6	0

5.2.3 Modelling Methodology

Sediment plume impacts are associated with the transport, dispersion and settling of fine sediments released during the proposed construction. This section uses DHI's MIKE 21 Mud Transport (MT) Model to describe the evaluation framework related to sediment plume impacts. The model assesses the spatial extent and concentration of the generated suspended sediments, as well as the sedimentation rate for key habitat, navigation and marine infrastructure receptors. In the present model, the sediment spill is represented by three fractions of sediment, representing the ranges from silt to clay characterised by their settling velocities, critical shear stress of deposition and erosion. A detailed description of the MT model setup and assumptions is provided in **Appendix B**.

Based on the Project design in Section 2.3, there are four (4) key sequences proposed for the construction works: 1) demolition of the Wharf, 2) installation of marine piles, 3) construction of pile deck, and 4) construction of floating boardwalk. Only the installation of marine piles is simulated in the model as the other aspects will likely generate minimal sediment plume as compared to the other construction aspects.

Modelling Scenarios

Four (4) representative scenarios were simulated for the Construction Phase (Table 5.3). The production period for the sediment plume modelling was twenty-eight (28) days, covering the spring-neap tidal cycle during the Northeast (NE) monsoon and inter-monsoon, with the last fourteen (14) days used for the assessment to consider the accumulation of suspended sediments. Each monsoon represents two different scenarios: 1) the NE monsoon, when currents are expected to be the strongest to simulate the maximum extent of sediment plume impacts on the relevant receptors, and 2) the inter-monsoon period to understand the impact on sensitive receptors when the flushing effect is minimal, as requested by the National Environment Agency (NEA) during the scoping stage.

Based on information from the Client, the construction duration for the installation of the marine pile is approximately 32 weeks. The Project involves the construction of two key structures, the pile deck for the residential building and the floating boardwalk, with a total of 354 piles to be installed in the water (Figure 5.10 and Figure 5.11). 222 piles will be installed for the pile deck and 132 piles for the floating boardwalk. Five (5) different pile diameters will be used: 1.1 m, 1.0 m, 0.9 m, 0.75 m, and 0.6 m. The construction of the marine piles comprises piling, cage insertion, and infilling. However, only the piling is considered in the model, as the other activities were determined to contribute relatively minimal amounts of sediment plume. According to the construction schedule, two (2) piles will be installed per day, with the assumption that construction hours are eight (8) hours per day and six (6) days per week. The model also conservatively assumes that two piles will be installed concurrently, using two different barges, within a 30-minute time duration. Finally, the piles for the pile deck and the floating boardwalk were simulated separately. Hence, Scenario 1 and Scenario 2 were simulated for piles in the pile deck, and Scenario 3 and Scenario 4 were simulated for piles for the floating boardwalk.

Due to the large number of piles, DHI designed piling scenarios which simulated the worst-case construction situation. The construction sequence of the piling works was assumed to commence from the southeast corner of the island, at the inner most layer of piles. Piles will be placed sequentially, progressively moving outwards to the next layer in a zig-zag manner (i.e., first towards the west, then to the east and back to the west). The piles east of the pile deck were selected to simulate the worst-case scenario for the receptors east of the Project (Figure 5.12). The piles at the west side of the floating boardwalk were selected to simulate the worst-case scenario for the receptors on the west side of the Project (Figure 5.13). The detailed sizes of the piles and the number of piles simulated per day in each scenario are presented in Table 5.4 and Table 5.5. Further details on the spill rate calculation and assumption are described in **Appendix B**.



Figure 5.10 Overview of piling plan with indicative pile sizes for the Project (source: Client)

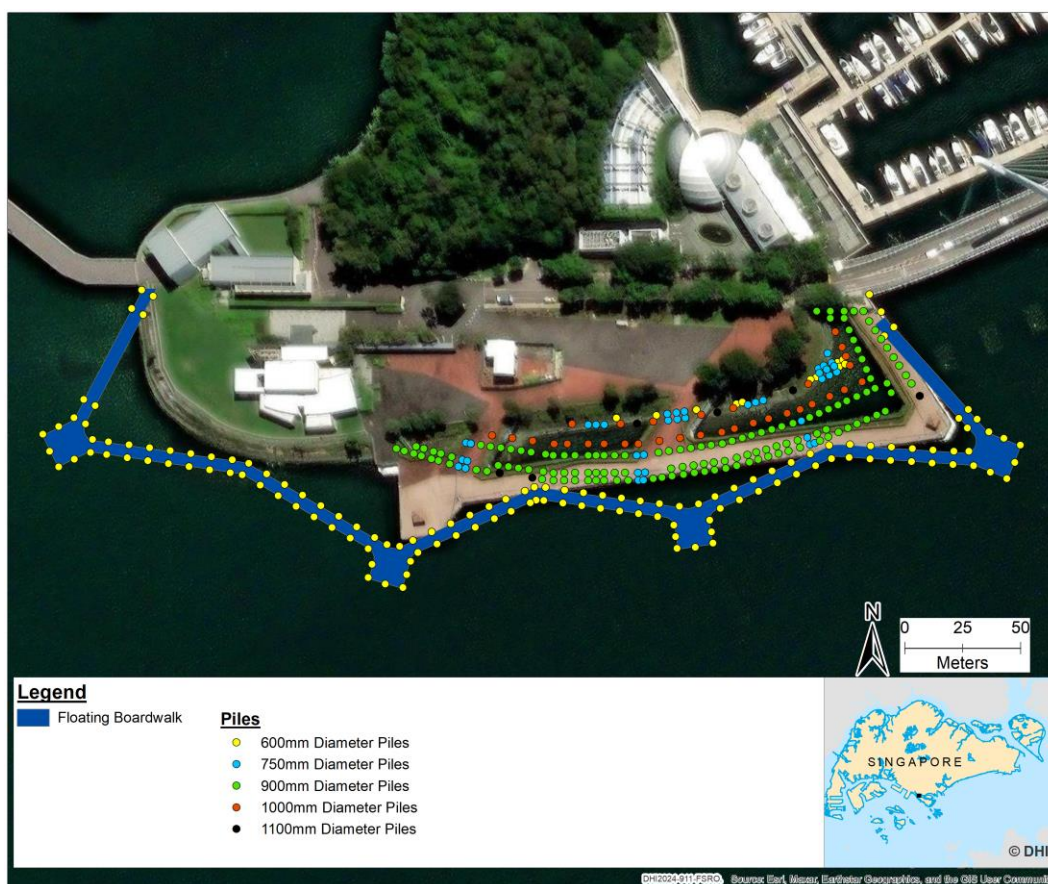


Figure 5.11 Pile locations with indicative pile sizes for the pile deck and floating boardwalk

Table 5.3 Modelling scenarios for sediment plume

Scenario	Location	Monsoon Period	Simulated of Piles Simulated per Day
1	Pile Deck	NE monsoon	2
2	Pile Deck	Inter-monsoon 1	2
3	Floating Boardwalk	NE monsoon	2
4	Floating Boardwalk	Inter-monsoon 1	2

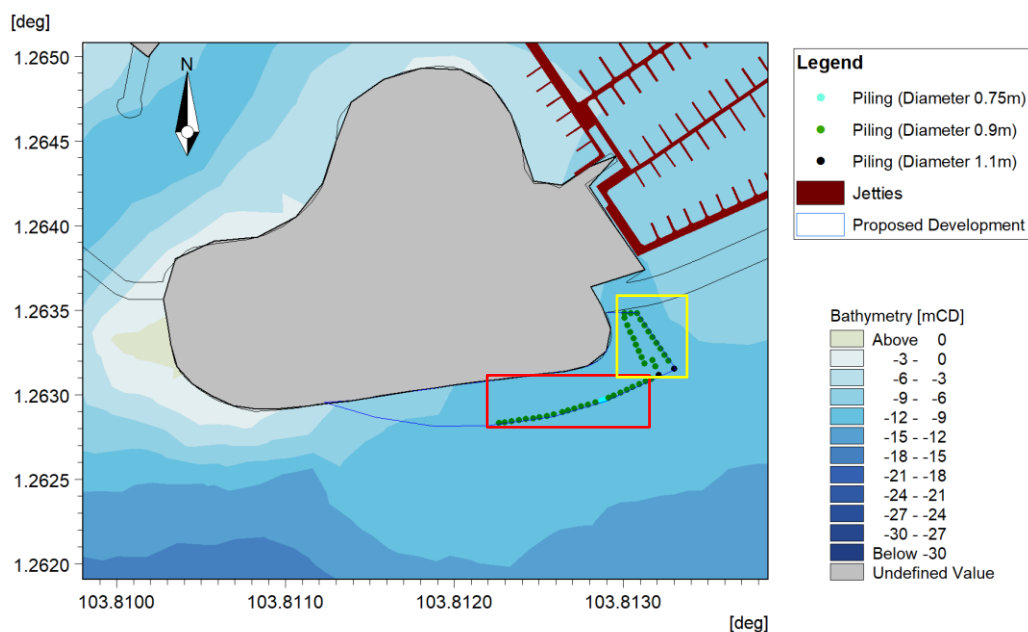


Figure 5.12 Piles selected at the pile deck for Scenarios 1 and 2. Red and yellow boxes indicate piling works for the 1st and 2nd fourteen (14) days, respectively.

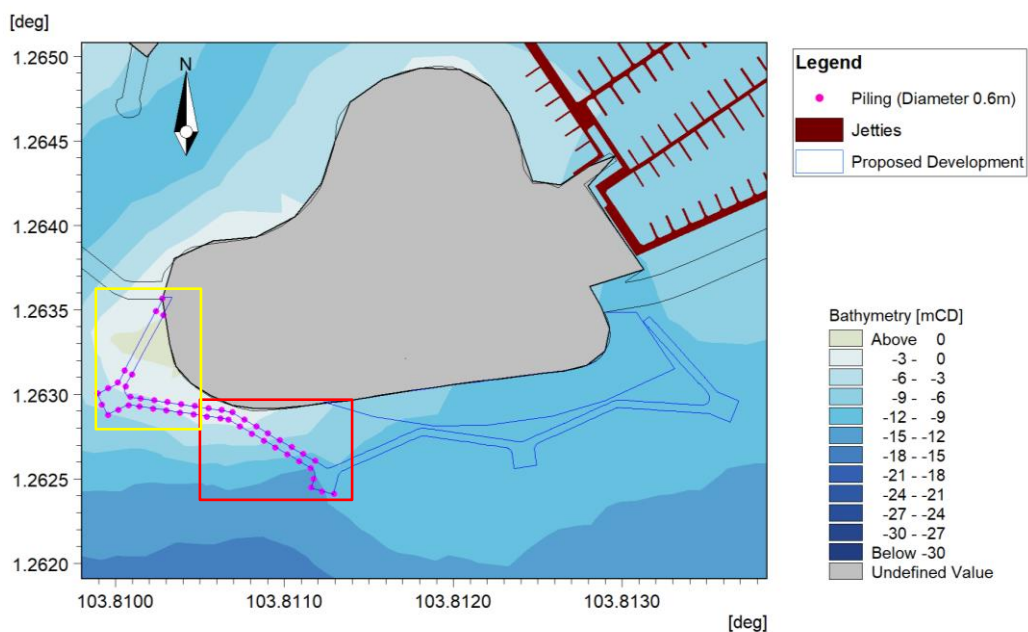


Figure 5.13 Piles selected at the floating boardwalk for Scenarios 3 and 4. Red and yellow boxes indicate piling works for the 1st and 2nd fourteen (14) days, respectively.

Table 5.4 Pile sizes and number of piles simulated per day for Scenarios 1 and 2

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Pile Size	Number of Piles Simulated in each Day																											
1.10 m															1												1	
1.00 m																												
0.90 m	2	2	2	2	2	2		2	1	1	2	2	2		1	2	2	2	2	2		2	2	2	2	2	1	
0.75 m									1	1																		
0.60 m																												

Table 5.5 Piles sizes and number of piles simulated per day for Scenarios 3 and 4

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Pile Size	Number of Piles Simulated in each Day																											
1.10 m																												
1.00 m																												
0.90 m																												
0.75 m																												
0.60 m	2	2	2	2	2	2		2	2	2	2	2	2		2	2	2	2	2	2		2	2	2	2	2	2	

5.2.4 Evaluation Framework

Sediment plume impacts as a result of piling works are assessed in terms of:

- Mean and 95th percentile incremental suspended sediment concentration (SSC);
- Percentage of time incremental SSC exceeds 5 mg/l, 10 mg/l, and 25 mg/l; and,
- Sedimentation over periods of 14-days and annually.

These descriptors are selected based on the tolerance limits of ecological, socio-economic, and marine infrastructure and navigation receptors with regard to suspended sediments and erosion or sedimentation. Extracting the sediment plume model results according to these descriptors allows for the subsequent benchmarking against the available thresholds of these receptors as presented in the corresponding Receptor chapters (Sections 5.8, 5.10, 5.11 and 5.12), along with the impact assessment. In addition, as discussed with NEA, the use of 95th percentile data is a good statistical representative for Environmental Study purposes, whilst avoiding the recording of numerical transients that are artefacts of the modelling results.

5.2.5 Results and Discussions

Suspended Sediments

Overall, the mean incremental SSC due to the installation of marine piles at the pile deck was predicted to be below 5 mg/l within the immediate footprint of the pile deck (see Scenario 2 on Figure 5.14 and Figure 5.15). The 95th percentile incremental SSC was modelled to be less than 20 mg/l within the construction area for the pile deck installation and less than 2 mg/l for the floating boardwalk's pile installation. Beyond the construction area, the 95th percentile incremental SSC was predicted to be below 1 mg/l (see Scenario 2 on Figure 5.16 and Figure 5.17).

Within the Study Area, incremental SSC was predicted to exceed 5 mg/l for less than 20 % of the time during the installation of piles for the pile deck (see Scenario 1 and 2 on Figure 5.18 and Figure 5.19) and less than 5 % of the time during the floating boardwalk's pile installation (see Scenario 3 and 4 on Figure 5.18 and Figure 5.19). Exceedance of 10 mg/l of SSC was predicted to be less than 10 % of the time for the works at the pile deck (Scenario 1 and 2 on Figure 5.20) and less than 2.5 % for the floating boardwalk's pile installation (Scenario 3 and 4 on Figure 5.20). The SSC was expected to exceed 25 mg/l for no more than 5 % of the time within the vicinity of the Project (see all scenarios for Figure 5.21).

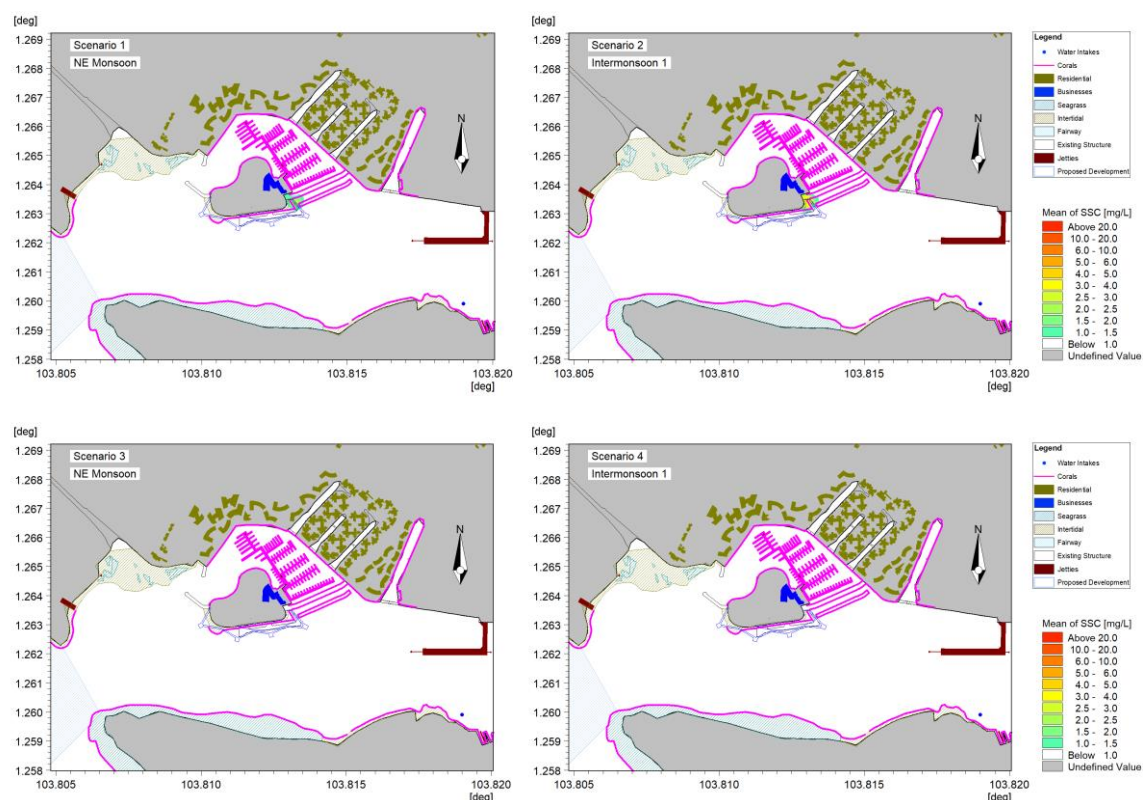


Figure 5.14 Mean incremental SSC due to the installation of marine piles. Top-left: Scenario 1; top-right: Scenario 2; bottom-left: Scenario 3; bottom-right: Scenario 4.

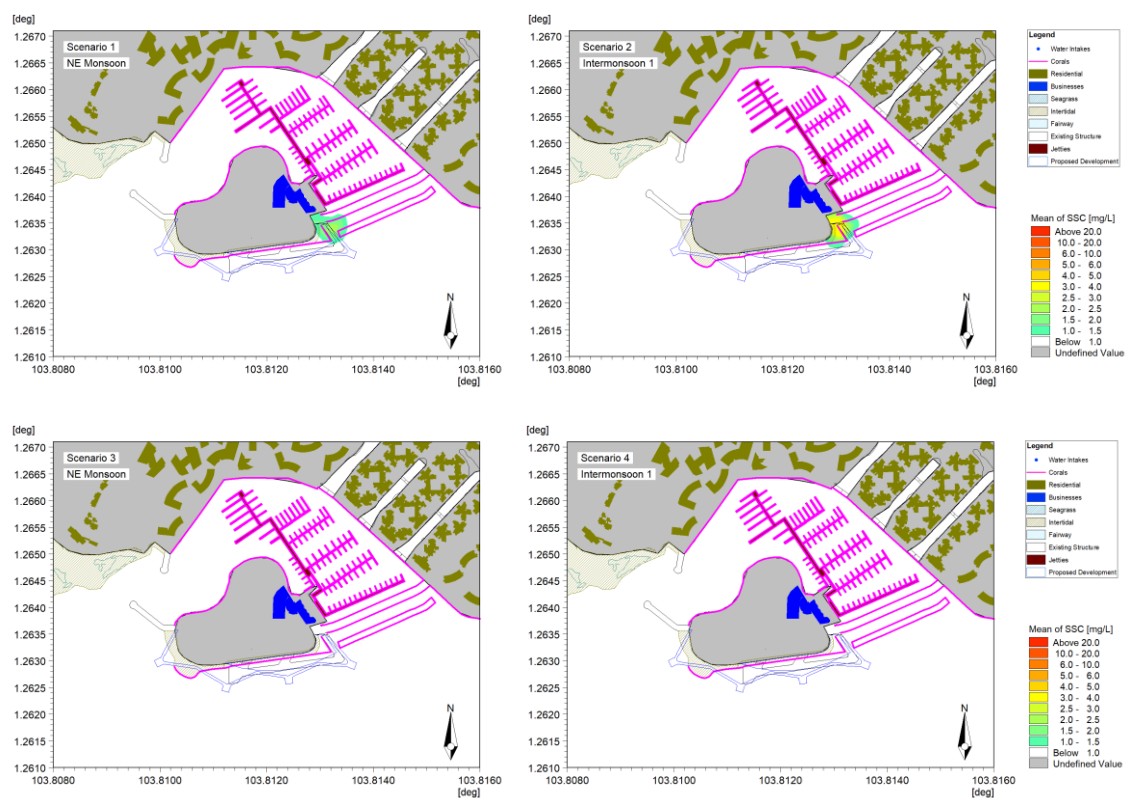


Figure 5.15 Mean incremental SSC due to the installation of marine piles (zoom in). Top-left: Scenario 1; top-right: Scenario 2; bottom-left: Scenario 3; bottom-right: Scenario 4.

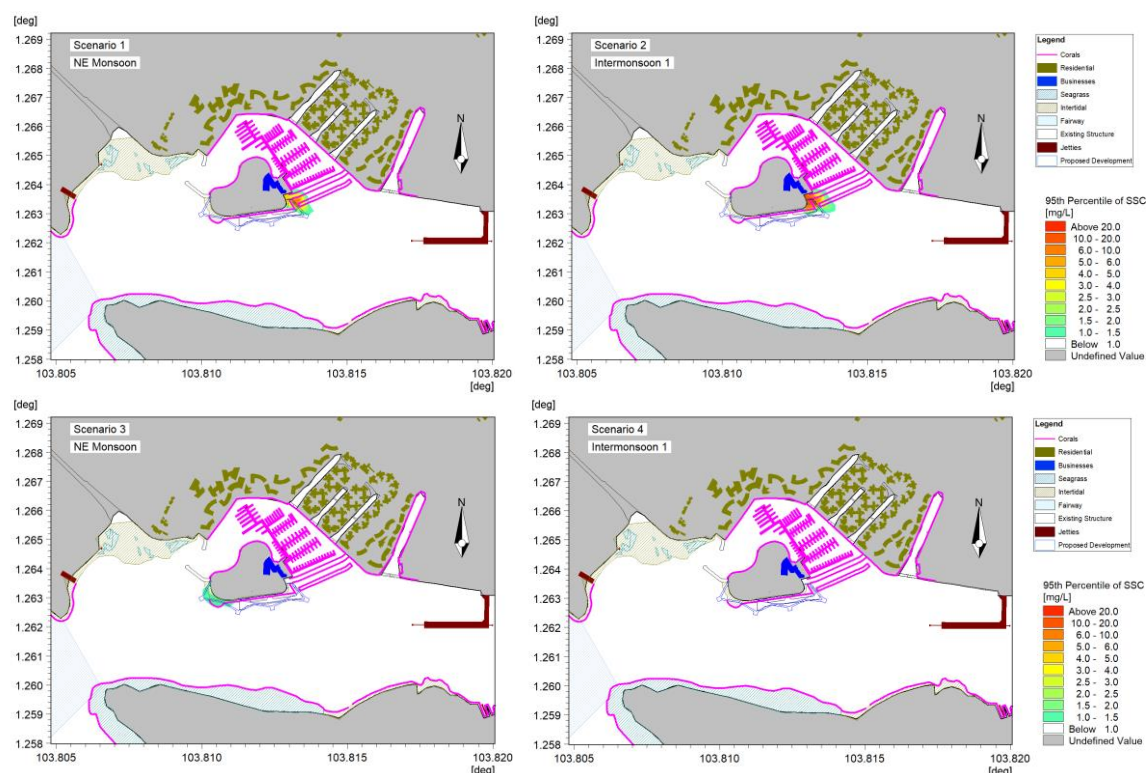


Figure 5.16 95th percentile incremental SSC due to the installation of marine piles. Top-left: Scenario 1; top-right: Scenario 2; bottom-left: Scenario 3; bottom-right: Scenario 4.

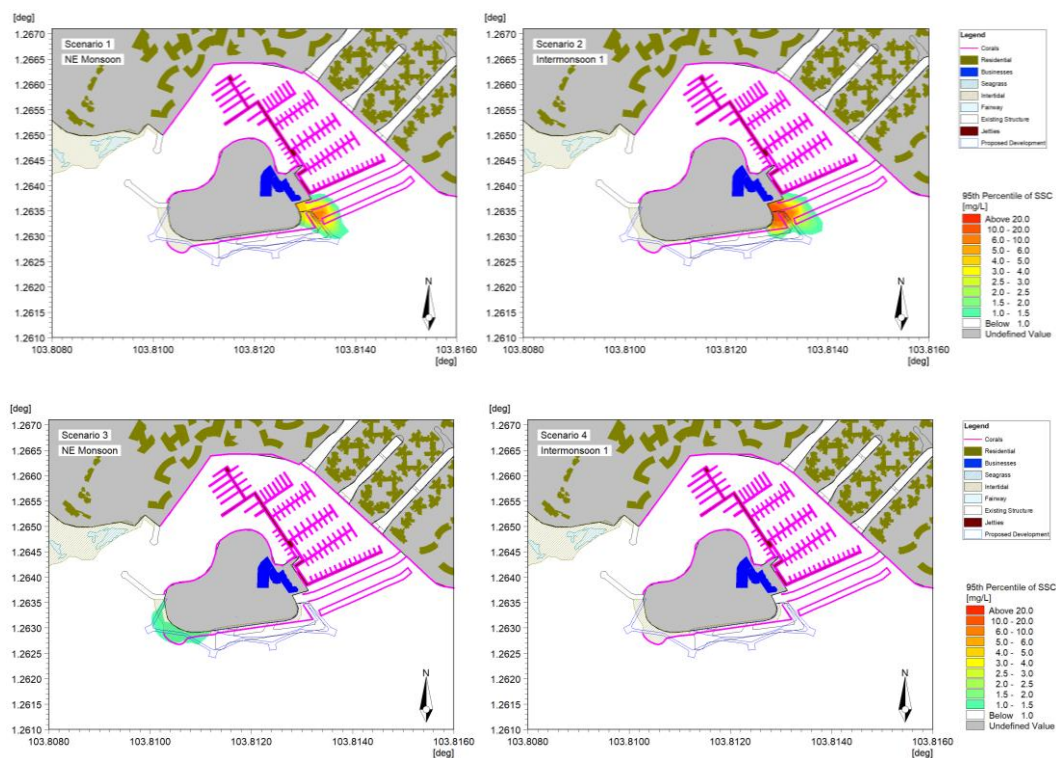


Figure 5.17 95th percentile incremental SSC due to the installation of marine piles (zoom in). Top-left: Scenario 1; top-right: Scenario 2; bottom-left: Scenario 3; bottom-right: Scenario 4.

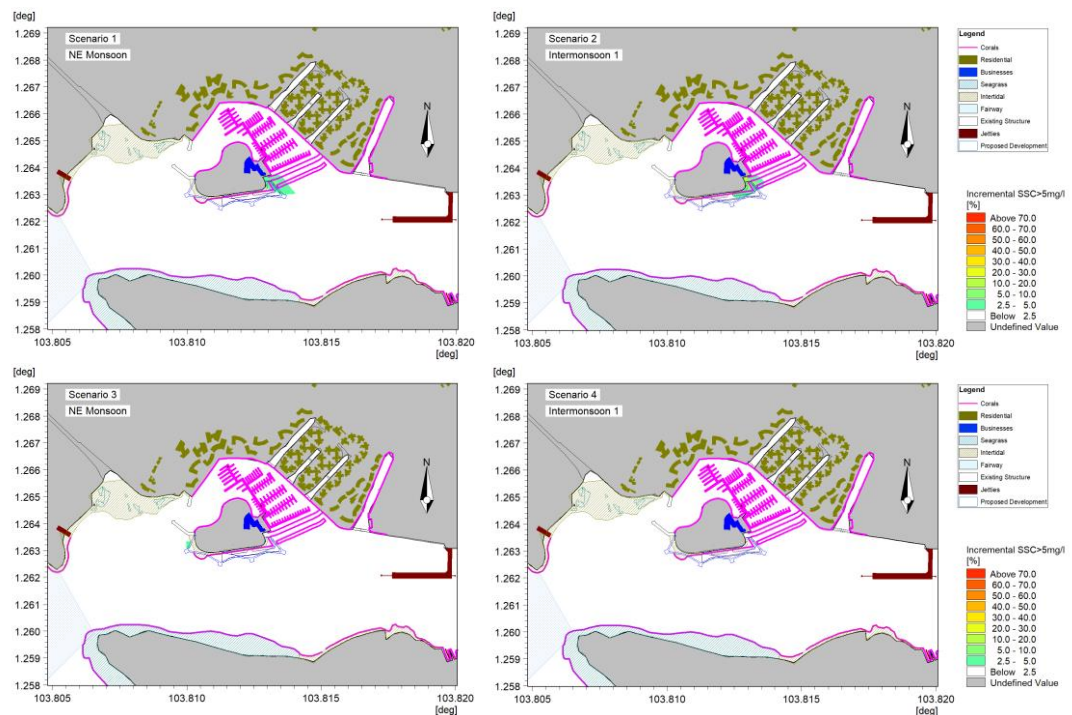


Figure 5.18 Percentage of time SSC is in exceedance of 5 mg/l due to the installation of marine piles. Top-left: Scenario 1; top-right: Scenario 2; bottom-left: Scenario 3; bottom-right: Scenario 4.

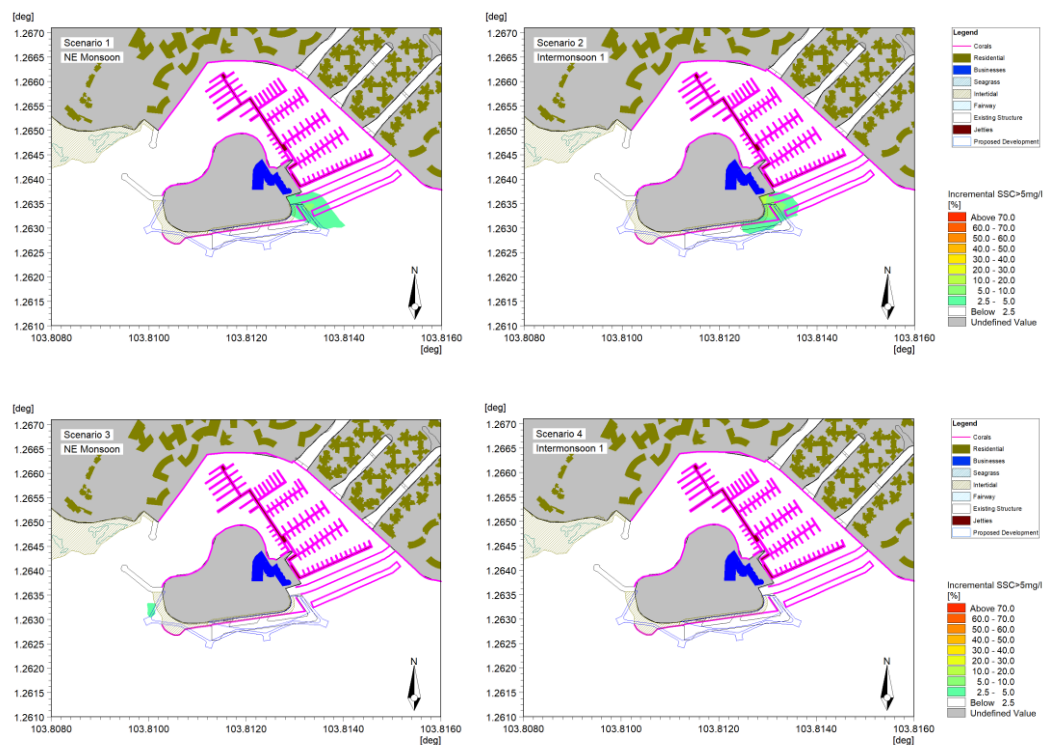


Figure 5.19 Percentage of time SSC is in exceedance of 5 mg/l due to the installation of marine piles (zoom in). Top-left: Scenario 1; top-right: Scenario 2; bottom-left: Scenario 3; bottom-right: Scenario 4.

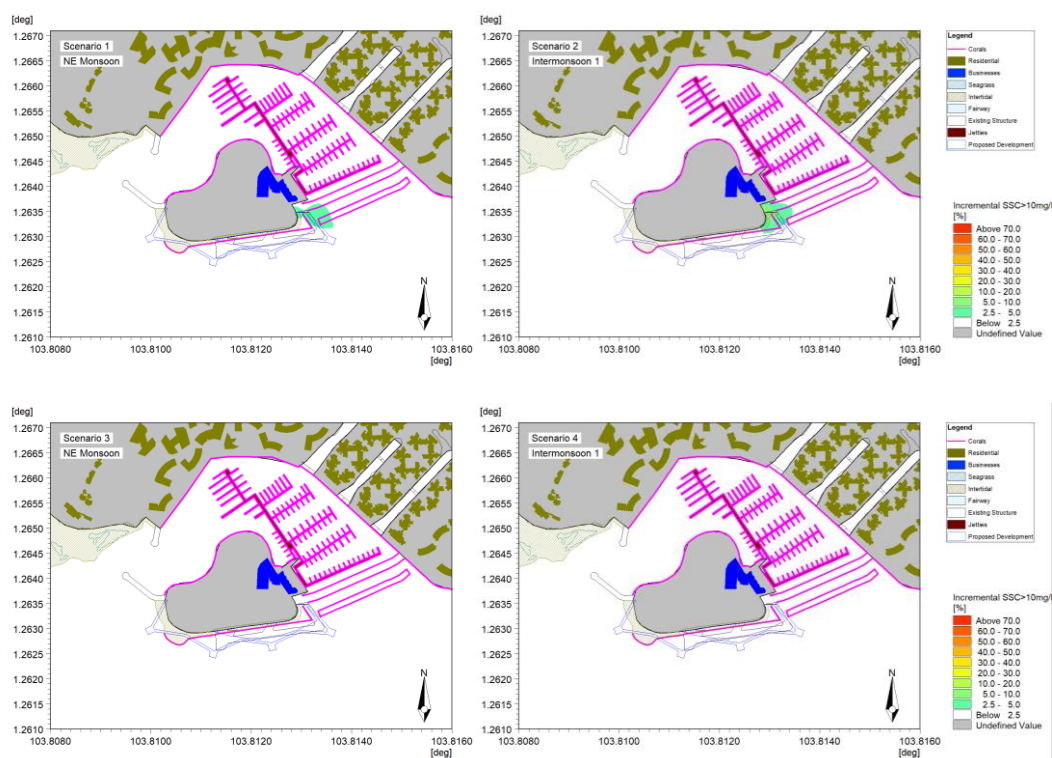


Figure 5.20 Percentage of time SSC in exceedance of 10 mg/l due to the installation of marine piles. Top-left: Scenario 1; top-right: Scenario 2; bottom-left: Scenario 3; bottom-right: Scenario 4.

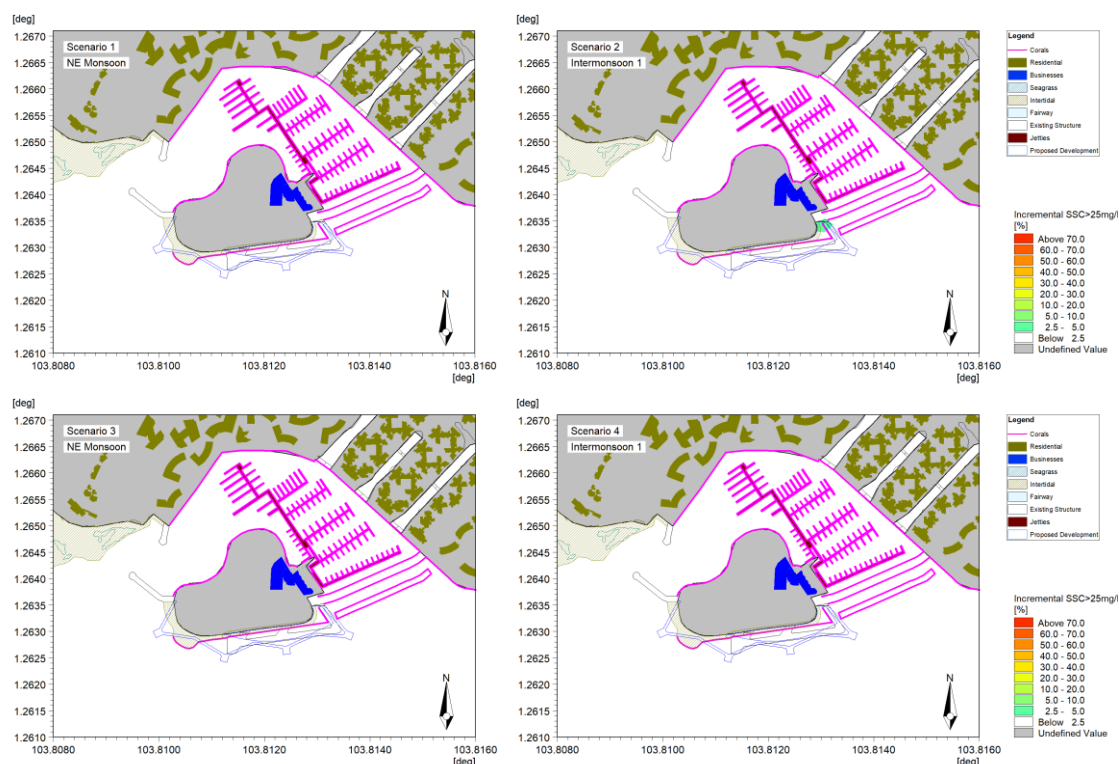


Figure 5.21 Percentage of time SSC in exceedance of 25 mg/l due to the installation of marine piles. Top-left: Scenario 1; top-right: Scenario 2; bottom-left: Scenario 3; bottom-right: Scenario 4.

Sedimentation

Figure 5.22 and Figure 5.23 presents the predicted sedimentation rates over a period of 14 days and a year, respectively. The results indicate that sedimentation due to the installation of marine piles was localised around the immediate Project site. Sedimentation rates were predicted to exceed 35 mm over 14 days for Scenarios 1 and 2 only (see Scenario 1 and 2 on Figure 5.22) and 250 mm per year for all scenarios (Figure 5.23). Sedimentation rates were not expected to exceed 1.70 mm over 14 days (see all scenarios on Figure 5.22) and 50 mm per year (Figure 5.23) outside the Project footprint.

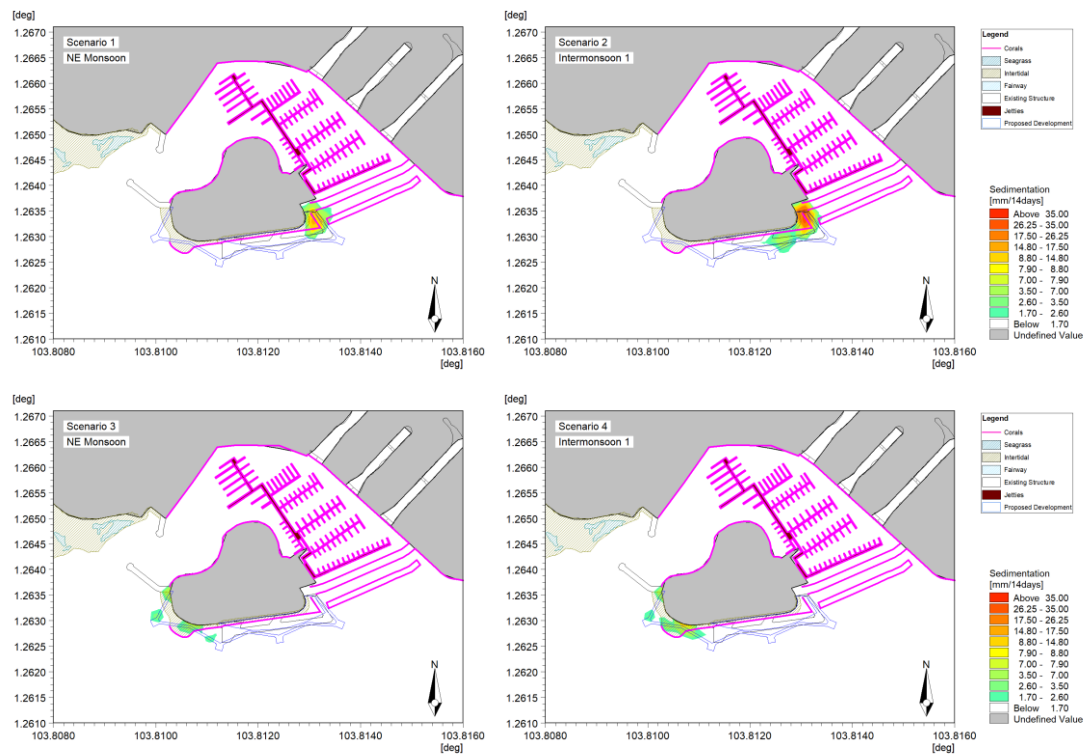


Figure 5.22 Sedimentation rates over 14-days due to the installation of marine piles. Top-left: Scenario 1; top-right: Scenario 2; bottom-left: Scenario 3; bottom-right: Scenario 4.

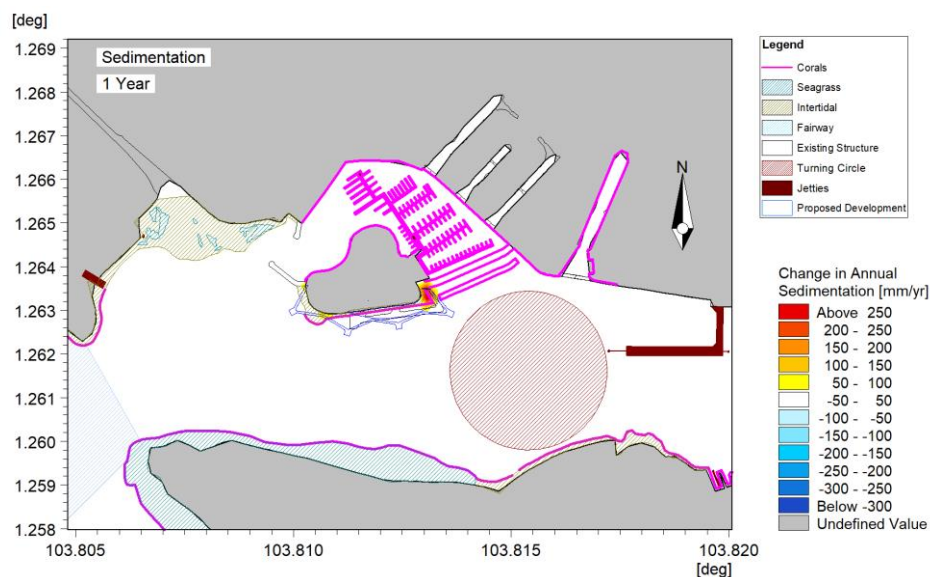


Figure 5.23 Annual sedimentation rates due to the installation of marine piles

5.2.6 Sediment Plume Summary

During the Construction Phase, the installation of two (2) piles per day was simulated each for the pile deck and the floating boardwalk in the sediment plume modelling, with a spill duration of thirty (30) minutes for each pile. The results show that the piling works will generate localised sediment plumes within the Study Area. Outside the Study Area, there was no significant increase in SSC (mean, 95th percentile, exceedance of 5 mg/l, 10 mg/l and 25 mg/l). Sedimentation was predicted to be localised around the Study Area. Assessment of sediment plume impacts on marine ecology and biodiversity, marine intakes, marine navigation and infrastructure, and socio-economic receptors are evaluated in Sections 5.8, 5.10, 5.11 and 5.12, respectively.

5.3 Pollution Release

The main driver for water quality changes during the Construction Phase is the presence of suspended sediments due to piling and demolition works. Besides reducing light penetration (assessed in the Marine Ecology and Biodiversity section, Section 5.8), the sediment may release pollutants that it carries into the water column. This section analyses the pollution level of the seabed and waters within the Study Area and estimates the quantity of pollutants likely released into the water column. The goal is to determine the risk of exceeding ambient marine water quality criteria.

5.3.1 Relevant Receptors

The relevant groups of receptors with respect to changes in pollution release are:

- Marine ecology and biodiversity (i.e., intertidal, seagrass, mangroves, corals, and marine fauna)
- Marine intakes; and,
- Socio-economic (i.e., residents, staff of businesses, and recreational users).

This section only discusses the pressures or stressors. The corresponding receptor chapters will assess the resulting impacts on the above-listed receptors (Sections 5.8 and 5.10).

5.3.2 Baseline Conditions

The assessment of potential water quality impact during the Construction Phase requires understanding the baseline pollutant content in the seabed sediment (which could potentially be released into the water column) and the water column itself. This section presents existing pollutant concentrations in samples collected during DHI's baseline seabed sediment and water quality surveys in the Study Area. The laboratory results for marine water quality and sediment quality can be found in **Appendix C**.

5.3.2.1 Marine Water Quality

Marine water measurements and sampling were carried out on 23 February 2024 and 05 March 2024 to investigate the baseline water quality conditions in the Study Area. Sampling was carried out at three (3) locations (Figure 5.5), covering spring and neap tides during the flood and ebb tides; water sample collection was carried out at surface depth only (1 m below surface).

At each location, six (6) water quality parameters were measured *in-situ* (on-site), and twenty (20) parameters were measured *ex-situ* (in the laboratory), covering a range of chemical and biochemical parameters. The *in-situ* measurements and laboratory results are presented in the following subsections; the method detection limit (MDL) and ASEAN MWQC are shown in the results plots where relevant. Where no bar is plotted for a given sample, it indicates that the concentration for the particular sample is below the MDL.

In-situ Water Quality Parameters

This section includes *in-situ* physical-chemical water quality parameters, including water temperature, salinity, dissolved oxygen, pH, and Secchi depth. These parameters were measured using a multi-parameter probe programmed to collect discrete physical-chemical measurements throughout the water column. The bar graphs present the depth-averaged

values. The graphs are discussed in the subsequent sections, and a summary of *in-situ* readings is provided in Table 5.6.

Table 5.6 Summary of *in-situ* water quality results across three (3) locations during spring and neap tides covering flood and ebb tides; results are benchmarked against the ASEAN MWQC (if relevant)

Reading	Spring Tide						Neap Tide						ASEAN MWQC
	WQ01 (F)	WQ01 (E)	WQ02 (F)	WQ02 (E)	WQ03 (F)	WQ03 (E)	WQ01 (F)	WQ01 (E)	WQ02 (F)	WQ02 (E)	WQ03 (F)	WQ03 (E)	
Temperature (°C)													
5 th percentile	28.83	28.82	28.81	28.84	28.81	28.78	29.04	29.00	29.06	29.02	29.14	29.04	-
Median	28.83	28.83	28.82	28.84	28.82	28.80	29.05	29.01	29.05	29.02	29.14	29.04	
95 th percentile	28.84	28.91	28.82	28.96	28.82	28.87	29.16	29.07	29.24	29.10	29.15	29.07	
pH													
5 th percentile	7.94	7.93	7.94	7.95	7.94	7.95	8.17	8.18	8.18	8.18	8.19	8.20	-
Median	7.94	7.94	7.94	7.95	7.94	7.95	8.17	8.18	8.18	8.18	8.19	8.20	
95 th percentile	7.94	7.95	7.94	7.95	7.94	7.95	8.18	8.19	8.19	8.18	8.19	8.20	
Salinity (psu)													
5 th percentile	31.58	31.60	31.61	31.61	31.59	31.60	31.41	31.37	31.42	31.39	31.46	31.29	-
Median	31.63	31.62	31.62	31.61	31.59	31.62	31.50	31.49	31.51	31.51	31.47	31.49	
95 th percentile	31.63	31.65	31.63	31.63	31.60	31.62	31.51	31.51	31.51	31.51	31.48	31.49	
Turbidity (NTU)													
5 th percentile	1.94	2.37	2.17	1.77	2.19	1.83	1.36	1.17	1.47	1.51	1.66	1.69	-
Median	2.39	2.51	2.35	2.10	2.36	2.09	1.50	1.27	1.64	2.41	1.81	1.85	
95 th percentile	2.69	2.72	2.61	2.23	2.75	2.23	1.69	1.47	1.99	3.02	1.92	2.15	
Dissolved Oxygen (mg/l)													
5 th percentile	6.07	6.06	6.07	6.05	6.06	6.13	6.09	6.10	6.11	6.10	6.23	6.16	>4 mg/l
Median	6.09	6.11	6.10	6.10	6.10	6.15	6.13	6.16	6.13	6.14	6.24	6.18	
95 th percentile	6.11	6.17	6.16	6.18	6.13	6.18	6.24	6.23	6.22	6.20	6.26	6.21	
Secchi Depth (m)													
Reading	2.6	2.9	2.4	2.9	2.6	3.0	2.8	2.9	2.4	3.1	2.4	2.5	-

Temperature

Temperature is a crucial driver of water quality, directly influencing dissolved oxygen concentrations, salinity, and, to a lesser extent, pH. Temperature is also coupled to diurnal cycles and associated photosynthetic activity. Ambient water temperature in Singapore's near-shore coastal waters varies demonstrably, although these changes are slight over temporal and spatial scales.

The median of the depth-averaged temperatures across each sampling station ranged from 28.80 °C to 29.14 °C (Table 5.6). The results of temperature showed low spatial variation (<1.00 °C), with similarly low variability between tides (<1.00 °C) in Figure 5.24. These results indicate no temperature-driven water column stratification, and that the temperature had little variability throughout the sampling period.

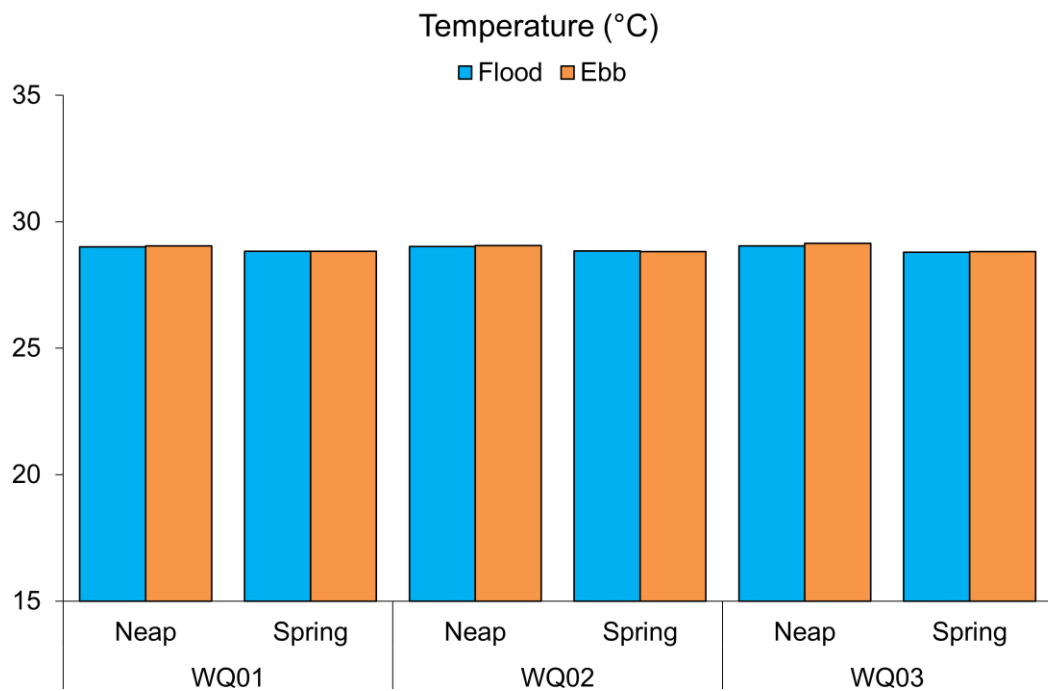


Figure 5.24 Median temperature results across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

pH

pH is a key physiological driver for many species of aquatic biota. The pH of marine waters should fall within the range of 7.0 to 8.7 (Canadian Water Quality Guidelines for the Protection of Aquatic Life, 1999), and adverse physiological stress for marine biota is likely to occur when it is beyond this range.

All surveyed water stations were generally alkaline, with a pH between 7.94 and 8.20, as shown in the median values (Table 5.6). Results in Figure 5.25 show slight variability in pH over the sampling period, with higher pH during neap tide. All depth-averaged pH values were within the guidelines for the protection of aquatic life.

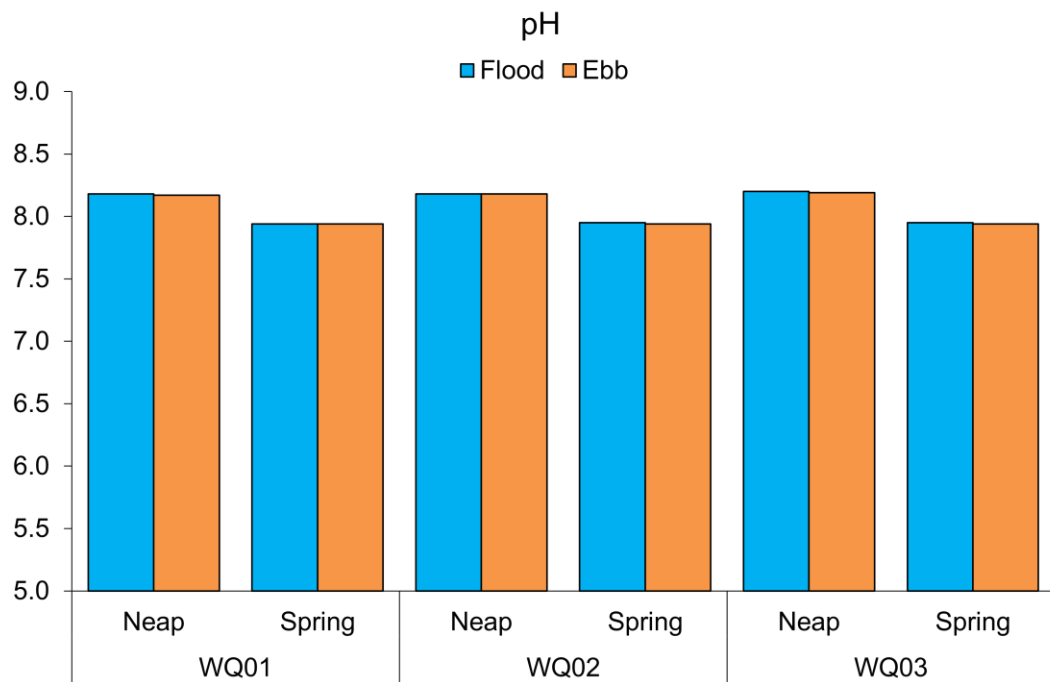


Figure 5.25 Median pH results across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

Salinity

Salinity varies according to season and is mainly influenced by freshwater runoff during the pronounced monsoon events experienced in Singapore’s territorial waters. The water’s salinity indicates the extent of mixing and the presence of salinity stratification, which may occur when there is significant freshwater runoff.

The median of the depth-averaged salinity levels across all three (3) sampling stations falls within 31.47 psu and 31.63 psu (Table 5.6). The range of salinity recorded (Figure 5.26) was expected based on ranges recorded for the Singapore Strait in two published studies: 28.7 psu to 32.2 psu (Gin *et al.*, 2000) and ≤ 30 psu to 33 psu (Zhou *et al.*, 2021).

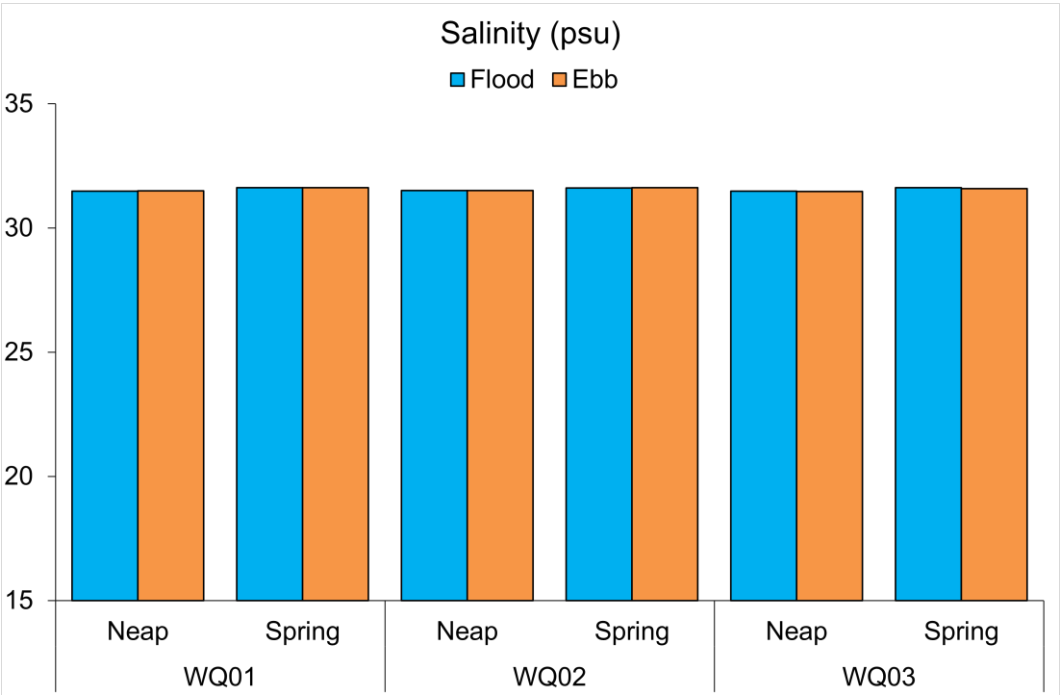


Figure 5.26 Median salinity results across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

Dissolved Oxygen (DO)

The DO concentration is used as an indicator to determine the ecological condition of the waters. It is primarily maintained through bio-physical processes such as wind-driven agitation of surface waters, tidal exchange and biological processes such as photosynthesis from aquatic flora (algae, seagrass and phytoplankton).

The median DO across all three (3) sampling locations ranged from 6.09 mg/l to 6.24 mg/l (Table 5.6; Figure 5.27), above the ASEAN MWQC of more than 4 mg/l. Hence, the waters around the Project site are generally well-oxygenated.

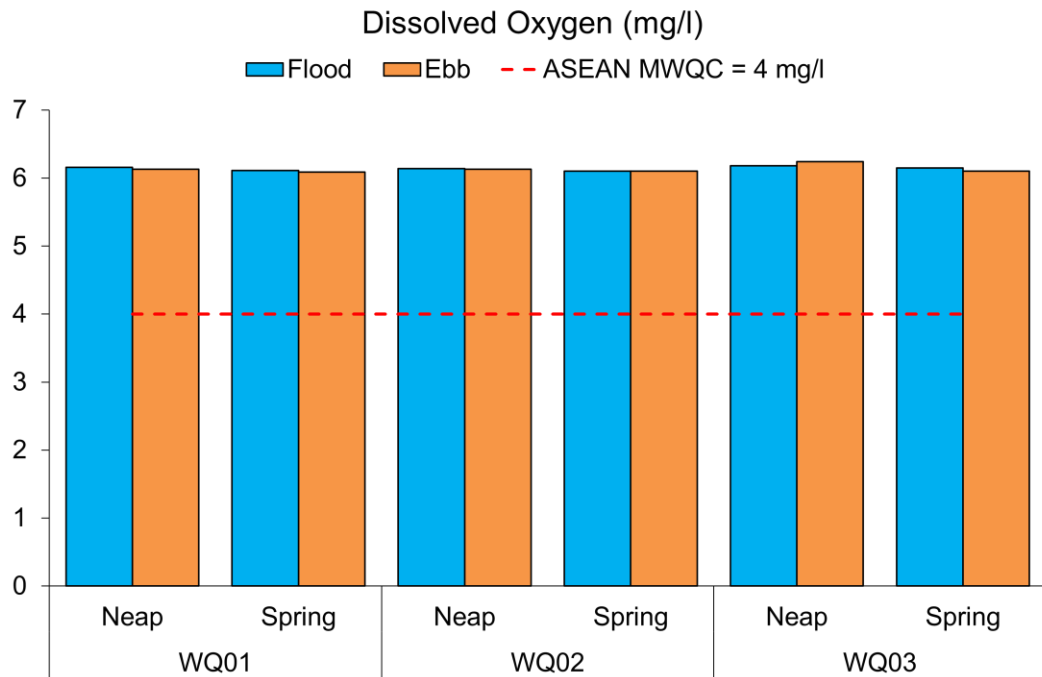


Figure 5.27 Median dissolved oxygen results across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

Secchi Disc Depth

Secchi depth is the depth at which a Secchi disc (a disc with alternating black and white quadrants) is lowered in a body of water until it is no longer visible, indicating the clarity and transparency of a water body. It is inversely correlated with turbidity and light attenuation. Conversely, the higher the Secchi disc value, the greater the light penetration and the better the water clarity. While there is no ASEAN MWQC for Secchi depth, an indicative value of more than 1.2 m has been used as a guide in other Singapore studies.

The Secchi disc depth measurements ranged from 2.4 m to 3.1 m across all sampling locations, which is generally above the target depth of 1.2 m (Table 5.26; Figure 5.28).

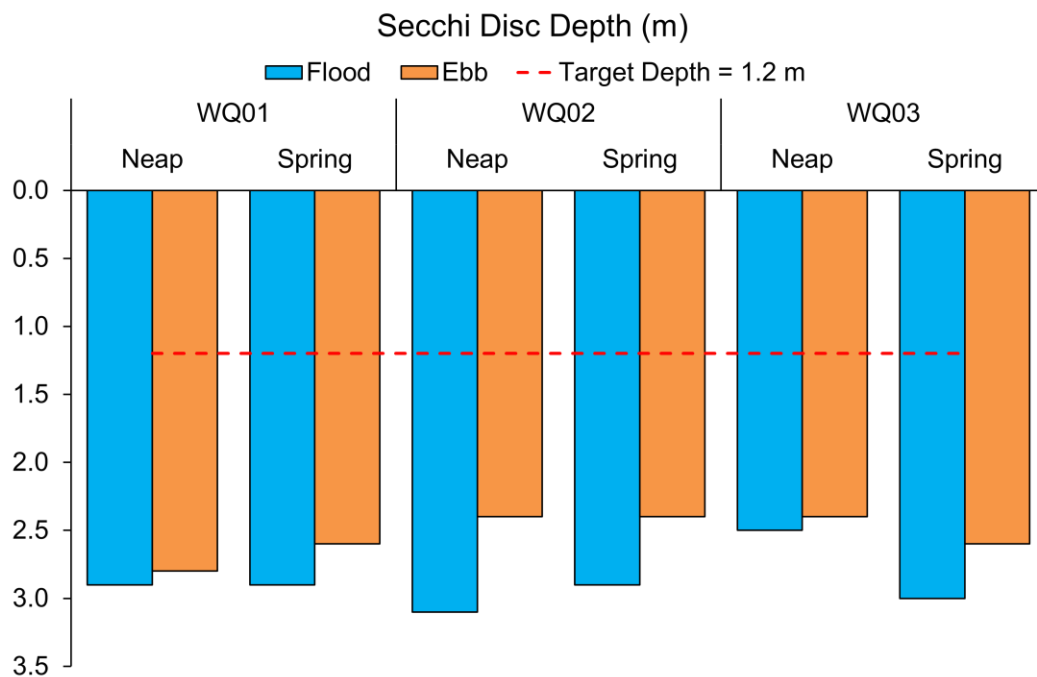


Figure 5.28 Secchi disc depth results across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

Ex-situ Water Quality Results

This section summarises the *ex-situ* analytical water quality parameters. The parameters include Total Ammoniacal Nitrogen (TAN), phosphate (PO₄-P), Nitrate (NO₃-N), Nitrite (NO₂-N), Biochemical Oxygen Demand (BOD₅), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), Zinc (Zn), Oil and Grease (Total and Hydrocarbon), *Escherichia coli* (*E. coli*), Faecal Coliform, Enterococci and Chlorophyll-a. Laboratory analyses of water quality samples were undertaken by a Singapore Laboratory Accreditation Scheme (SINGLAS) accredited laboratory in accordance with the Singapore Accreditation Council requirements for standard procedures.

The analytical results are summarised in Table 5.7. Reported concentrations of Oil and Grease (total and hydrocarbon), BOD₅, Cd, Pb, Hg, and Zn were below the detection limits and will not be discussed in this section. Most of the stations indicated compliance with the ASEAN MWQC, where applicable. Phosphate concentration at WQ03, during spring, flood tide, exceeded the ASEAN MWQC and elevated levels of faecal coliforms at WQ01 and WQ03, both during neap, ebb tide, were also observed, exceeding ASEAN MWQC for recreational waters.

Table 5.7 Summary of *ex-situ* water quality results at surface level only across three (3) locations during spring and neap tides covering flood and ebb tides; results are benchmarked against the ASEAN MWQC (if applicable). Values in red indicate exceedance of ASEAN MWQC for Aquatic Life Protection in Coastal areas.

Parameter	Unit	Depth	Spring Tide						Neap Tide						ASEAN MWQC
			WQ01 (F)	WQ01 (E)	WQ02 (F)	WQ02 (E)	WQ03 (F)	WQ03 (E)	WQ01 (F)	WQ01 (E)	WQ02 (F)	WQ02 (E)	WQ03 (F)	WQ03 (E)	
Total Suspended Solids (TSS)	mg/l	Surface	5.50	5.80	8.90	7.70	7.80	5.80	5.00	4.00	5.00	4.30	5.10	5.30	-
Nitrate as NO ₃ -N	mg/l	Surface	<0.003	0.007	0.006	0.010	<0.003	0.008	0.004	0.005	0.004	0.005	<0.003	0.004	<0.060
Nitrite as NO ₂ -N	mg/l	Surface	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.003	0.004	0.003	0.004	<0.003	0.003	<0.055
Phosphate as PO ₄ -P	mg/l	Surface	0.008	0.006	<0.003	0.004	0.004	0.022	0.005	0.004	0.005	0.003	<0.003	<0.003	<0.015
Total Ammoniacal Nitrogen (NH ₃ -N + NH ₄ -N)	mg/l	Surface	0.007	0.011	0.007	0.008	0.007	0.010	0.006	0.007	0.008	0.007	0.009	0.006	-
Oil and grease (Hydrocarbon)	mg/l	Surface	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.14
Oil and grease (Total)	mg/l	Surface	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.14
Dissolved Arsenic	µg/l	Surface	5.73	6.44	5.36	6.31	5.29	5.23	5.78	4.76	5.81	5.18	7.06	7.14	-
Dissolved Cadmium	µg/l	Surface	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<10
Dissolved Chromium	µg/l	Surface	0.46	0.45	0.46	0.50	0.46	0.51	1.00	1.29	0.78	1.11	1.13	1.24	<50
Dissolved Copper	µg/l	Surface	3.56	2.71	4.31	3.64	5.26	3.08	1.14	1.41	0.92	1.22	1.30	1.45	<8
Dissolved Lead	µg/l	Surface	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<8.5
Dissolved Mercury	µg/l	Surface	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.16
Dissolved Nickel	µg/l	Surface	1.42	1.31	1.51	1.44	1.48	1.35	1.48	1.29	4.17	1.09	1.38	1.41	-
Dissolved Zinc	µg/l	Surface	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	-
Chlorophyll-a	µg/l	Surface	1.19	1.65	1.28	1.60	1.37	1.55	0.67	0.76	0.62	0.60	0.78	0.48	-
E. coli	MPN/100ml	Surface	7.80	2.00	11.00	<1.8	4.50	4.50	12.00	40.00	12.00	24.00	27.00	9.30	-
Biological Oxygen Demand (BOD ₅)	mg/l	Surface	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-
Faecal Coliform	MPN/100ml	Surface	7.8	2.0	11.0	12.0	7.8	4.5	79.0	220	27.0	39.0	27.0	920	<100
Enterococci	CFU/100ml	Surface	6	3	2	2	4	<1	1	2	2	12	6	9	<35

* Value for recreational waters

Nitrogen

Nitrogen compounds are necessary for plant and algal growth. They are often a limiting factor in the growth of phytoplankton in marine waters. Excess quantities of nitrogen can lead to undesirable algal blooms, resulting in incidents of oxygen depletion (hypoxia). Nitrogen parameters include Total Ammoniacal Nitrogen (TAN), nitrate ($\text{NO}_3\text{-N}$), and nitrite ($\text{NO}_2\text{-N}$). Both nitrate and nitrite concentrations were below the ASEAN MWQC of 0.060 mg/l and 0.055 mg/l, respectively, whereas there is no available ASEAN MWQC guideline for TAN (Figure 5.29).

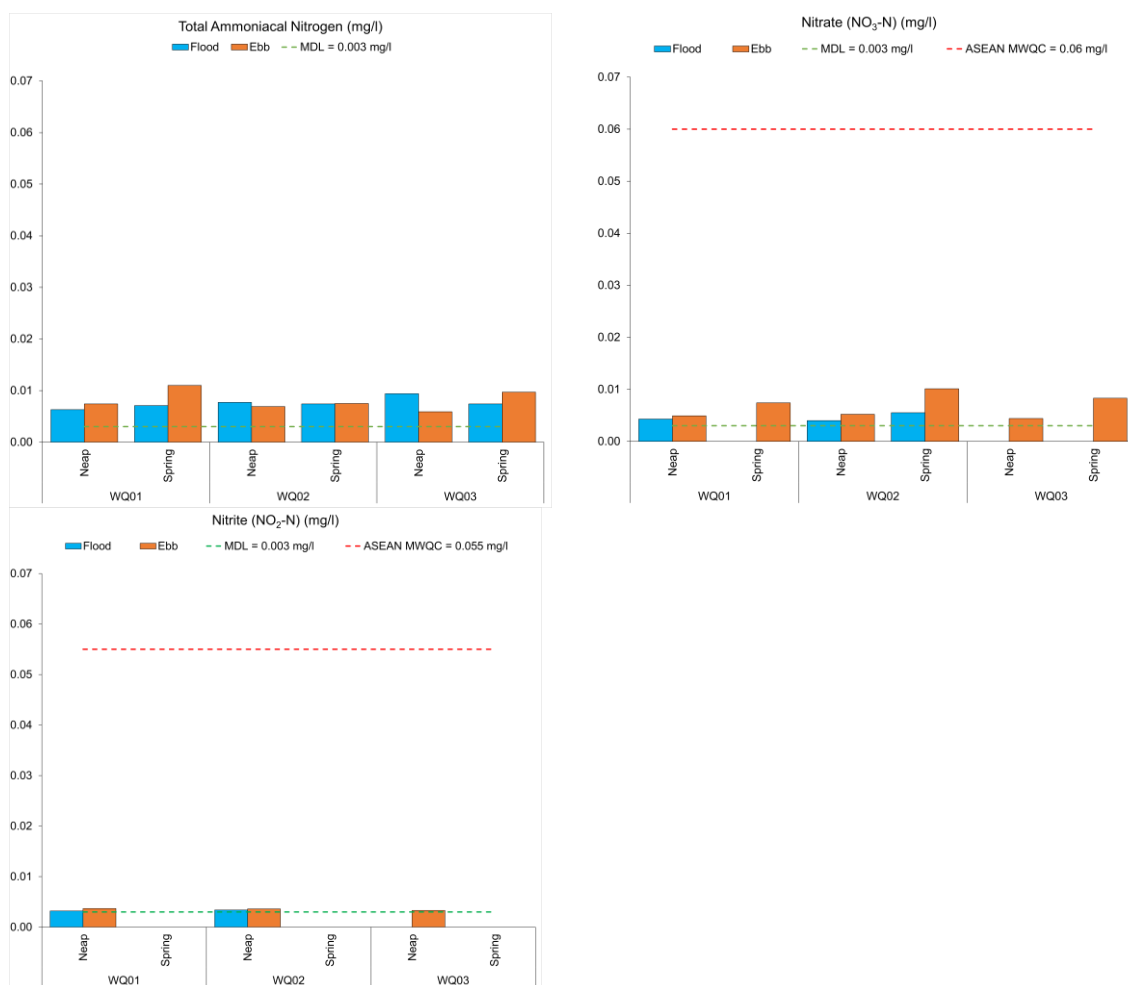


Figure 5.29 Total Ammoniacal Nitrogen (TAN), Nitrate and Nitrite concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

Phosphate ($PO_4\text{-P}$)

Elevated phosphate levels may be associated with stormwater runoff carrying traces of fertiliser, animal wastes, or fish farms, where feed containing phosphorus is the main factor of pollution in aquaculture (Américo *et al.*, 2013; Araújo-Silva *et al.*, 2014; Caramel *et al.*, 2014; Moraes *et al.*, 2015).

The concentrations of phosphate found during the survey ranged between <0.003 and 0.022 mg/l (Figure 5.30). All stations, except at WQ03 during spring ebb tide, met the ASEAN MWQC guideline (0.015 mg/l for coastal habitats).

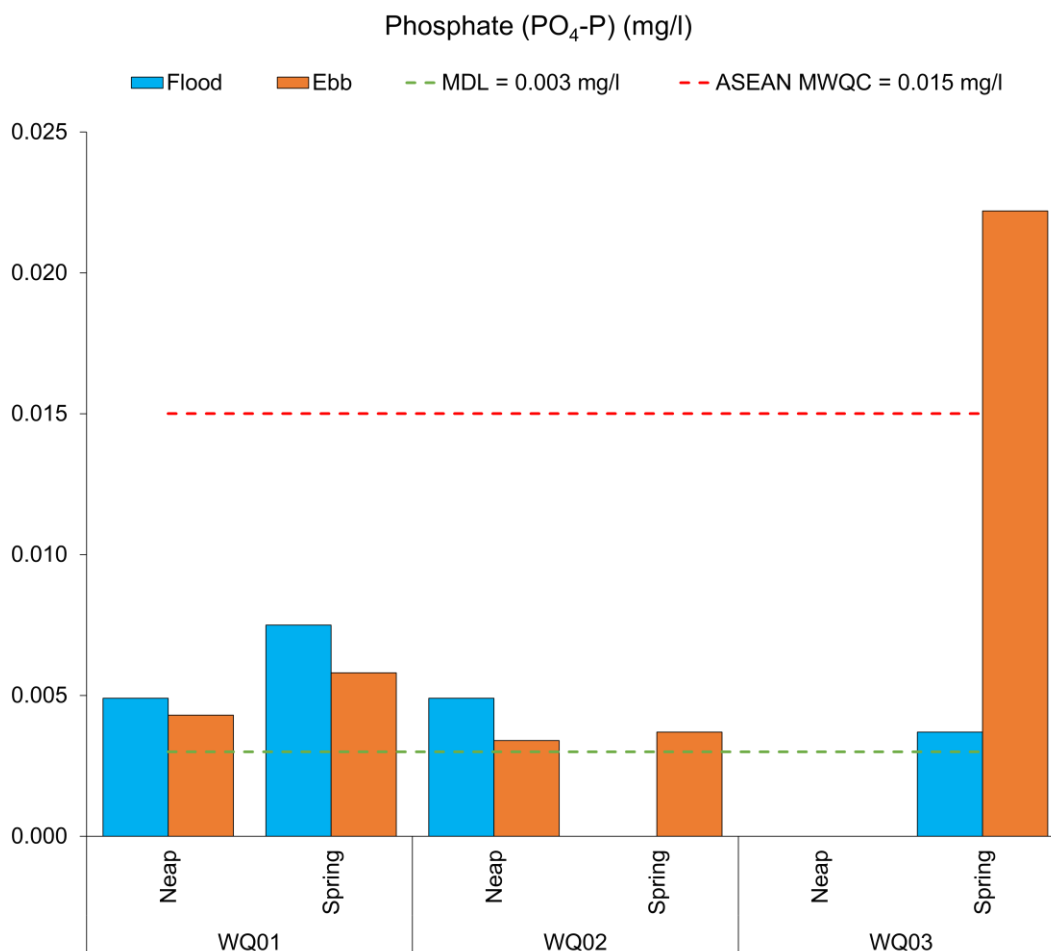


Figure 5.30 Phosphate ($PO_4\text{-P}$) concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

Chlorophyll-a

Chlorophyll-a, in various forms, is bound within the living cells of phytoplankton (microalgae) in surface water. Chlorophyll-a levels and other parameters can indicate possible eutrophic conditions and project-induced changes, so this parameter should be closely examined despite the lack of ASEAN or other standards in Singapore.

During the baseline surveys, chlorophyll-a concentrations ranged from 0.48 µg/l to 1.65 µg/l (Figure 5.31).

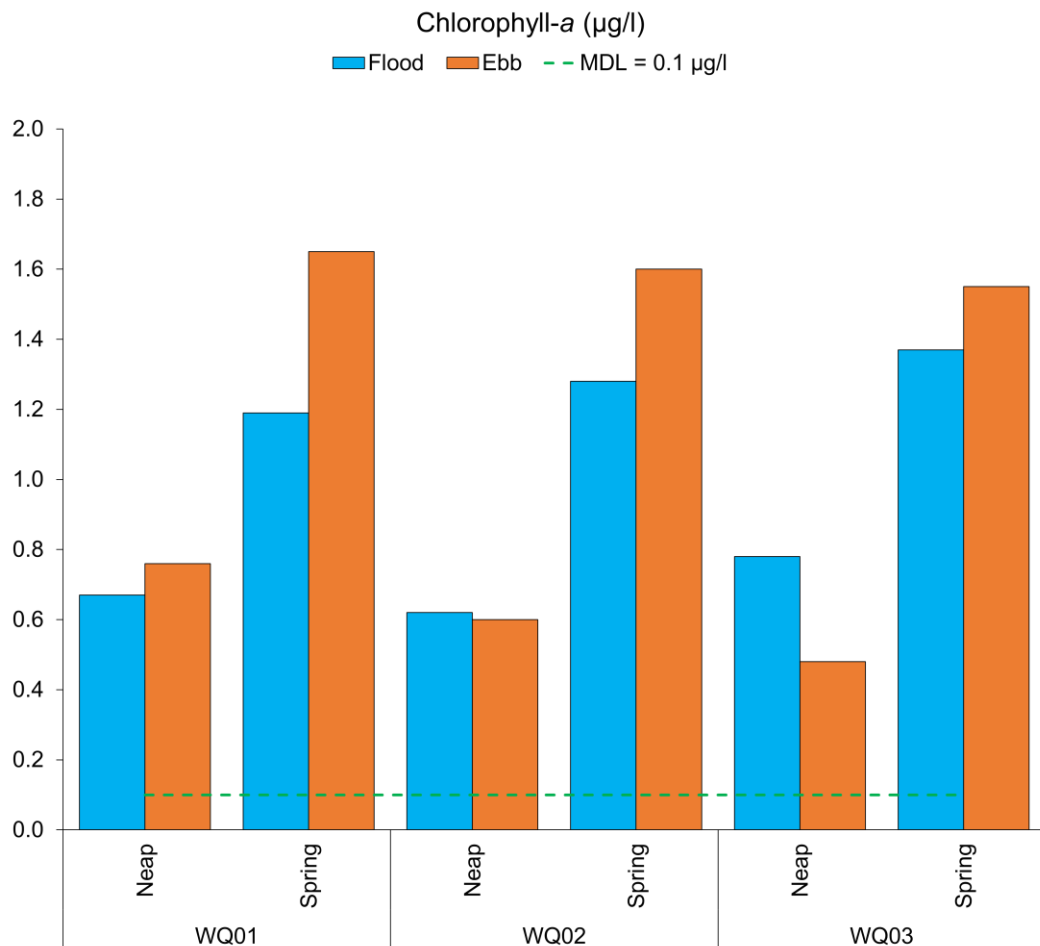


Figure 5.31 Chlorophyll-a concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

E. coli

E. coli is a species of faecal coliform bacteria specific to faecal material from humans and other warm-blooded animals. The United States Environmental Protection Agency (USEPA) recommends *E. coli* as the best indicator of health risks from water contact in recreational waters.

As shown in Table 5.7, *E. coli* ranged from < 1.8 MPN/100ml to 40 MPN/100ml. Several spikes of up to 40 MPN/100ml were also observed at all stations, as illustrated in Figure 5.32.

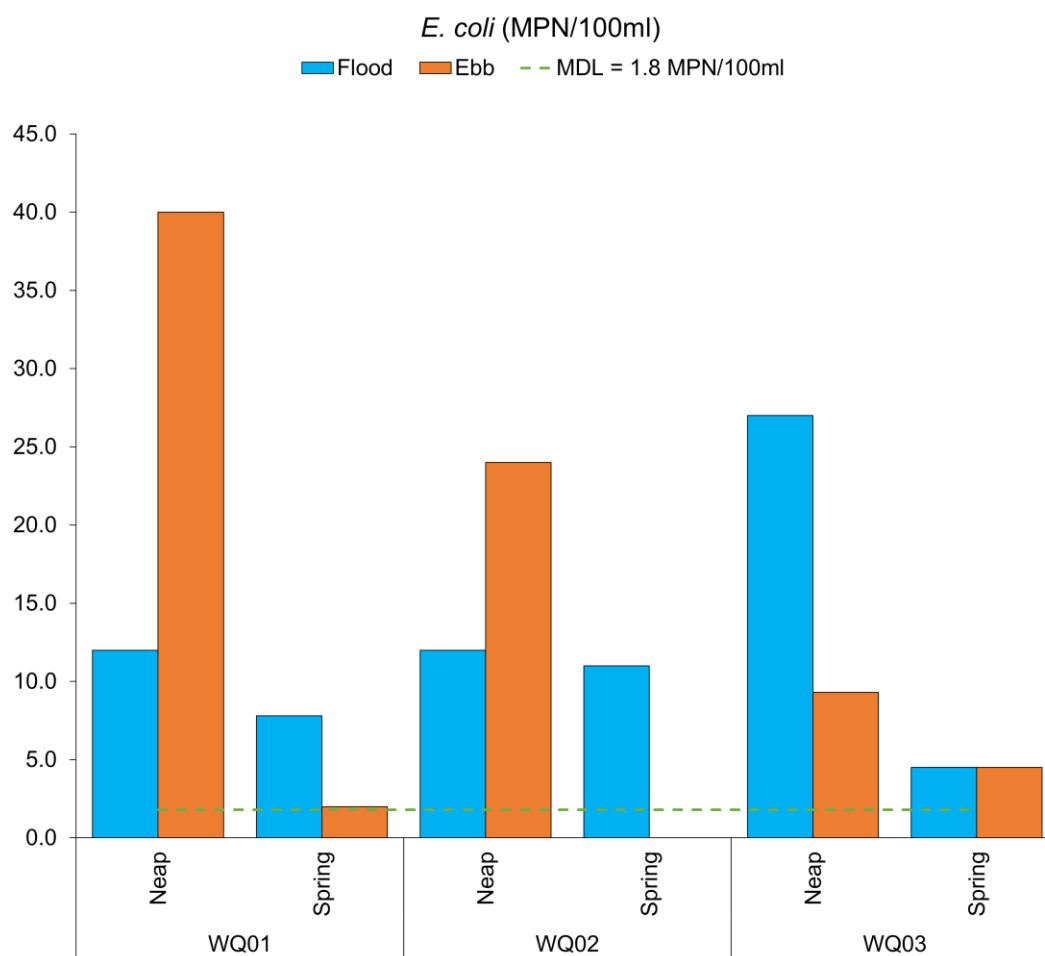


Figure 5.32 *E. coli* concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

Faecal Coliform

Bacterial counts of faecal coliform are commonly used in water quality monitoring as indicators of water hygiene and faecal contamination, as these concentrations determine potential risks to human health. Some sources of faecal indicator bacteria include stormwater runoff, leaking septic systems, sewage discharged or dumped from recreational boats, domestic animal and wildlife waste, and runoff from manure storage areas. ASEAN MWQC states that concentrations of 100 MPN/mL for faecal coliforms should apply.

Concentrations of faecal coliform ranged from 2 MPN/100ml to 920 MPN/100ml (Figure 5.33). Several exceedances above the ASEAN MWQC for faecal coliform were observed across WQ01 and WQ03 during neap ebb tide with concentrations as high as 920 MPN/100ml (Table 5.7).

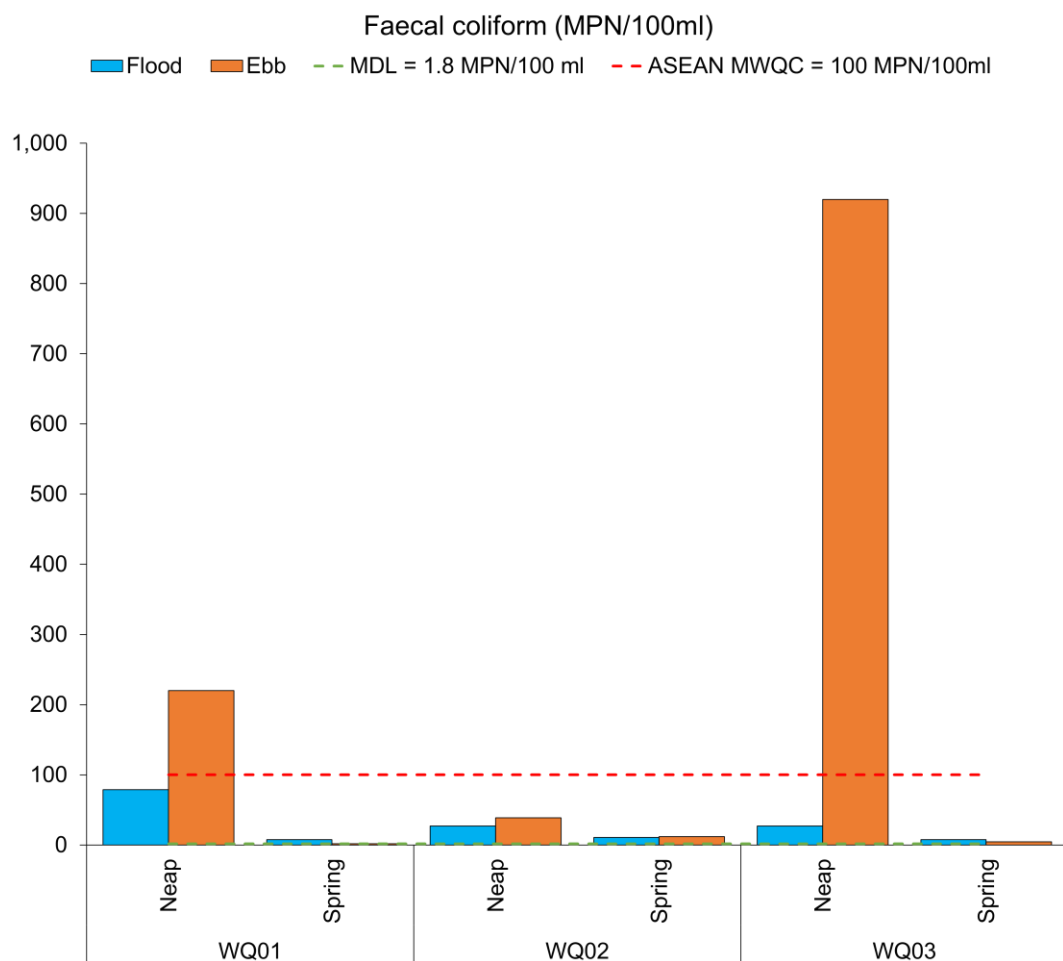


Figure 5.33 Faecal coliform concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

Enterococci

In contrast to faecal coliforms, enterococci survive for longer periods in seawater and are thought to be more tightly associated with pathogens harmful to humans (Wymer *et al.*, 2005). Hence, enterococci are good indicators of the presence of aged faecal contamination. ASEAN MWQC states that enterococci concentrations of 35 CFU/100ml should apply.

The enterococci concentrations ranged from <1 CFU/100ml to 12 CFU/100ml. The enterococci results shown in Figure 5.34 indicate that observed concentrations are generally below the ASEAN MWQC across all stations.

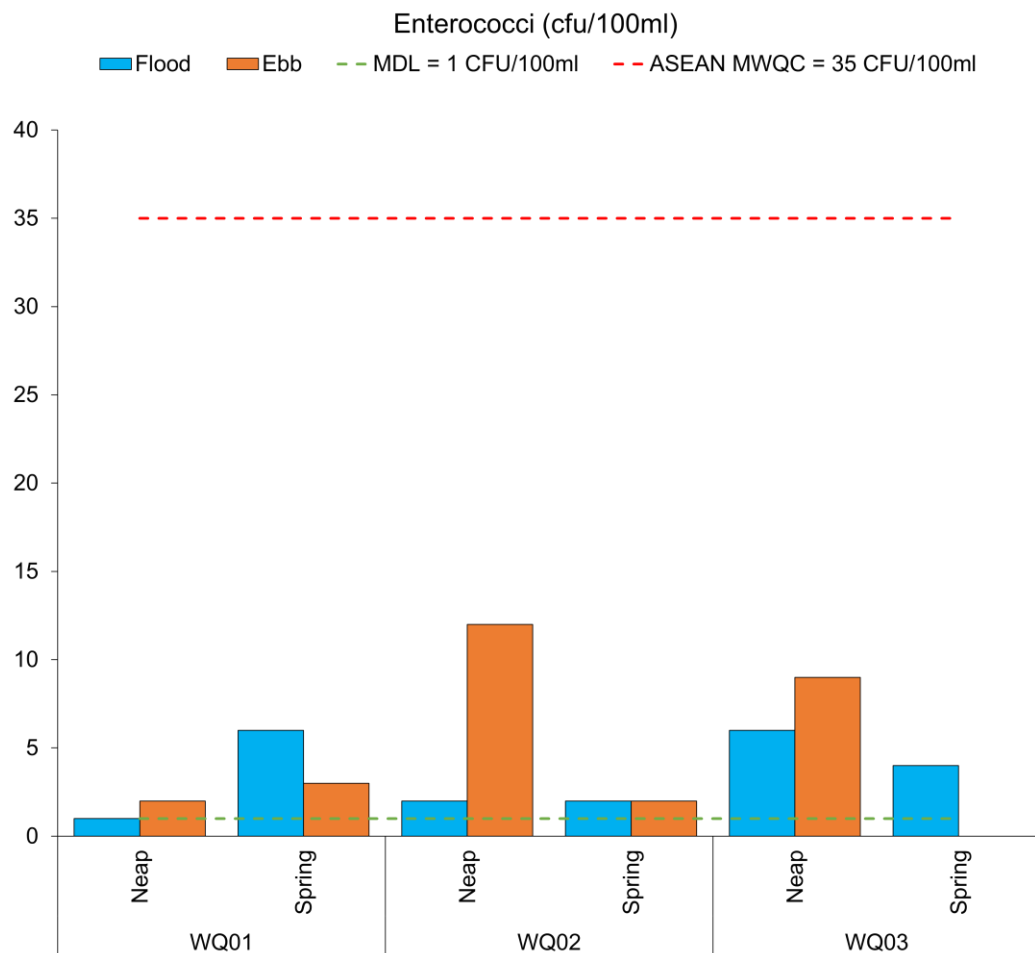


Figure 5.34 Enterococci concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

Heavy Metals

The ecological health of a marine community is dependent on environmental quality to a large degree. High concentrations of heavy metals in marine ecosystems could cause toxicity in various groups of marine organisms. Additionally, primary producers can take up toxic heavy metals, enter the food web and be potentially transferred to higher trophic levels and threaten human beings (Wang, 2002).

All heavy metal parameters were well below the stated ASEAN MWQC, as indicated in the results in Table 5.7. There is no ASEAN MWQC for Arsenic and Nickel. Overall, all detected heavy metal concentrations were below 8.0 µg/l. Results for Arsenic (Figure 5.35), Chromium (Figure 5.36), Copper (Figure 5.37), and Nickel (Figure 5.38) showed low concentrations (i.e., below 7.5 µg/l). Arsenic had the highest average concentration across all stations, ranging from 4.76 µg/l to 7.14 µg/l.

Sources of these metals can be diverse, including stormwater runoff carrying catchment-based contaminants, vessels' waste and wastewater releases, or re-suspension as a legacy of historical activities.

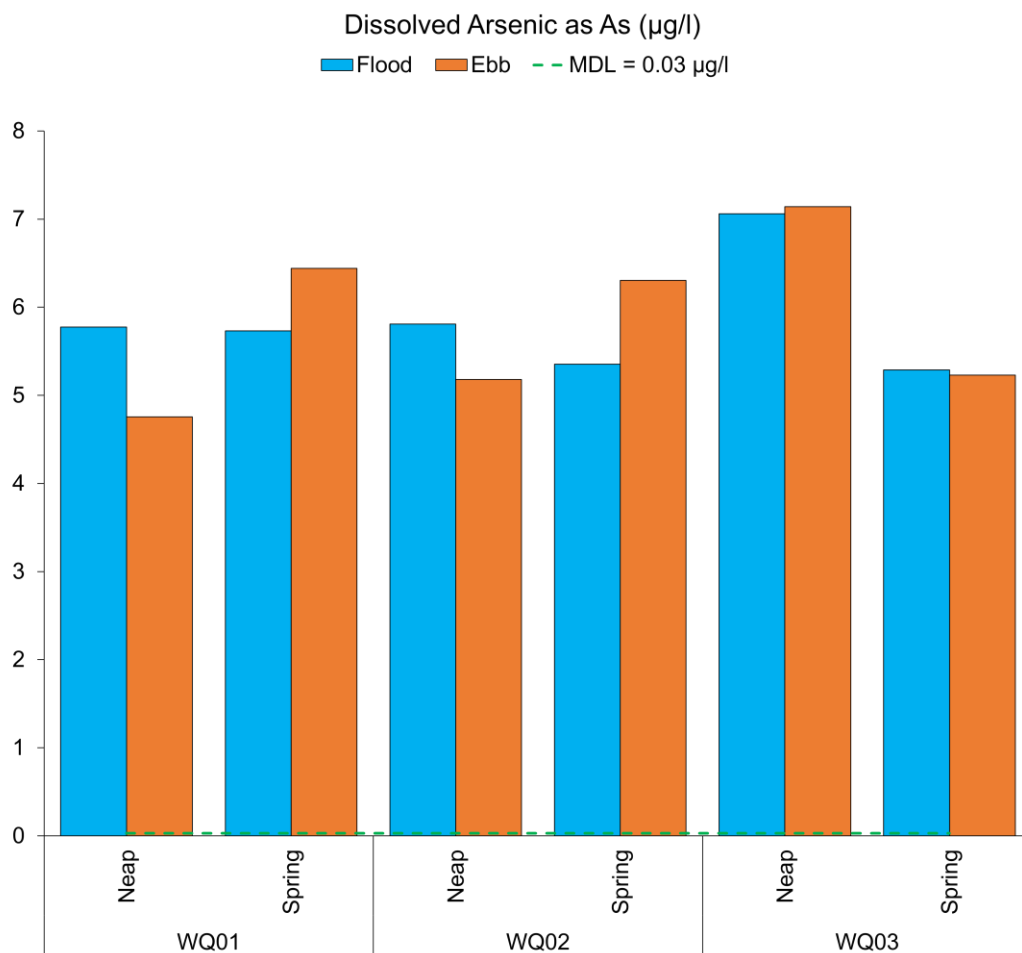


Figure 5.35 Arsenic concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

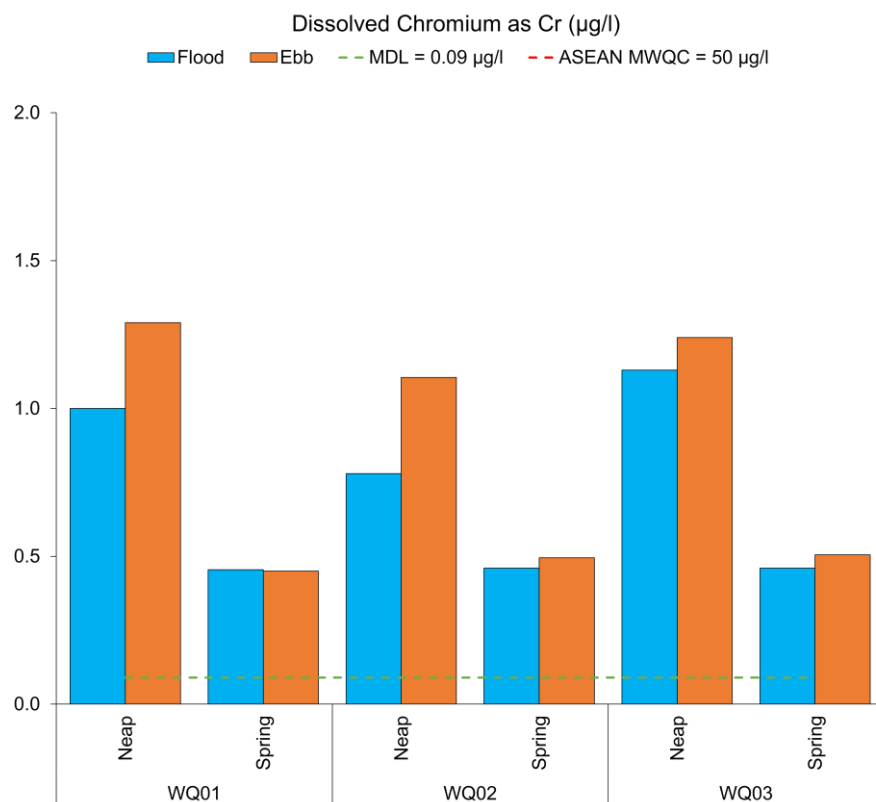


Figure 5.36 Chromium concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

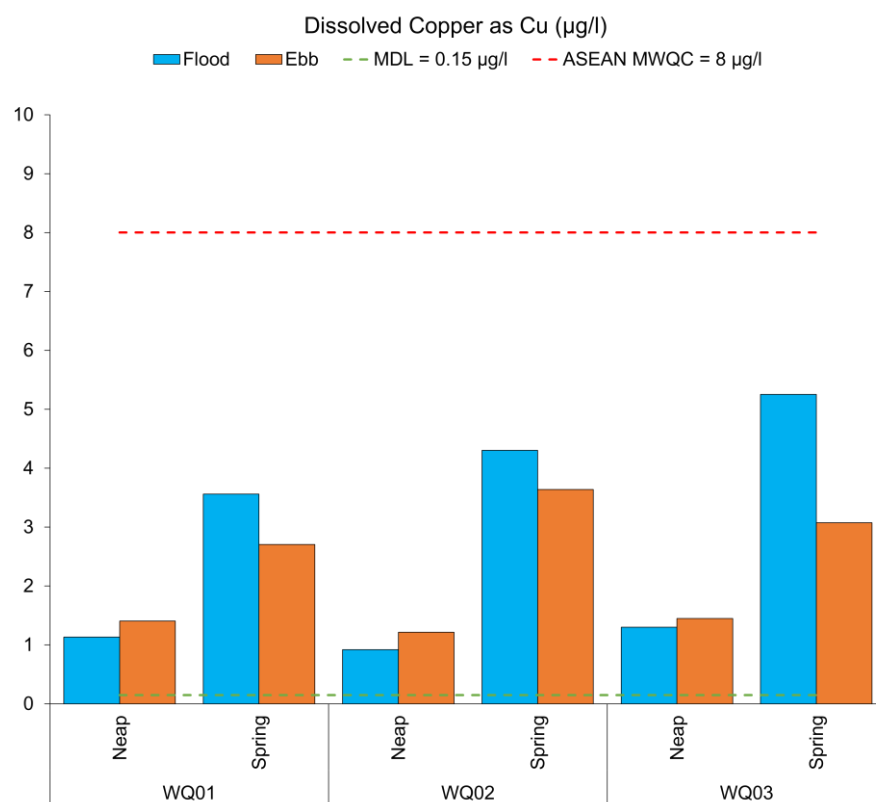


Figure 5.37 Copper concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

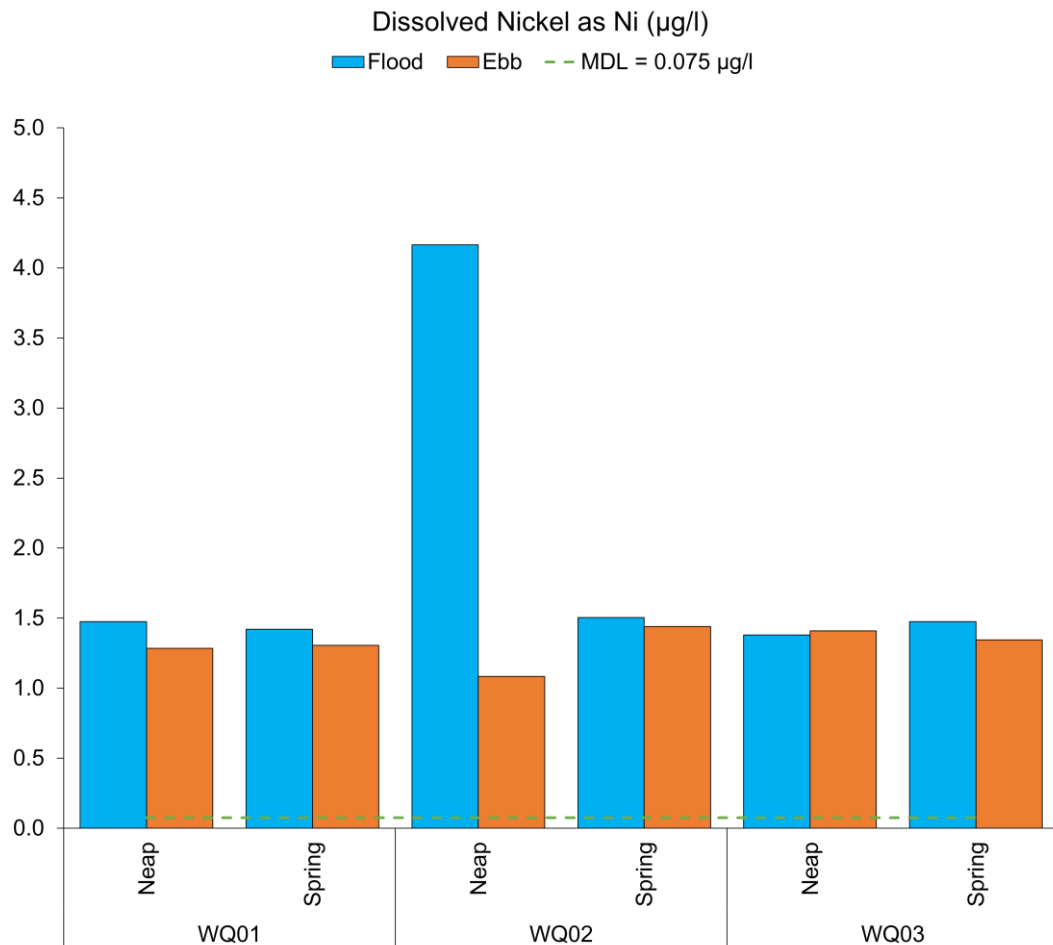


Figure 5.38 Nickel concentrations across all three (3) locations (WQ01 to WQ03) during spring and neap tides covering flood and ebb tides

5.3.2.2 Sediment Quality

The purpose of the sediment quality surveys was to provide input for the bed characteristics description for the morphology and sediment transport impact modelling and the sources of seabed pollutants that may be resuspended during the construction. These pollutants, when resuspended, may affect the water quality around the Project site. Sediment quality and grading surveys were conducted on 23 February and 05 March 2024. Sampling was conducted at three (3) locations (Figure 5.6).

The sediment quality results for chemical and heavy metals analysis are presented in Table 5.8. The sediment quality parameters from the laboratory results did not exceed the limits in all the guidelines.

Table 5.8 Sediment quality laboratory results in comparison to MPA, Dutch, and Hong Kong Guidelines for SQ01 to SQ03

Parameters	Unit	SQ01	SQ02	SQ03	Limit of Reporting	MPA Guidelines [mg/kg]	Dutch Guidelines [mg/kg]	Hong Kong Guidelines	
								Lower Chemical Exceedance Level [mg/kg]	Upper Chemical exceedance Level [mg/kg]
Total Nitrogen	mg/kg	1,533	1,296	950	1	-	-	-	-
Total Phosphorus	mg/kg	6.97	10.8	6.37	1	-	-	-	-
Arsenic as As	mg/kg	10.7	7.88	11.0	0.5	30	29	12	42
Cadmium as Cd	mg/kg	0.57	0.31	0.33	0.05	1	0.8	1.5	4
Chromium as Cr	mg/kg	28.5	19.8	19.2	0.02	50	100	80	160
Copper as Cu	mg/kg	29.0	25.2	21.6	0.1	55	36	65	110
Mercury as Hg	mg/kg	0.16	<0.01	<0.01	0.01	0.8	0.3	0.5	1
Nickel as Ni	mg/kg	15.5	11.2	11.5	0.1	35	35	40	40
Lead as Pb	mg/kg	30.3	25.8	26.8	0.5	65	85	75	110
Zinc as Zn	mg/kg	103	88.2	87.9	0.05	-	140	200	270

Total Nitrogen (TN)

TN concentration levels are an important source of sediment conditions in terrestrial and aquatic ecosystems. TN is derived mainly from the decomposition of plankton, fertilisers, plants, and chemical contaminations (Avramidis *et al.*, 2015).

As shown in Table 5.8, TN concentration levels results show that SQ01 and SQ02 had high TN values of 1,533 mg/kg and 1,296 mg/kg, respectively. SQ03 showed lower concentration levels at 950 mg/kg. No existing criteria exist for TN in the MPA, Dutch, and Hong Kong Guidelines.

Total Phosphorous (TP)

As shown in Table 5.8, TP concentration level results show that most locations had TP values less than 15 mg/kg. No existing criteria exist for TP in the MPA, Dutch, and Hong Kong Guidelines.

Heavy Metals

Overall, sediment quality parameters across all three (3) sampling locations did not exceed MPA, Dutch, and Hong Kong guidelines for all heavy metal parameters, indicating that heavy metal levels are not elevated. As no elevated heavy metal content was found in the sediment around the works, modelling of heavy metals is not required.

5.3.3 Analysis Methodology

This analysis focuses on the release of heavy metals from suspended sediments in the Study Area. The elevated nutrient level in the sediments mean that nutrients in suspended sediments may influence the receiving sites where the sediment plume have spread to. In the absence of information on nutrient release from suspended sediments, the assessment of the resultant change in water quality is primarily qualitative in the relevant receptor chapters. No quantification of nutrient release from suspended sediments was carried out.

Release of Heavy Metals from Suspended Sediments

The quantification of heavy metal release from suspended sediments is typically carried out via scaling the sediment plume model results in terms of mg/l SSC (Section 5.2) against the pollutant concentrations in the sediment (based on total heavy metal levels in sediment collected in baseline surveys) and a scale factor. The results predict *incremental* dissolved heavy metals in the water column due to potential release from suspended sediments. These *incremental* values are then added to baseline dissolved heavy metal concentrations in the water to ascertain the total concentrations, which are then compared against the relevant ambient water quality guidelines. This method is considered conservative and has been adopted as a standard practice for marine environmental studies in Singapore.

According to a study in Germany, up to 2 % of the particulate-bound heavy metals were remobilised from the sediments (Petersen *et al.*, 1997). The study noted that metal release is significantly affected by biological activity, i.e., microbial processes in the sediment. This was supported by a similar study at the University of Michigan that indicated that metals were released from all sediments during four-hour continuous resuspension. Metal concentrations remained constant after the resuspension began, with less than 2 % of total metal released into the water column for the majority of runs.

The study found that the highest total dissolved fraction of arsenic was less than 5.40 %, copper less than 1.53 %, and zinc less than 0.97 % in the laboratory experiments for four (4) different sediment types (Eggleston, 2012).

The pollutant release from the sediment plumes generated during the Construction Phase is evaluated using a conservative approach. The calculation adopts the *maximum* concentration recorded in the seabed sediment for each heavy metal during the baseline

surveys. The modelled mean incremental SSC at each relevant receptor varies among the four (4) sediment plume model scenarios, and hence the highest value is also conservatively selected for this calculation. The calculation formula is as follows:

$$\begin{array}{ccccccc} \text{Max.} & & & & & & \\ \text{Incremental HM} & & & & & & \\ \text{concentration in} & = & \text{Max. HM} & & \text{2 \% release of} & & \text{Highest modelled} \\ \text{water column} & & \text{concentration in} & \times & \text{the HM} & \times & \text{mean excess SSC} \\ \text{(mg/l)} & & \text{seabed (mg/kg)} & & & & \text{(mg/l)} \end{array}$$

*HM = heavy metals

5.3.4 Evaluation Framework

The calculated heavy metal levels in water quality due to pollution release from suspended sediments are benchmarked against the marine water quality criteria for the ASEAN region, hereafter referred to as ASEAN MWQC, and Thailand Marine Water Quality Class Designators and Beneficial Uses. The criteria suggested by these guidelines are presented in Table 5.9. The limits for heavy metals (arsenic, cadmium, chromium, copper, lead, mercury and zinc) are relevant to the present assessment. They relate to the dissolved fraction in the water, as opposed to the adsorbed fraction (i.e., that fraction bound to sediment particles in the water). The assessment covers nickel as Ni but note that no water quality guideline for this heavy metal is available.

Table 5.9 Marine Water Quality Criteria for the ASEAN region for relevant water quality parameters to this Project

Parameter	Units	Aquatic Life Protection	Human Health Protection
Faecal Coliforms	MPN/100ml	NA	100
Enterococci	MPN/100ml	NA	35
Arsenic (As)	µg/l	120*	NA
Cadmium (Cd)	µg/l	10	NA
Chromium (VI) (Cr)	µg/l	50	NA
Copper (Cu)	µg/l	8	NA
Lead (Pb)	µg/l	8.5	NA
Mercury (Hg)	µg/l	0.16	NA
Zinc (Zn)	µg/l	50*	NA
Ammonia	µg/L	70	NA
Nitrite (NO ₂ ⁻ -N)	µg/L	55	NA
Nitrate (NO ₃ ⁻ -N)	µg/L	60	NA
Phosphate (PO ₄ ³⁻ - P)	µg/L	45 (estuaries) 15 (coastal)	NA

Parameter	Units	Aquatic Life Protection	Human Health Protection
Dissolved Oxygen (DO)	mg/l	4	NA
Temperature	°C	≤2°C increase over maximum ambient	NA
Oil and grease	mg/l	0.14	NA
Tributyltin	ng/l	10	NA

* Not formally adopted by ASEAN. This value is from the Thailand Marine Water Quality Class Designators and Beneficial Uses

5.3.5 Results and Discussions

Heavy Metal Concentrations

Table 5.10 presents the total heavy metal concentrations due to short-term water quality changes, considering both the baseline levels in the water and the additional contribution from suspended sediments induced by the installation of the marine piles. The highest mean excess SSC from the four modelled scenarios was used.

It is evident that even in the worst case of maximum amounts of suspended sediments generated, conservative inputs from the baseline sediment quality data and water quality data result in a negligible increase in heavy metal levels, which are still within the relevant limits for ambient water quality. This indicates a low risk of heavy metal contamination in the water due to sediment resuspension during construction.

Table 5.10 Heavy metals analysis from the SSC expected during the Construction Phase, including comparisons against ASEAN Marine Water Quality Criteria (MWQC) for protection of aquatic life for the heavy metal parameters

Parameter	Max. Sediment Content (mg/kg) (MPA limits)	Parameter Release (%)	Highest Mean Excess SSC Concentration (mg/l)	Incremental Concentration in Water (µg/l)	Predicted Concentration in Water (µg/l)	ASEAN MWQC (µg/l)
Arsenic (As)	30	2	19.86	0.0044	7.14	120**
Cadmium (Cd)	1	2	19.86	0.0002	0.15	10
Chromium (Cr)	50	2	19.86	0.0113	1.30	50***
Copper (Cu)	55	2	19.86	0.0115	5.27	8
Lead (Pb)	65	2	19.86	0.0120	0.16	8.5
Mercury (Hg)	0.8	2	19.86	0.0001	0.10	0.16
Nickel (Ni)	35	2	19.86	0.0062	4.17	-
Zinc (Zn)	150	2	19.86	0.0409	1.54	50**

* For each heavy metal, the highest mean concentration among the baseline monitoring locations is used for this calculation.

** Not formally adopted by ASEAN. This value is from the Thailand Marine Water Quality Class Designators and Beneficial Uses.

*** ASEAN MWQC for protection of aquatic life is for Cr (VI)

5.3.6 Pollution Release Summary

Suspended sediments from construction activities can potentially carry pollutants to nearby receptors. The baseline results showed that heavy metals were present in the seabed sediment samples in the Study Area at levels within the MPA's and The Netherlands' guidelines. The same heavy metals were also detected in the water samples in the Study Area but at levels not exceeding the relevant marine water quality guidelines.

The potential release of heavy metals from suspended sediments due to piling activities was studied by scaling the sediment plume model results in terms of mg/l of SSC against the pollutant concentrations in the sediment from environmental baseline data. A conservative assessment of pollutant release from the seabed shows that sediment plumes would not lead to any exceedances of the ASEAN MWQC limits for cadmium, chromium, copper, lead or mercury outside of the immediate work area. These results assess water quality impacts on marine ecology, marine intakes and socio-economic receptors in Sections 5.8, 5.10 and 5.11, respectively.

5.4 Air Quality

Dust emission is one of the key pressures of most construction projects. This section presents air pollution analyses related to the demolition of the existing Wharf structure and the construction of the residential buildings. Dust emission occurs in all construction stages but most significantly during the demolition stage due to the crumbling of materials such as concrete.

This section presents the baseline results of the air quality monitoring, the framework for the semi-quantitative analysis of the predicted change in particulate matter concentrations in the vicinity of the Project, and the analysis results.

5.4.1 Relevant Receptors

Socio-economic and terrestrial ecological receptors near the construction of the Project have been identified as air-sensitive receptors (ASRs) that could be impacted by dust from the construction works. A defined 250 m Study Area was set for the air quality assessment (Figure 4.2). The identified relevant ASRs to air quality pressures include:

- Terrestrial ecology and biodiversity in the Hillock Area; and,
- Socio-economic (i.e., residents, staff of businesses, and recreational users).

This section only discusses the pressures or stressors. The corresponding receptor chapters will assess the resulting impacts on the above-listed receptors (Sections 5.9 and 5.12).

5.4.2 Baseline Conditions

Baseline ambient air quality measurements were conducted at three (3) stations (Figure 5.39 and Table 5.11) for seven (7) consecutive days to represent the ambient air quality at the respective ASRs. Monitored parameters consisted of NEA's six (6) criteria air pollutants, i.e., Sulphur Dioxide (SO₂), Nitrogen Dioxide (NO₂), Ozone (O₃), Carbon Monoxide (CO) and particulate matter with diameters of less than 10 (PM₁₀) and 2.5 micrometres (PM_{2.5}). Kunak Air Pro sets deployed at the three (3) stations had undergone a co-location study at a nearby site from 13 April to 21 April 2024, and the survey results have been calibrated accordingly. A summary of the survey results compared against applicable Singapore's Air Quality Target is presented in Table 5.12. The complete set of ambient air quality measurements is presented in **Appendix C**. The periods when the air quality measurements were measured are as follows:

- AQ01: 06 to 14 June 2024
- AQ02: 06 to 14 June 2024
- AQ03: 14 to 21 June 2024

Table 5.11 Ambient air quality monitoring stations coordinates

Station ID	Coordinates		Air-Sensitive Receptors (ASRs)
	Latitude	Longitude	
AQ01	1.26406	103.80951	Fauna in Hillock Area
AQ02	1.26518	103.81422	Residents residing within Caribbean at Keppel Bay and recreational users

Station ID	Coordinates		Air-Sensitive Receptors (ASRs)
	Latitude	Longitude	
AQ03	1.26516	103.80963	Residents residing within Reflections at Keppel Bay and recreational users

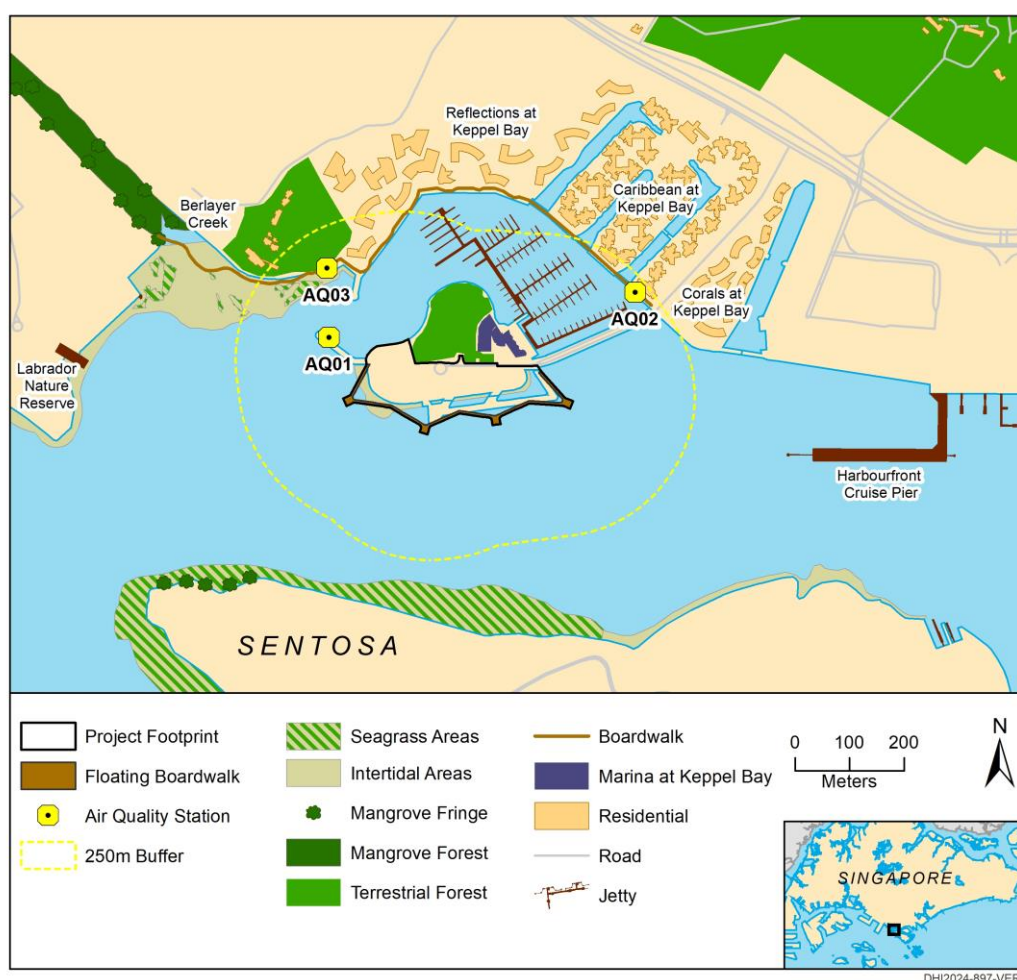


Figure 5.39 Locations of air quality monitoring stations including the 250m buffer.

Table 5.12 Baseline ambient air quality survey results against applicable Singapore's Air Quality Target. Exceedance of SG AQT are highlighted in orange.

Parameter	Unit	Standard SG AQT	Survey Results		
			AQ01	AQ02	AQ03
SO ₂ – 24hr (Maximum)	µg/m ³	50 (by 2020) 20 (Long Term)	46.30	19.25	43.22
PM ₁₀ – 24hr (Maximum)	µg/m ³	50	34.89	17.91	24.64
PM _{2.5} – 24hr (Maximum)	µg/m ³	37.5 (by 2020) 25 (Long Term)	26.74	13.20	17.66

Parameter	Unit	Standard SG AQT	Survey Results		
			AQ01	AQ02	AQ03
O ₃ – 8hr (Maximum)	µg/m ³	100	57.89	63.29	39.42
NO ₂ – 1hr (Maximum)	µg/m ³	200	50.23	45.03	39.51
CO – 1hr (Maximum)	mg/m ³	30	0.61	0.59	0.54
CO – 8hr (Maximum)	mg/m ³	10	0.49	0.46	0.29

SO₂ (Sulphur Dioxide)

The measured 24-hour mean SO₂ concentrations are plotted in Figure 5.40. The 24-hour mean SO₂ concentrations across all three (3) stations were below the SG AQT (by 2020) but were above the long-term SG AQT on 12 June and 13 June 2024 at AQ01 and on 21 June 2024 at AQ03. It is noted that SO₂ concentrations in the area were high, with occasional high spikes of up to 260.74 µg/m³ recorded at AQ03 during the monitoring period. The localised high SO₂ is likely attributed to emissions from vessel movements around Keppel Island.



Figure 5.40 Measured 24-hour mean SO₂ concentrations at AQ01, AQ02, and AQ03 and the benchmarked SG AQTs

Particulate Matter (PM₁₀ and PM_{2.5})

The measured 24-hour mean PM₁₀ and PM_{2.5} concentrations are plotted in Figure 5.41 and Figure 5.42, respectively. The SG AQTs were not exceeded during the monitoring period except for the long-term SG AQT for PM_{2.5} on 07 June and 08 June 2024 at AQ01. The generally high PM₁₀ and PM_{2.5} concentrations could be a potential contribution from sea spray due to the close proximity of the monitoring station to the sea.



Figure 5.41 Measured 24-hour mean PM₁₀ concentrations at AQ01, AQ02, and AQ03 and the benchmarked SG AQT

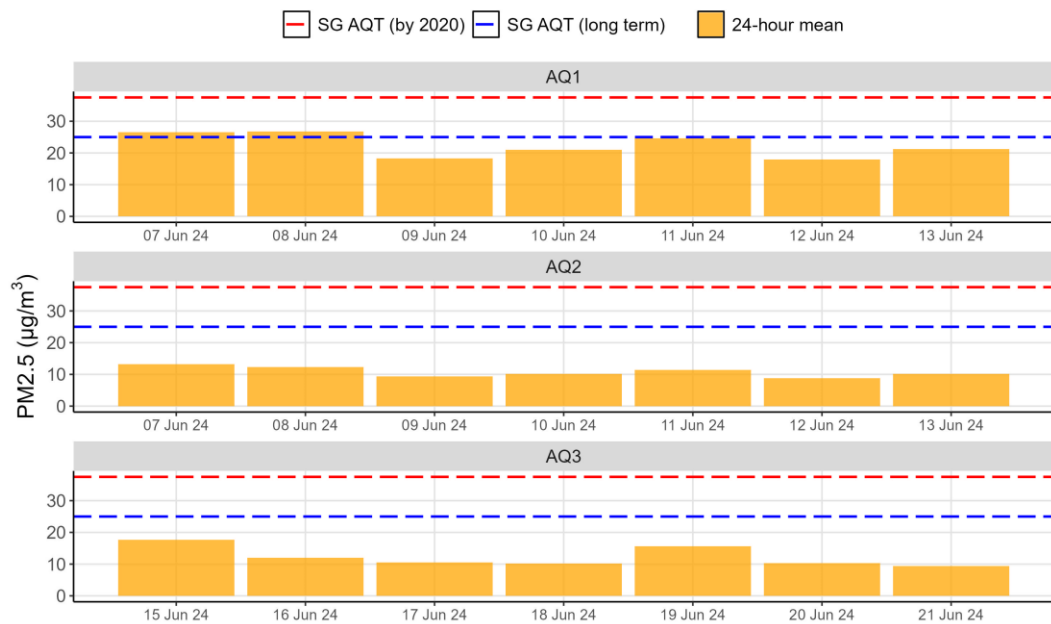


Figure 5.42 Measured 24-hour mean PM_{2.5} concentrations at AQ01, AQ02, and AQ03 and the benchmarked SG AQTs

O₃ (Ozone)

The measured 8-hour mean O₃ concentrations are plotted in Figure 5.43. The 8-hour mean O₃ concentrations recorded at AQ01, AQ02, and AQ03 during the monitoring period were below the benchmarked SG AQT. Please note that ozone in ambient air is not from a direct emission, but a secondary pollutant formed from a chemical reaction between nitrogen oxides and volatile organic compounds driven by sunlight.



Figure 5.43 Measured 8-hour mean O_3 concentrations at AQ01, AQ02, and AQ03 and the benchmarked SG AQT

NO_2 (Nitrogen Dioxide)

The measured hourly NO_2 concentrations are plotted in Figure 5.44. The 1-hour mean NO_2 concentrations recorded at AQ01, AQ02, and AQ03 during the monitoring period were below the benchmarked SG AQT.

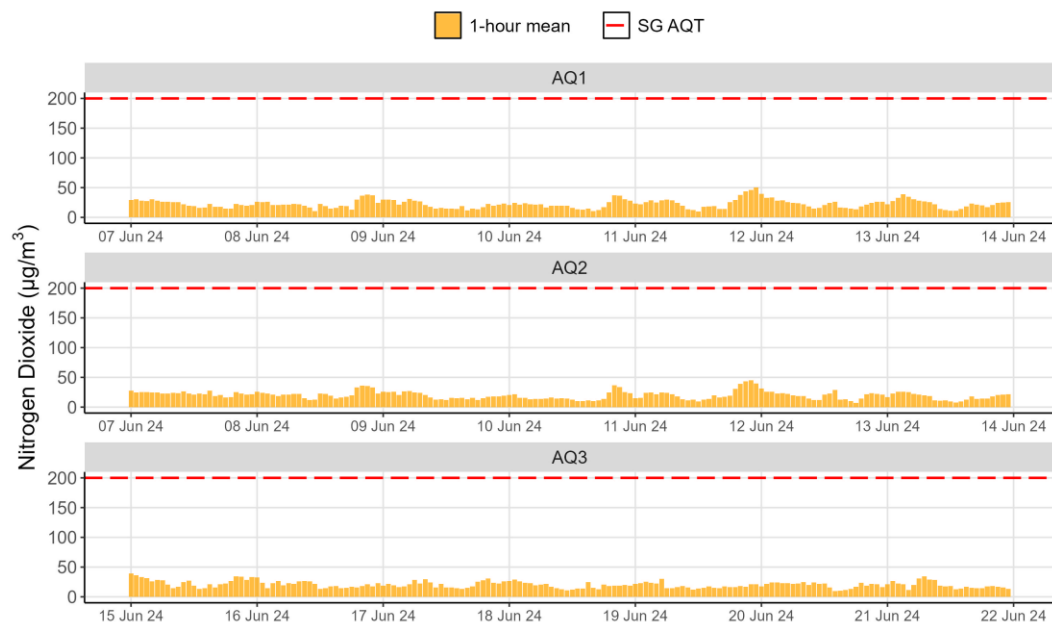


Figure 5.44 Measured 1-hour mean NO_2 concentrations at AQ01, AQ02, and AQ03 and the benchmarked SG AQT

CO (Carbon Monoxide)

The measured hourly and 8-hour mean CO concentrations are plotted in Figure 5.45 and Figure 5.46. The 1-hour and 8-hour mean CO concentrations recorded at AQ1, AQ2, and AQ03 during the monitoring period were below the benchmarked SG AQTs. The main CO contributor is likely from road and/or vessel traffic, with no other known CO emission sources in the area.



Figure 5.45 Measured 1-hour mean CO concentrations at AQ01, AQ02, and AQ03 and the benchmarked SG AQT



Figure 5.46 Measured 8-hour mean CO concentrations at AQ01, AQ02, and AQ03 and the benchmarked SG AQT

5.4.3 Evaluation Framework

Air quality impact could potentially result from dust emissions from demolition, general construction works and vehicle movements (Trackout). Potential impacts due to CO, NO₂, and SO₂ emissions from heavy vehicles and powered machinery were expected to be low due to the size and timespan of the construction works. In particular, with effect from 01 July 2012, all off-road diesel engines (including construction machinery) imported into Singapore must comply with the EU Stage II, US Tier II or Japan Tier I off-road diesel engine emission standards, according to Environmental Protection and Management (Off-Road Diesel Engine Emissions) Regulations 2012.

For the assessment of potential dust (i.e., PM₁₀ and PM_{2.5}) impacts (which informs the Magnitude of Change in RIAM), DHI referred to the Institute of Air Quality Management (IAQM)'s Guidance on the Assessment of Dust from Demolition and Construction (the Guidance). Due to the small nature of the Project, air quality modelling was not conducted and was scoped out during the Scoping stage.

The process suggested in the Guidance includes the following steps:

- **Step 1:** Screening the requirement for a more detailed assessment. This was carried out by setting a study boundary of 250 m, followed by the identifying relevant social-economic and ecological receptors within the established Study Area. Step 1 was completed in the expert scoping exercise prior to this Environmental Study, as presented in Section 4.
- **Step 2:** Assessing the risk of dust impacts from each of the anticipated emission sources during Project construction, taking into account the scale and nature of the work and the sensitivity of receptors. This step is discussed further below.
- **Step 3 & 4:** Prescribing site-specific mitigation measures to abate anticipated air quality impacts and determining the significance of the residual impacts to each ASR. These steps are discussed if the impact significance exceeds the acceptable level (see Section 8 for more details).

Step 2 according to IAQM guidance includes (1) calculating potential dust emission magnitude based on an estimated volume of the work; (2) assessing sensitivity of the human receptors based on exposure duration, and sensitivity to exposure; and (3) evaluation of risk.

This section focuses on the emission calculation for construction activities on construction sites that will potentially result in dust impact, i.e., Demolition, Earthworks, Construction, and Trackout. It utilises a set of quantitative definitions provided in the IAQM's Guidance as shown in Table 5.13.

The sensitivity discussion is receptor specific, hence so is risk evaluation. These assessments are therefore discussed in the socio-economic receptor section (Section 0).

Table 5.13 Evaluation framework for magnitude of change in air quality

Type of Activity	Dust Emission Magnitude Classification Reference		
	Large	Medium	Small
Demolition	- Total building volume >75,000 m³ - Potentially dusty construction material (e.g., concrete) - On-site crushing and screening ^a - Demolition activities >12 m above ground level	- Total building volume 12,000 m³ – 75,000 m³ - Potentially dusty construction material - Demolition activities 6 m – 12 m above ground level	- Total building volume <12,000 m³ - Construction material with low potential for dust release (e.g., metal cladding or timber) - Demolition activities <6 m above ground - Demolition during wetter months
Earthworks	- Total site area >110,000 m² - Potentially dusty soil type (e.g., clay) >10 heavy moving earth vehicles active at any one time - Formation of bunds >6 m in height	- Total site area 18,000 m² – 110,000 m² - Moderately dusty soil type (e.g., silt) 5 – 10 heavy moving earth vehicles active at any one time - Formation of bunds 3 m – 6 m in height	- Total site area <18,000 m² - Soil type with large grain size (e.g., sand) <5 heavy moving earth vehicles active at any one time - Formation of bunds <3 m in height
Construction	- Total building volume >75,000 m³ - On site concrete batching ^a - Sandblasting	- Total building volume 12,000 m³ – 75,000 m³ - Potentially dusty construction material (e.g., concrete) - On site concrete batching ^a	- Total building volume <12,000 m³ - Construction material with low potential for dust release (e.g., metal cladding or timber)
Trackout	>50 heavy duty vehicle (HDV) (>3.5 tonnes) outward movements ^c in any one day ^c - Potentially dusty surface material (e.g., high clay content) - Unpaved road length >100 m	20 – 50 HDV outward movements ^b in any one day ^c - Moderately dusty surface material (e.g., high clay content) - Unpaved road length 50 m – 100 m	<20 HDV outward movements ^b in any one day ^c - Surface material with low potential for dust release - Unpaved road length <50 m

^a Mobile crushing equipment and concrete batching plants can be significant sources of dust. Professional judgement will be required to determine how the use of crushing and screening equipment, or on-site concrete batching will affect the dust emission magnitude.

^b A vehicle movement is a one-way journey, i.e., from A to B, and excludes the return journey.

^c HDV movements during a construction project vary over its lifetime, and the number of movements is the maximum not the average.

5.4.4 Results and Discussions

Key dust emitting activities identified for this construction include:

- Demolition of the existing Wharf structure;
- Construction of residential buildings; and
- Construction vehicle movement.

The predicted magnitude of change in air quality due to potential dust emission from each source is discussed in detail in the following sub-sections.

Demolition

Demolition of the existing Wharf structure, which involves saw-cutting of concrete slabs, is expected to generate large amounts of dust. The existing Wharf is approximately 45,000 m³, and the handling of debris will be above water. Although the demolition is < 6 m above ground level, the total demolition volume and dust emissions from the concrete slabs will warrant a classification of “Medium” according to IAQM guidelines (Table 5.14).

Earthworks

Construction of residential buildings involves soil excavation at the land area to form the basement level. Soil excavation can be a significant source of dust emissions depending on the total site area, soil type and the number of heavy-moving earth vehicles active at any time. The total site area for the construction of residential buildings is approximately 21,000 m³. Based on the Environmental Site Assessment Report (SECS, 2023), soil samples in Keppel Island ranged from silty sand to clayey silt, which is a moderately dusty soil type. Therefore, Earthwork is expected to cause “Medium” dust emission (Table 5.14).

Construction

The construction of superstructure for residential buildings is known to generate dust. The key issues when determining the potential dust emission magnitude during the Construction Phase include the building or infrastructure size, method of construction and construction materials. Based on the site area and floor heights of the residential buildings, the building volume is approximately 300,000 m³. There is no information on the construction method and material at the time of writing. As the building volume is more than 75,000 m³, dust emissions from Construction will be classified as “Large” (Table 5.14).

Trackout

It is expected that dust and dirt from the construction/demolition site, if unmanaged, may accumulate and then be re-suspended into the air by vehicles using the road network. The number of Heavy-Duty Vehicle (HDV) per day was unavailable at the time of writing. Based on the demolition building volume and the tight duration of the demolition phase, it is assumed that there will be more than fifty (50) HDV outward movements a day. Given the construction site's area, it is reasonable to assume that the trucks' movement on unpaved roads would be more than 100 m. Therefore, by conservative assumptions, Trackout activities would result in “Large” dust emissions (Table 5.14).

Table 5.14 Key dust emitting activity and their respective dust emission magnitude

Dust-Emitting Activity	Dust Emission Magnitude
Demolition	Medium
Earthworks	Medium
Construction	Large
Trackout	Large

5.4.5 Air Quality Summary

Dust emission magnitude for demolition and earthworks were assessed to be “Medium” as the potentially dusty construction material is expected to be generated from saw-cutting of approximately 45,000 m³ of concrete slabs, and soil excavation of about 21,000 m³ of moderately dusty soil type is expected, respectively. Construction and Trackout were assessed to be “Large” as the residential building volume is more than 75,000 m³ and HDV movements were estimated to be more than fifty (50) a day, respectively. Assessment of air quality impacts on the specific receptors are not discussed within this section but in the respective receptor sections (Sections 5.9 and 5.12).

5.5 Airborne Noise

Noise is defined as unwanted sound that disrupts normal activities or diminishes the quality of the environment. It is usually caused by human activity and detracts from an area's natural acoustic setting, sometimes known as the soundscape. Moving transportation-related sources, including vehicular traffic, ship traffic, and aircraft flyovers, contribute to regional ambient noise levels.

Noise impacts during construction are expected due to increased atmospheric sound levels from the equipment used during the construction activities (i.e., excavation, piling, and demolition). Airborne noise modelling was carried out to assess the sound propagation from construction activities to the sensitive receptors near the construction area.

5.5.1 Relevant Receptors

Several sensitive receptors are located within the vicinity of the Project and could experience noise disturbances from the planned construction activities. The potential impact zone for airborne noise is typically limited as noise attenuates quickly with distance. NEA's Environmental Protection and Management (Control of Noise at Construction Sites) Regulations set the maximum permissible construction noise levels for buildings within 150 m of a construction site. This Environmental Study conservatively adopts 500 m as the spatial boundary for airborne noise impact assessment (Figure 5.47), covering the following Noise Sensitive Receptors (NSRs):

- Terrestrial ecology and biodiversity in the Hillock Area; and,
- Socio-economic (i.e., residents, staff of businesses, and recreational users).

This section only discusses the pressures or stressors. The corresponding receptor chapters will assess the resulting impacts on the above-listed receptors (Sections 5.9 and 5.12).

5.5.2 Baseline Conditions

DHI carried out baseline airborne noise monitoring from 29 February 2024 to 08 March 2024 at selected NSRs, covering the residential, recreational and terrestrial biodiversity receptors (Table 5.15 and Figure 5.47) near the Project footprint, as summarised in Table 5.17. Measurements were taken using calibrated NEA-approved Type 1 sound level meters set on a tripod about 1.2 m above the ground. The airborne noise baseline data was collected continuously for seven (7) days, including at least two (2) full weekdays and two (2) full weekend days at each location. The parameters measured are presented in A-weighted equivalent continuous noise levels of Leq 5 mins, Leq 1 hr and Leq 12 hrs. The complete set of airborne noise data is presented in **Appendix C**.

Table 5.15 Airborne noise monitoring stations coordinates

Station ID	Coordinates		Noise Sensitive Receptors (NSRs)
	Latitude	Longitude	
AN01	1.2636	103.8116	Terrestrial fauna in Hillock Area
AN02	1.2652	103.8142	Residents residing within Caribbean at Keppel Bay

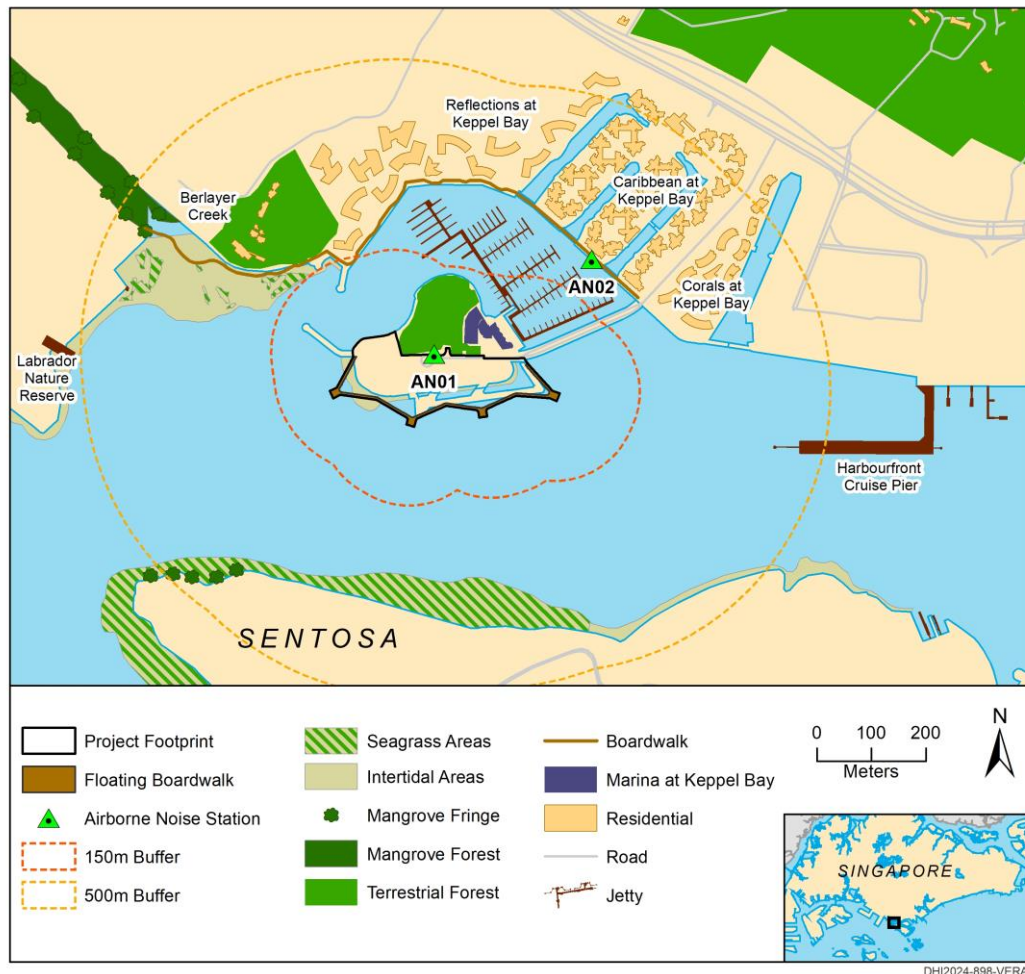


Figure 5.47 Locations of airborne noise monitoring stations including the 500m buffer for Noise Sensitive Receptors (NSRs)

The baseline noise levels are discussed in terms of equivalent noise levels over 5 minutes, 1 hour and 12 hours, or Leq 5 mins, Leq 1 hr and Leq 12 hrs, which will be explained further in Section 5.5.3 below. Figure 5.48 and Figure 5.49 present Leq 5 mins at Keppel Island (AN01) and Caribbean at Keppel Bay (AN02).

A summary of the ranges and L_{10} of Leq 5 mins, Leq 1 hr and Leq 12 hrs values measured at the two (2) locations are presented in Table 5.17, Table 5.18 and Table 5.19, respectively. L_{10} represents the noise level exceeding 10 % of the recorded time, which means that during the remaining 90 % of the recording time, the observed noise level falls below this value. The use of L_{10} values filter out the higher 10 % of recorded noise levels, which are likely due to sporadic or intermittent events.

The data sets obtained at AN01 and AN02 are compared against maximum permissible noise limits for Other Premises (i.e., buildings other than those that are highly sensitive noise receivers or residential buildings located less than 150 m from the construction site) and Residential Buildings, respectively. The Study Area is characterised by relatively low noise levels, with no exceedance over the noise limits stipulated by NEA.

The noise limit is adjusted with a correction factor where appropriate. According to the regulation, a correction factor is to be applied to the maximum permissible noise levels or the baseline noise level at respective NSRs, whichever is higher. The stipulated correction factors correspond to the difference between the applicable permissible level and the background noise level, as shown in Table 5.16. The adjusted noise limits at the NSRs are

tabulated in Table 5.17, Table 5.18 and Table 5.19. It must be acknowledged that the comparison is not for highlighting non-compliance, as the limits are for construction noise, not for operational noise levels.

Table 5.16 Correction factor to be applied to adjust the maximum permissible noise level at NSRs

Difference Between Two Noise Levels (dBA)	Correction Factor
Below 2	3
2 to less than 4	2
4 to less than 10	1
10 and above	0

AN01

Airborne noise monitoring station AN01 was located within Keppel Island, representing the baseline noise level at Hillock Area and Keppel Bay Marina. The continuous measurement of Leq 5 mins at AN01 and the respective permissible construction noise limits are plotted in Figure 5.48.

The measured Leq 5 mins, ranging between 45 dBA to 87 dBA, were consistently below the permissible construction noise limit for Other Premises.

Noise levels to protect sensitive animal species are recommended to be ideally levels lower than 55 dBA, within 100 m from the source. Baseline monitoring data shows that sound levels are already approaching or exceeding this level at AN01. This indicates that the terrestrial fauna that were surveyed within the Hillock Area (refer to Section 5.9) could have already adapted to this level of ambient noise level. This Environmental Study will consider how the potential change in noise level due to the proposed development will impact ecology in the area.

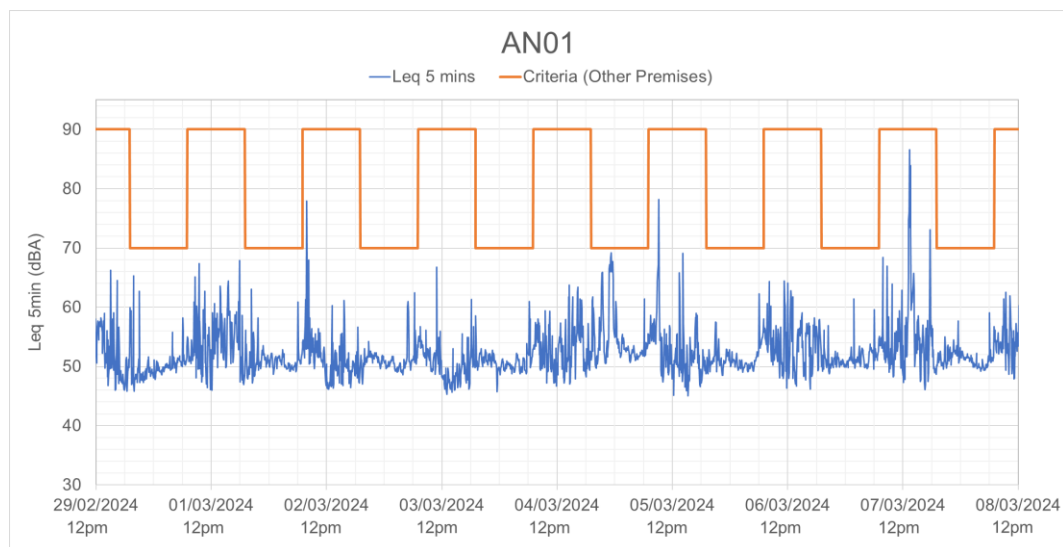


Figure 5.48 Equivalent noise level over 5 minutes, or Leq 5 mins, recorded at Keppel Island (AN01) against maximum permissible noise limit for Other Premises

AN02

Airborne noise monitoring station AN02 was located at the Caribbean at Keppel Bay. The continuous measurement of Leq 5 mins at AN02 and the respective permissible construction noise limits are plotted in Figure 5.49.

The measurements ranged between 35 dBA and 74 dBA. While the maximum Leq 5 mins was higher than the NEA's criteria on Weekdays from 10pm – 7am at AN02, the L_{10} was below the corresponding limits.

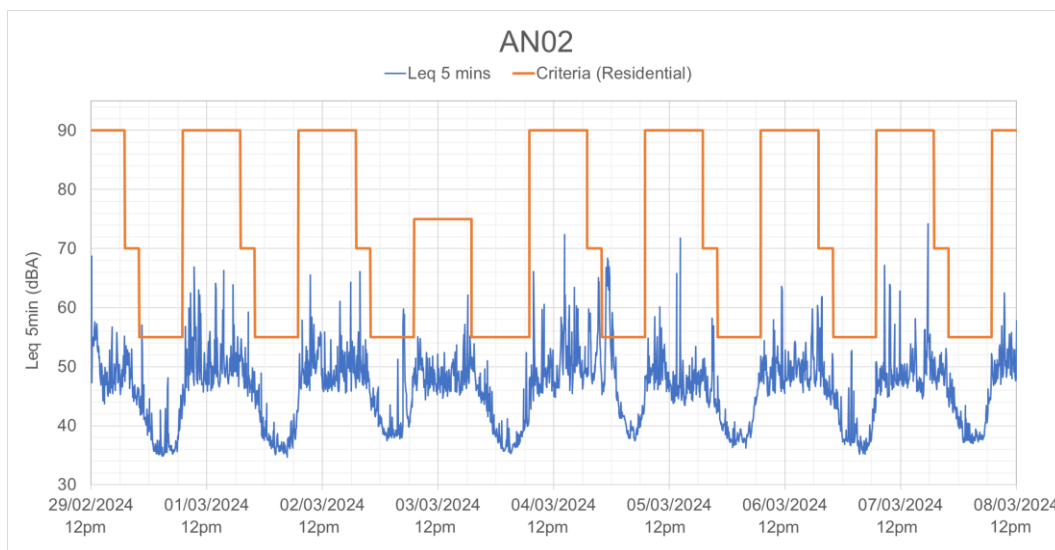


Figure 5.49 Equivalent noise level over 5 minutes, or Leq 5 mins, recorded Caribbean at Keppel Bay (AN02) against maximum permissible noise limit for Residential Buildings

Table 5.17 Summary of baseline noise monitoring data (Leq 5 mins) and correction factor applied to permissible noise limit. Exceedance values are indicated in red.

Location	Time Period	Measured baseline noise level (dBA) (Leq 5 mins)			Maximum Permissible Noise Level (dBA) (Leq 5 mins)	Difference (between Permissible Noise Level and L10 Baseline Noise Level)	Correction Factor	Adjusted Noise Limit (dBA) (Leq 5 mins)
		Min.	Max.	L10				
AN01	Weekday 7am - 7pm	45	87	59	90	31	0	90
	Weekday 7pm – 7am	46	69	57	70	13	0	70
	Sunday/PH 7am - 7pm	45	67	54	90	36	0	90
	Sunday/PH 7pm - 7am	46	59	57	70	13	0	70
AN02	Weekday 7am - 7pm	43	74	55	90	35	0	90
	Weekday 7pm - 10pm	35	68	53	70	17	0	70
	Weekday 10pm - 7am	35	68	53	55	2	3	58
	Sunday/PH 7am - 7pm	44	62	52	75	23	0	75
	Sunday/PH 7pm - 7am	37	54	53	55	2	3	58

Table 5.18 Summary of baseline noise monitoring data (Leq 1 hr) and correction factor applied to permissible noise limit

Location	Time Period	Measured baseline noise level (dBA) (Leq 1 hr)			Maximum Permissible Noise Level (dBA) (Leq 1 hr)	Difference (between Permissible Noise Level and L ₁₀ Baseline Noise Level)	Correction Factor	Adjusted Noise Limit (dBA) (Leq 1 hr)
		Min.	Max.	L ₁₀				
AN02	Weekday 7pm - 10pm	46	59	56	65	9	1	66
	Weekday 10pm – 7am	36	65	50	55	5	1	56

Table 5.19 Summary of baseline noise monitoring data (Leq 12 hrs) and correction factor applied to permissible noise limit

Location	Time Period	Measured baseline noise level (dBA) (Leq 12 hrs)			Maximum Permissible Noise Level (dBA) (Leq 12 hrs)	Difference (between Permissible Noise Level and L ₁₀ Baseline Noise Level)	Correction Factor	Adjusted Noise Limit (dBA) (Leq 12 hrs)
		Min.	Max.	L ₁₀				
AN01	Weekday 7am - 7pm	55	68	64	75	11	0	75
	Weekday 7pm – 7am	52	59	55	65	10	1	66
	Sunday/PH 7am - 7pm	52			75	23	0	75
	Sunday/PH 7pm - 7am	51	52	52	65	13	0	65
AN02	Weekday 7am - 7pm	52	56	55	75	20	0	75
	Sunday/PH 7am - 7pm	50			75	25	0	75

5.5.3 Evaluation Framework

Construction noise in Singapore is regulated through the Environmental Protection and Management (Control of Noise at Construction Sites) Regulations (NEA, 2011). In 2011, the NEA established a set of maximum permissible noise levels at premises within 150 m of construction sites to address the impacts of construction noise on human receptors. The limits are in the form of equivalent sound levels over 5 mins, 1 hour and 12 hours durations (Leq 5 mins, Leq 1 hr and Leq 12 hrs, respectively) for different periods in a day, 7am to 7pm, 7pm to 10pm, and 10pm to 7am. Note that there is a differentiation in the maximum permissible limits for different types of premises (i.e., residential buildings within 150 m from the construction site) versus highly sensitive noise receivers (i.e., hospitals, schools and homes for the aged), and Other Premises.

A commercial premise identified within 150 m of the Project footprint is the Marina at Keppel Bay. Residential premises near the Project are Reflections at Keppel Bay, Caribbean at Keppel Bay, and Corals at Keppel Bay. They are outside the 150 m radius of the Project footprint but within the 500 m radius that this Environmental Study conservatively adopts for airborne noise assessment. There are no known industries, hospitals, schools, institutions of higher learning or homes for the aged in the close vicinity within a 150 m radius of the Project footprint. The regulated limits for buildings are presented in Table 5.20.

Table 5.20 NEA guidelines for maximum permissible noise levels for construction work commenced on or after 1st October 2007 (NEA, 2011)

Types of Affected Buildings	Monday to Saturday			Sunday and Public Holidays		
	7am – 7pm	7pm – 10pm	10pm – 7am	7am – 7pm	7pm – 10pm	10pm – 7am
a) Hospital, schools, institutions of higher learning, homes for aged and sick.	60 dBA (Leq 12 hrs)	50 dBA (Leq 12 hrs)		60 dBA (Leq 12 hrs)	50 dBA (Leq 12 hrs)	
	75 dBA (Leq 5 mins)	55 dBA (Leq 5 mins)		75 dBA (Leq 5 mins)	55 dBA (Leq 5 mins)	
b) Residential buildings located less than 150 m from the construction site	75 dBA (Leq 12 hrs)	65 dBA (Leq 1 hr)	55 dBA (Leq 1 hr)	75 dBA (Leq 12 hrs)	-	
	90 dBA (Leq 5 mins)	70 dBA (Leq 5 mins)	55 dBA (Leq 5 mins)	75 dBA (Leq 5 mins)	55 dBA (Leq 5 mins)	
c) Buildings other than those in (a) and (b) above	75 dBA (Leq 12 hrs)	65 dBA (Leq 12 hrs)		75 dBA (Leq 12 hrs)	65 dBA (Leq 12 hrs)	
	90 dBA (Leq 5 mins)	70 dBA (Leq 5 mins)		90 dBA (Leq 5 mins)	70 dBA (Leq 5 mins)	

5.5.4 Modelling Methodology

The airborne noise impact assessment is based on a 3D noise propagation model (SoundPLAN Version 8.2) to predict noise generated from the equipment anticipated to be used during construction. The software adopts the widely used international standard, British Standard 5228, and the model assumes hemispherical propagation from all noise sources at 0.5 m over a ground surface.

The Construction Phase consists of demolition, piling, and residential building construction work and will be carried out sequentially. It was assumed that all work phases would overlap by at least one (1) month, and the most noise generated would be during the overlapping work phases (i.e., 1) demolition and piling, and 2) piling and superstructure construction). After further evaluation, the demolition and piling work phase was identified as the noisiest due to the intensity and nature of the equipment used. Hence, the demolition and piling work phase represents the worst-case work phase to be modelled.

The noise sources in the model correspondingly include heavy equipment for demolition and piling works. The model does not include noise contribution from other construction equipment or nearby marine traffic; they are considered highly transient.

A noise contour map was prepared for each modelled scenario, presenting the predicted sound level contributed by the proposed development. The map provides an overview of noise propagation from the modelled demolition and piling activities. Predicted noise levels are extracted at the listed NSRs (Table 5.21) and are compared against their response limits to assess the potential noise impact during construction.

Table 5.21 List of NSRs and their distance to the nearest construction works of the Project

ID	Receptor	Type	Distance nearest to construction (m)
NM01	Terrestrial fauna in Hillock Area	Ecology	22
NM02	Staff of businesses and recreational users in Marina at Keppel Bay	Other premises	26
NM03	Recreational users along the Keppel Bay Promenade (in short, the "Promenade")	Other premises	163
NM04	Residents residing within Caribbean at Keppel Bay	Residential	245
NM05	Residents residing within Reflections at Keppel Bay	Residential	175
NM06	Residents residing within Corals at Keppel Bay	Residential	275

The following assumptions were made in this assessment:

- The construction activities are assumed to be stationary and carried out from 7am to 7pm on Mondays to Saturdays. There is no work carried out on Sundays.
- The Sound Power Levels (L_w) at the source are referenced with the standard values in the BS 5228-1:2009 standard and adopted in SoundPLAN for the simulations.
- For Leq 12 hrs assessment, all equipment is considered to have an overall 70 % operation time throughout the operating duration.

5.5.5 Results and Discussions

In this simulation, no mitigation measures, such as noise barriers, were included to model the maximum extent of noise propagation and the noise intensity received by the NSRs. The simulated equipment list is illustrated in Table 5.22.

Table 5.22 Anticipated construction equipment and its respective sound power level

Modelled Construction Equipment	Sound Pressure Level at 10 m from source*	Operation Hours
Diesel Generator x 2	66 dBA	7am – 7pm
Dump Truck x 2	87 dBA	7am – 7pm
Excavator x 2	79 dBA	7am – 7pm
Mobile Crane x 2	82 dBA	7am – 7pm
Petrol Hand-held Circular Saw x 1	91 dBA	7am – 7pm
Vibratory Piling Rig x 4	88 dBA	7am – 7pm

*From BS 5228-1:2009 Code of practice for noise and vibration control on construction and open sites

The simulation results for Leq 5 mins and Leq 12 hrs are presented in the summary tables in Table 5.23 and Table 5.24, respectively; only the maximum predicted noise levels at the NSRs are presented. The predicted noise levels received at all storeys of each building are presented in **Appendix C**. Figure 5.50 shows the noise contribution map for daytime (7 am – 7 pm). Figure 5.51 and Figure 5.52 show the vertical cross-section profiles of noise contribution during works in the daytime (7 am – 7 pm) at Marina at Keppel Bay and Hillock Area, respectively.

The model results show that noise diminishes quickly to 65 dBA within 100 m of the noise sources. Receptors at Marina at Keppel Bay are most affected by the construction works; noise levels of up to 77 dBA are predicted at the southeast face of the building. Faunae in the Hillock Area will be exposed to up to 72 dBA noise levels when piling works are closest to the forest.

The residential building closest to the construction site in Reflections at Keppel Bay is predicted to be exposed to noise levels of up to 63 dBA. The residential buildings on the fringes of the Keppel Marina are slightly less affected and expected to be exposed to noise levels of up to 61 dBA.

The recreational users along the section of the Promenade next to the breakwater near Reflections at Keppel Bay are predicted to be exposed to noise levels of up to 63 dBA. Similar to the residential buildings, the rest of the sections along the Promenade are slightly less affected and expected to be exposed to noise levels up to 60 dBA.

Overall, the predicted noise levels for Leq 5 mins and Leq 12 hrs at all receptors complied with the respective adjusted permissible noise levels during daytime (7 am – 7 pm), except at NM01 (Terrestrial fauna in Hillock Area), where noise levels will exceed the threshold for fauna receptors (i.e., 60 dBA).

Table 5.23 Predicted noise levels at NSRs, Leq 5 mins. The maximum value for each NSR is presented. Exceedance values are indicated in red.

ID	NSR	Type	Predicted noise contribution from construction (dBA)	Baseline noise level (L10, dBA)	Predicted noise level at NSR (dBA)	Adjusted Noise Limit (dBA)
			7am – 7pm	7am – 7pm	7am – 7pm	7am – 7pm
NM01	Hillock Area	Ecology	72	59	72	60*
NM02	Marina at Keppel Bay	Other premises	77	59	77	90
NM03	Promenade	Other premises	63	55	64	90
NM04	Caribbean at Keppel Bay	Residential	61	55	62	90
NM05	Reflections at Keppel Bay	Residential	63	55	64	90
NM06	Corals at Keppel Bay	Residential	60	55	61	90

* Threshold for fauna receptors; detailed explanation found in Table 5.84 under Section 5.9.3.2

Table 5.24 Predicted noise level at NSRs, Leq 12 hrs. The maximum value for each NSR is presented. Exceedance values are indicated in red.

ID	NSR	Type	Predicted noise contribution from construction (dBA)	Baseline noise level (L10, dBA)	Predicted noise level at NSR (dBA)	Adjusted Noise Limit (dBA)
			7am – 7pm	7am – 7pm	7am – 7pm	7am – 7pm
NM01	Hillock Area	Ecology	70	59	70	60*
NM02	Marina at Keppel Bay	Other premises	76	59	76	90
NM03	Promenade	Other premises	62	55	62	90
NM04	Caribbean at Keppel Bay	Residential	59	55	60	90
NM05	Reflections at Keppel Bay	Residential	62	55	62	90
NM06	Corals at Keppel Bay	Residential	59	55	60	90

* Threshold for fauna receptors; detailed explanation found in Table 5.84 under Section 5.9.3.2

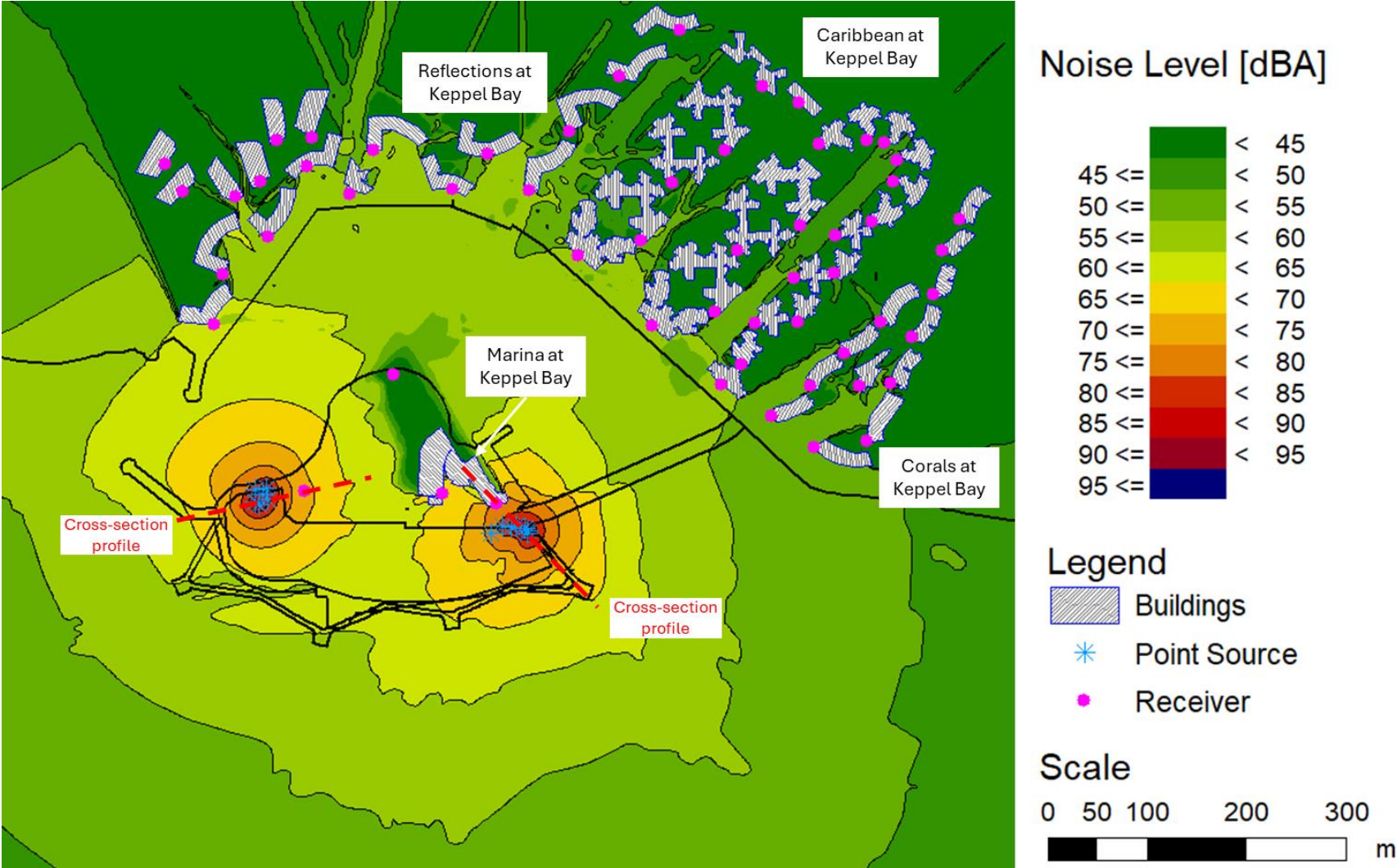


Figure 5.50 Noise contribution from construction activities during daytime (7am – 7pm)

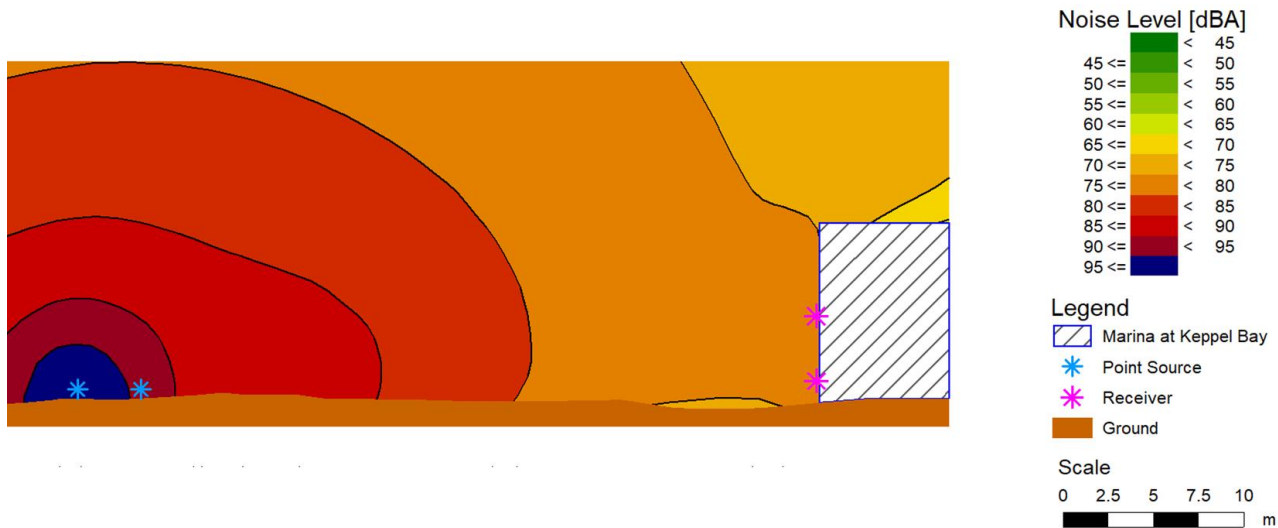


Figure 5.51 Vertical cross section profile at Marina at Keppel Bay from construction activities during daytime (7am – 7pm)

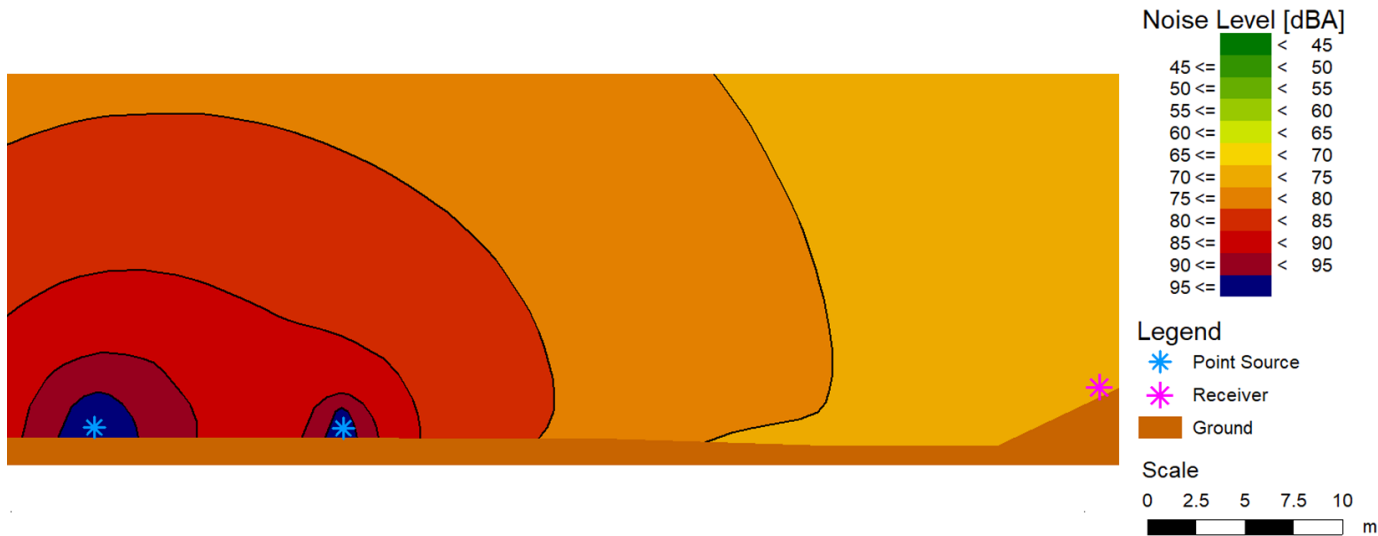


Figure 5.52 Vertical cross section profile at Hillock Area from construction activities during daytime (7am – 7pm)

5.5.6 Modelling Mitigation Measures

A noise barrier of 4.0 m is proposed to cut off the pathway between the pressure source (demolition and piling works) and the receptors (fauna within the Hillock Area and humans in Marina at Keppel Bay). The simulated equipment list is similar to that in Scenario 1 (Table 5.22). The simulation results for Leq 5 mins and Leq 12 hrs are presented in the summary tables in Table 5.25 and Table 5.26, respectively; only the maximum predicted noise levels at the NSRs are presented. The predicted noise levels received at all storeys of each building are presented in **Appendix C**. The noise contribution map for daytime (7am – 7pm) is shown in Figure 5.53. A vertical cross-section profile of noise contributions during daytime works at Marina at Keppel Bay and Hillock Area are shown in Figure 5.54 and Figure 5.55 respectively.

With the noise barrier, the residual noise level at the Hillock Area is predicted to be 61 dBA. Hence, the predicted noise levels for Leq 5 mins slightly exceeded the threshold for fauna receptors (i.e., 1 dBA), whereas the predicted noise levels for Leq 12 hrs complied with the threshold during daytime (7am – 7pm). The receptors at Marina at Keppel Bay were predicted to be exposed to residual noise level of 62 dBA and 63 dBA for Leq 5 mins and Leq 12 hrs, respectively.

Table 5.25 Predicted noise levels at NSRs, Leq 5 mins, for mitigated scenario. Maximum value for each NSR is presented. Exceedance values are indicated in red.

ID	NSR	Type	Predicted noise contribution from construction (dBA)	Baseline noise level (L10, dBA)	Predicted noise level at NSR (dBA)	Adjusted Noise Limit (dBA)
			7am – 7pm	7am – 7pm	7am – 7pm	7am – 7pm
NM01	Hillock Area	Ecology	55	59	61	60*
NM02	Marina at Keppel Bay	Other premises	60	59	62	90
NM03	Promenade	Other premises	63	55	64	90
NM04	Caribbean at Keppel Bay	Residential	55	55	58	90
NM05	Reflections at Keppel Bay	Residential	63	55	64	90
NM06	Corals at Keppel Bay	Residential	58	55	60	90

* Threshold for fauna receptors; detailed explanation found in Table 5.84 under Section 5.9.3.2

Table 5.26 Predicted noise level at NSRs, Leq 12 hrs, for Scenario 2. Maximum value for each NSR is presented. Exceedance values are indicated in red.

ID	NSR	Type	Predicted noise contribution from construction (dBA)	Baseline noise level (L10, dBA)	Predicted noise level at NSR (dBA)	Adjusted Noise Limit (dBA)
			7am – 7pm	7am – 7pm	7am – 7pm	7am – 7pm
NM01	Hillock Area	Ecology	54	59	60	60*
NM02	Marina at Keppel Bay	Other premises	60	59	63	90
NM03	Promenade	Other premises	61	55	62	90
NM04	Caribbean at Keppel Bay	Residential	55	55	58	90
NM05	Reflections at Keppel Bay	Residential	61	55	62	90
NM06	Corals at Keppel Bay	Residential	58	55	60	90

* Threshold for fauna receptors; detailed explanation found in Table 5.83 under Section 5.9.3.2

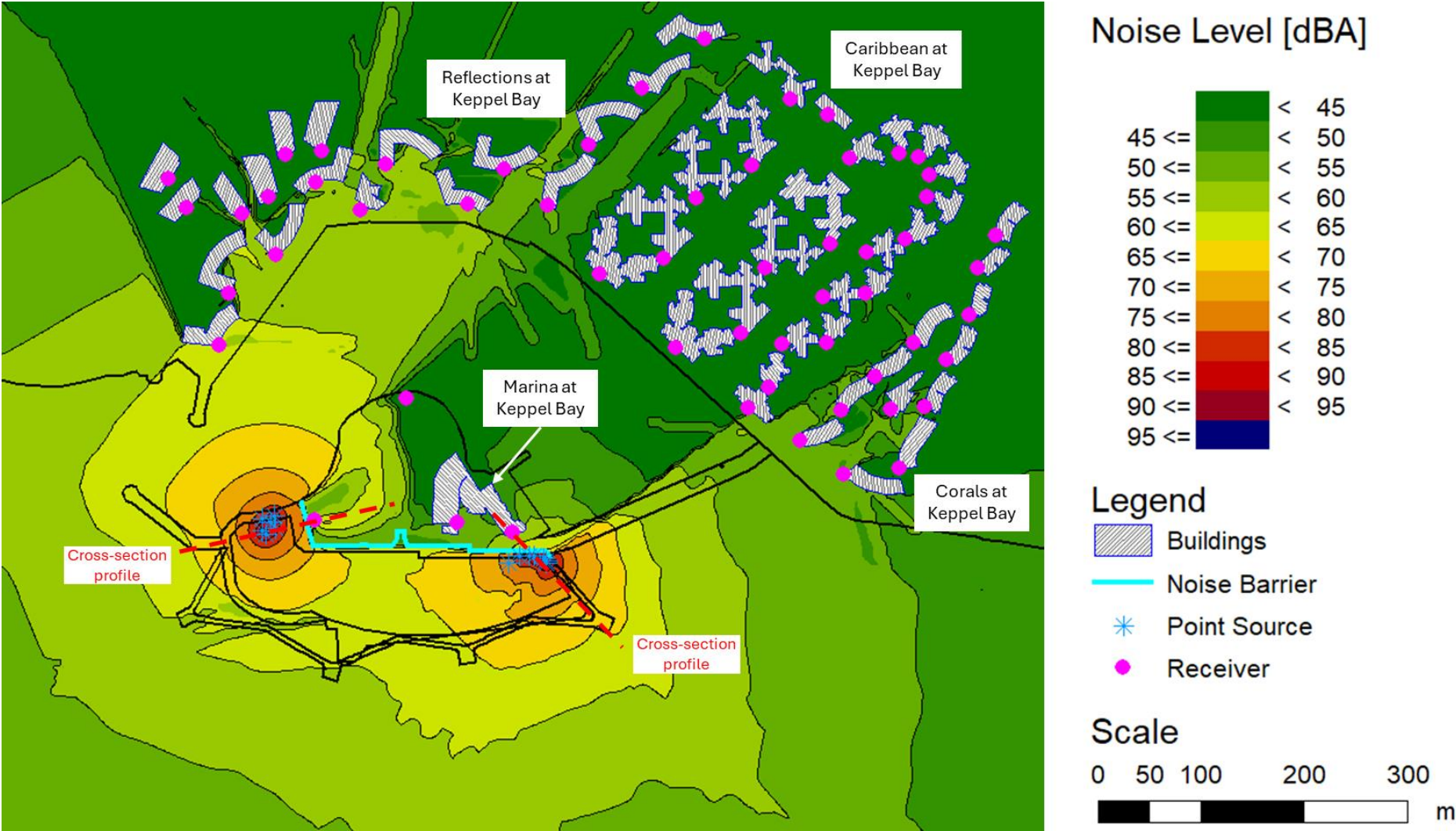


Figure 5.53 Noise contribution from Scenario 2 construction activities during daytime (7am – 7pm)

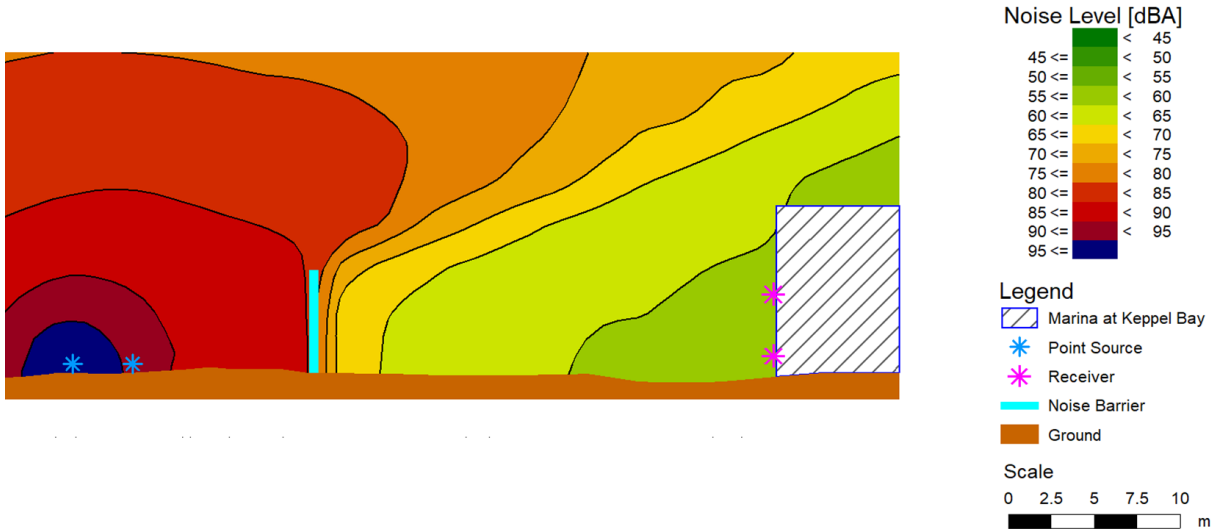


Figure 5.54 Vertical cross section profile at Marina at Keppel Bay from Scenario 2 construction activities during daytime (7am – 7pm)

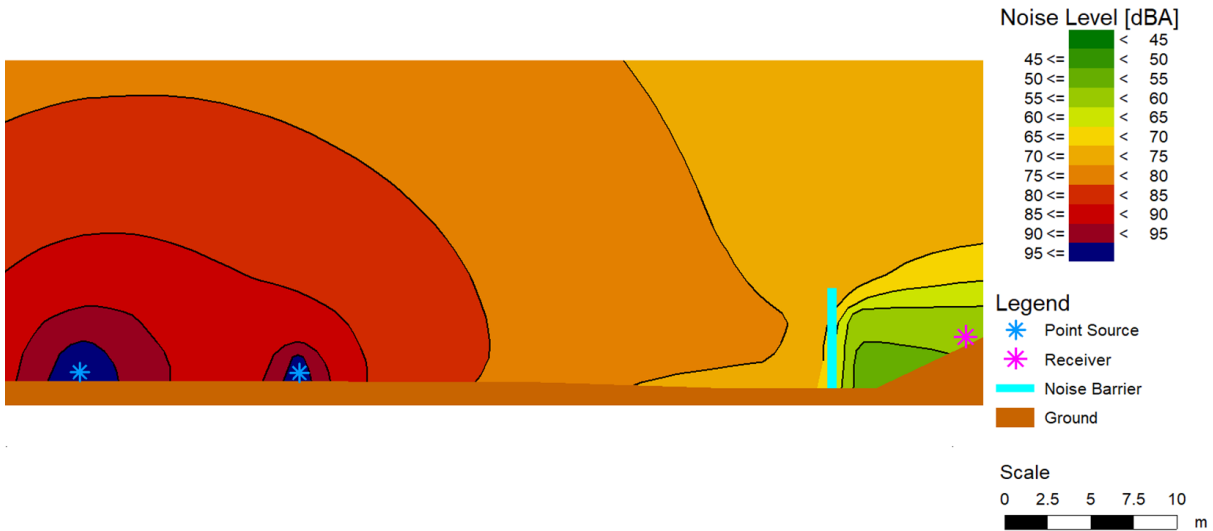


Figure 5.55 Vertical cross section profile at Hillock Area from Scenario 2 construction activities during daytime (7am – 7pm)

5.5.7 Airborne Noise Summary

The Study Area has a low ambient noise level in general. Development works involve several noise-intensive activities (demolition and piling) that may alter the ambient noise during the Construction Phase for several years. Two construction scenarios were established, where these noise sources and the sound propagation are incorporated in 3D sound models.

It was found that construction noise stays rather localised around the work area. The model results also show that only terrestrial fauna in the Hillock Area and socio-economic receptors at Marina at Keppel Bay will be exposed to excessive noise level from construction works. It was demonstrated that a noise barrier of 4.0 m high will reduce the noise level to 61 dBA and 62 dBA at the Hillock Area and Marina at Keppel Bay, respectively. In both modelled scenarios, other receptors were predicted to experience no more than 64 dBA.

The impacts of these changes on terrestrial ecology and biodiversity in the Hillock Area and socio-economic receptors in the vicinity of the Project are assessed in the relevant receptor sections (Sections 5.9 and 5.12).

5.6 Ground Vibration

Ground-borne noise and vibration usually result from the energy created by construction activities and vehicles and are propagated through the ground to the buildings, humans and other receptors. When impacted by vibration waves, the building components radiate the vibration and generate ground-borne noise. Ground-borne noise is typically only assessed when there is no airborne noise path since ground-borne noise is masked by airborne noise, which is more audible. In this Environmental Study, the airborne noise was assessed in Section 5.5; therefore, only ground-borne vibration will be evaluated in this section. According to FTA (2018), the vibration from sources such as traffic movement is hardly perceptible even in close vicinity. Therefore, this section assesses the more significant vibration impact from the operational construction equipment during construction activities, which can cause continuous, intermittent or impulsive vibration above background levels perceivable by the surrounding sensitive receptors.

5.6.1 Relevant Receptors

Empirical formulas commonly predict the impact on the receptors within 110 m of the vibration sources. For a comprehensive and conservative evaluation of the vibration impact on the nearby receptors, the area within 150 m of the construction site's boundary was assessed.

With reference to the vibration impact criteria described in FTA and based on the context of the Project, the receptors that are sensitive to vibration impact fall under the following categories:

- Terrestrial ecology and biodiversity in the Hillock Area; and,
- Socio-economic (i.e., staff of businesses, and recreational users).

In this Environmental Study, the identified vibration-sensitive receptors (VSRs) are similar to the noise-sensitive receptors. The nearest receptor to the vibration-generating activities from the Project is the fauna receptor in Hillock Area, located 22 m from the construction site. The human receptors that will be potentially impacted by ground vibrations include the staff of businesses and recreational users (land users) in Marina at Keppel Bay (Table 5.27).

Table 5.27 List of VSRs and their distance to the nearest construction works of the Project

S/N	Receptor	Distance nearest to construction (m)
1	Terrestrial fauna in Hillock Area	22
2	Staff of businesses and recreational users (land users) in Marina at Keppel Bay	26

This section only discusses the pressures or stressors. The corresponding Receptor chapters will assess the resulting impacts on the above-listed receptors (Sections 5.9 and 5.12).

5.6.2 Evaluation Framework

Ground vibrations caused by pile driving can be predicted with empirical models that account for attenuation with distance from the source (Grizi et al., 2018). Bornitz (1931) presented such an empirical equation and is referred to as the Bornitz equation:

$$v_2 = v_1 \times \left(\frac{d_1}{d_2}\right)^n \times e^{-\alpha(d_2-d_1)}$$

Where,

- v_1 and v_2 are the vibration amplitudes at distance d_1 and d_2 from the source
- α is the attenuation coefficient
- n is the geometric attenuation coefficient (for point source and Rayleigh waves, $n = 0.5$)

This formula integrates two types of attenuation: geometric damping related to the distance from the source and material damping as waves move through the soil. With reference to data from the soil investigation report conducted by the Client, the attenuation coefficient, α , was determined to be <0.00033 and <0.0033 for frequencies of 5 Hz and 50 Hz, respectively (Woods and Jede, 1985). The soil investigation report can be found in **Appendix G**.

There are no other standards or guidance on the vibration impact on ecological and human receptors except for the guidance on the effect of vibration levels on human receptors in BS 5228-2 published by the British Standard Institute, summarised below in Table 5.28 (BS, 2009b).

Table 5.28 Effect of vibration on humans as referenced from BS 5228-2

Vibration Level	Effect Description
0.14 mm/s	Vibration might just be perceptible in the most sensitive situation
0.3 mm/s	Vibration might just be perceptible in residential environments
1 mm/s	This vibration level in residential environments may likely cause complaint, can be tolerated if warning and explanation has been given to the residents in advance
10 mm/s	Vibration is likely intolerable for more than only a very brief exposure

5.6.3 Results and Discussions

As discussed for noise assessment, the heavy equipment anticipated for the demolition and piling works are tabulated in Table 5.22. The worst-case work phase for vibration is the demolition and piling work phase. The calculation does not include vibration contribution from the marine barge, diesel generator, and the petrol hand-held circular saw due to a lack of information on the reference peak particle velocity.

With reference to historic case data on vibration levels in BS 5228-2 and Roberts (2009), the standard vibration levels of each equipment used for the assessment is listed in Table 5.29. The assessment of vibration impact from demolition and piling construction works are evaluated based on the most impactful equipment, i.e., vibratory piling rig.

Table 5.29 Assumed construction equipment and reference vibration emission level

Construction Activity	Equipment	Reference PPV (mm/s)	Distance from Source (m)
Demolition & Piling Works	Dump Truck	1.9	7.6
	Excavator	2.3	7.6
	Mobile Crane	1.9	7.6
	Vibratory Piling Rig	40*	2.0

* referenced from BS 5228-2:2009 Code of practice for noise and vibration control on construction and open sites

In the context of the receptors near the Project, predicted vibration levels experienced by the fauna in Hillock Area, and staff of businesses, and recreational users (land users) in Marina at Keppel Bay are shown in Table 5.30.

Table 5.30 Predicted ground vibration levels from proposed construction equipment

Construction Activity	VSR	Distance nearest to Construction (m)	Predicted PPV at VSR (mm/s)
Demolition & Piling Works	Fauna in Hillock Area	22	2.86
	Staff of businesses and recreational users (land users) in Marina at Keppel Bay	26	2.60

The expected vibrational effect on humans is that the vibrations are perceptible and can be tolerated if warning and explanation has been given to affected people in advance, however there is a likelihood of complaint. The fauna in Hillock Area exposed to the predicted vibrations levels would experience stress levels that are similar or slightly more intense as compared to humans.

5.6.4 Mitigation Measures

For the vibration impact caused by use of vibration piling, a less impactful piling method should be adopted, such as rotary bored piling. This can significantly reduce the receptors' exposure to vibration levels to below 0.56 mm/s. Mitigation measures are listed in the specific receptor sections (Sections 5.9 and 5.12).

5.6.5 Ground Vibration Summary

Ground vibration can interfere with human's working efficiency by inducing stress, by disturbing concentration and by increasing accident risk. Ground vibrations transmitted from site activities to the neighbourhood can, therefore, cause anxiety as well as annoyance, and can disturb sleep, work or leisure activities. Predicted ground vibration levels based on the worst-case work phase shows that the fauna in Hillock Area will be exposed to PPV up to 2.86 mm/s, while the staff of businesses, and recreational users (land users) in Marina at Keppel Bay will be exposed to PPV up to 2.60 mm/s. Assessment of ground vibration impacts on the specific receptors are not discussed within this section but in their respective sections (Sections 5.9 and 5.12).

5.7 Underwater Noise

This section presents the results of baseline underwater noise monitoring and underwater noise modelling to assess the effect of the proposed construction activities, mainly the installation of marine piles for the pile deck and floating boardwalk, on the levels of underwater noise in the vicinity of the construction area.

5.7.1 Relevant Receptors

The underwater noise receptor near the Project site comprises marine fauna (fish). This section only discusses the pressure or stressor. The corresponding receptor chapter will assess the resulting impacts on the above-listed receptor (Section 5.8).

5.7.2 Baseline Conditions

Baseline underwater noise monitoring was carried out using a SoundTrap ST600 hydrophone at one (1) location (UN1) at the southeastern tip of the Wharf (Figure 5.56) for four (4) continuous days, including weekdays and weekends (i.e., 16 to 19 March 2024).

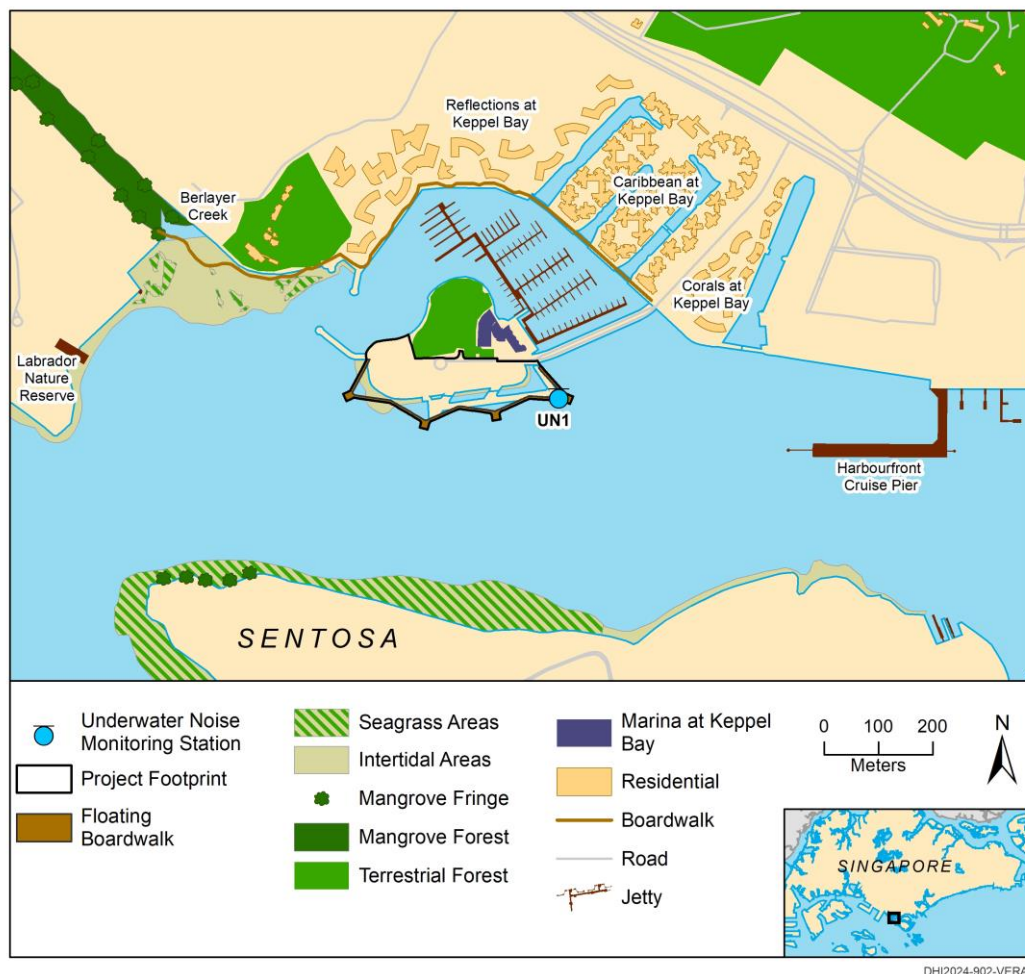


Figure 5.56 Location of underwater noise monitoring station

The hydrophone was factory-calibrated with a high gain relating to recorded waveforms and received sound pressure levels of 176.1 dB, as reported by the manufacturer. The

acoustic data was processed using dBWav tools with a Butterworth filter order 2, a sampling interval of 60 seconds, and a bandwidth of 2 Hz to 48 kHz. We also analysed the frequency spectrum of the noise in 1/3 octave bands, which is a common way to analyse sounds as the frequency resolution of hearing in marine mammals resembles 1/3 band filtering; see Thomsen *et al.* (2006). Noise level statistics were also calculated for specific frequency bands (e.g., low, medium and high ranges), which sheds light on three different noise sources detected within the Cruise Bay area.

In this section, the baseline underwater noise results are presented in two subsections: (1) noise level variability; and (2) noise level statistics.

Noise Level Variability

Figure 5.57 shows the spectrogram and waveform for the entire monitoring campaign derived at the UN1 monitoring site.

The first underwater noise category is natural sources comprising of tidal current and biological noise (snapping shrimp). The tidal current (typically in the range of 60 to 90 dB) can be identified in the entire period by its low-frequency content (usually below 100 Hz) and its repetitive occurrence (here lasting over several hours to 12-hour intervals) (Figure 5.57 Label A). The acoustic signature of the currents varied according to the tidal range with peaks up to 90 dB and a low-frequency band below 30 Hz (as indicated by Label A, white box in Figure 5.57). The sound levels observed below ~30 Hz were likely caused by water flow and tidal periodicity. This type of noise is usually termed 'pseudo-noise', caused by turbulence around the hydrophone and contributes little to the ambient sound level (Merchant *et al.*, 2016). Biological noise from snapping shrimp is identifiable by its high-frequency content (specifically above 8 kHz) with a peak up to 120 dB (as indicated by Label C, Figure 5.57). This type of noise is predominant in Southeast Asian coastal regions, where the ambient environment features warm and shallow waters (Potter *et al.*, 1997).

The second category of underwater noise is anthropogenic ambient noise, which consists of shipping vessel and tonal noise. Anthropogenic sources (smaller and medium-sized vessels and industrial noise) represent the low-medium frequencies ranging from 10 Hz to 8 kHz (Figure 5.57, Label B). This category of noise contribution was detected at UN1 from 16 to 19 March 2024, with the most prominent noise evidenced by four peaks up to ~148 dB in frequency bands between 50 Hz and 8 kHz (Figure 5.57, Label B, red boxes). The ambient noise trend recorded during the monitoring period varies. For example, from 17 March 2024 1400hrs to 17 March 2024 1500hrs, there were high peaks up to 148 dB at frequency bands between 80 Hz and 8 kHz; from 18 March 2024 1000hrs to 18 March 2024 1100hrs, there were peaks up to 140 dB at frequency bands between 200 Hz and 1 kHz, and from 18 March 2024 1700hrs to 18 March 2024 1745hrs, lower peaks up to 138 dB were detected at frequency bands between 500 Hz and 1.25 kHz. Examples of sources that could cause anthropogenic ambient noise include vessel traffic and industrial activities. According to extracted AIS data during the monitoring period, passing vessels in the area were dominated by high-speed crafts and passenger vessels with LOA between 0 to 50 m (Figure 5.58).

The tonal noise, which is continuous and concentrated in a narrow part of the spectrum at a consistent frequency, was recorded at levels up to 110 dB. It was observed during the entire monitoring period at a low band 100 Hz frequency and ~200 Hz frequency band for the last measurement from 18 March 2024 1000hrs to 19 March 2024 0600hrs 2024 (Figure 5.57, Label D). This tonal noise was likely generated by rotating equipment. Examples of sources that could generate tonal noise include compressors, motors, waterjet pumps and transformers.

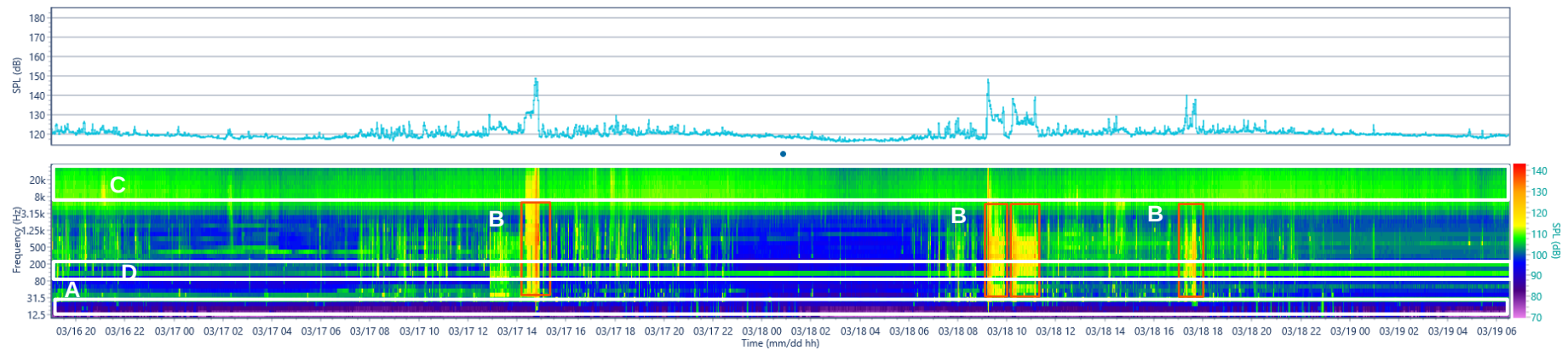


Figure 5.57 Waveform (above) and spectrogram (below) of recording from the entire monitoring campaign. The colour legend presented on the right side of the spectrogram indicates the sound pressure level (SPL) in decibels (dB); the vertical axis on the left side of the spectrogram indicates the frequency band in hertz (Hz). Label A indicates the acoustic signature of tidal currents, Label B shipping noise, Label C snapping shrimp, and Label D tonal noise

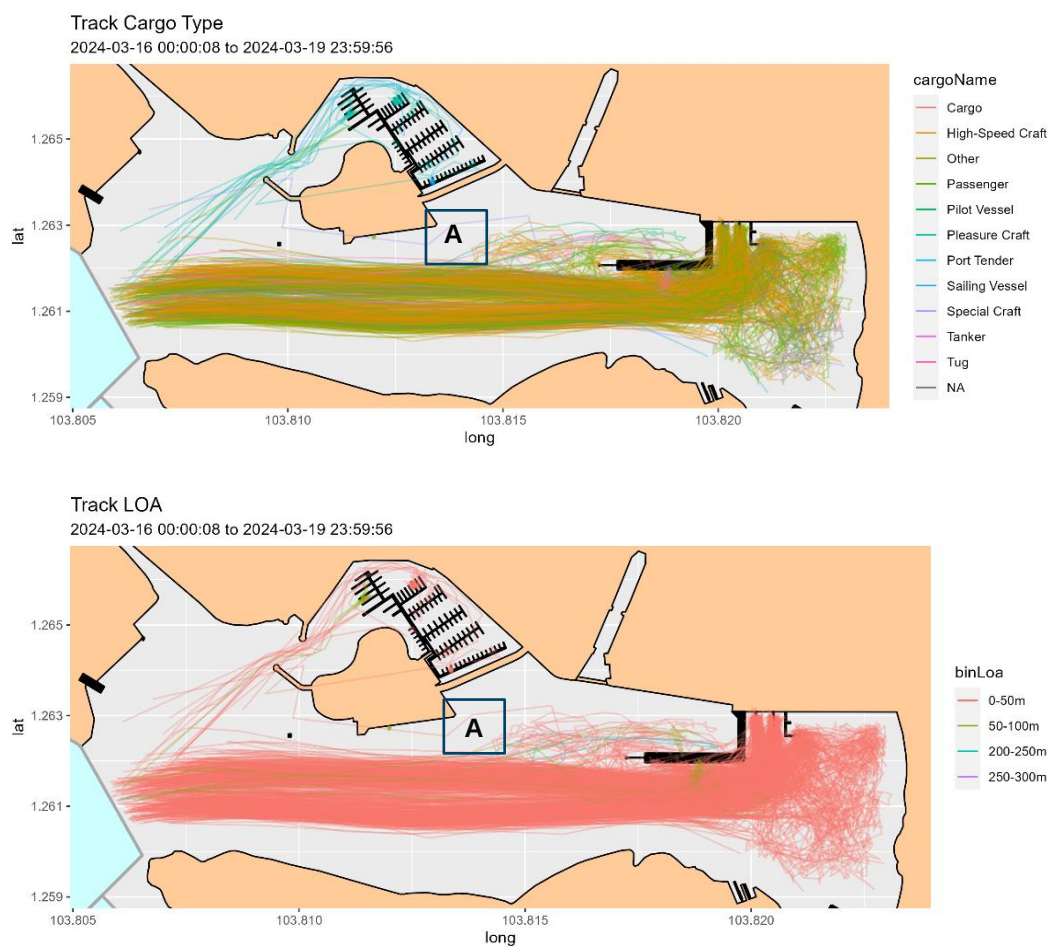


Figure 5.58 Passing vessel recorded by AIS data between 16 and 19 March 2024: vessel track by Cargo Name (top), and vessel track by LOA (Length Overall) (bottom). Label “A” represents the underwater noise monitoring area UN1.

Noise Level Statistics

Figure 5.59 shows the frequency spectrum of the background noise for the entire monitoring period. Background sound levels recorded below 100 Hz, which are dominated by tidal flow, had median values ranging from 78 to 103 dB. At frequencies from 100 Hz to 1 kHz, which are dominated by vessel passages and industrial activities, the median values ranged from 97 to 106 dB, and the 95th percentile ranged from 110 to 113 dB. Sound pressure levels recorded in frequencies above 8 kHz, which are dominated by snapping shrimp, had median values ranging up to 107 dB and the 95th percentile spanning up to 109 dB.

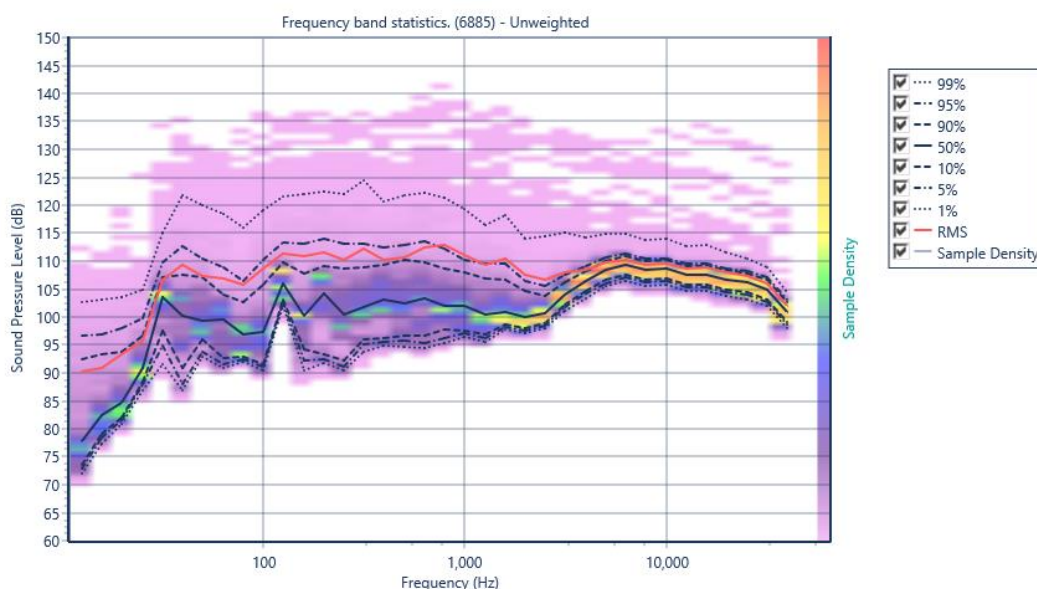


Figure 5.59 Density probability spectra for the recording period at UN1. The 5th, 50th, and 95th percentiles and RMS are plotted. Sample density is the spectral probability density.

For specific frequency bands, four (4) summary metrics of sound level were computed: 5th percentile (minimum), 50th percentile (median), 95th percentile (maximum), and Root Mean Square (RMS) level, as summarised in Table 5.31. RMS is the square root of the mean square pressure, which conventionally represents the mean for variables of a continuous nature in time.

The RMS exceeded the 95th percentile for several frequencies (i.e., between frequency bands of 1 to 3 kHz), which means the 95th percentile metric is more appropriate to represent the ambient noise level at UN1. RMS was found to overlap with typical open ocean ambient noise levels (74 to 100 dB) and vessel presence (up to 120 dB) measured in the band 20 to 1 kHz (Urick, 1983).

Table 5.31 Summary of the statistical metrics of noise levels (dB) at the monitoring station UN1

Station	Statistical Metric	63 Hz	100 Hz	160 Hz	250 Hz	500 Hz	1 kHz	12.5 kHz
UN1	5 th percentile	91.7	91.0	92.3	91.1	95.9	97.0	105.4
	Median	99.5	97.4	100.3	100.5	102.5	102.0	107.5
	95 th percentile	108.9	110.2	113.1	113.0	112.9	110.2	109.6
	RMS	106.8	108.7	111.0	110.3	110.6	111.1	108.6

In summary, the acoustic metric of the 95th percentile successfully captured the ambient sound levels around the Project site, and they were found to be higher compared to other regions. For example, the frequency at 63 – 500 Hz was found to be 81.5 – 95.5 dB around UK sites (Merchant *et al.*, 2016), and the frequency at 300 Hz – 3 kHz was found to be 70 – 80 dB around Singapore waters (Potter *et al.*, 1997).

5.7.3 Modelling Methodology

This Environmental Study adopts an acoustic calculation tool from National Marine Fisheries Service (NMFS) Multi-Species Pile Driving Calculator (NMFS, 2022). The tool provides an extensive database of underwater acoustic measurements from a number of marine projects and various behavioural and hearing impairment thresholds for ecological receptors (including fish and sea turtles). The tool estimates potential effects zone of pile driving works (including pile hammering and vibratory method) through calculation of the effect distance within which sound pressure level or sound exposure level (SEL) has potential to create behavioural or hearing impairment effects on fish and sea turtles. The NMFS's auditory weighting functions has been applied in this tool for specific group of animals, i.e., sea turtles, to emphasise frequencies where sensitivity to noise is high and to de-emphasise frequencies where sensitivity is low. Dolphins were not assessed in this methodology as we do not have records of the exact species that are found in the Study Area.

Modelling Scenarios

Two (2) scenarios of underwater noise modelling were assessed in the assessment of underwater noise and its impacts. As described in Section 2.3, the construction scope requires the erection of a pile deck at the proposed pile deck area. The pile diameter sizes used for assessment were 1000 mm and 1100 mm, chosen to be the worst-case, i.e., the most noise-intensive, scenario during the works. The piles were steel sheet pile types installed using the vibratory method, taking 30 minutes to drive a single pile to the final depth. A summary of the modelling scenario for underwater noise impact assessment is shown in Table 5.32.

Table 5.32 Modelling scenario for underwater noise impact assessment during Construction Phase

Scenario	Pile Diameter (mm)	Number of piles per day	Vibration time per pile (minute)	SPL _{rms} (dB re 1 μ Pa @ 1m)
S01	1100	2	30	190
S02	1000	2	30	185

5.7.4 Evaluation Framework

Several metrics used to assess effect criteria for fish and sea turtles are typically expressed in terms of:

- Root Mean Square pressure level (SPL_{rms}): the square root of the average squared pressures over the duration of a pulse.
- Cumulative sound exposure level (cSEL): the energy accumulated over multiple strikes or continuous vibration over a period of time; the cSEL value is not a measure of the instantaneous or maximum noise level but is a measure of the accumulated energy over a period of time to which an animal is exposed.

For vibratory pile driving, the effect threshold for fish is limited to behavioural reactions, while for sea turtles, it includes both the onset of Permanent Threshold Shift (PTS) and behavioural changes. These threshold values are based on the international standards and guidelines for underwater noise assessment, specifically those provided by NOAA NMFS (2023).

5.7.5 Results and Discussions

Overall, the installation of a 1100 mm diameter pile (S01) is predicted to have a greater effect in terms of distance as compared to a 1000 mm diameter pile (S02). The cumulative exposure levels generated by vibratory piling of the 1100 mm pile can potentially cause PTS to sea turtles within 2.4 m of the work area, while behavioural changes could be expected from the Project site up to 10 m for sea turtles and 464 m for fish (Table 5.33). For the 1000 mm diameter pile, the model predicts that the cumulative sound exposure level within less than 1.1 m of the work area has the potential to cause a PTS to sea turtles, while behavioural shifts for fish and sea turtles are anticipated up to 215 m and 4.6 m from the site, respectively (Table 5.34). Receptor-specific assessments (considering sensitivity and distance) are presented in Section 5.8.

Table 5.33 Scenario 01: Calculation of distance at which sound pressure level and cumulative sound exposure level meet threshold value for fish and sea turtles

Parameters	Sea Turtles		Fish
	PTS Onset	Behavioural Change	Behavioural Change
	Cumulative SEL (dB)	SPL _{rms} (dB)	SPL _{rms} (dB)
Threshold value	220	175	150
Distance to threshold (m)	2.4	10	464

Table 5.34 Scenario 02: Calculation of distance at which sound pressure level and cumulative sound exposure level meet threshold value for fish and sea turtles

Parameters	Sea Turtles		Fish
	PTS Onset	Behavioural Change	Behavioural Change
	Cumulative SEL (dB)	SPL _{rms} (dB)	SPL _{rms} (dB)
Threshold value	220	175	150
Distance to threshold (m)	1.1	4.6	215

5.7.6 Underwater Noise Summary

Underwater noise emissions from vibratory piling associated with the Project may cause behavioural changes in sea turtles and fish up to 10 m and 464 m from the Project site, respectively, with minimal PTS effects on sea turtles (within 2.4 m of the site). Impacts on the underwater noise receptors are assessed in the corresponding receptor sections later in this report (Section 5.8).

5.8 Marine Ecology and Biodiversity

Keppel Island and its surrounding areas are home to a variety of coastal environments and their associated flora and fauna, including coral reef habitats along the rock revetments of Keppel Island itself and seagrass habitats along the mouth of Berlayer Creek across the channel.

Given these ecologically sensitive marine receptors, baseline studies on the intertidal areas and coral reef habitats were carried out to assess potential impacts on these coastal communities. Construction activities associated with marine works can change hydrodynamics, suspended sediment concentrations, and pollution concentration loads in the surrounding water. Sediment spills from piling works may temporarily increase the concentration of suspended sediments, resulting in increased turbidity.

5.8.1 Relevant Pressures

Given the nature of the proposed construction methodology described in Section 2, the following sources of environmental pressures and potential impact on sensitive receptors in the marine ecosystem will be assessed (with analyses of the respective pressure shown in brackets, if any):

- Physical disturbance due to construction activities;
- Sedimentation and suspended sediments (Section 5.2);
- Pollution release from the suspended sediments (Section 5.3);
- Underwater noise (Section 5.7); and,
- Secondary impacts due to changes to marine environmental quality due to accidental spills and leaks.

This section, where relevant, references numerical modelling results from the preceding chapters, which correspond to the Construction Phase of the Project. These results are reviewed for compliance with relevant standards and/or tolerance limits where applicable.

5.8.2 Baseline Features and Key Receptors

The present section provides a baseline description of the ecological receptors located near the proposed development and the larger zone of potential impacts that may arise as a result of the proposed construction works.

While impacts on overall marine ecology will be considered within the assessment, several key receptors of particular relevance to the Project have been identified. These include sensitive habitats, sensitive communities, and protected and threatened species identified adjacent to the site and within the area of Project influence, which include:

- Intertidal areas;
- Seagrass meadows;
- Mangrove habitats;
- Coral reef habitats;
- Marine fauna and megafauna; and,

- Macrobenchos.

A mixture of literature reviews and baseline surveys was carried out to establish an understanding of the marine ecology receptors at and around the Project area. For areas where a detailed understanding of biodiversity was required, baseline surveys were conducted. For this Project, the chosen surveys were coral reef surveys, seagrass/intertidal surveys, and macrobenchos surveys.

This section aims to discuss the most relevant baseline features for the ecological environmental assessment. These features will frame the discussion of impacts in the following sections. The locations would be further considered in relation to extraction points applied during the modelling, as shown in Figure 5.60, with extraction locations described in Table 5.35.

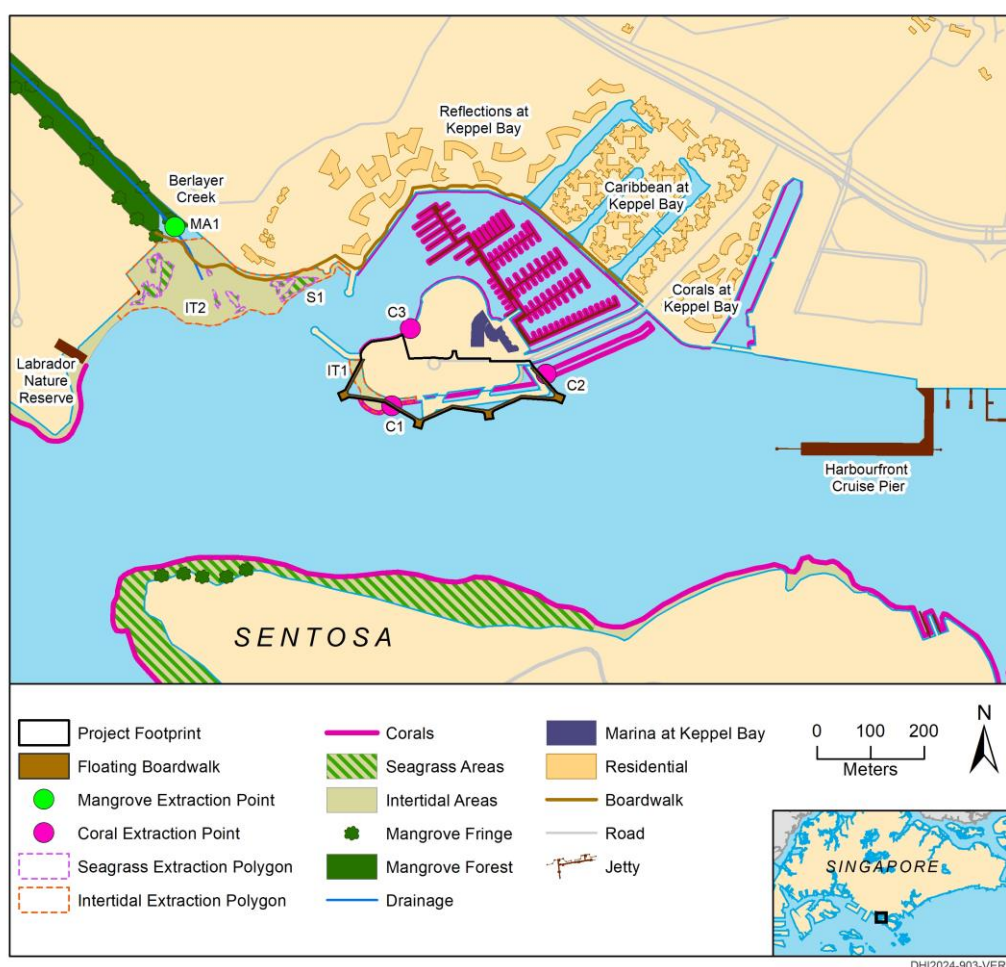


Figure 5.60 Overview of marine ecology receptors and relevant labelled extraction points for assessment of impacts to marine ecology

Table 5.35 Table of respective label IDs and description for marine ecology receptors

ID	Description
C1	Keppel Island Corals
C2	Caisson Corals
C3	Keppel Marina Corals

ID	Description
IT1	Keppel Island Intertidal
IT2	Labrador Intertidal
MA1	Berlayer Creek Mangrove
S1	Labrador Seagrass Meadow

5.8.2.1 Intertidal Habitat Surveys

The intertidal habitat is generally dominated by organisms adapted to fluctuations in water level being home to various flora and fauna, such as algae, hard corals, sponges and numerous benthic organisms like gastropods and crustaceans. When prevailing conditions are suitable, i.e., site is sheltered from significant wave action with suitable substrate, and some water is still trapped during the low tide, seagrasses also thrive in the intertidal zone (McKenzie *et al.*, 2016).

Visual Quadrat Point Surveys

Methods

The Visual Quadrat Point (VQP) method (Figure 5.61) was used due to the narrow nature of the intertidal area near Keppel Island and the patchy seagrass at the mouth of Berlayer Creek. Surveys were conducted during periods of spring low tide. Six (6) replicate 0.25 m² (0.5 m by 0.5 m) quadrats were placed randomly around each predetermined point, which were distributed across the site (Figure 5.63) to ensure adequate representation of the Study Area.

The VQP surveys documented and characterised the intertidal communities (and seagrass, if any), including:

- Benthic percentage cover of a predetermined list of flora and fauna, including seagrass, macroalgae, and abiotic substrate;
- Counts of individual motile organisms from major fauna classes; and,
- Biodiversity of major intertidal flora and fauna identified at the taxonomic species level.

Where possible, all major flora and macro-invertebrate fauna encountered were identified to the taxonomic level of species. Species of conservation significance were identified in accordance with published lists (e.g., the IUCN Red List and the Singapore Red Data Book version 3 by NParks, 2024). Where possible, in-situ photographs of the taxa encountered were recorded.

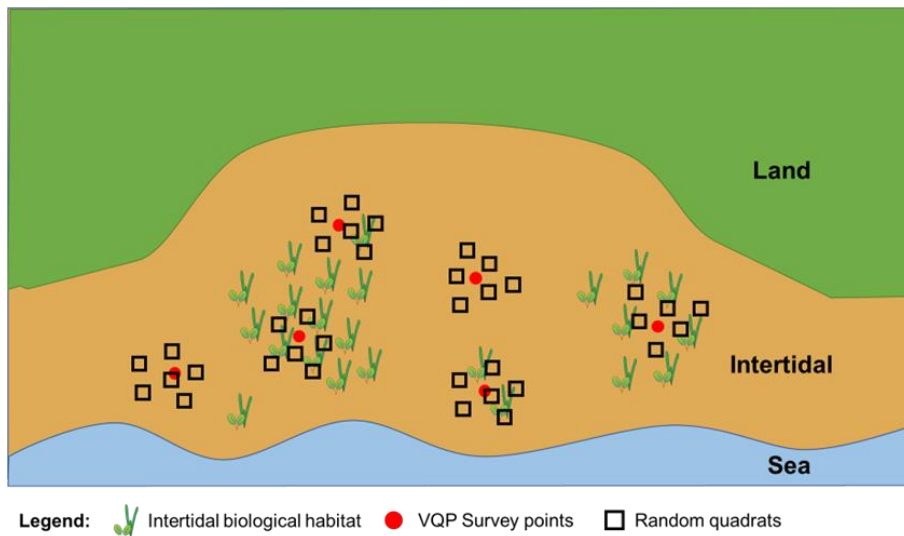


Figure 5.61 Placement of 0.25 m² quadrats within the intertidal area based on the VQP method. Red dots: Survey location marked by GPS; Squares: six (6) quadrats randomly placed around the survey location



Figure 5.62 Images showing an overview of the intertidal area at Berlayer Creek (left) and a surveyor quantifying benthic coverage on the intertidal area (right)

Locations

Two areas were identified as sensitive receptors intertidal habitats along the mouth of Berlayer Creek and the southern coast of Keppel Island.

Berlayer Creek

Berlayer Creek intertidal area is located northeast of Keppel Island, separated by a 50 m wide navigation channel leading into the Marina at Keppel Bay. Due to the substantial area that needed to be covered, ten (10) points along the intertidal area were identified for surveying (Figure 5.63; Table 5.36).



Figure 5.63 Location of intertidal survey areas and point stations, ten (10) at Berlayer Creek and four (4) at Keppel Island. Conservation-significant species of seagrass detected during surveys are also marked.

Table 5.36 Coordinates of the ten (10) VQP stations carried out for the intertidal surveys at Berlayer Creek

Stations	Coordinates	
	Longitude (°)	Latitude (°)
BR01	103.809459°	1.265003°
BR02	103.808953°	1.264665°
BR03	103.808616°	1.264789°
BR04	103.808267°	1.264538°
BR05	103.808104°	1.264991°
BR06	103.807706°	1.264659°
BR07	103.807522°	1.265463°
BR08	103.807244°	1.264932°
BR09	103.806852°	1.265140°
BR10	103.806877°	1.264567°

Keppel Island

The intertidal area of Keppel Island is located on its southern coast, approximately 300 m in length. Five (5) points along this coast was identified for surveying (Figure 5.63; Table 5.37).

Table 5.37 Coordinates of the five (5) VQP stations carried out for the intertidal surveys at Keppel Island

Stations	Coordinates	
	Longitude (°)	Latitude (°)
KP01	103.812953°	1.263361°
KP02	103.812634°	1.263094°
KP03	103.812016°	1.263022°
KP04	103.811159°	1.262902°
KP05	103.810464°	1.263023°

Results

Berlayer Creek

The site's benthic coverage was predominantly abiotic, with a significant 89.45 ± 2.13 % being sandy substrate (67.22 ± 4.49 %) (Table 5.38). The remaining 10.55 % was biotic cover, primarily seagrass (6.13 ± 1.86 %) and macroalgae (4.32 ± 0.82 %) (Table 5.39). Seagrass cover within the quadrats consisted entirely of spoon seagrass (*Halophila ovalis*) which is a fast-growing seagrass species and is often dominant along the shores in Singapore where seagrass is present (Yaakub *et al.*, 2013). Outside of the survey quadrats, tape seagrass (*Enhalus acroides*) (SRDB3: locally "Critically Endangered") was also observed (Figure 5.63). The most dominant faunal class recorded within the quadrats was Gastropoda (e.g., snails) at a density of 3.00 ± 1.20 indiv/m², followed by Malacostraca (e.g., crabs) at 1.27 ± 0.54 indiv/m² (Figure 5.64).

A total of 25 species of fauna were encountered within the survey quadrats and in the surrounding intertidal area, none of which were of local conservation significance (Table 5.39). Some examples of fauna that were recorded include the Haeckel's anemone (*Actinostephanus haeckeli*), and the orange-striped hermit crab (*Clibanarius infraspinus*), species that are frequently documented on Singapore's shores (Figure 5.65)

While not recorded during the baseline surveys, literature reviews of intertidal fauna in the area have also recorded a number of conservation-significant invertebrate and even fish. Of note due to their rarity or conservation significance are species such as the Coastal Horseshoe Crab (*Tachypleus gigas*, locally "Vulnerable"), knobbly sea star (*Protoreaster nodosus*, locally "Endangered") and the cryptic sea star (*Cryptasterina* sp.).

Table 5.38 Mean percentage cover (%) and standard error (SE) of the major benthic categories recorded during the VQP surveys at Berlayer Creek

Major Benthic Category	Mean (%)	SE (%)
Seagrass	6.13	1.86
Macroalgae	4.32	0.82
Ascidian	0.00	0.00

Major Benthic Category	Mean (%)	SE (%)
Anemone	0.02	0.02
Hard coral	0.02	0.02
Soft coral	0.00	0.00
Sponge	0.03	0.03
Zoanthid	0.02	0.02
Other fauna	0.02	0.02
Abiotic	89.45	2.13

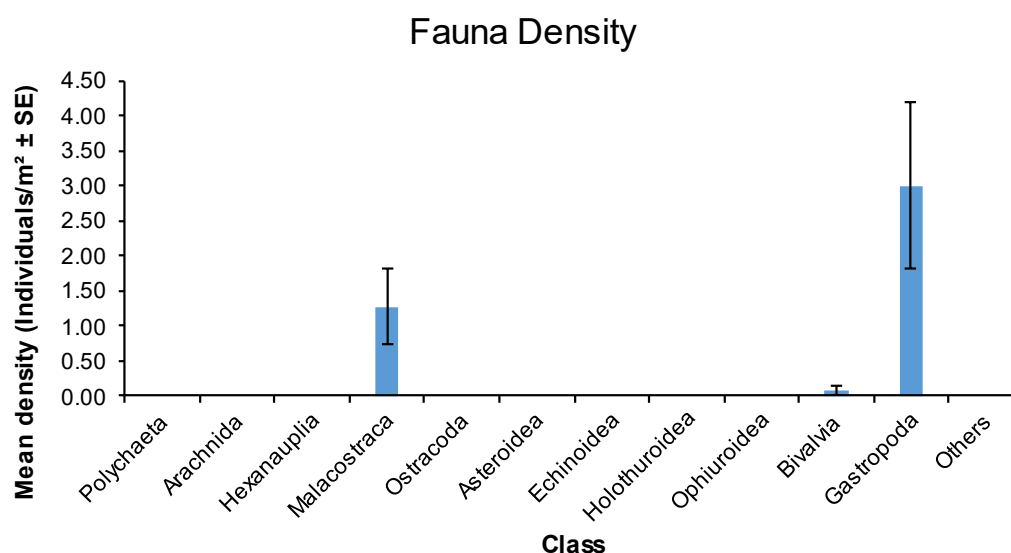


Figure 5.64 Mean density ($\pm$ SE) of different classes of fauna detected during VQP surveys

Table 5.39 List of species found during VQP surveys at the intertidal areas around Berlayer Creek

No.	Family	Scientific Name	Common Name	SRDB3 Status
1	Actinodendridae	<i>Actinostephanus haeckeli</i>	Haeckel's anemone	LC
2	Batillariidae	<i>Batillaria zonalis</i>	Bazillion snail	NA
3	Cardiidae	Family Cardiidae spp.	Large cockle	NA
4	Cerithiidae	<i>Cerithium coralium</i>	Coral cerith/creeper snail	LC
5	Columbellidae	<i>Pardalinops testudinaria</i>	Turtle dove snail	LC
6	Columbellidae	<i>Pictocolumbella ocellata</i>	Lightning dove snail	LC
7	Diogenidae	<i>Clibanarius infraspinus</i>	Orange-striped hermit crab	NA
8	Dotillidae	<i>Scopimera</i> sp.	Sand bubbler crab	NA

No.	Family	Scientific Name	Common Name	SRDB3 Status
9	Littorinidae	Family Littorinidae spp.	Rock periwinkle snail	NA
10	Matutidae	<i>Ashtoret lunaris</i>	Spotted moon crab	NA
11	Menippidae	<i>Myomenippe hardwickii</i>	Stone crab	LC
12	Nassariidae	<i>Nassarius livescens</i>	Common whelk	LC
13	Nassariidae	<i>Nassarius olivaceus</i>	Olive whelk	LC
14	Neritidae	<i>Nerita chamaeleon</i>	Chameleon nerite	LC
15	Neritidae	<i>Nerita undata</i>	Waved nerite	NA
16	Onchidiidae	Family Onchidiidae	Onch slug	NA
17	Oulastreidae	<i>Oulastrea crispata</i>	Zebra coral	LC
18	Phymantidae	<i>Phymanthus pinnulatus</i>	Banded frilly sea anemone	LC
19	Pinnidae	Family Pinnidae spp.	Fan shell	NA
20	Portunidae	<i>Thalamita danae</i>	Blue swimming crab	NA
21	Stichodactylidae	<i>Stichodactyla haddoni</i>	Haddon's carpet anemone	LC
22	Strombidae	Family Strombidae spp.	Conch snails	NA
23	Tegulidae	<i>Rochia</i> sp.	Giant top shell snail	NA
24	Tetillidae	<i>Cinachyrella australiensis</i>	Golf ball sponge	LC
25	Turbinidae	<i>Turbo intercostalis</i>	Ribbed turban snail	NA

Table 5.40 List of additional conservation-significant species found via literature review in the waters and intertidal areas around Berlayer Creek. The full list is found in **Appendix D**.

No.	Family	Scientific Name	Common Name	SRDB3 Status
1	Limulidae	<i>Tachypleus gigas</i>	Coastal horseshoe crab	VU
2	Mustelidae	<i>Lutrogale perspicillata</i>	Smooth-coated otter	EN
3	Carangidae	<i>Megalaspis cordyla</i>	Torpedo scad	VU
4	Gobiidae	<i>Periophthalmus walailakae</i>	Yellow-spotted mudskipper	VU
5	Gobiidae	<i>Periophthalmus gracilis</i>	Slender mudskipper	VU
6	Laganidae	<i>Jacksonaster depressum</i>	Thick-edged sand dollar	VU
7	Goniasteridae	<i>Stellaster childreni</i>	Galloping sea star	VU
8	Oreasteridae	<i>Protoreaster nodosus</i>	Knobbly sea star	EN

No.	Family	Scientific Name	Common Name	SRDB3 Status
9	Archasteridae	<i>Archaster typicus</i>	Common Sandstar	VU
10	Asterinidae	<i>Cryptasterina sp.</i>	Cryptic sea star	VU
11	Tegulidae	<i>Tectus niloticus</i>	Giant top shell	Not listed
12	Delphinidae	NA	Dolphin	CR



Figure 5.65 Representative photos of the intertidal area at Berlayer Creek

Keppel Island

Benthic coverage on the site was primarily abiotic ($70.17 \pm 4.04\%$), comprising of rocky-sandy substrate (Table 5.41). The remaining 29.83% was biotic cover, dominated by 16.73% of hard corals. The rest of the biotic cover comprised of small percentage of macroalgae, soft coral, anemone, sponge, zoanthids, seagrass and other fauna (Table 5.41). The percentage of hard corals is considered quite a significant coverage for an intertidal area. For fauna found within the quadrats, Gastropoda (e.g., snails) were detected at the highest density of 5.73 indiv/m^2 , followed by Bivalvia (e.g., oysters) at a density of 0.67 indiv/m^2 . It is likely that seagrass was not found in this area as the substrata of these areas consisted primarily of consolidated rock, rubble, or were part of the seawall, making it non-ideal for seagrass growth.

A total of 15 species of fauna were recorded during surveys, none of which are conservation-significant (CS) species (Table 5.42). Some examples of fauna that were recorded include the Jewelled Chiton (*Acanthopleura gemmata*), the Ox-tongue nerite snail (*Nerita albicilla*) and the Banded frilly sea anemone (*Phymanthus pinnulatus*), species that are frequently documented in Singapore's rocky shores (Figure 5.67). In addition, literature review results reveal records of locally "Vulnerable" fish species (e.g., the Ringed pipefish (*Dunckerocampus dactyliophorus*) and Sixspine butterflyfish (*Parachaetodon ocellatus*) as well as charismatic species such as dolphins and sea turtles. While the latter two could not be narrowed down to species, all species of these families have national and international conservation status at least "Vulnerable" and above in the SRDB3 and IUCN Red List. It

should also be noted that sea turtles have also been sighted at a distance away (too far to identify down to species) during the coral diving surveys.

Table 5.41 Mean percentage cover (%) and standard error (SE) of the major benthic categories recorded during the VQP surveys

Major Benthic Category	Mean (%)	SE (%)
Seagrass	0.17	0.17
Macroalgae	8.03	1.78
Ascidian	0.00	0.00
Anemone	0.73	0.40
Hard coral	16.73	3.67
Soft coral	2.67	1.53
Sponge	0.67	0.52
Zoanthid	0.50	0.50
Other fauna	0.33	0.33
Abiotic	70.17	4.04

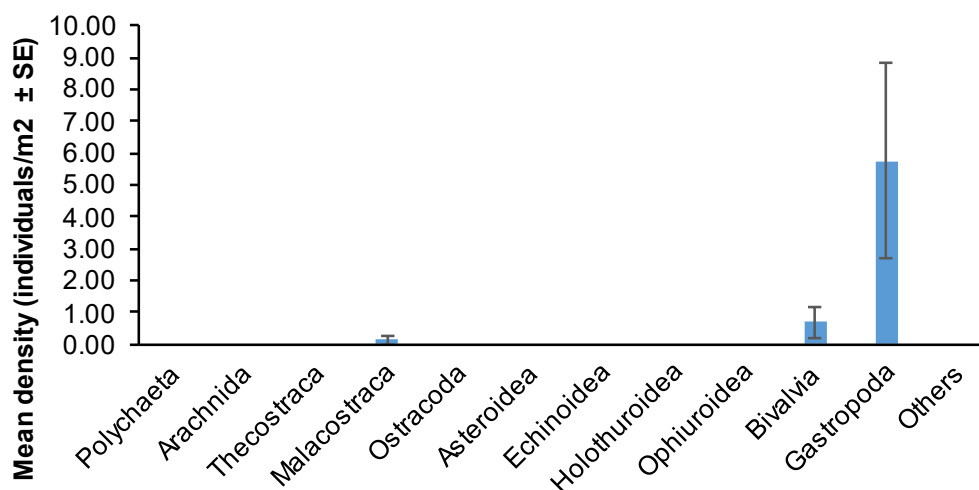


Figure 5.66 Mean density ($\pm$ SE) of different classes of fauna detected during VQP surveys

Table 5.42 List of species found during VQP surveys at the intertidal areas around Keppel Island

No.	Family	Scientific Name	Common Name	SRDB3 Status
1	Phymanthidae	<i>Phymanthus pinnulatus</i>	Banded frilly sea anemone	LC
2	Stichodactylidae	<i>Stichodactyla gigantea</i>	Giant carpet anemone	LC
3	Cladiellidae	<i>Cladiella</i> sp.	Finger leather soft coral	DD
4	Sarcophytidae	<i>Lobophytum</i> sp.	Devil's hand soft coral	DD
5	Sarcophytidae	<i>Sarcophyton</i> sp.	Sarcophyton soft coral	DD
6	Sinulariidae	<i>Sinularia</i> sp.	Smooth leathery soft coral	LC
7	Discosomidae	<i>Discosoma nummiforme</i>	Beaded corallimorph	LC
8	Dendrophylliidae	<i>Turbinaria</i> sp.	Disk coral	LC
9	Merulinidae	<i>Platygyra</i> sp.	Lesser valley coral	LC
10	Merulinidae	<i>Pectinia</i> sp.	Carnation coral	LC
11	Sphenopidae	<i>Palythoa tuberculosa</i>	Sea mat zoanthid	LC
12	Littorinidae	<i>Echinolittorina</i> sp.	Round periwinkle snail	LC
13	Neritidae	<i>Nerita albicilla</i>	Ox-tongue nerite snail	LC
14	Chitonidae	<i>Acanthopleura gemmata</i>	Jewelled chiton	NT
15	Diadematidae	<i>Diadema setosum</i>	Diadema sea urchin	DD

Table 5.43 List of additional conservation-significant species found via literature review in the waters and intertidal areas around Keppel Island. The full list is found in **Appendix D**.

No.	Family	Scientific Name	Common Name	SRDB3 Status
1	Syngnathidae	<i>Dunckerocampus dactyliophorus</i>	Ringed pipefish	VU
2	Chaetodontidae	<i>Parachaetodon ocellatus</i>	Sixspine butterflyfish	VU
3	Delphinidae	NA	Dolphin	CR
4	Cheloniidae	NA	Sea Turtle	CR



Figure 5.67 Survey photographs depicting the overview of the intertidal area and various fauna found at Keppel Island

5.8.2.2 Subtidal Habitat Surveys

Coral Habitat Surveys – Line Intercept Transect (LIT)

Coral reefs are diverse underwater ecosystems held together by calcium carbonate structures. Reef-forming corals secrete this hard carbonate exoskeleton to support and protect the coral polyps. Although coral reefs occupy less than 0.1 % of the world's ocean surface, they are home to many marine species, including fish, molluscs, worms, crustaceans, echinoderms, sponges, and tunicates. Most reefs grow best in shallow depths in tropical waters, but deep- and cold-water corals also exist on smaller scales in other areas.

The two types of reefs commonly found in Singapore include the fringing reef and patch reef. A fringing reef is formed immediately adjacent to the shore at the low water level, expanding seawards as they grow. Patch reefs can form in the middle of the open ocean when the seabed rises close enough to the ocean's surface to enable the growth of reef-building corals. The exposed part of the patch reefs is usually comprised of sand and rubble, which provide a suitable substrate for seagrasses and other marine fauna to grow

on. A typical zonation pattern of the reef includes the back reef or reef flat, followed by the reef crest, reef slope (forereef) and the lower reef (deep forereef) (Figure 5.68). Along the reef, the photic zone where sunlight reaches stretches from the reef flat to the reef crest and down the reef slope. Photosynthetic organisms such as corals and macroalgae tend to inhabit these parts of the reef. The lower reef is aphotic and comprised mainly of organisms such as sponges and sea fans, which filter feed.

The various methods (both quantitative and qualitative) employed in assessing coral reefs are mentioned in the sections below.

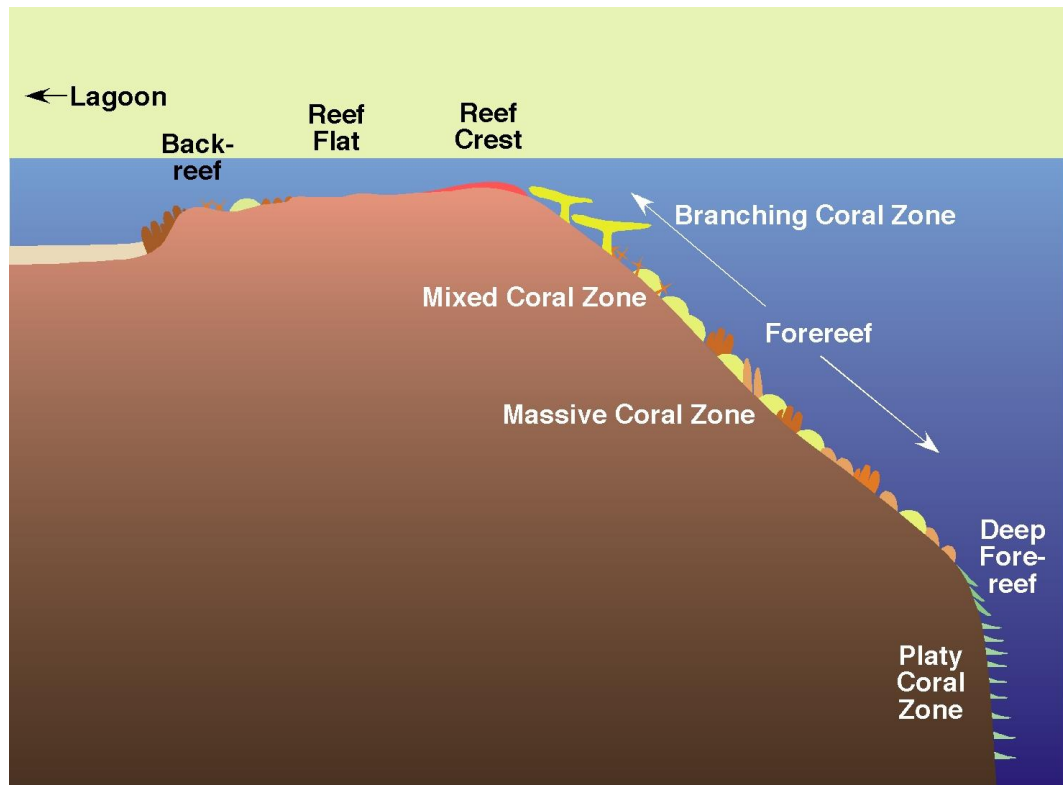


Figure 5.68 Typical reef zonation

Methods

Data Acquisition

The Line Intercept Transect (LIT) method described by English *et al.* (1997) was employed to monitor and assess the status of the benthic reef community for the baseline study and the monitoring programme. This method is recommended by the Global Coral Reef Monitoring Network (GCRMN) (Hill and Wilkinson, 2004). It is widely used in Singapore and around the Indo-Pacific region to quantify the percentage cover of Scleractinian or reef-building corals and other major benthic lifeforms typical of a tropical coral reef. The individual benthic categories used to characterise the benthic morphology of the sites are described in Table 5.44.

Along each designated survey depth at the reef crest and reef slope, five (5) replicate transects measuring 20 m in length will be laid in a longitudinal direction to the reef (Figure 5.69). The transition points between successive predetermined benthic lifeforms occurring directly under the tape will be recorded on waterproof paper. Hard corals, when encountered, will be identified up to the taxonomic classification of the genus (following Veron, 2000). The size of each hard coral will also be estimated along its widest axis or diameter according to the eight (8) size classes outlined in Table 5.45. For such horizontal reef surveys in Singapore, the reef crest where corals are most diverse and abundant is

designated as 0 m Chart Datum (CD) from which all other deeper zones are referenced, e.g., reef slope -3 m CD.

Based on the LIT survey results, the condition of the reef will be defined in terms of percentage (%) of live hard coral cover and generic diversity, as defined by the Shannon-Wiener Diversity Index (H') and Equitability Index (E). The LIT method also records the presence of other life forms, such as macroalgae, sponges, gorgonians, sea urchins and anemones. All other fauna encountered will be identified using their lowest taxonomic classifications where possible. The conservation status of flora and fauna will be determined based on the Singapore Red Data Book version 3 by NParks (2024) and the IUCN Red List.

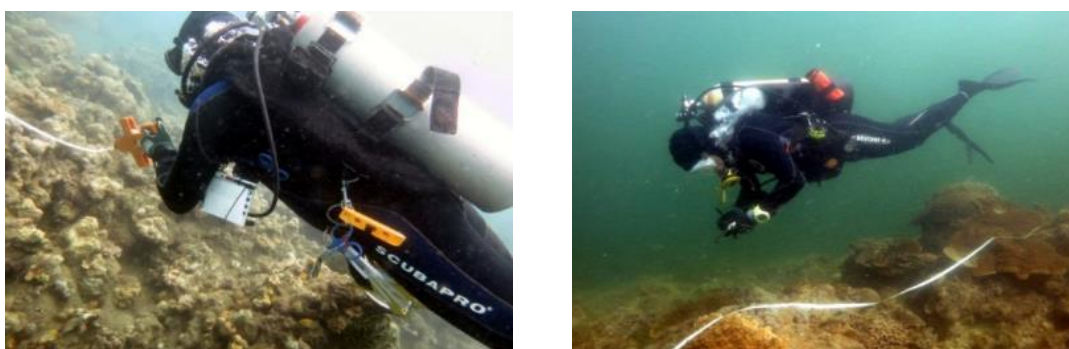


Figure 5.69 Surveyors laying the survey transect along the reef using a graduated fibreglass tape (left); Surveyors swimming along survey transects and recording benthic lifeforms (right)

Table 5.44 Individual benthic categories used in the LIT survey (English *et al.* 1997)

Major Benthic Lifeform Category	Individual Lifeform Category	Remarks/Comments
Live Coral Non-Acropora Corals	Massive coral	Solid boulder or mound
	Foliose coral	Coral attached at one or more points, leaf-like appearance
	Branching	At least secondary branching
	Encrusting	Major portion attached to substratum as a laminar plate
	Submassive	Tends to form small colonies, knobs and wedges
	Mushroom	Solitary, free-living corals
Live Coral Acropora Corals	Branching	At least secondary branching
	Encrusting	Usually the base-plate of immature <i>Acropora</i> forms
	Submassive	Robust with knob or wedge-like form
	Digitate	No secondary branching
	Tabulate	Horizontally flattened plates
Dead Coral	Dead coral	Recently dead, white to dirty white

Major Benthic Lifeform Category	Individual Lifeform Category	Remarks/Comments
	Dead coral with algae	Coral is standing but no longer white
Other Fauna	Soft coral	Soft-bodied corals from the order Alcyonaceae
	Sponges	A group of mostly filter-feeding sessile marine invertebrates from the phylum Porifera
	Zoanthids	Invertebrates of the order Zoanthidae, e.g., <i>Platythoa</i>
	Others	Scidians, anemones, gorgonians, giant clams etc.
Algae	Turf algae	Lush filamentous algae
	Coralline Algae	Encrusting, red or pink, sometimes like leaves
	Macroalgae	Weedy/fleshy greens, browns and reds
	Algal Assemblage	Non-distinct mass of algae consisting of more than 1 species
Abiotic	Rubble	Unconsolidated coral fragments
	Rock	Non-carbonate, e.g., Granite rock
	Silt	Particles with grain size <63 µm; settles slowly when disturbed
	Sand	Particles with grain size >63 µm; settles fast when disturbed
	Water	Fissures deeper than 50 cm
	Debris	Marine litter from land-based sources, e.g., Fishing net

Table 5.45 Hard coral size classes

Size Class	Diameter (cm)
Size 1	< 5
Size 2	5 – 10
Size 3	10 – 25
Size 4	25 – 50
Size 5	50 – 75
Size 6	75 – 100
Size 7	> 100

Size Class	Diameter (cm)
Size 8	> 100; Consists of mono-specific stands

Data Processing and Analysis

Benthic Cover Determination

Raw data collected in the field will be transcribed, entered into DHI's coral database and verified before being analysed. A morphological picture or description of the reef will be determined by expressing the benthic categories as a percentage of transect length. The percentage cover for each benthic category will be calculated as follows:

$$\text{Percent cover} = \frac{\text{Total length of category}}{\text{Length of transect (20m)}} \times 100\%$$

An average percentage cover and standard deviation of the benthic categories for each site will then be determined from the five (5) individual replicate transects.

Hard Coral Diversity Assessment

A diversity index is a mathematical measure of diversity within a community. It may provide additional information about a coral reef's community structure or composition beyond species richness. Diversity indices are established by considering the richness and evenness with which species are distributed.

Ideally, hard corals are identified to the taxonomic level of species for biodiversity assessments. Still, correct and accurate non-extractive field identification of hard coral species is difficult and can lead to substantial errors if misidentified. On the other hand, identifying non-extractive hard coral genera is easier and can provide high levels of accuracy even with minimal taxonomic expertise. Field identification of hard corals for the hard coral diversity assessment at each site or transect will be limited to the taxonomic level of genera based on Veron (2000) to ensure consistently high accuracy.

Coral Habitat Surveys – Horizontal Visual Quadrat Transect (HVQT)

A quantitative survey beyond the photic depth of each site will be carried out along the base of the reef slope to provide a thorough assessment of the entire reef benthos, including the zone within which gorgonians, ahermatypic corals, sponges, and other associated heterotrophs are abundant, especially when suitable hard substrate is present. For this purpose, the Horizontal Visual Quadrat Transect (HVQT) adapted from the Atlantic and Gulf Rapid Reef Assessment (AGRRA) will be employed (Kramer *et al.* 2005).

The survey depth will be established after an initial assessment of the lower reef community where the dominant target organisms, e.g., gorgonians and sponges, are observed to be the richest. The lower reef zone in Singapore is typically located near the seabed at depths beyond 6 m and may vary between sites. Although this zone may extend beyond 15 m at some sites, it is usually found at depths of about 10 m where the base of the reef slope meets the seafloor.

Methods

Along the lower reef, three (3) replicate transects measuring 10 m will be laid in a longitudinal direction to the reef, with a 10 m interval between each successive transect. Quadrats measuring 1 m² will be sampled at every other meter on alternate sides of each replicate transect (Figure 5.70). The number of colonies from each target group listed in Table 5.46 will be counted within each quadrat. Six (6) quadrats will be sampled along each replicate transect.

The condition of the lower reef quality will be defined in terms of the mean density of target organisms as individuals per square metre (individuals/m²).



Figure 5.70 Recording and counting target organisms within a quadrat (left); High density of sea fans and sea whips along the lower reef (right)

Table 5.46 Pre-determined list of target organisms recorded during the visual quadrat transect (HVQT) survey

No.	Target Organisms	Description
1	Sea Fans	Sessile colonial cnidarians with inner axial-like layers or axis formed from sclerites from the order Alcyonaceae, e.g., <i>Subergorgia</i> sp.
2	Whip Corals	
3	Black Corals	Deep water, tree-like corals with distinctive black or dark brown skeleton of the order Antipatharia, e.g., <i>Antipathes</i> sp.
4	Soft Corals	Non-reef building fleshy corals without a supporting axis of horny and/or calcareous material from the order Alcyonaceae, e.g., <i>Sinularia</i> sp.
5	Hard Corals	Reef building corals from the order Scleractinia.
6	Ahermatypic Corals	Filter-feeding hard corals that do not contain symbiotic zooxanthellae from the order Scleractinia, e.g., <i>Tubastrea</i> sp.
7	Sponges	A group of mostly filter-feeding sessile marine invertebrates from the phylum Porifera
8	Ascidians	Solitary or colonial sac-like marine invertebrate filter feeders from the class Ascidiaceae, which are also commonly known as sea squirts e.g., <i>Atriolum</i> sp.
9	Bryozoans	Small sessile filter-feeding colonial invertebrates that are typically encrusting or form lacy fan-like colonies from the phylum Bryozoa, e.g., <i>Triphyllozoon</i> sp..

Locations

Four (4) locations within the Project area were identified along the coast of Keppel Island to conduct coral habitat surveys. These survey points were designated as C01, C02, C03 & C04 (Figure 5.71).

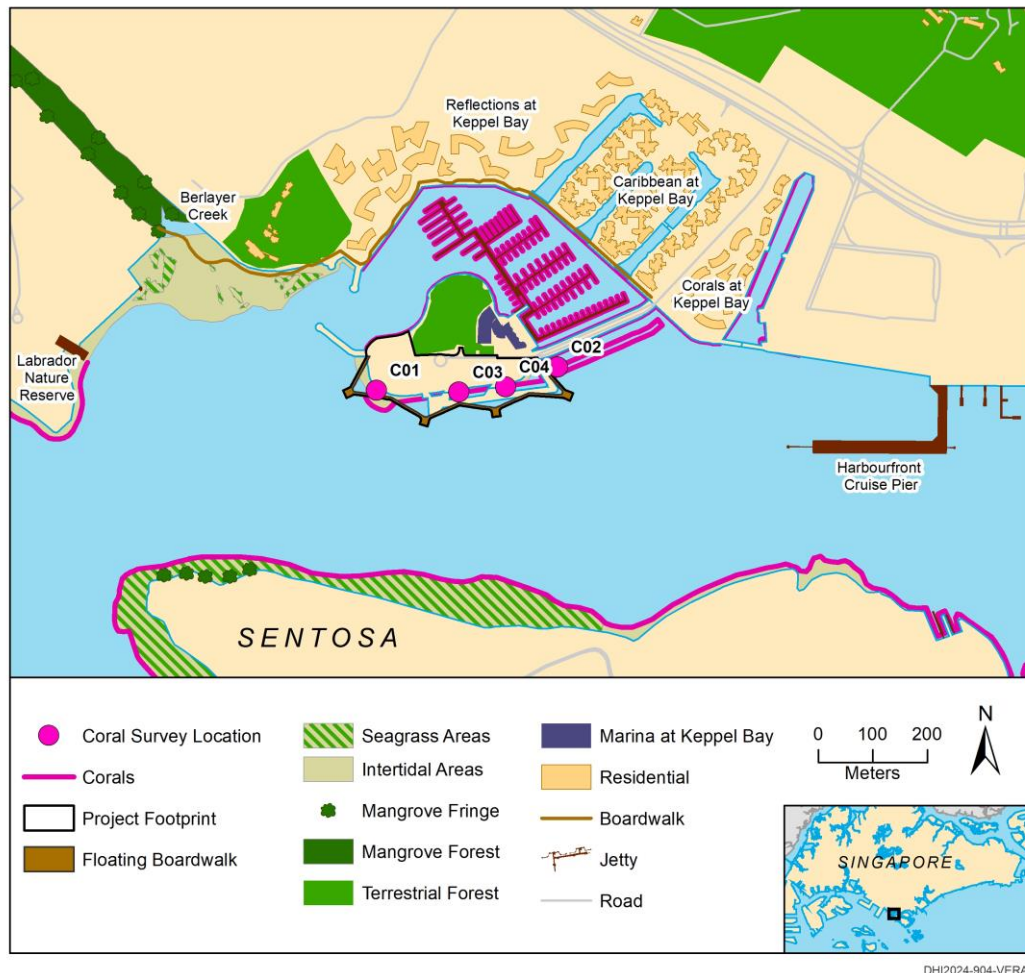


Figure 5.71 Locations of coral survey stations within the Study Area

It should be noted that survey data from C02 was taken from a separate project, in September 2023, with permission from the respective owners. C02 was also recorded as C02-1 and C02-2 due to the unique, irregular nature of the site. C02 is actually an artificial caisson structure that was installed in the water spanning the length of the bridge that links Keppel Island with mainland Singapore. The caisson structure roughly consists of 11 raised concrete “boxes” with sheer vertical walls on the sides of each box/platform, resulting in the lack of a reef slope at C02. This unique structure is unusual with regards to developing contiguous reefs, thereby requiring C02 to be represented as two sub-sites C02-1 & C02-2 to allow for a clearer understanding of the coral cover on the caisson structure. Additionally, no reef slope was observed at any of the other sites, while lower reefs were only observed at C02 and C04. Hence, the reef crest LIT was carried out for all four stations, while the HVQT was carried out only for C02 and C04 (Table 5.47).

Table 5.47 Details of the coral habitat surveys carried out within the Study Area

Station	Location	Survey Date	Reef Zone		
			Reef Crest	Reef Slope	Lower Reef
C01	Keppel Island	22 April 2024	X		
C02	Keppel Island	05 September 2023*	X		X
C03	Keppel Island	21 April 2024	X		
C04	Keppel Island	21 April 2024	X		X

* Survey data taken from another project

Results

Line Intercept Transect (LIT)

Overall, the coral reef in and around the Project footprint exhibited relatively high species diversity, most likely due to the primary substrata being consolidated rock revetment or artificial structures coastal and bridge protection measures which serves as ideal substrate for coral recruitment and growth. A compiled list of species of hard corals detected during the study's surveys are found in **Appendix D**.

Keppel Island (Southwestern) Reef Crest – C01

The reef crest of the fringing coral reef at C01 was mainly composed of algae with a mean percentage cover of 30.30 ± 4.30 % ($\pm$ SE). The remaining substrate was largely composed of abiotic substrate like rock (37.05 ± 10.15 %), sand (23.75 ± 8.37 %), rubble (0.70 ± 0.70 %) and dead coral (0.60 ± 0.60 %) (Figure 5.72). Nationally “Critically Endangered” Paddle seagrass, *Halophila decipiens* (NParks, 2023), was also observed at this location.

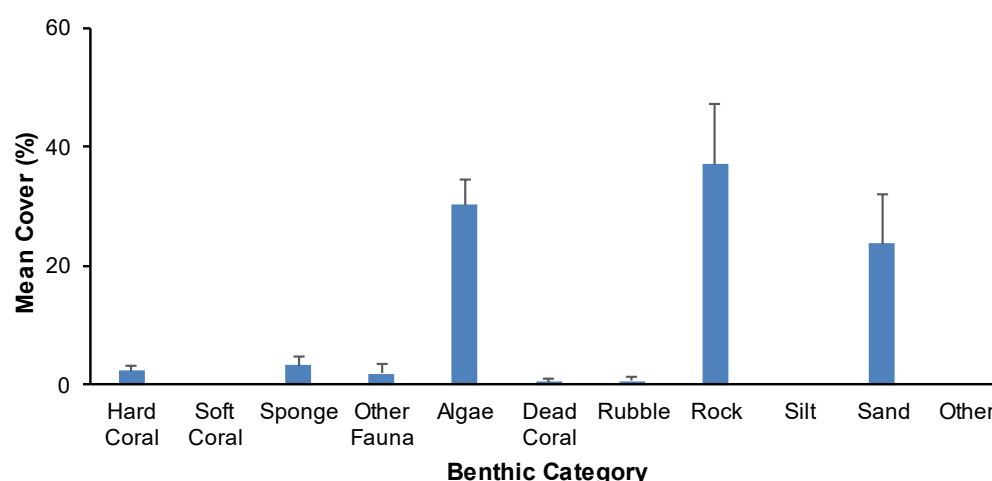


Figure 5.72 Mean ($\pm$ SE) percentage cover of the major benthic categories recorded at site C01 during the baseline surveys

Twelve (12) hard coral colonies from twelve (12) genera were recorded along the reef crest of the surveyed transects Table 5.48. A general biodiversity survey of the site found one (1) more genus beyond the survey transects, resulting in thirteen (13) genera observed at the

reef crest. *Turbinaria* spp. was the most dominant genus (both by percentage cover and by occurrence; Table 5.48) recorded during the survey.

According to the DACOR coral abundance catalogue, a classification method by the UNICEF to classify coral genera (D = Dominant, A. = Abundant, C = Common, O = Occasional, R = Rare) (Table 5.49), no corals of conservation significance were recorded.

Table 5.48 Biodiversity indices of various hard coral diversity attributes recorded at site C01 along the coast of Keppel Island

Biodiversity Indices	C01 Reef Crest
Total Number of Genera	12
Total Number of Colonies	12
Most Common Genus (By Occurrence)	<i>Turbinaria</i>
Occurrence	5
Most Common Genus (By Percentage)	<i>Turbinaria</i>
Percentage	34.69

Table 5.49 DACOR Coral Abundance Catalogue for the coral genera found at C01

Family	Genera	DACOR	C01 Reef Crest
Dendrophylliidae	<i>Duncanopsammia</i> *	Common	X
Dendrophylliidae	<i>Turbinaria</i>	Common	X
Leptastreidae	<i>Leptastrea</i>	Occasional	X
Merulinidae	<i>Cyphastrea</i>	Common	X
Merulinidae	<i>Dipsastraea</i>	Common	X
Merulinidae	<i>Favites</i>	Common	X
Merulinidae	<i>Platygyra</i>	Common	X
Poritidae	<i>Bernardpora</i>	Common	X
Poritidae	<i>Goniopora</i>	Common	X
Poritidae	<i>Porites</i>	Abundant	X
Total			10

*Species recorded during the survey in genus *Duncanopsammia* was previously placed in genus *Turbinaria*

**Species recorded in genus *Symphylia* have now been reclassified to genus *Lobophyllia*

Coral life forms reflect the life history strategy of a colony, and the same species of coral can exhibit different life forms in their lifetime or under different environmental conditions (Todd, 2008). Therefore, different sites may be characterised by different life form compositions, depending on abiotic parameters.

The most dominant growth form of the hard coral colonies observed at the C01 reef crest was foliose, which was 0.85 % of the total percent cover. Foliose growth forms documented during the survey were mainly comprised of *Turbinaria* spp. The other growth forms observed included encrusting (0.85 %) and massive (0.75 %) corals (Figure 5.73).

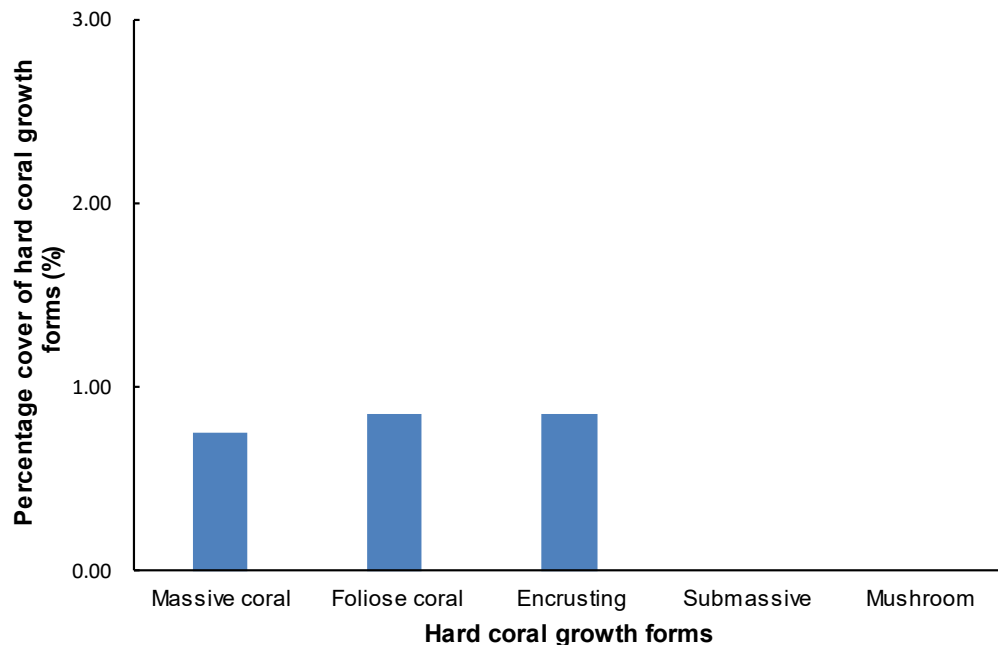


Figure 5.73 Growth form composition of hard coral cover at site C01 for the baseline surveys

The size of hard corals provides an indication of the colony's age, as they become progressively larger with age. As such, size class distributions can reveal a coral community's general age and maturity level.

Coral colonies recorded at C01 were generally small, with sizes no bigger than 75 cm in diameter (size class 5, 8.33 %). 50 % of the corals observed were in size class 3 (25 cm), followed by 40 % in size class 4 (50 cm), while the remaining colonies (~30 %) were mainly smaller, with a size of 10 cm in diameter or smaller (Figure 5.74).

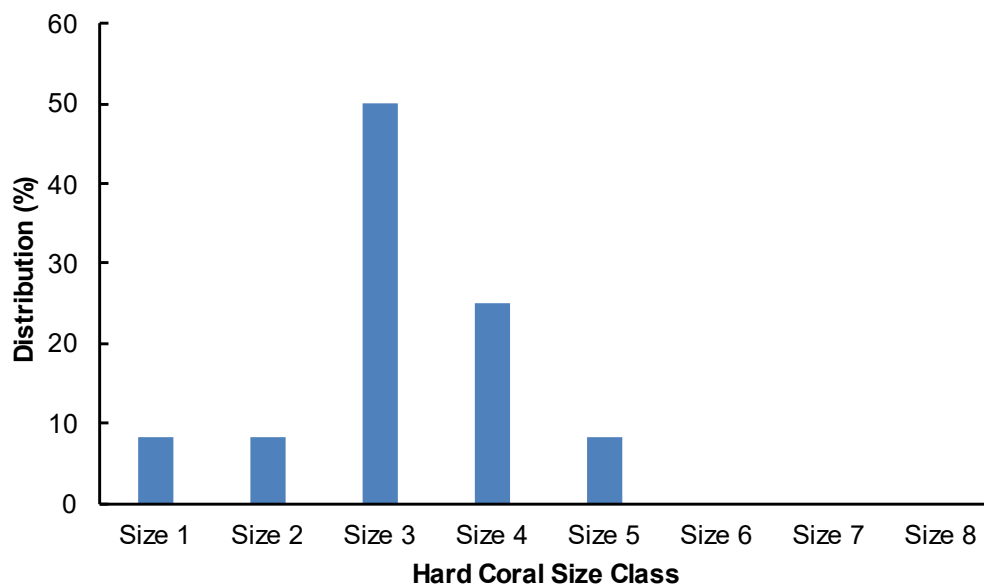


Figure 5.74 Size class distribution of hard corals at site C01 for the baseline surveys

An overview of the site conditions and key species recorded during the baseline surveys of C01 are presented in Figure 5.75.



Overview of the reef environment at C01



Most common hard coral genus by occurrence and by percentage cover, *Turbinaria* spp.



Acropora spp.



Flowerpot Coral,
Goniopora spp.



Figure 5.75 Selected photographs of the reef environment at site C01 during the baseline survey

Keppel Island Caisson Reef Crest – C02

The coral reef at C02-1 was mainly composed of hard coral (Figure 5.76) with a mean percentage cover of 67.23 ± 10.13 % (Mean $\pm$ SE). The remaining substrate was largely composed of rock (23.22 ± 6.61 %), sponge (3.80 ± 2.03 %) and dead coral (3.65 ± 2.01 %), with a small percentage of other fauna (1.00 ± 0.65 %), algae (0.55 ± 0.36 %) and soft coral (0.55 ± 0.55 %).

Hard coral cover was comparatively lower at C02-2 (Figure 5.76) but was still the dominant benthic substrate (56.33 ± 11.73 %). The remaining substrate was largely composed of rock (30.80 ± 11.07 %), sponge (5.84 ± 2.34 %), dead coral (3.40 ± 1.16 %), other fauna (3.23 ± 1.20 %), with a small percentage of algae (0.40 ± 0.29 %).

No reef slope surveys were conducted at C02 as the hard coral cover was almost entirely concentrated on the top of the caissons.

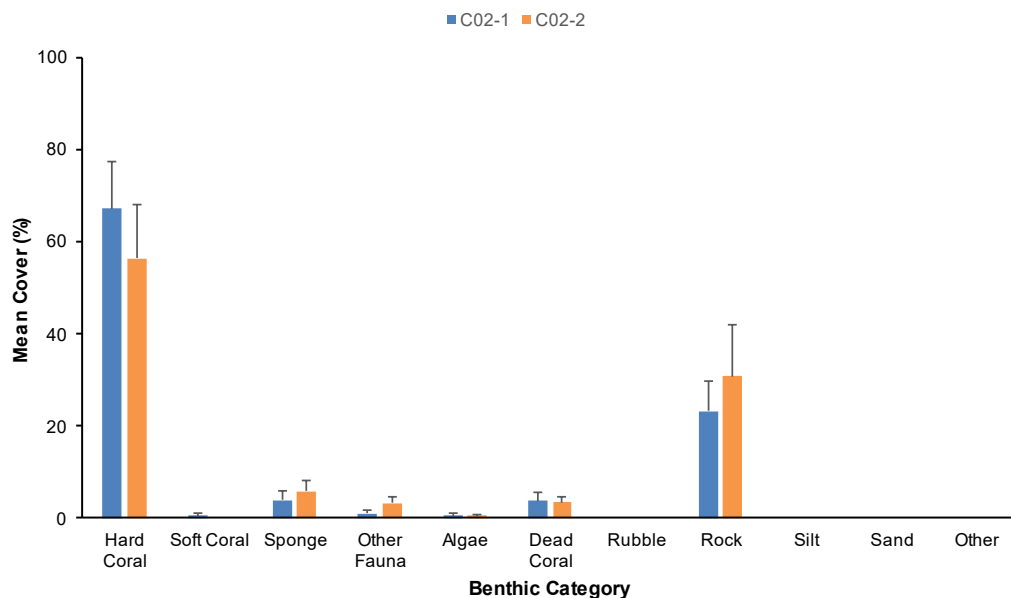


Figure 5.76 Mean ($\pm$ SE) percentage cover of the major benthic categories recorded at site C02 during the baseline surveys

A total of seventy-five (75) hard coral colonies from eleven (11) genera were recorded along C02-1's surveyed transects (Table 5.50). A general biodiversity survey of the site found 14 more genera beyond the survey transects, resulting in twenty-five (25) genera observed at

C02-1. *Montipora* spp. was the most dominant genus (both by percentage cover and by occurrence) recorded during the survey.

A total of seventy-four (74) hard coral colonies from fifteen (15) genera were recorded along C02-2's surveyed transects (Table 5.50). A general biodiversity survey of the site found ten (10) more genera beyond the survey transects, resulting in a total of twenty-five (25) genera observed at C02-2. *Montipora* spp. was also the most dominant genus (both by percentage cover and by occurrence) recorded during the survey.

Polyphyllia talpina. was recorded at C02-2 and listed as a Rare genus under the DACOR coral abundance catalogue (Table 5.51). Additionally, three (3) species recorded are also listed in the Singapore Red Data Book version 3 (SRDB3). *Montipora digitata* and *Polyphyllia talpina* are locally "Vulnerable", while *Acropora millepora* is locally "Endangered" (National Parks Board, 2023) (Figure 5.77). Further information on the SRDB 3 statuses of the surveyed coral can be found in **Appendix D**.

Table 5.50 Biodiversity indices of various hard coral diversity attributes recorded at site C02 along the coast of Keppel Island

Biodiversity Indices	C02-1	C02-2
Total Number of Genera	11	15
Total Number of Colonies	75	74
Most Common Genus (By Occurrence)	<i>Montipora</i>	<i>Montipora</i>
Occurrence	45	34
Most Common Genus (By Percentage)	<i>Montipora</i>	<i>Montipora</i>
Percentage	88.87	82.87

Table 5.51 DACOR Coral Abundance Catalogue for the coral genera found at the C02

Family	Genera	DACOR	C02-1	C02-2
Acroporidae	<i>Acropora</i>	Occasional	X	X
Acroporidae	<i>Montipora</i>	Common	X	X
Agariciidae	<i>Pachyseris</i>	Dominant	X	X
Dendrophylliidae	<i>Duncanopsammia</i> *	Common	X	X
Dendrophylliidae	<i>Turbinaria</i>	Common	X	X
Euphylliidae	<i>Euphyllia</i>	Occasional		X
Euphylliidae	<i>Galaxea</i>	Common		X
Fungiidae	<i>Fungia</i>	Common	X	X
Fungiidae	<i>Herpolitha</i>	Occasional	X	
Fungiidae	<i>Podabacia</i>	Common	X	X

Family	Genera	DACOR	C02-1	C02-2
Fungiidae	<i>Polyphyllia</i>	Rare		X
Leptastreidae	<i>Leptastrea</i>	Occasional	X	X
Lobophylliidae	<i>Acanthastrea</i>	Occasional	X	
Lobophylliidae	<i>Echinophyllia</i>	Common	X	
Lobophylliidae	<i>Lobophyllia</i>	Occasional	X	
Lobophylliidae	<i>Oxypora</i>	Common	X	
Lobophylliidae	<i>Symphyllia</i> **	Occasional		X
Merulinidae	<i>Cyphastrea</i>	Common		X
Merulinidae	<i>Dipsastraea</i>	Common	X	X
Merulinidae	<i>Echinopora</i>	Common	X	
Merulinidae	<i>Favites</i>	Common	X	X
Merulinidae	<i>Hydnophora</i>	Common	X	X
Merulinidae	<i>Merulina</i>	Dominant	X	X
Merulinidae	<i>Pectinia</i>	Dominant	X	X
Merulinidae	<i>Platygyra</i>	Common	X	X
Oulastreidae	<i>Oulastrea</i>	Occasional	X	X
Pocilloporidae	<i>Pocillopora</i>	Occasional	X	X
Poritidae	<i>Goniopora</i>	Common	X	X
Poritidae	<i>Porites</i>	Abundant	X	X
Psammocoridae	<i>Psammocora</i>	Occasional	X	X
Rhizangiidae	<i>Pseudosiderastrea</i>	Occasional		X
Total			25	25

*Species recorded during the survey in genus *Duncanopsammia* was previously placed in genus *Turbinaria*

**Species recorded in genus *Symphyllia* have now been reclassified to genus *Lobophyllia*



Finger Coral, *Montipora digitata*
(SRDB3: Vulnerable)



Mole Mushroom Coral, *Polyphyllia talpina*
(SRDB3: Vulnerable)



Plate Acropora, *Acropora millepora*
(SRDB3: Endangered)

Figure 5.77 Coral species of conservation significance in the Singapore Red Data Book version 3 at C02

The most dominant growth form of the hard coral colonies observed at the C02-1 was foliose (65.58 %). Foliose growth forms documented during the survey were mainly comprised of *Montipora* spp., with smaller percentages of *Turbinaria* spp., *Pectinia* spp., and *Duncanopsammia* spp. The other growth forms were encrusting (26.61 %), massive (2.45 %), branching *Acropora* (2.08 %), branching (1.64 %) and submassive (1.64 %) (Figure 5.78).

Similarly, the most dominant growth form of the hard coral colonies observed at C02-2 was foliose (86.06 %). Foliose growth forms documented during the survey were mainly comprised of *Montipora* spp., with smaller percentages of *Turbinaria* spp., *Merulina* spp., and *Duncanopsammia* spp. The other growth forms were encrusting (5.15 %), branching *Acropora* (4.97 %), massive (2.84 %) and branching (0.98 %) (Figure 5.78). Foliose growth form of corals allows for the greatest surface area for exposure to light for photosynthesis in Singapore's waters (Chou *et al.*, 2012).

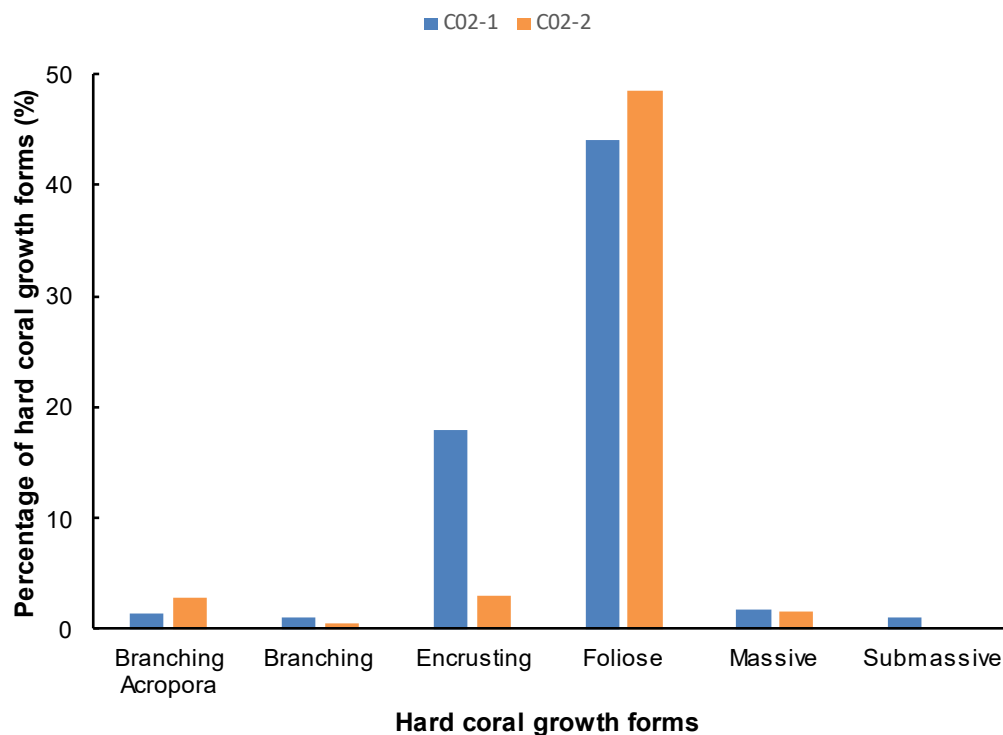


Figure 5.78 Growth form composition of hard corals at site C02 for the baseline surveys

The modal size class of coral colonies at C02-1 was class 7 (i.e., >100 cm) for 34.67 % of hard coral colonies, followed by size class 5 (i.e., 50 cm to 75 cm) with 16.00 % and size class 4 (25 cm to 50 cm) with 14.67 % (Figure 5.79). No hard corals of size class 8 were recorded during the survey.

Similarly, the modal size class of coral colonies at C02-2 was 7 (> 100 cm) with 36.49 % of hard coral colonies, followed by size class 3 (10 cm to 25 cm) with 13.51 % and size class 2 (5 cm to 10 cm) (Figure 5.79). No hard corals of size class 8 were recorded during the survey.

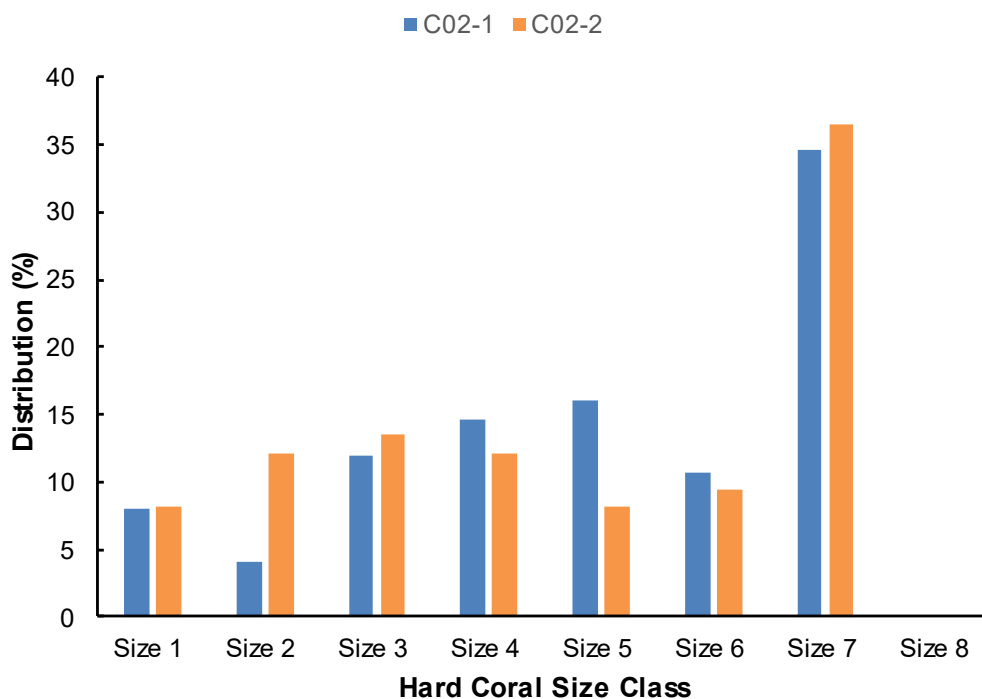
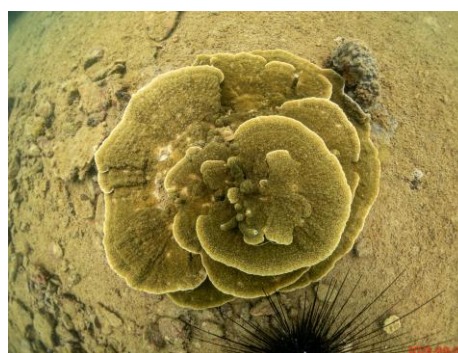


Figure 5.79 Size class distribution of hard corals at site C02 for the baseline surveys

An overview of the site conditions and key species recorded during the baseline surveys of C02 are presented in Figure 5.80.



Overview of the reef environment at C02



Most common hard coral genus by occurrence and by percentage cover, *Montipora* spp.



Vase Coral, *Turbinaria mesenterina*



Long Spine Sea Urchins, *Diadema setosum*

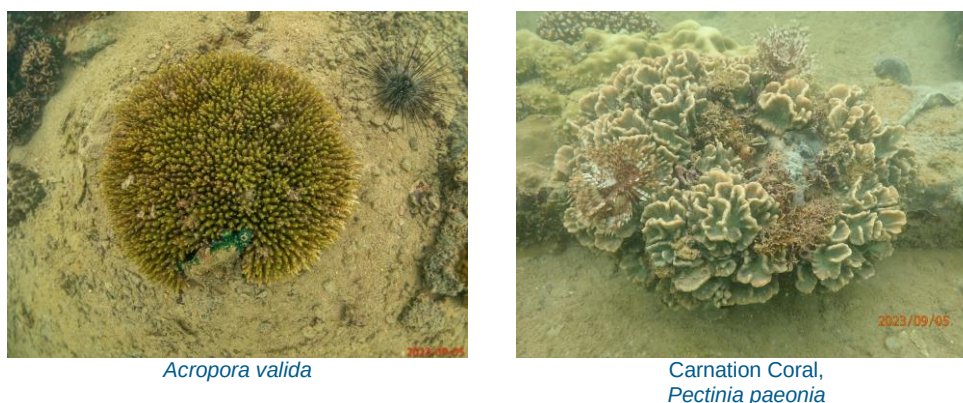


Figure 5.80 Selected photographs of the reef environment at site C02 during the 2021 baseline survey

Keppel Island Western Lagoon Reef Crest – C03

The reef crest of the fringing coral reef at C03 was mainly composed of sponges and hard coral (Figure 5.81), with a mean percentage cover of 6.13 ± 3.07 % and 5.68 ± 1.21 %, respectively. The remaining substrate was largely composed of abiotic substrate like silt (45.95 ± 14.30 %), rock (20.43 ± 5.71 %), rubble (8.57 ± 5.28 %) and sand (4.18 ± 4.18 %). Spoon seagrass, *Halophila ovalis*, was also observed during the survey.

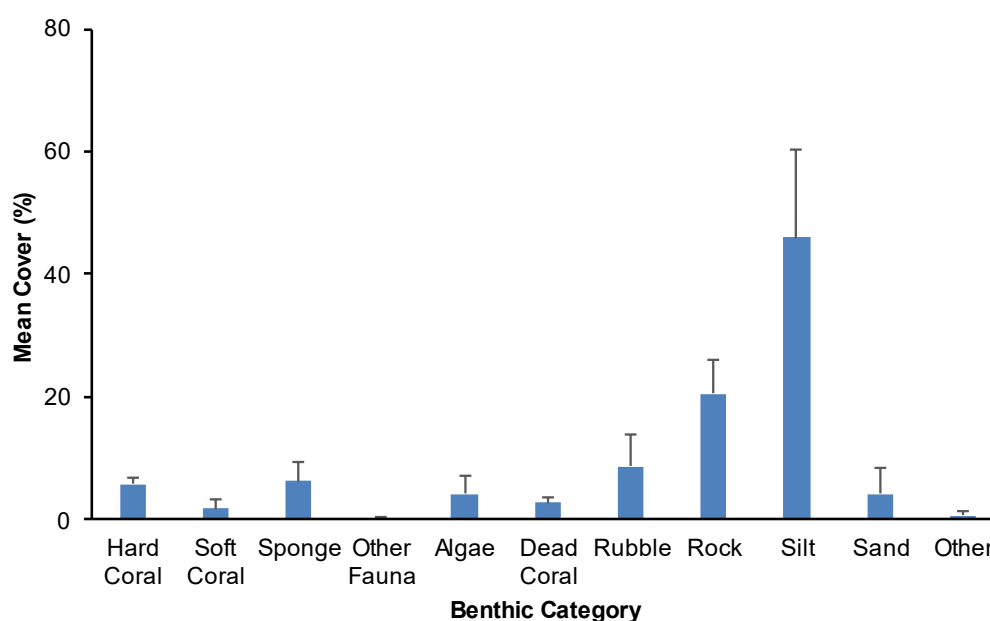


Figure 5.81 Mean ($\pm$ SE) percentage cover of the major benthic categories recorded at site C03 during the baseline surveys

A total of twenty (20) hard coral colonies from twelve (12) genera were recorded along the reef crest of the surveyed transects (Table 5.52). A general biodiversity survey of the site found sixteen (16) more genera beyond the survey transects, resulting in a total of twenty-eight (28) genera observed at the reef crest. *Cyphastrea* spp. and *Pectinia* spp. was the most dominant genus by occurrence, while *Bernardopora* spp. was the most dominant genus by percentage recorded during the survey. The overwhelming domination of the reef crest by *Pectinia* sp. has resulted in hard coral genera diversity being lower than one would typically see on a Singaporean reef (Huang *et al.*, 2009).

According to the DACOR coral abundance catalogue (Table 5.53), no corals of conservation significance were recorded. No reef slope surveys were conducted.

Table 5.52 Biodiversity indices of various hard coral diversity attributes recorded at site C03 along the coast of Keppel Island

Biodiversity Indices	C03 Reef Crest
Total Number of Genera	12
Total Number of Colonies	20
Most Common Genus (By Occurrence)	<i>Cyphastrea</i> & <i>Pectinia</i>
Occurrence	3
Most Common Genus (By Percentage)	<i>Bernardpora</i>
Percentage	16.13

Table 5.53 DACOR Coral Abundance Catalogue for the coral genera found at C03

Family	Genera	DACOR	C03 Reef Crest
Acroporidae	<i>Astreopora</i>	Common	X
Dendrophylliidae	<i>Duncanopsammia</i> *	Common	X
Dendrophylliidae	<i>Turbinaria</i>	Common	X
Fungiidae	<i>Podabacia</i>	Common	X
Merulinidae	<i>Cyphastrea</i>	Common	X
Merulinidae	<i>Dipsastraea</i>	Common	X
Merulinidae	<i>Favites</i>	Common	X
Merulinidae	<i>Hydnophora</i>	Common	X
Merulinidae	<i>Merulina</i>	Dominant	X
Merulinidae	<i>Pectinia</i>	Dominant	X
Poritidae	<i>Bernardpora</i>	Common	X
Poritidae	<i>Goniopora</i>	Common	X
Poritidae	<i>Porites</i>	Abundant	X
Total			13

*Species recorded during the survey in genus *Duncanopsammia* was previously placed in genus *Turbinaria*

**Species recorded in genus *Symphylia* have now been reclassified to genus *Lobophyllia*

The most dominant growth form of the hard coral colonies observed at the C03 reef crest was foliose, which was 2.77 % of the total percent cover. Foliose growth forms documented during the survey were mainly comprised of *Pectinia* spp., with smaller percentages of *Turbinaria* spp., *Podabacia* spp., *Merulina* spp., *Astreopora* spp., *Duncanopsammia* spp. The other growth forms observed included massive (1.25 %), submassive (0.92 %) and massive (0.75 %) corals (Figure 5.82).

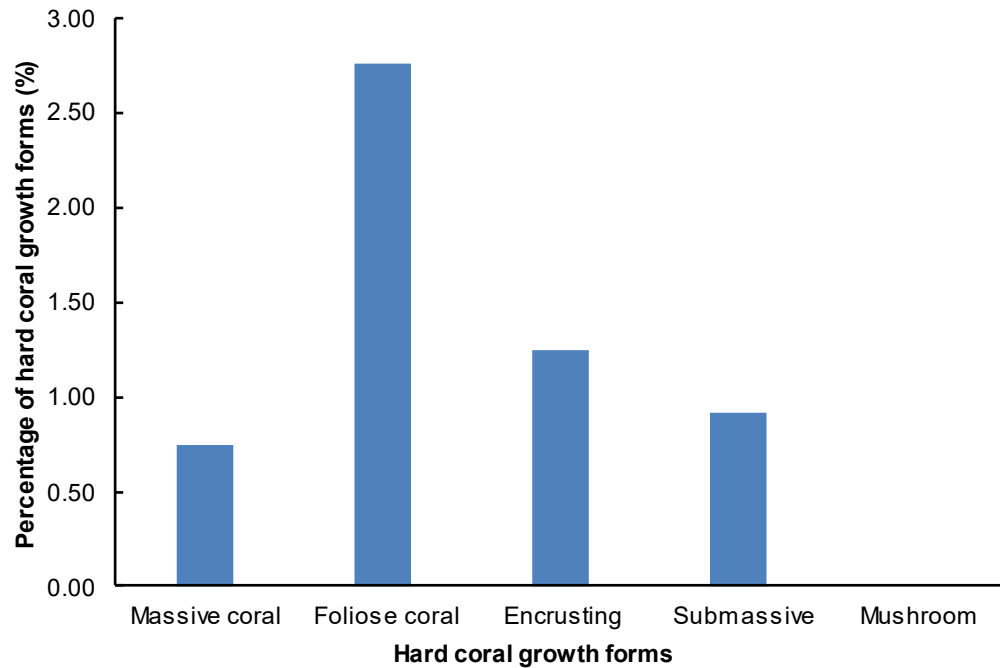


Figure 5.82 Growth form composition of hard corals at site C03 for the baseline surveys

Coral colonies recorded at C03 were generally small to medium size, with sizes no bigger than size class 5 (5 %). Most of the corals recorded were in size class 3 (40 %) and size class 2 (35 %). The remaining colonies (20 %) were mostly medium with a size of 50 cm in diameter (Figure 5.83).

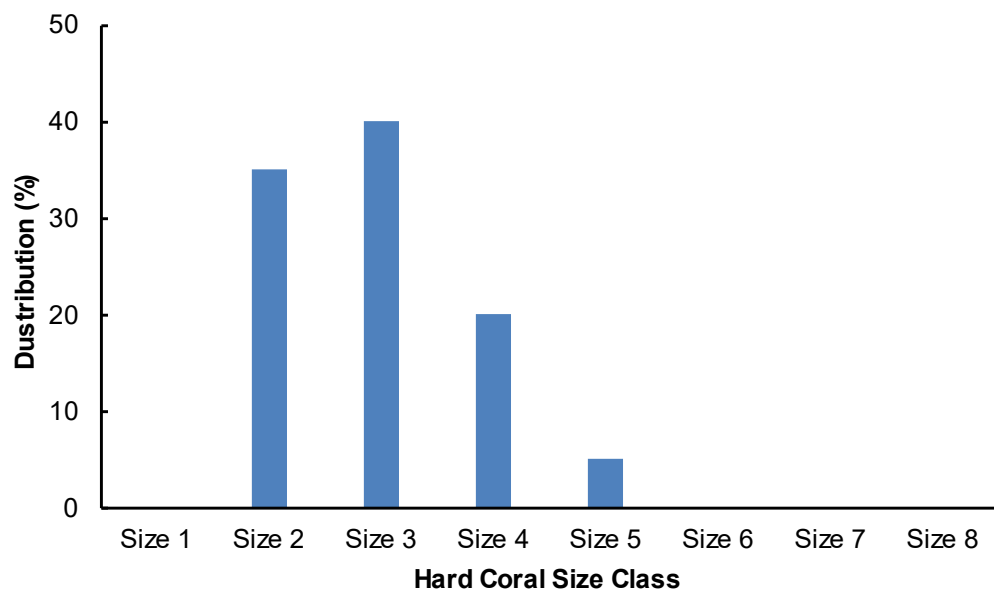


Figure 5.83 Size class distribution of hard corals at site C03 for the baseline surveys

An overview of the site conditions and key species recorded during the baseline surveys of C03 are presented in Figure 5.84.



Figure 5.84 Selected photographs of the reef environment at site C03 during the baseline survey

Keppel Island Eastern Lagoon Reef Crest – C04

The reef crest of the fringing coral reef at C04 was mainly composed of hard coral (Figure 5.85), with a mean percentage cover of 45.46 ± 4.66 %. The remaining substrate was largely composed of abiotic substrate such as rock (19.80 ± 7.48 %), silt (13.50 ± 6.99 %), dead coral (7.58 ± 1.39 %) and rubble (5.50 ± 2.18 %). In comparison, a small percentage of sponge (5.11 ± 3.24 %), other fauna (1.68 ± 0.98 %), soft coral (1.02 ± 0.73 %) and algae (0.35 ± 0.24 %) made up the remaining benthos. Nationally “Critically Endangered” (NParks, 2023) Paddle seagrass, *Halophila decipiens*, was also found at the site.

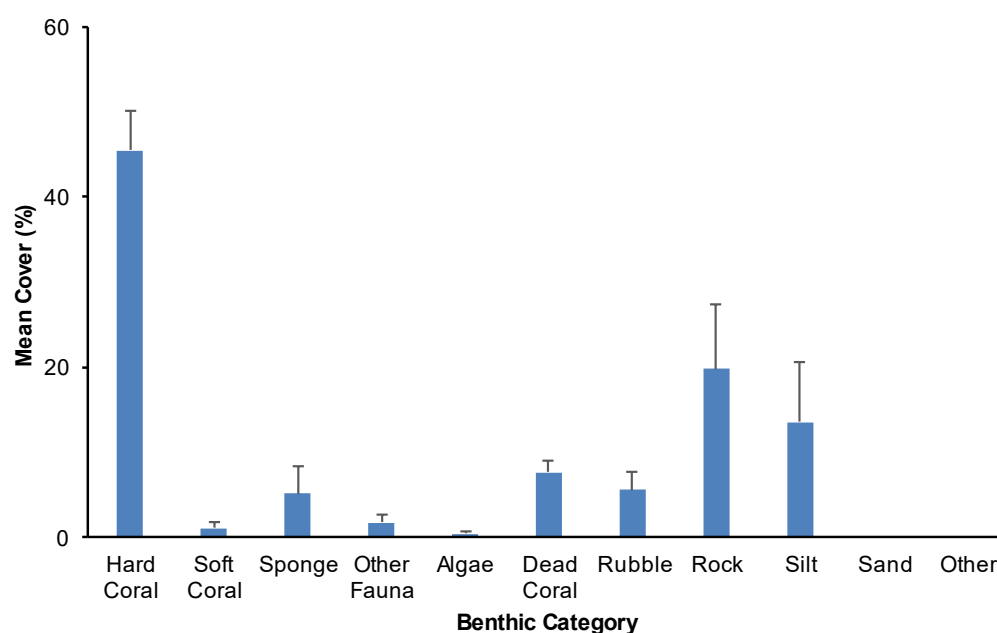


Figure 5.85 Mean ($\pm$ SE) percentage cover of the major benthic categories recorded at site C04 during the baseline surveys

A total of 165 hard coral colonies from 27 genera were recorded along the reef crest of the surveyed transects (Table 5.54). *Pectinia* spp. was the most dominant genus (both by percentage cover and by occurrence) recorded during the survey.

No corals of conservation significance were recorded according to the DACOR coral abundance catalogue (Table 5.55). No reef slope surveys were conducted.

Table 5.54 Biodiversity indices of various hard coral diversity attributes recorded at site C04 along the coast of Keppel Island

Biodiversity Indices	C04 Reef Crest
Total Number of Genera	27
Total Number of Colonies	165
Most Common Genus (By Occurrence)	<i>Pectinia</i>
Occurrence	43
Most Common Genus (By Percentage)	<i>Pectinia</i>
Percentage	31.61

Table 5.55 DACOR Coral Abundance Catalogue for the coral genera found at C04

Family	Genera	DACOR	C04 Reef Crest
Acroporidae	<i>Montipora</i>	Common	X
Agariciidae	<i>Pachyseris</i>	Dominant	X

Family	Genera	DACOR	C04 Reef Crest
Agariciidae	<i>Pavona</i>	Common	X
Dendrophylliidae	<i>Duncanopsammia*</i>	Common	X
Dendrophylliidae	<i>Turbinaria</i>	Common	X
Euphylliidae	<i>Galaxea</i>	Common	X
Fungiidae	<i>Lithophyllon</i>	Occasional	X
Fungiidae	<i>Podabacia</i>	Common	X
Leptastreidae	<i>Leptastrea</i>	Occasional	X
Lobophylliidae	<i>Echinophyllia</i>	Common	X
Lobophylliidae	<i>Oxypora</i>	Common	X
Lobophylliidae	<i>Symphyllia**</i>	Occasional	X
Merulinidae	<i>Cyphastrea</i>	Common	X
Merulinidae	<i>Dipsastraea</i>	Common	X
Merulinidae	<i>Favites</i>	Common	X
Merulinidae	<i>Merulina</i>	Dominant	X
Merulinidae	<i>Mycedium</i>	Common	X
Merulinidae	<i>Pectinia</i>	Dominant	X
Merulinidae	<i>Platygyra</i>	Common	X
Poritidae	<i>Bernardpora</i>	Common	X
Poritidae	<i>Goniopora</i>	Common	X
Poritidae	<i>Porites</i>	Abundant	X
Psammocoridae	<i>Psammocora</i>	Occasional	X
Rhizangiidae	<i>Pseudosiderastrea</i>	Occasional	X
Total			24

*Species recorded during the survey in genus *Duncanopsammia* was previously placed in genus *Turbinaria*

**Species recorded in genus *Symphyllia* have now been reclassified to genus *Lobophyllia*

The most dominant growth form of the hard coral colonies observed at the C04 reef crest was foliose, amounting to 33.44 % of the total percent cover. Foliose growth forms documented during the survey were mainly comprised of *Pectinia* spp., with smaller percentages of *Echinophyllia* spp., *Podabacia* spp. and *Turbinaria* spp., The other growth

forms observed included submassive (4.35 %), encrusting (3.61 %), massive (3.31 %) and mushroom (0.75 %) corals (Figure 5.86).

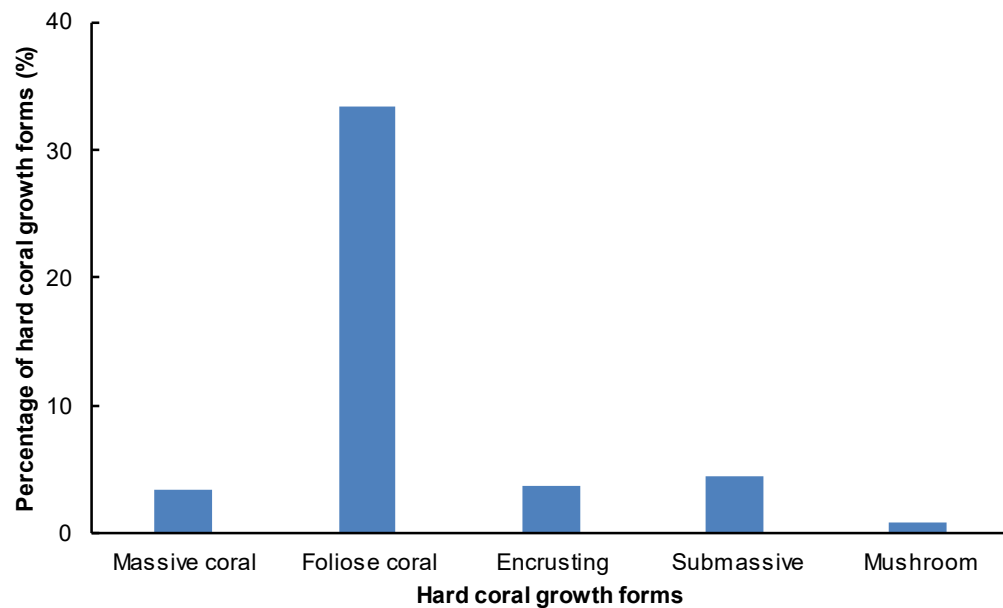


Figure 5.86 Growth form composition of hard corals at site C04 for the baseline surveys

Coral colonies recorded at C04 were generally small to medium; size class 5 and smaller, accounting for 89.71 % of the colonies recorded. Some large colonies of size class 6 (5.45 %) and size 7 (4.85 %) were also observed (Figure 5.87).

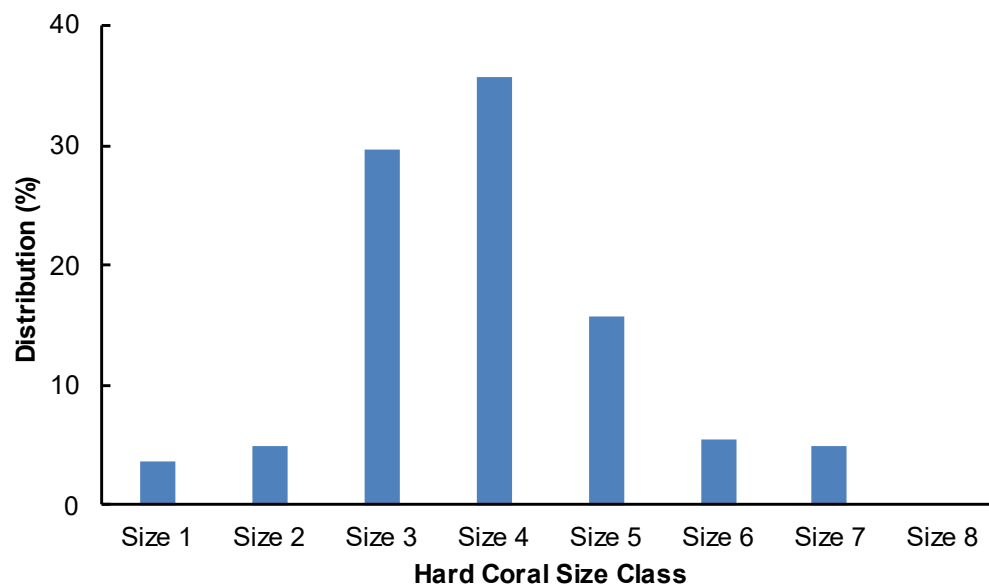


Figure 5.87 Size class distribution of hard corals at site C04 for the baseline surveys

An overview of the site conditions and key species recorded during the baseline surveys of C04 are presented in Figure 5.88.

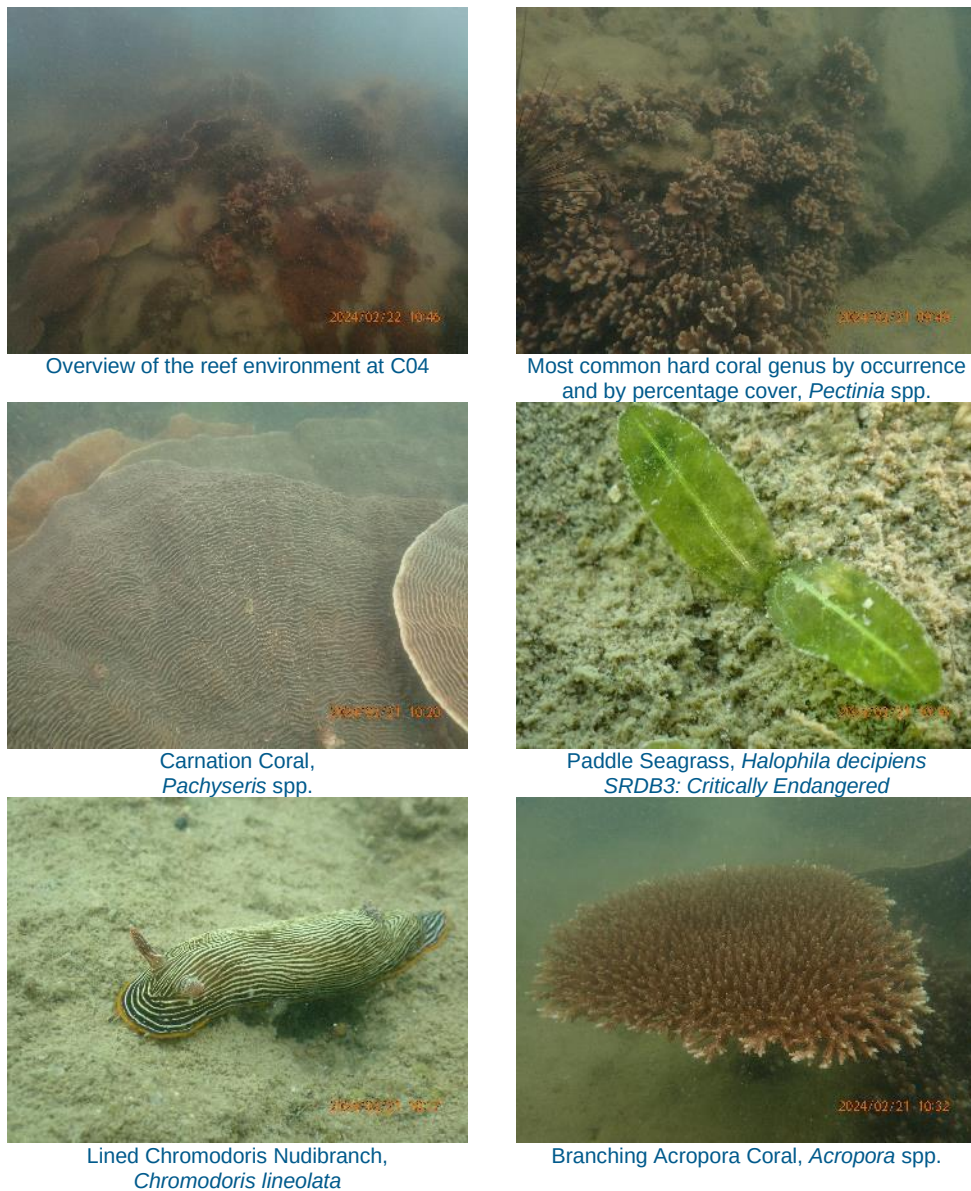


Figure 5.88 Selected photographs of the reef environment at site C04 during the baseline survey

Horizontal Visual Quadrat Transect (HVQT)

Keppel Island Caisson Lower Reef – C02

The lower reef community at C02-1 was dominated by ascidians (2.61 ± 0.70 indiv/m²), sponges (2.00 ± 0.75 indiv/m²), black coral (1.67 ± 0.63 indiv/m²) and whip coral (1.17 ± 0.56 indiv/m²). Hard coral (0.33 ± 0.11 indiv/m²) and sea fans (0.33 ± 0.24 indiv/m²) were also recorded at lower densities. On average, 22.22 ± 6.45 % of the lower reef substrate was consolidated (Figure 5.89).

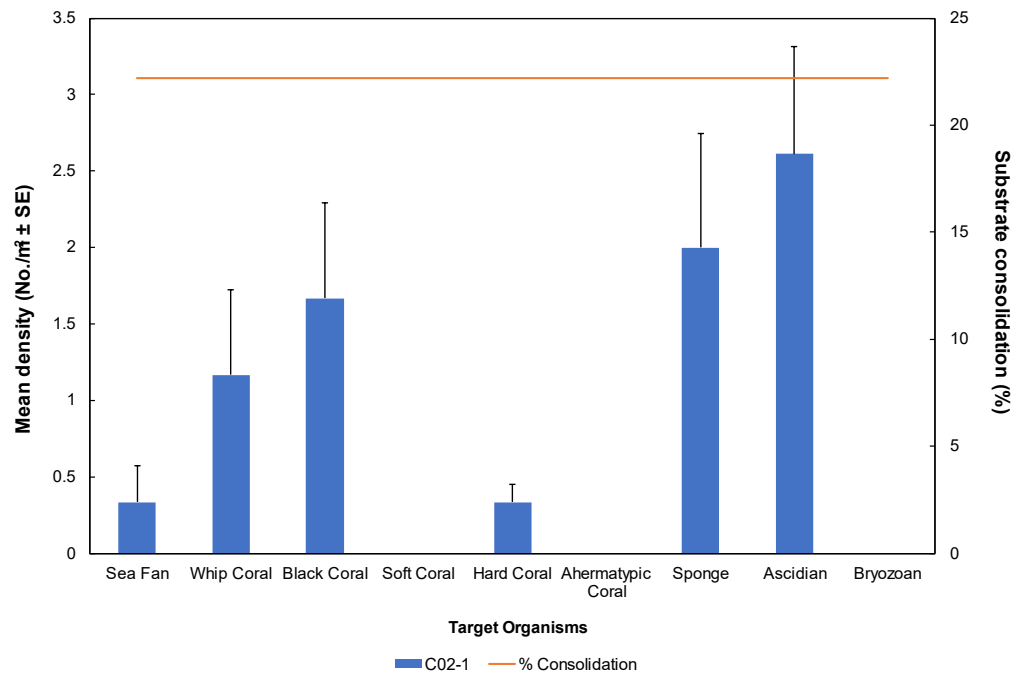


Figure 5.89 Mean density (individuals m⁻²) and standard error (SE) of target organisms recorded along the lower reef community at C02-1

The lower reef community at C02-2 was dominated by black coral (1.94 ± 0.64 indiv/m²) and sponges (0.78 ± 0.39 indiv/m²). Whip coral (0.22 ± 0.17 indiv/m²) and ascidians (0.17 ± 0.12 indiv/m²) were also recorded at lower densities. On average, 9.22 ± 5.01 % of the lower reef substrate was consolidated (Figure 5.90). The relatively sparse lower reef fauna densities at C02-2 were likely related to low substrate consolidation at the site.

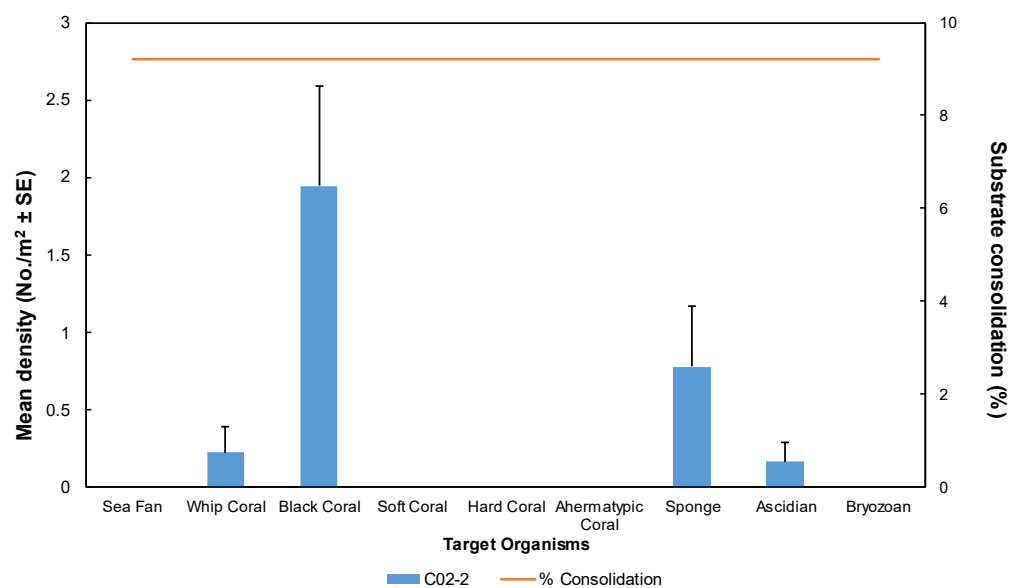


Figure 5.90 Mean density (individuals m⁻²) and standard error (SE) of target organisms recorded along the lower reef community at C02-2

Fauna recorded during the survey with an SRDB3 status of Vulnerable or higher, including the Reticulated pufferfish (*Arothron reticularis*) and the Stellate pufferfish (*Arothron*

stellatus). The Bubble Coral (*Plerogyra sinuosa*), with a Vulnerable status, was also found on the C02 lower reef.

Selected photographs illustrating the general reef environment at C02 during both baseline surveys are presented in Figure 5.91.



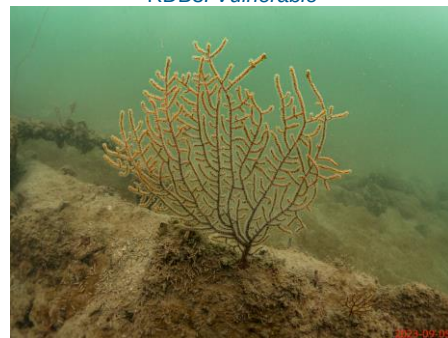
Overview of the lower reef at C02



Bubble Coral, *Plerogyra sinuosa*
RDB3: Vulnerable



Castle Coral, *Pachyseris speciosa*



Black coral, Order Antipatharia



Bracket Coral, *Podabacia crustacea*



Oxypora spp.



Reticulated Pufferfish, *Arothron reticularis*
RDB3: Vulnerable



Stellate Puffer, *Arothron stellatus*
RDB3: Vulnerable

Figure 5.91 General overview of the lower reef at C02

Keppel Island Eastern Lagoon Lower Reef – C04

The lower reef community at C04 was composed of black corals (5.39 ± 0.58 indiv/m²), ahermatypic coral (4.39 ± 0.51 indiv/m²), ascidians (1.94 ± 0.29 indiv/m²) and hard coral (1.22 ± 0.40 indiv/m²). On average, 75.00 ± 5.73 % of the lower reef substrate was consolidated (Figure 5.92). The relatively average lower reef fauna densities at C04 were likely related to high substrate consolidation at the site.

Selected photographs illustrating the general reef environment at C04 during both baseline surveys are presented in Figure 5.93.

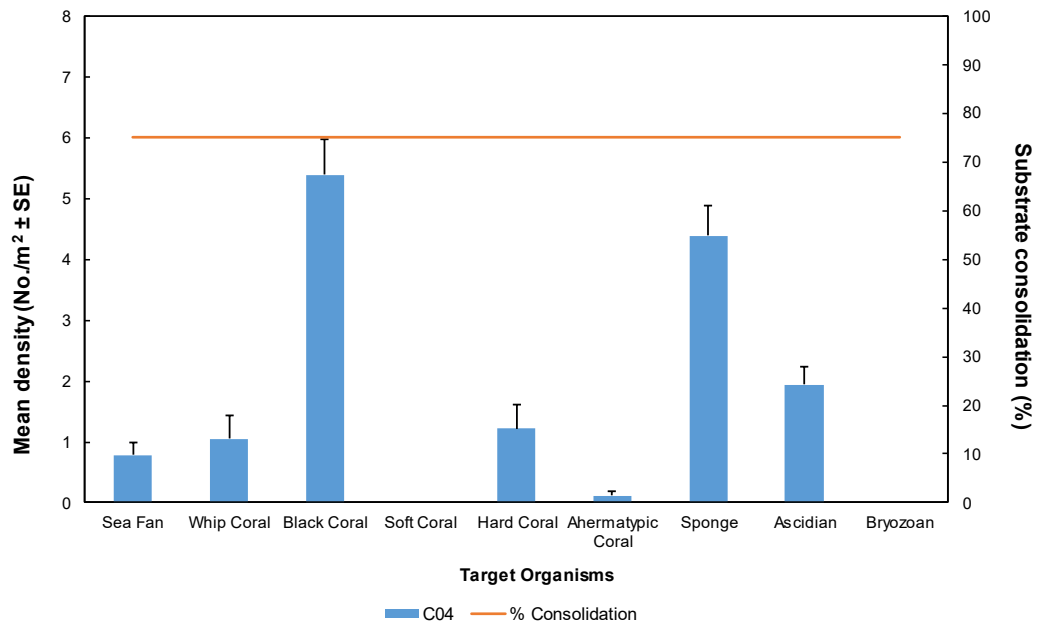
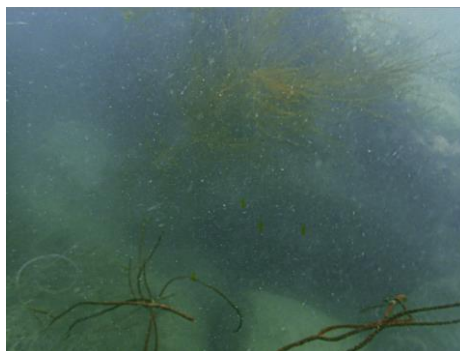


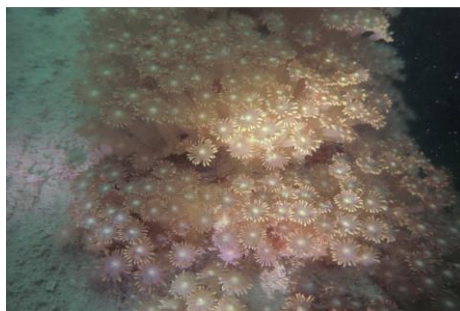
Figure 5.92 Mean density (individuals m⁻²) and standard error (SE) of target organisms recorded along the lower reef community at C04 during the baseline surveys



Overview of the lower reef at C04



Pachyseris spp.



Flowerpot Coral,
Goniopora spp.



Banded Pipefish,
Doryrhamphus dactyliophorus (SRDB3: VU)



A large black coral colony on the C04 lower reef

Pink Puffball Sponge,
Oceanapia sagittaria

Figure 5.93 General overview of the lower reef at C04

5.8.2.3 Macrobenthos Surveys

Methods

Grab sampling is one commonly employed method used in the quantitative assessment of the macrobenthic fauna that inhabit the soft-bottom seafloor communities. The seafloor community will be sampled using a Van Veen grab (Figure 5.94), which facilitates the capture of slow moving and sessile epifauna and infauna.

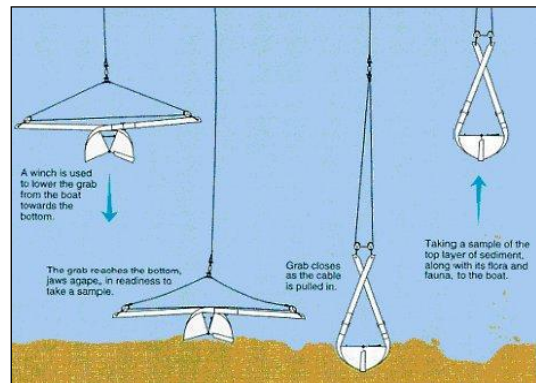


Figure 5.94 Van Veen grab sampler (left); Operation of a Van Veen grab sampler (right)

Animals living on or attached onto the seafloor are referred to as epifauna, while those which burrow into soft substrate or live in between the particulate matter of the sediment are described as infauna. The term infauna is used to categorise organisms whose activities are focused on the sediment–water interface where their detrital food source is concentrated (Gage, 2001). While most infauna-like polychaetes are burrowed out of sight (Gage, 2001), some infauna such as crabs are able to move out of their burrows and forage on the sediment surface (Figure 5.95). Conversely, although epifauna like sponges and bivalves generally inhabit areas of rock exposed by water currents and turbulence, many epifauna such as sea stars are motile and can also forage over the surface of sediments (Gage, 2001).

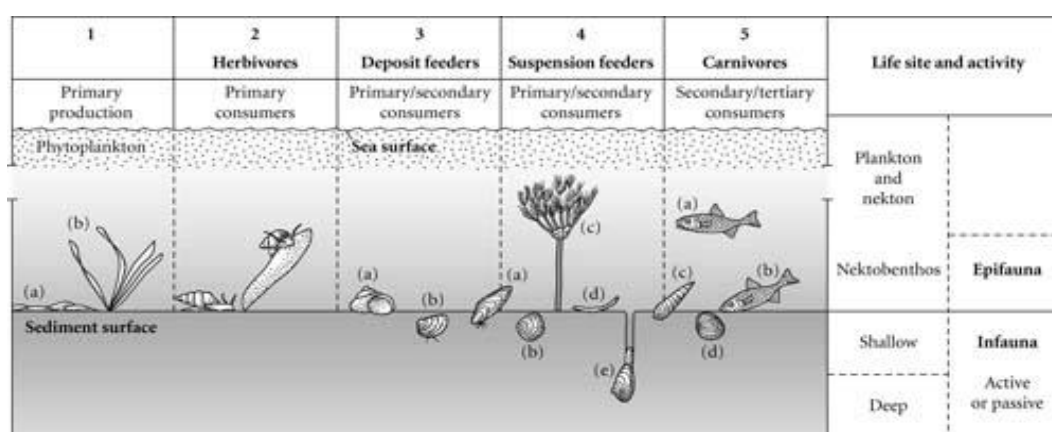


Figure 5.95 Illustration of trophic groups, activity of members and their life sites (Source: Brenchley and Harper, 1998)

Suitably spaced sampling points will be identified across the site to ensure adequate representation of the area. At each sampling point, three replicate grab samples measuring 0.063 m² will be collected from the upper 10 cm to 15 cm of the seabed. Subsequently, a qualitative assessment of the sediment type will be conducted. Thereafter, each successful sample retrieved by the grab will be sieved through 1 mm mesh-size test-sieves and macrobenthos specimens retained in the sieve will be counted, sorted and preserved in labelled containers containing 70 % ethanol (Tagliapietra and Sigovini, 2010). The collected specimens will then be analysed in DHI's laboratory and identified to the taxonomic rank of class and subsequently photographed using a stereo zoom microscope with a maximum magnification of up to 126 ×.

Results

A total of 15 individual organisms were recorded from five (5) replicates at each of the three (3) sampling stations around the Project site. The overall mean density recorded was 15.87 ± 5.80 indiv/m² (Table 5.56). All three (3) sites averaged the same mean density of organisms, with MB03 having the variation, having a standard error of only 4.32 indiv/m².

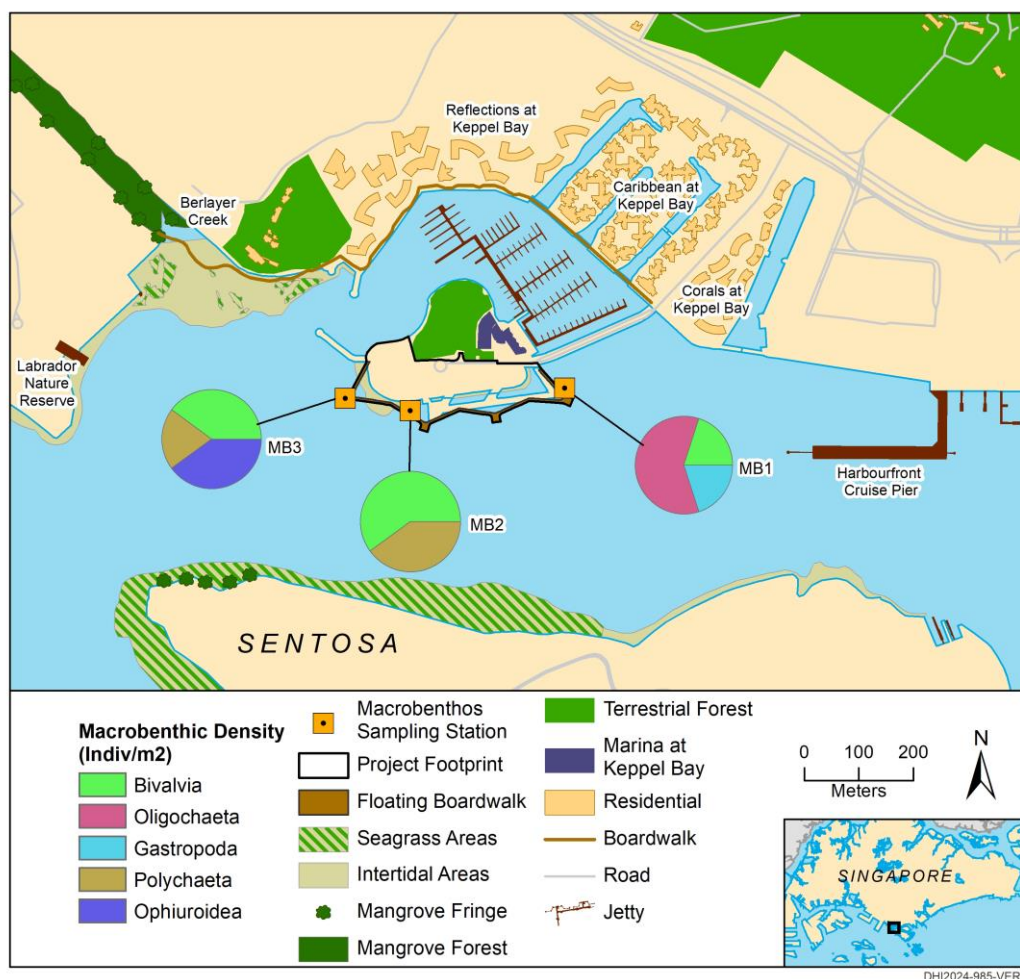


Figure 5.96 Benthic composition (based on abundance) of each of the five (5) classes of organisms at the sediment quality stations.

Five (5) classes of macrobenthos were recorded, with *Bivalvia* being the most dominant class of organisms, with a mean density of 6.35 ± 2.76 indiv/m² (Table 5.57). *Polychaeta* was next, which had a mean density of 3.17 ± 1.89 indiv/m². Figure 5.97 shows representative photos from the five (5) classes of organisms recorded from the sampling stations.

Table 5.56 Macrobenthic density distribution across the sediment quality stations.

Stations	Average Density per station (individuals/m ²)	SE
MB01	26.46	15.58
MB02	26.46	5.29
MB03	26.46	4.32

Table 5.57 Macrobenthic density distribution across taxonomic classes recorded from the sediment quality stations

Class	Average Density per Class (individuals/m ²)	SE
Bivalvia	6.35	2.76
Oligochaeta	3.17	2.84
Gastropoda	1.06	0.95
Polychaeta	3.17	1.89
Ophiuroidea	2.12	1.89

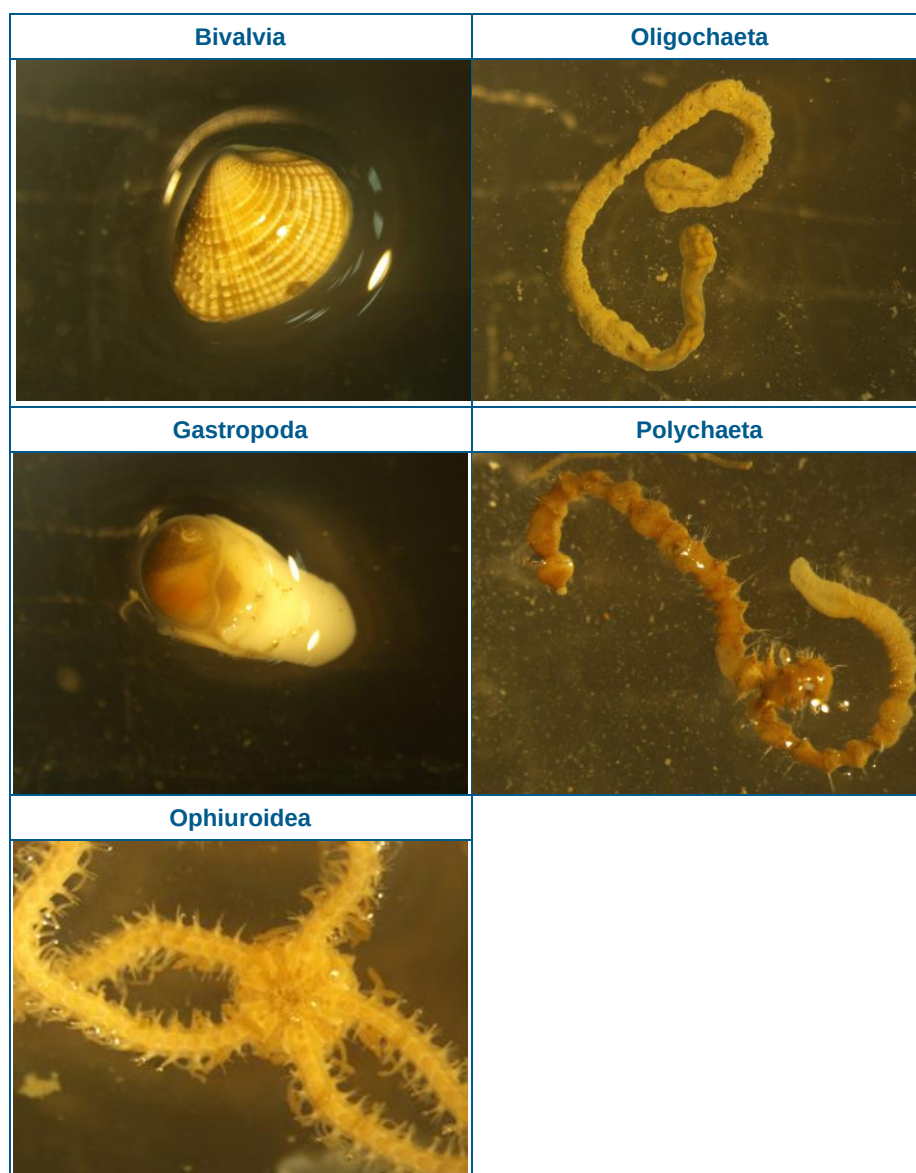


Figure 5.97 Selected images of macrobenthos recorded from the sediment quality stations

5.8.2.4 Mangrove Habitats

A literature review was conducted to obtain a baseline understanding of the mangroves in Berlayer Creek. Berlayer Creek is a six (6) ha stretch of mangrove adjacent to the Labrador Nature Reserve (LNR). In addition, it is also one of two remaining mangroves on Singapore's southern shores (NParks, n.d.). Despite its small size, up to fourteen (14) species of true mangrove trees have been recorded within (NParks, n.d.), and its diversity of mangrove associates also comprises rare and nationally threatened species.

Notable major mangrove species that are found within Berlayer Creek include *Rhizophora stylosa* (Bakau pasir, nationally "Vulnerable") and *Nypa fruticans* (the Nipah palm, nationally "Vulnerable"). According to Yang *et al.* (2013), Berlayer Creek is home to one of the last few strongholds of viable populations of *R. stylosa* on mainland Singapore and is an essential subpopulation for the species. Other major mangrove species detected include *Avicennia officianlis*, *Sonneratia ovata* and *Bruguiera cylindrica*. For the mangrove associates, there are no records of total species diversity; however, there are records of rare and threatened species. For example, locally "Critically Endangered" species such as *Podocarpus polystachyus* (the sea teak) and *Suregada glomerulata* (the Limau Hantu, previously *S. multiflora*) have been previously found there (Yeo, 2012). In addition, a recent environmental study (AECOM, 2022) also found the "Critically Endangered" climber *Dalbergia junghunii* at the back mangroves of Berlayer Creek.

5.8.3 Evaluation Framework

Coral Reef Tolerance to Suspended Sediments

Hard or hermatypic corals depend upon symbiotic photosynthesising zooxanthellae for survival and are, therefore, highly sensitive to increases in suspended sediment and corresponding reductions in light penetration (Terrados, 1997; Fabricius, 2005). Elevated suspended sediment levels can also clog the corals' respiratory and feeding apparatus.

Suspended sediments and light attenuation can have contrasting effects on corals; some species can gain a substantial proportion of their energy budgets from heterotrophic feeding on suspended sediments, while others obtain most of their nutrition from phototrophy regardless of the availability of particulate matter (Anthony & Fabricius, 2000). At deeper depths, the energy gained from utilising suspended sediments is most likely offset by the energy lost from reduced light availability (Fabricius, 2005). Corals can photo-acclimatise to changes in light levels by adjusting the concentration of photosynthetic pigments and/or the density of their symbionts. The coral-symbiont association can adapt to low irradiance by increasing concentrations of photosynthetic pigments and/or the density of the symbionts (Falkowski & Dubinsky, 1981; McCloskey & Muscatine, 1984).

Symbionts adapted to high irradiance have less photosynthetic pigments and/or occur at lower cell density and thus exhibit lower light absorption characteristics (e.g., PAR-absorptivity; Ralph *et al.*, 2005). The latter may increase with increasing contents of photosynthetically active pigments (Ralph *et al.*, 2005). Furthermore, maximal photosynthetic rate and minimum saturation irradiance (E_k) are higher, whereas light utilisation efficiency (α) is low (Ralph & Gademann, 2005; Ulstrup *et al.*, 2006a). In contrast, symbionts adapted to low irradiance are characterised by low maximal photosynthetic rate and E_k , and high α (Ralph & Gademann, 2005). Corals that cannot compensate energetically for reduced light availability may experience decreased rates of calcification and thinner tissue in the coral host (Rogers, 1979). Due to the variable abilities of corals in deeper water to compensate for low light, increased turbidity may lead to reduced density and diversity of corals, thus reducing the limit of depth distribution in coral communities (Yentsch *et al.*, 2002).

There is a growing body of evidence from field studies and controlled aquaria experiments showing that turbidity and sedimentation can degrade coral reefs at local scales (Anthony

& Connolly, 2004; Cooper *et al.*, 2007 Fabricius 2005; Fabricius *et al.*, 2007; Gilmour *et al.*, 2006). This research was quantified by Hawker and Connell (1992), who found that a 30 % increase in average long-term background suspended sediment levels resulted in a 20 % reduction in the annual growth rates of corals.

Background turbidity levels vary temporally at local and regional scales (Cooper *et al.*, 2007; Cooper *et al.*, 2008; Wolanski *et al.*, 2008). In addition, turbidity is strongly influenced by local weather conditions such as wind, waves and tides (Cooper *et al.*, 2008). In Singapore waters with a long-term background concentration in the coral reef areas in the order of 10 mg/l to 20 mg/l, a 30 % increase in background concentration corresponds to either an increase of 3 mg/l to 6 mg/l with 100 % exceedance or a 6 mg/l to 12mg/l increase with 50 % exceedance, or a 12 mg/l to 24 mg/l increase with 25 % exceedance, etc.

Background levels vary from region to region and are site-specific. It is known from research on the Great Barrier Reef that colonies present in the inshore areas (fringing reefs), by virtue of their environment, are prone to regular episodes of sedimentation from a variety of sources, such as terrestrial run-off (Wolanski, 1994; Wolanski *et al.*, 2005). These sediments are often re-suspended during and following wind and wave action, resulting in low light penetration levels due to turbidity.

Similarly, Hawker and Connell (1992) outlined that corals at the Great Barrier Reef have a tolerance to suspended sediments up to 4 mg/l. In Hong Kong, when assessing the environmental impacts of projects, the government has previously accepted an elevation criterion of 10 mg/l as the critical value, above which suspended sediments impact to corals may occur. Such a limit may be considered suitable for Singapore waters.

For coral reefs, experience from feedback monitoring in the region implies that the tolerance limits specified in Table 5.58 are conservative for areas with elevated background concentration. In addition, recent findings by Flores *et al.* (2011) established that the lowest suspended sediment concentrations resulting in complete mortality were 30 mg/l for *Montipora aequituberculata* and 100 mg/l for *Acropora millepora* after 12 weeks of exposure. These findings corroborated with DHI's existing lethal threshold levels while highlighting the more stringent and conservative nature of the DHI's threshold criteria.

Table 5.58 Magnitude of condition matrix for impact on coral reefs in Singapore from excess (i.e., in addition to background) suspended sediment concentrations (SSC)

Magnitude	Definition
No Change	- Excess SSC > 5 mg/l for less than 5 % of the time, or - Excess SSC < 5 mg/l
Slight Negative Change	- Excess SSC > 10 mg/l for less than 5 % of the time, or - Excess SSC > 5 mg/l for 5 – 20 % of the time
Minor Negative Change	- Excess SSC > 25 mg/l for less than 5 % of the time, or - Excess SSC > 10 mg/l for 5 – 20 % of the time, or - Excess SSC > 5 mg/l for more than 20 % of the time
Moderate Negative Change	- Excess SSC > 100 mg/l for less than 1 % of the time, or - Excess SSC > 25 mg/l for 5 – 20 % of the time, or - Excess SSC > 10 mg/l for more than 20 % of the time
Major Negative Change	- Excess SSC > 100 mg/l for more than 1 % of the time, or - Excess SSC > 25 mg/l for more than 20 % of the time

In Table 5.58, the exceedance percentage is based on cumulative occurrence. It is possible that a given occurrence may meet the criterion for multiple magnitude levels, in which case the more stringent magnitude should be taken as the resultant magnitude of the condition.

In addition, the matrix refers to daylight hours only, as the impact of suspended sediments is on light availability and is not a controlling factor during nighttime hours. However, in order to ensure a conservative assessment of impact, the daytime tolerance limits have also been applied to the assessment of nighttime activities as part of this Environmental Study.

There is insufficient data on filter-feeder (e.g., octocoral and sponges) tolerance to suspended sediments available from the literature to develop the same comprehensive tolerance limits proposed for corals. However, based on evidence from DHI's monitoring experience in Southeast Asia, it has been assumed that filter-feeder tolerance to suspended sediments is similar to (or not less than) hard corals. Since octocorals are commonly found at the same depth or even deeper than hard corals like *Turbinaria*, which are known to tolerate suspended sediments well, it is reasonable to assume that octocorals and sponges would be similarly or less sensitive compared to the hard coral species on which the coral tolerance limits are determined. Therefore, the same tolerance limits are also applied to filter feeders.

Coral Reef Tolerance to Sedimentation

Accumulation of sediments on corals is determined by the settling rate and physical characteristics of suspended sediments, the morphology of coral colonies, the colonies' ability to rid themselves of deposited particles and local hydrodynamic conditions. Horizontal foliose, plate-like or tabulate (e.g., *Montipora* and *Acropora*) and encrusting (e.g., *Montipora* and *Pavona*) growth forms present stable surfaces for retention of settling sediments. In contrast, vertical foliose (e.g., *Turbinaria* and *Pavona*) and upright branching growth forms (e.g., *Acropora*) are less likely to retain sediments. Digitate and massive colonies (e.g., *Porites* and *Favia*) typically exhibit intermediate susceptibility to sedimentation as these growth forms are likely to only partially retain sediments (Hawker & Connell, 1992; Gilmour *et al.*, 2006). It is also acknowledged that sensitivities to sediment loads can vary markedly between species within the same genus (Hawker & Connell, 1992).

Sediments on corals may be removed by producing and releasing mucus, which lifts particles from the coral tissue (Riegl & Branch, 1995). Furthermore, corals may actively trap and reject particles using their tentacles (Anthony & Fabricius, 2000). These processes come at an energetic expense to the coral through the loss of carbon from mucus release and enhanced respiration (Anthony & Fabricius, 2000) and contribute to the compromise of the fitness of the coral. Furthermore, the deposition of particles in excess of what may be removed through mucus release or particle trapping may clog the feeding apparatus of the corals and cause elevated mortality (Philipp & Fabricius, 2003).

Based on open-water reef environments with low levels of natural sedimentation, Pastorok and Bilyard (1985) have suggested the following criteria:

- | | |
|-------------------------------------|----------------------------|
| • 0.01 – 0.1 kg/m ² /day | Slight to Moderate impacts |
| • 0.1 – 0.5 kg/m ² /day | Moderate to Severe |
| • >0.5 kg/m ² /day | Severe to Catastrophic |

However, fringing and inshore reef environments are known to experience sedimentation events in exceedance of 0.5 kg/m²/day (severe to catastrophic) and still support flourishing coral communities (Ayling & Ayling, 1987). Therefore, adopting a strict criterion for impact assessment based on Pastorok & Bilyard's system may be overly protective in environments where coral assemblages are resilient to periodic or consistently high background rates of sedimentation. Hawker and Connell (1992) have suggested that a

value of 0.3 kg/m²/day is regarded as the absolute limit for sediment deposition in the inshore areas. Meanwhile, Rogers (1990) indicated that 'normal' sedimentation rates for Caribbean coral reefs appear to be 0.1 kg/m²/day. These studies suggest considerable variation in maximum sedimentation thresholds for corals and highlight that in-depth knowledge of local conditions is important for accurate recommendations.

Acceptable levels of sedimentation will depend on hydrodynamic conditions, background sedimentation rates, resuspension rates, and background turbidity; therefore, they must be adjusted to local conditions (Sofonia & Anthony, 2008). Data from feedback monitoring in the region indicate that a threshold value of 0.05 kg/m²/day is appropriate for the type of coral habitats and current conditions in the Project area. This threshold value is slightly more restrictive than the 0.1 kg/m²/day, which has been adopted as the critical value for corals in previous Environmental Impact Assessments, such as in Hong Kong. This criterion can be compared to measured long-term ambient (pre-1979) sedimentation rates in the Singapore coral reef areas of 0.03 kg/m²/day to 0.06 kg/m²/day.

Recent findings by Flores *et al.* (2011) established that the lowest sedimentation that resulted in total mortality was 0.25 kg/m²/day for *Montipora aequituberculata* and 0.83 kg/m²/day for *Acropora millepora* after 12 weeks of exposure. These findings again not only corroborate DHI's existing lethal threshold levels but also highlight the more stringent and conservative nature of DHI's threshold criteria.

For coral reefs, experience from feedback monitoring in the region implies that the tolerance limits specified in Table 5.59 are conservative for areas with elevated background sedimentation, assuming an initial deposition density of 400 kg/m³.

As there is insufficient data on filter feeders, such as octocorals and sponges, tolerance to sedimentation available from existing literature, DHI proposes the same approach as for suspended sediments, based on the assumption that the tolerance of filter-feeders to sedimentation is similar to hard corals. Therefore, the tolerance limits in Table 5.59 are also applied to filter feeders.

Table 5.59 Magnitude of condition matrix for impact on coral reefs in Singapore from excess (i.e., in addition to background) sedimentation

Magnitude	Definitions
No Change	< 1.7 mm/14 days (<0.05 kg/m ² /day*)
Slight Negative Change	1.7 to 3.5 mm/14 days (0.05 to 0.1 kg/m ² /day*)
Minor Negative Change	3.5 to 7.0 mm/14 days (0.1 to 0.2 kg/m ² /day*)
Moderate Negative Change	7.0 to 17.5 mm/14 days (0.2 to 0.5 kg/m ² /day*)
Major Negative Change	> 17.5 mm/14 days (>0.5 kg/m ² /day*)

* based on assumed initial deposition density of 400 kg/m³

Seagrass Tolerance to Suspended Sediment

The main impact of suspended sediments on seagrass is reduced light availability, although scouring by sediment particles can also have some impact. Seagrass requirements for light penetration have been well described (Duarte, 1991), with the habitat being confined to water depths where light levels are above 10 – 15 % of surface irradiance.

Light attenuation in the water column follows Lambert-Beer's law:

$$I = I_0 e^{-kd}$$

Where,

$$k = k_0 + k_1 C$$

Where,

- I_0 is the light intensity at the surface
- k_0 is the background absorption rate
- k_1 is the absorption rate for suspended sediments
- C is the depth-averaged concentration of suspended sediments
- d is the water depth

k_0 can be determined on the basis of Secchi disc depth in open water. For example, observations around Singapore's largest seagrass bed at Cyrene Reefs indicate Secchi disc depths in the order of 0.5 to 2.5 m, resulting in a k_0 value of between 0.4 and 2.0. This gives outer habitat limits between 2.5 m (deepest) and 0.5 m (shallowest). These figures concur well with the observations within Singapore waters that seagrass is generally limited to seabed areas shallower than -1 mCD.

Working through the equations for a change in limiting habitat water depth of 0.5 m requires an excess concentration between 5 mg/l (deep beds) and 75 mg/l (shallow beds). At low tide, the seagrass in Singapore is often exposed to high levels of suspended sediments, as shown in Figure 5.98. As evident, they can maintain a high level of tolerance. For the deeper meadows, the tolerance is less. However, given the natural background variability in suspended sediment load in the Singapore waters, 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 concentration of 5 mg/l to 10 mg/l, such that excess loadings higher than 5 mg/l will be required to induce a noticeable habitat change. These conclusions, coupled with monitoring experience from the region, result in the proposed magnitude of the condition matrix presented in Table 5.60.



Figure 5.98 Typical seagrass habitat found in Singapore

Table 5.60 Magnitude of condition matrix for impact on seagrass from excess (i.e., in addition to background) suspended sediment concentrations (SSC)

Magnitude	Definitions
No Change	- Excess SSC > 5 mg/l for less than 20 % of the time, or - Excess SSC < 5 mg/l
Slight Negative Change	- Excess SSC > 10 mg/l for less than 20 % of the time, or - Excess SSC > 5 mg/l for more than 20 % of the time
Minor Negative Change	- Excess SSC > 25 mg/l for less than 5 % of the time, or - Excess SSC > 10 mg/l for more than 20 % of the time
Moderate Negative Change	- Excess SSC > 75 mg/l for less than 1 % of the time, or - Excess SSC > 25 mg/l for 5 - 20 % of the time
Major Negative Change	- Excess SSC > 75 mg/l for more than 1, or - Excess SSC > 25 mg/l for more than 20 % of the time

Seagrass Tolerance to Sedimentation

Seagrass growth rates can be high, with growth rates in the order of 1 cm to 2 cm per day recorded for *Thalassia spp.* (Driscoll *et al.*, 1997). Meanwhile, growth rates in the order of 0.9 cm per day have been recorded for *Enhalus spp.* in the Philippines (Estacion & Fortes, 1988), enabling them to cope better with partial or full burial. For smaller colonising species such as *Halophila*, growth rates play an important part in coping with sedimentation (Cabaco *et al.*, 2008).

In the case of very high sedimentation rates, the short-term survival of larger seagrass species will depend on their anaerobic performance. However, such critical sedimentation rates will normally only occur close to a dredging or reclamation site. Suppose sedimentation is below this short-term critical level. In that case, the long-term survivability of the plant will then depend on its aerobic metabolism, which is dominated by oxygen supply through the root system. Several factors affect this, including the porosity and organic content of the sediment material.

For low sedimentation rates, plant growth is often positively related to increasing sediment nutrient contents supplied by sedimentary material (Danish Hydraulic Institute, 1997; Terrados *et al.*, 1999). However, suppose siltation occurs above a level corresponding to sediment organic matter content of about 5 to 20 % of the dry weight of the seagrass in any given area. In that case, it is likely to have a negative impact on seagrass density (Duarte, 1991; Nienhuis *et al.*, 1989). This is due to depletion in oxygen availability through the decay of the organic matter in the sediments, with the most typical limit being 10 to 15 % of organic matter dry weight (Duarte, 1991; Terrados *et al.*, 1999).

A second sedimentation factor potentially affecting seagrass arises from the fact that material remotely deposited from reclamation activities will generally be finer than the natural material present in the seagrass areas, resulting in a potential reduction in the overall porosity of the bottom material. Studies in Thailand and the Philippines have indicated a limiting level of silt and clay content of 15 % (Terrados *et al.*, 1998), above which species richness and community biomass declined sharply. Given the location of the seagrass beds in the Study Area, it can be expected that the clay content in the existing habitat areas falls below this threshold limit. However, for further reduction in porosity to materialise, incremental sedimentation would have to be concentrated and prolonged for consolidation to occur in the face of periodic wave action. This is unlikely, given the remote

location of the seagrass beds from the dredging and reclamation area, and changes in bed material composition are therefore not considered further.

A final factor relating sedimentation to seagrass habitat status is the growth of new shoots. This factor is also limited by sediment depth over the root system, but little information is available on this limiting factor.

These conclusions, coupled with monitoring experience from the region, resulted in the proposed Magnitude of the condition matrix presented in Table 5.61.

Table 5.61 Magnitude of condition matrix for impact on seagrass from excess (i.e., in addition to background) sedimentation

Magnitude	Definitions
No Change	Sedimentation < 3.5 mm/14 day (<0.1 kg/m ² /day*)
Slight Negative Change	Sedimentation 3.5 – 8.82 mm/14 day (0.1 – 0.25 kg/m ² /day*)
Minor Negative Change	Sedimentation 8.82 – 17.5 mm/14 day (0.25 – 0.5 kg/m ² /day*)
Moderate Negative Change	Sedimentation 17.5 – 35 mm/14 day (0.5 – 1.0 kg/m ² /day*)
Major Negative Change	Sedimentation > 35 mm/14 day (>1.0 kg/m ² /day*)

* based on assumed initial deposition density of 400 kg/m³

Mangrove Tolerance to Sedimentation

Mangroves are able to withstand gradual sediment accumulation, as this is part of their natural, dynamic state. However, acute increases in sedimentation due to natural or anthropogenic dumping of material can result in burial of pneumatophores, reducing their ability to supply oxygen to the root system (Wolanski 1995). The most sensitive components of the mangrove ecosystem to sedimentation impacts are seedlings and pneumatophores, as both have a relatively small vertical extent, and may therefore be partially or fully buried by high sedimentation rates within a short period of time.

In simple terms, there are two main types of mangrove root structures: those with stilt roots (e.g. *Rhizophora*) and those with pneumatophores (e.g. *Avicennia*). Mangrove root structures with pneumatophores are normally located on the outer fringe of the mangrove forest with higher tidal range and are thus at higher risk of sediment ingress.

Some field data regarding tolerance levels of mangroves to levels of sedimentation are available. A study by Terrados *et al.* (1997) showed that sediment burial of 8cm and above retarded growth and increased mortality of *Rhizophora apiculata* seedlings as a result of altered oxygen supply to the hypocotyl root system. Experimental field work in Thailand carried out by Thampanya *et al.* (2002) on seedlings of *Avicennia officinalis*, *Rhizophora mucronata* and *Sonneratia caseolaris* showed that *Avicennia officinalis* was five times more sensitive to burial than *Sonneratia caseolaris*, whilst *Rhizophora mucronata* showed no significant difference between the control and burial treatments (0, 4, 8, 16, 24 and 32cm). There was 100% mortality in *Avicennia officinalis* after 225 days at 32 cm burial, and almost 90% mortality at 24 cm.

These figures are consistent with the fact that the pneumatophores of *Avicennia* typically extend 10 cm but can reach 30 cm or more above ground level, such that it requires extensive and prolonged sedimentation to have any effect on respiration.

It is therefore considered extremely unlikely that sedimentation rates generated from the proposed reclamation activities are sufficiently high to introduce stress on the mangroves found around the project area.

Mangrove Tolerance to Erosion

While erosion is a natural process, it may be exacerbated by human influence. Dredging and reclamation works both alter tidal flow patterns and it is important to distinguish their impact from the natural rate of erosion. However, few studies have been carried out on erosion in mangroves, and earlier works suggest highly variable erosion rates on a temporal and spatial scale (Paling *et al.* 2003, Semeniuk 1980).

DHI has undertaken a number of studies assessing erosion impacts on mangroves at various locations throughout Southeast Asia. Mild to moderate erosion may expose pneumatophores, which will affect the respiration of mangroves, but is not likely to result in mortalities. Mortalities generally result once an erosion berm of more than 50–100 cm has formed, undercutting the mangroves trees along the shoreline and causing trees to lean or fall into the water.

The impacts of erosion to mangroves will be assessed directly via the coastal process modelling. This modelling will predict the area of mangrove habitat that will be affected by erosion, with a conservative assumption that erosion greater than 50 cm will result in mangrove mortality.

Fish Tolerance to Suspended Sediments

The tolerance of fish to suspended sediments varies widely from species to species. Fish in open-water environments will generally move away from areas of high suspended sediment concentration (so-called turbidity barriers) to seek new habitats. If there has been no permanent damage to a fish's natural habitat in a given area (e.g., coral reef), the fish will eventually return after the suspended sediment loading has been removed.

The situation is different for cage culture, as the fish cannot move out of the affected area. Elevated concentrations will predominantly affect fish respiration, which will affect growth rates under sub-lethal loading. Other issues related to the clogging of the nets surrounding the cages with resultant depression in water quality within the cage due to reduced flushing. This clogging will increase in areas with high Suspended Sediment Concentrations (SSCs).

A detailed literature review of suspended sediments in a wide range of fish species was conducted in order to establish tolerance thresholds for fish against suspended sediments. It is noted that data for tropical fish are scarce. Most available data are for temperate fish, the thresholds derived from which must be applied with caution. The limits that are proposed for this impact evaluation (Table 5.63) take guidance primarily from Aquaculture Stewardship Council (ASC) Tropical Marine Finfish Standard Version 1.0 and Best Aquaculture Practices (BAP) Farm Standard 3.1 (Table 5.62). The lower value of < 25 mg/l TSS allowable in recirculating aquaculture system discharge suggests that the fish can tolerate SSC levels of < 25 mg/l and anything above is deemed to potentially cause stress onset in the fish. Analysing available data for temperate fish's non-acute exposure to SSC shows that Moderate Change happens at around 50 mg/l and Major Change onsets at more than 100 mg/l.

It is noted that these conservative tolerance limits have not been used or validated by DHI in Singapore. They are used as conservative estimates in this Study to assess the Magnitude of Change to fish and aquaculture facilities (Section 5.8.4.6).

Table 5.62 Allowable level of total suspended solids for production systems in discharged effluent across the two standards

Standard	Ponds	Recirculating Aquaculture System
ASC Tropical Marine Finfish Standard Version 1.0	≤ 30 mg/l average and no higher than 50 mg/l	N/A
BAP Farm Standard 3.1	< 50 mg/l	< 25 mg/l

Table 5.63 Magnitude of condition matrix for suspended sediment impact on fish

Magnitude	Definitions
No Change	Excess SSC ≤ 5 mg/l
Slight Negative Change	Excess SSC > 5 mg/l to 25 mg/l
Minor Negative Change	Excess SSC > 25 mg/l to 50 mg/l
Moderate Negative Change	Excess SSC > 50 mg/l to 100mg/l
Major Negative Change	Excess SSC > 100 mg/l

Marine Fauna Tolerance to Underwater Noise

The assessment of marine fauna tolerance to sound exposure involves evaluating the potential impacts of anthropogenic noise on the fish and sea turtles expected to be present within the Study Area. Underwater sounds are typically classified according to whether they are continuous or impulsive in nature:

- Continuous sounds are produced without pauses, such as ambient noise produced by the environment or from rotating machinery like engines or pumps. Example of continuous sounds include vibratory pile driving, which produces a sustained, consistent noise as the pile is driven into the seabed.
- Impulsive sounds are discrete events that are of short duration and can occur singularly, irregularly or as part of a repeated sequence. For example, impulsive sounds can include single events such as explosions/blasts or repeating events such as hammer piling strikes or a geophysical survey.

Underwater noise generated by vibratory piling can potentially affect marine life, particularly species such as fish and sea turtles that rely on sound for communication, navigation, and foraging. A crucial factor when considering the impact of noise on fish is the presence or absence of a swim bladder. Fish with swim bladders are more susceptible to pressure-mediated injuries to the ears and other tissues, making them more vulnerable than species without swim bladders (Carlson, 2012). Additionally, fish species with swim bladders can detect sounds over a broader frequency range and at greater distances, extending the influence of man-made noise over a larger area (Popper et al., 2014). Unlike fishes, sea turtles do not possess a swim bladder and are generally less sensitive to pressure changes. However, they can still detect low-frequency sounds and are affected by underwater noise in different ways. Sea turtles rely on auditory cues for navigation, especially during migration and when locating nesting sites. Excessive noise can disorient them, leading to altered migration routes, delayed nesting, or even stranding (Samuel et al., 2005). Moreover, chronic exposure to elevated noise levels can lead to stress, behavioural changes, and a reduction in foraging efficiency, ultimately impacting their overall fitness and survival (Piniak et al., 2012).

The most comprehensive noise criteria for assessing the impact of non-impulsive or continuous noise on fish and sea turtles has been established by U.S. regulators, specifically the NOAA National Marine Fisheries Service (NMFS, 2023). The NMFS (2023)

outlines acoustic thresholds for assessing the effects of underwater noise on marine mammals, protected fish species, and sea turtles, focusing on hearing impairment such as Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS), as well as behavioural changes. These thresholds are based on the best available science at the time of their development. In accordance with NMFS's 2023 guidelines, the acoustic thresholds used to assess the effects of continuous sound exposure (i.e., pile vibratory driving) on fish and sea turtles are summarised in Table 5.64.

Table 5.64 Threshold value criteria for fishes and sea turtles used for the calculation of effect ranges during exposure to continuous sound (PTS = Permanent threshold shift; SEL_{cum} = Cumulative sound exposure level; SPL_{rms} = root mean square sound pressure level).

Hearing group	Effect	Parameters	
		SEL _{cum} (24h)	SPL _{rms}
Fish	Behavioural disturbance	-	150 dB re 1 μPa
Sea Turtles	PTS	220 dB re 1 $\mu Pa^2 s$	-
	Behavioural changes	-	175 dB re 1 μPa

This Study adopts the thresholds reported by NOAA NMFS (2023) to assess the effects of underwater noise on fish and sea turtles, focusing on potential hearing impairments and behavioural changes resulting from continuous sound exposure.

Evaluation of Magnitude of Change due to Accidental Spills and Leaks

There are no tolerance limits for assessing impacts from accidental spills or leaks. Therefore, the general definitions of Magnitude of Change as per the RIAM framework apply (Table 5.65).

Table 5.65 Criteria used for scoring Magnitude of Change on biodiversity and ecological receptors. Where multiple criteria result in multiple possible scores, the more conservative score (higher Magnitude) is adopted.

Score	Generic Criteria	Specific Criteria
-4	Major negative disadvantage or change	- Affects the entire habitat or a significant proportion (>70 %) of it and the long-term viability or function of the habitat is threatened. - Affects entire population or a significant part of it causing a substantial decline in abundance or change in and recovery of the population (or another dependent on it) is not possible either at all or within several generations due to natural recruitment.
-3	Moderate negative disadvantage or change	- Affects part of the habitat (40 – 70 %) but does not threaten the long-term viability or function of the habitat. - Effect causes a substantial change in abundance or reduction in distribution of a population over one or more generations but does not threaten the long-term viability or function of that population, or any population dependent on it.
-2	Minor negative disadvantage or change	- Affects only a small area of habitat (10 – 40 %) such that there is no loss of viability or function of the habitat. - Effect does not cause a substantial change in the population of the species, or other species dependent on it.

Score	Generic Criteria	Specific Criteria
-1	Slight negative disadvantage or change	• Very limited loss of habitat (<10 %). • Effect is within the normal range of natural variation accustomed to by the population of the species.
0	No change	• Status quo or no loss of habitat.

5.8.4 Impact Assessment

Each receptor is allocated an Importance score based on the criteria stated in Table 4.11. For marine ecology and biodiversity receptors around the Project, the scores generally ranged between “3” to “5”, with the exception of macrobenthos receptors.

Due to the low density of individuals found for macrobenthos around the site (i.e. < 10 indiv/m²; Section 5.8.2.3), this receptor was therefore given an Importance score of “1”.

The other receptors generally had a higher Importance score due to the locality and their richness within the waters around the Project site.

Coral habitat around the Project were given an Importance score of “4” due to the high species diversity, potentially due to the primary substrate being consolidated rock revetment or artificial structures coastal and bridge protection measures, which serve as ideal substrates for coral recruitment and growth. Within this species diversity, two (2) were locally “Vulnerable”, *Montipora digitata* and *Polyphyllia talpina*, and one (1) was locally “Endangered”, *Acropora millepora*. Integrated within the substrate of the coral habitats, is also the presence of subtidal seagrass, *Halophila decipiens*, a locally “Critically Endangered” species. Hence, subtidal seagrass receptors are given an Importance score of “5” due to the national importance of this species. Typically, coral reefs and subtidal seagrass are grouped together for ease of understanding, due to overlapping spatial extents. For these assessments, the higher Importance score will be used to ensure a conservative assessment is carried out.

For intertidal areas and seagrass habitat, they are separate into two areas due to differing communities found there. The first is the intertidal area south of Keppel Island, which refers to the consolidated rock and rubble that make up the sea wall along the coast of Keppel Island. This area was given an Importance score of “3” due to the presence of around 16 % of hard coral cover at this site. In contrast, the second intertidal area at the mouth of Berlayer Creek, harbours the nationally “Critically Endangered” *Enhalus acroides*. The intertidal areas around Labrador Park and Berlayer Creek are one of the few locations around mainland Singapore which harbours this species of seagrass. Hence, this area was given an Importance score of “5”.

The next marine ecology receptor is marine fauna and megafauna, including fishes and turtles which have been recorded in the surrounding waters. Most of the records of CS species, such as sea turtles, dolphins (both minimally “Vulnerable” status internationally) and fish species (e.g. the Ringed pipefish (*Dunckerocampus dactyliophorus*) and Sixspine butterflyfish (*Parachaetodon ocellatus*), both locally “Vulnerable”), were obtained from literature review. However, no specific location data could be obtained. As such, this receptor was scored a “5” due to potential international relevance of the organisms found in the Project area.

Finally, for the mangroves at Berlayer Creek, which harbours one of two remaining mangroves on Singapore’s mainland, as well as the last few strongholds of viable

Rhizophora stylosa (locally “Vulnerable”) in Singapore, this area was given an Importance score of “4”.

As four scenarios were carried out for the sediment plume modelling, the scenarios which gave the highest parameter value (e.g., Mean, 95th percentile, percentage of time >5 mg/l, etc.) across all four scenarios was chosen for the impact assessment to be carried out. This is to ensure that the assessment method is as conservative as possible for the receptor.

The other scores required for RIAM are the Permanence (P), Reversibility (R) and Cumulativity (C) of the pressure, on the specific receptor. Typically, Construction phase measures are short term and temporary, hence are given a Permanence score of “2”. These pressures can often be controlled, limited or mitigated with proper construction SOPs, and are hence given a score of “2” for Reversibility. Finally, the marine environment is highly interconnected. Hence impact to one part or habitat, will usually have knock off or cascading effects on other habitats, hence Cumulativity is usually scored “3”. Should there be exceptions to this, for example, for a certain pressure-receptor combination, it will be elaborated upon in the text below.

5.8.4.1 Impact of Construction Activities on Intertidal Areas and Seagrass Habitat at Keppel Island

Construction activities refer to the movements of boats, barges, construction materials, vehicles and the demolition of existing Wharf structures. Due to spatial location, only the intertidal areas at Keppel Island fall within the proposed marine work area.

Construction activities can affect the intertidal area in a number of ways, such as accidental grounding on the intertidal area if the construction vessel is caught unawares when the tide goes out. The moving and transportation of construction debris during the demolition stage also introduces the risk of construction debris falling off the barges and smothering or crushing corals or seagrasses in the area. This would cause physical damage to the corals and intertidal habitat in the area. This is considered localised damaged, and hence the Magnitude of Change is assessed to be “-1”, giving an impact significance of **Slight Negative Impact**.

5.8.4.2 Impact of Construction Activities on Coral Reefs and Subtidal Seagrass at Keppel Island

For the subtidal area, where the majority of the coral reefs and seagrass at Keppel Island are located, the construction activities have the potential to cause more serious impacts, compared to the intertidal area (see Section 5.8.4.2 above). For example, with increased vessel traffic in the marine working space, which is a relatively shallow area, boats could damage the reef both by direct collision or by placing down anchors into the waters, causing physical damage to the receptors. Strong propeller action could also disturb the seabed sediments, inducing silt to settle on or smother coral colonies, or cause direct physical damage if care is not taken by the operator. As the potential pathways to damage the subtidal areas are more varied and could result in significant damage as the operators are not able to see these receptors, the Magnitude of Change is given a higher score of “-2”, giving a **Minor Negative Impact**.

5.8.4.3 Construction Vessel Collision Impacts on Marine Fauna and Megafauna

Marine fauna receptors in the area include both fishes and marine megafauna, of which the latter are of greater concern for vessel collision impacts. Sea turtles and dolphins have been spotted in the waters surrounding the Project area, and all species have a “Critically Endangered” status in the SRDB3 (NParks, 2024a), as well as IUCN Red List statuses

ranging from “Vulnerable” to “Critically Endangered”. Yet, these two groups of megafaunas are known to linger near the surface of the waters to breathe, rendering them vulnerable to boat strikes by vessels.

Although the probability of such occurrence is relatively low, the chance of such an event occurring increases with the presence of more construction vessel traffic. Therefore, a Magnitude of Change of “-2” was assigned as a boat strike to an individual of these megafauna groups could potentially cause mortality and affect the already threatened population numbers of these species. Hence, the impact of construction activities on marine fauna and megafauna, is assessed as a **Minor Negative Impact**.

5.8.4.4 Impact of Suspended Sediments on Intertidal Areas and Seagrass Habitats

During construction activities, marine sediments from the seabed will be resuspended into the water column. These sediments’ spread is influenced by the local hydrodynamic conditions, potentially resulting in the shading of benthic photosynthetic organisms, such as seagrass and corals, affecting their photosynthetic ability and potentially causing mortality.

DHI has modelled the potential sediment plumes that will arise from the proposed works in Section 5.2.5, and the results are compared against the tolerance limits shown in Table 5.58 (used for the intertidal area at Keppel island, which has relatively significant coral cover) and Table 5.60 (used for the intertidal area at Berlayer Creek, which has seagrass cover). Based on the modelling results (Figure 5.18 to Figure 5.20), SSC in exceedance of 5 mg/l was less than 5 % of time for all scenarios. This value falls into the category of No Change (score “0”) for the Magnitude of Change of suspended sediments on both coral reef and seagrass receptors, giving an impact significance of **No Impact** for both locations.

5.8.4.5 Impact of Suspended Sediments on Coral Reefs & Subtidal Seagrass

Similar to intertidal and seagrass habitats, coral reefs and subtidal seagrass are also affected by sediments suspended in the water column. Based on sediment plume modelling results (Figure 5.18 to Figure 5.20), SSC in exceedance of 5 mg/l was expected to be less than 5 % of the time for the coral reefs and subtidal seagrass habitats, including the corals on the caissons. Specifically for the latter, the value is about 4.42 % of time. Hence, a Magnitude of Change score of “0” or No Change is assessed for the impact of suspended sediments on coral reef and subtidal seagrass habitat, translating to **No Impact**.

5.8.4.6 Impact of Suspended Sediments on Marine Fauna and Megafauna

Suspended sediments affect marine fauna, primarily fishes, in a slightly different way, by clogging fish gills and affecting their ability to breathe. Based on sediment plume modelling results (Figure 5.14 and Figure 5.15), the amount of sediment plumes that fishes can be exposed to, conservatively, can be up to a maximum of 10.2 mg/l, which falls into a score of “-1”, Slight Negative Magnitude of Change. In addition, due to fishes have the mobility that allows them to practice avoidance behaviour, i.e., they can move away from areas that temporarily become unsuitable for them to inhabit, the pressure does not result in a cumulative impact, hence, Cumulativity is scored a “2”. This gives an impact significance of **Slight Negative Impact**.

5.8.4.7 Impact of Underwater Noise on Marine Fauna and Megafauna

Water is a highly effective medium for the transmission of underwater noise. Piling works result in significant amounts of underwater noise that can disturb marine fauna and

megafauna in the vicinity of the works, as modelled in Section 5.7.5. Surveys and literature reviews have found the occurrence of megafauna such as sea turtles in the nearby waters.

Underwater noise modelling results have found that the largest area of effect for sea turtles and fishes are 10 m and 464 m respectively. This means that the fishes that could potentially be affected within the area of effect could include fishes in the northern shore of Sentosa island and those at Berlayer Creek, some of which are conservation significant species (Table 5.43). Currently there is no known information about feeding grounds for the fauna and megafauna in the area. However, it should be noted that mangroves (i.e., Berlayer Creek) are known nursery locations for fishes (Barbier et al., 2023). Hence, the underwater noise impacts would likely displace marine fauna and megafauna from the area, causing stress to a portion of animals utilising the waters around Keppel Island. As such, the Magnitude of Change is assessed as “-2”. However, the displaced marine mammals will likely find refuge in adjacent areas, given the presence of marine habitats nearby, hence, the Cumulativity of this pressure is assessed as “2”. This gives a final impact significance of **Minor Negative impact**.

5.8.4.8 Impact of Erosion/Sedimentation on Intertidal Areas and Seagrass Habitats

Eventually, sediment plumes will settle out into the soil as sedimentation effects. These pressures can cause smothering of intertidal and seagrass habitats, causing declines in health of and/or mortality on these receptors. Since this area is primarily abiotic cover and consisting of rocky-sandy substrate (Section 5.8.2.1; Results; Keppel Island), there are no known tolerance limits for sedimentation to intertidal areas. This is because intertidal area communities are highly varied and often of lower biodiversity than other key areas such as seagrass communities or coral reefs.

From our modelling results, the highest sedimentation rate over the intertidal area southwest of Keppel Island is between 7 – 17.5 mm/14 days (Figure 5.22). Despite lower diversity there, such an amount of sedimentation would likely cause noticeable changes to the community, causing significant stress to it. As such, the Magnitude of Change of sedimentation to the intertidal area at Keppel is assessed to be minor or “-3”, giving an impact significance of **Minor Negative Impact**.

In contrast to the intertidal area at Keppel Island, the intertidal area of Berlayer Creek is home to patchy seagrass meadows, including locally “Critically Endangered” conservation significant species such as *Enhalus acroides*. As such, this area will use the seagrass tolerance limits to sedimentation for the assessment of sedimentation impact, as detailed in Table 5.60. Seagrass could experience mortality if the sedimentation is too sudden and drastic, affecting the ecosystem services of the habitat. From the sediment plume modelling results, the intertidal area at Berlayer Creek will not be subject to any sedimentation (Figure 5.22), as such the Magnitude of Change is “0”, giving an impact significance of **No Impact**.

5.8.4.9 Impact of Erosion/Sedimentation on Subtidal Seagrass

Due to different tolerance limits for the subtidal seagrass and coral reefs to sedimentation, the assessments of the impact of erosion/sedimentation to these two receptors are separated in this section and Section 5.8.4.10 below. For subtidal seagrass, Table 5.60 and Figure 5.22, from the sediment plume modelling results, will be used to assess potential impacts. The results show that sedimentation is expected on the subtidal seagrass, at a rate between 3.5 – 8.82 mm/14 days. This means that the Magnitude of Change is “-1”, giving an impact significance of **Slight Negative Impact**.

5.8.4.10 Impact of Erosion/Sedimentation on Coral Reefs

For coral reefs, the tolerance limits for coral habitats (Table 5.59) will be used as the tolerance limit for determining the Magnitude of Change on the corals from sedimentation impact. Combining the sediment plume results, which show that sedimentation is expected on the Southwestern reef at a rate between 3.5 – 7.0 mm/14 days (Figure 5.22), the coral reefs around Keppel Island will experience a minor negative Magnitude of Change, which translates to a score of “-2”. Hence, the impact significance of sedimentation effect on the corals around Keppel Island is **Minor Negative Impact**.

5.8.4.11 Impact of Erosion/Sedimentation on Macrobenthos Habitats

Generally, organisms found in the subtidal benthic environments tend to be adapted to highly sedimentary environments. However, it should be noted that there are no known tolerance limits for these organisms in response to sedimentation or erosion due to a lack of knowledge about these systems. It is likely that they are tolerant to movements of sediments, and the movement of around 5mm/14-days of sedimentation (Figure 5.22), particularly since most of the plumes are close to the shore. Hence, there should be minimal impact to these deep water, benthic organisms. Therefore, the Magnitude of Change is assessed to be “0”, giving an impact significance of **No Change**.

5.8.4.12 Impact of Erosion/Sedimentation on Mangrove Habitats

Based on the modelling results from the sediment plume modelling in Section 5.2.5, only sedimentation is anticipated during the construction phase of the works, mainly around eastern of western parts of Keppel Island. It does not reach the mangrove habitats found at the mouth of Berlayer Creek. Sedimentation has to be very extreme to affect mangroves, as their aerial roots, which are required for breathing, are of a certain height above the sediment (see further details in Section 5.8.3). As such, the Magnitude of Change of sedimentation on the mangroves at Berlayer Creek is assessed to be “0”, giving an impact significance of **No Change**.

5.8.4.13 Impact of Pollutant Release on Marine Ecology and Biodiversity

Construction activities often utilise potentially pollutive substances in the work process. Exposure of marine biodiversity to pollutants such as plastics, heavy metals, petrochemicals, and other construction-related materials have the potential to cause increased stress, toxicity, impaired reproduction, and potential bioaccumulation.

Based on the modelled sediment plumes at each receptor location, the estimated amount of heavy metals released into the waters is calculated based on Section 5.3.3 and shown in Table 5.66. Given there are no expected increases in heavy metal concentrations beyond the ASEAN guidelines, around the development, the Magnitude of Change is assigned at “0”. Hence, pollutant release of heavy metals from the works will have **No Impact** on the marine ecological receptors found at the Project area.

Table 5.66 Incremental heavy metal concentration at marine ecological receptors. Green shading signifies “No Change”.

ID	Incremental heavy metal in water (ug/l)							
	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
C1	0.0002	0.0000	0.0006	0.0007	0.0007	0.0000	0.0004	0.0023
C2	0.0010	0.0001	0.0026	0.0026	0.0027	0.0000	0.0014	0.0093

ID	Incremental heavy metal in water (ug/l)							
	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
C3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002
IT1	0.0003	0.0000	0.0008	0.0008	0.0008	0.0000	0.0004	0.0029
IT2	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0002
MA1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
S1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002

5.8.4.14 Impact of Spills and Leaks on Marine Ecology and Biodiversity

Due to the presence of designated onsite storage, as well as the increased frequency of vessel movement during the Construction Phase, the potential for oil, diesel, or other construction-related chemicals to be washed into the surrounding marine water body would increase. Poor handling and management practices of construction materials could cause substances to be washed into the surrounding water body during a rainfall event. With increased vessel traffic, the risk of marine vessel collisions, marine vessel grounding and leaks onboard vessels increases, which could result in an uncontrolled release of petrochemical substances into the marine environment. While the likelihood of these events is low, piling rigs and barges are expected to occupy the Project area during the Construction Phase, increasing the probability of adverse events occurring. If spills or leaks occur, the effects on the marine ecosystem would be readily and rapidly identified in the field (e.g., localised mortality), thus the Magnitude of Change is classified as “-3” for areas within the work area, i.e., intertidal and seagrass areas and coral reef and subtidal seagrass habitats around Keppel Island. This gives impact significances of **Moderate Negative Impact** for coral reefs and subtidal seagrass, and **Minor Negative Impact** for intertidal and seagrass habitats around Keppel Island.

Due to a slight distance of Berlayer Creek from the Project area, the Magnitude of Change for the impact of spills and leaks to that location is classified at “-2”. A similar Magnitude of Change is applied for marine fauna as the scale of construction spills are often small, and these organisms will be able to move away from the site of pollution. Therefore, the impact significance for these two receptor-pressure pathways is assessed as **Minor Negative Impact**.

Finally, for the mangroves at Berlayer Creek, which are the greatest distance away (~500m away), and because the currents would not often wash any spills in that direction (Figure 5.3 and Figure 5.4), the Magnitude of Change for potential spills and leak impacts to the mangroves are slight, i.e., “-1”, giving **Slight Negative Impact**.

5.8.5 Mitigation Measures

Mitigation measures are required to be implemented for good practice and when the assessed impact is higher than the proposed EQOs (Section 8.1). This section outlines the key construction stage mitigation measures for impacts on marine ecology and biodiversity.

A dedicated Construction-specific EMMP (CEMMP) shall be designed and executed during the construction process, to facilitate timely monitoring and management of the impacts that could arise from the works. Specifically for this Project, the CEMMP shall comprise of both marine and terrestrial aspects, of which only the marine aspects will be elaborated upon here. The terrestrial aspects of the CEMMP will be elaborated upon in Section 5.9.5.1.

5.8.5.1 Minimisation and Prevention of Construction Activity Impacts

First, to minimise the occurrence of vessels grounding in the intertidal areas of the work marine working space, the Contractor should map the intertidal areas (<0.3 mCD) around Keppel Island. This area shall be avoided during low tides or receding tide periods by construction vessels and barges in order to minimise vessel grounding during construction works.

Second, a no-anchor zone should be established within the work area. Specifically for this Project, the no-anchor zone shall be established at the caissons east of Keppel Island (Figure 5.99). This is to minimise the destruction of the rich and diverse corals colonies that are found at the caissons.

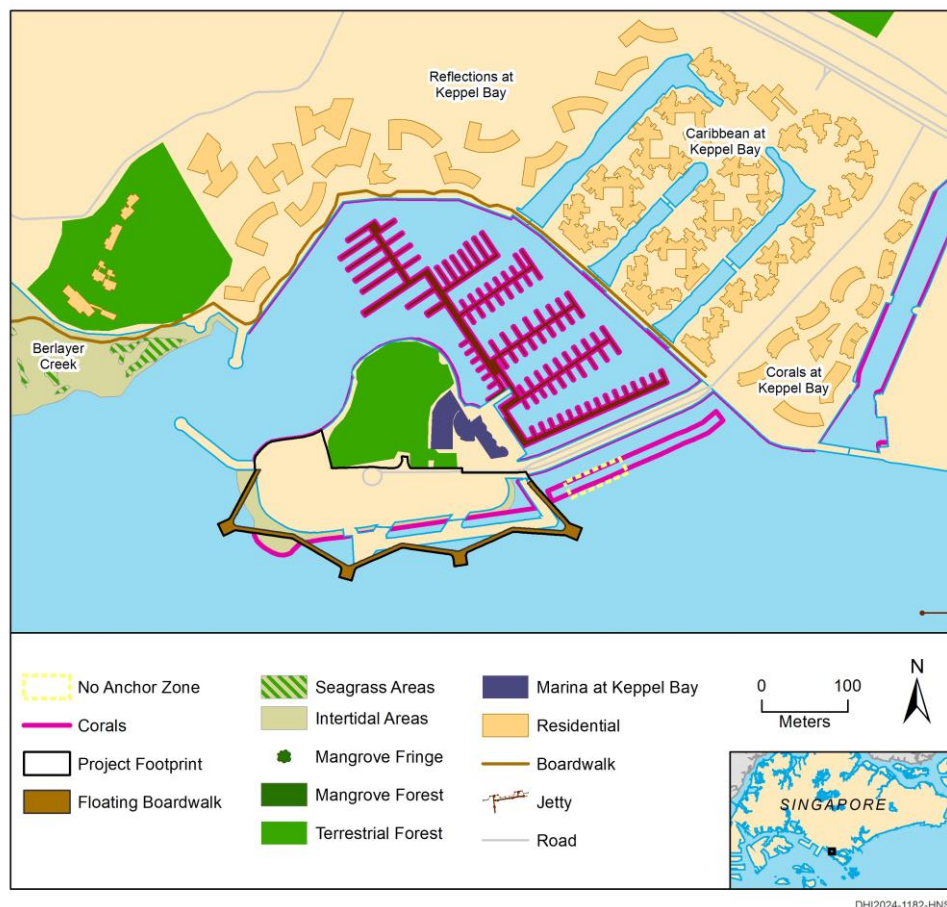


Figure 5.99 Map showing the indicative no-anchor zone, around the corals at the caissons east of Keppel Island

Third, a Marine Megafauna Action Plan shall be designed and put in place during the Construction Phase to mitigate underwater noise impacts. The plan is especially important during periods with significant vessel traffic (e.g., during the marine piling stage of works) and should apply to all species of sea turtles, dolphins, dugongs and any other large marine fauna. This action plan should include the following:

- A marine megafauna encounter plan, which instructs personnel on actions to take if marine megafauna is encountered within and around the work site. It should include measures for detecting and managing megafauna presence, such as the need for observations for 15 minutes prior to the start of piling to confirm there are no sensitive marine megafauna within the exclusion zone (300 m around the piling location), assigned staff to keep an active look out for marine megafauna during piling operations, stop-work procedures if sensitive marine fauna are spotted within the exclusion zone

during piling, vessel responses upon seeing marine mammals or turtles (Jefferson *et al.*, 2009; Schoeman *et al.*, 2020);

- Marine construction works shall avoid coral spawning periods, as requested by Nature Groups (NG) during the NG engagement;
- Procedures for implementing a soft start (ramp up) methodology to gradually increase sound pressure levels to drive fish and marine fauna away from the area; and
- Hydrophone deployment to monitor underwater noise at 300 m away from the Project site to ensure that the assumed exclusion zone of 300 m is suitably conservative. The hydrophone should be deployed at least 1 week prior to the start of piling at each jetty location, in order to record a minimum of 1 week of baseline underwater noise data before the start of piling, and then throughout the duration of the piling works

5.8.5.2 Controlling Erosion/Sedimentation Effects

Silt screen should be installed by the contractor for the duration of the piling works, to act as a sediment containment system while the piles are being installed. This measure is to specifically safeguard corals outside of the direct footprint of the works (i.e., corals found at the caissons), which could potentially be subject to sediment plume impacts. Simultaneously, sedimentation and monitoring should also be conducted at nearby coral receptors to monitor the health of the reef.

5.8.5.3 Accidental Spills and Leaks Mitigation Measures

A Waste Management Plan will be required to be prepared by the Contractor to estimate and log the waste types and volumes for the Project and plan for proper handling, storage and disposal methods. Proper segregation and management for each type of waste are needed to sort out recyclable materials and allow cost-efficient treatment and disposal by licensed waste management organisations. Waste and hazardous materials management shall comply with local regulations and guidelines listed in Section 3.3. Below are some management and mitigation measures that shall be observed during construction in handling hazardous materials and wastes.

Table 5.67 Mitigation measures to minimise impacts of accidental spills and leaks to marine ecology and biodiversity receptors during the Construction Phase

Aspect	Mitigation Measures
Management	• Prepare a Major Accident Prevention Plan (MAPP) and a Spill and Emergency Response Plan (SERP) for spills, leaks or other contamination. The Plans shall include emergency contacts for the authorities, training of staff, spill kits and oil spill booms (at least 100 m). There should be emergency access routes maintained with a realistic minimum response time established to contain any spills or leaks, e.g., 30 minutes. The final SERP should be linked to the Marine Emergency Action Procedure (MEAP) for combating major oil spills at sea via cooperation with MPA. • Communication to be established with MPA for the reporting of any oil spill incidents. • Transport and storage of hazardous substances to follow national and international dangerous goods regulations/guidelines. This includes compliance with The Environmental Protection and Management Act and Regulations administered by NEA and referencing the Basel Convention. The scope covers classification, inventory of materials, record keeping of volumes, safe and contained storage and handling/refuelling areas, signage, labelling of containers, training, and spill response. • An inventory of all anticipated hazardous materials should be created with records of stock movements in accordance with formats specified by the National Environment Agency (NEA) – Chemical Control and Management Department (CCMD). • Ensure all sewage, ballast water, bilge water and other vessel wastewater shall not be discharged at the project site and shall be disposed following national and international regulations/guidelines. This includes compliance with the Prevention of Pollution of the Sea Act and Regulations administered by MPA and referencing International Maritime Organization (IMO). • It is recommended that the construction-specific environmental management and monitoring plan include a hazardous material management plan with the following: ○ Dedicated hazardous material management procedures for transporting and handling of hazardous materials ○ Dedicated hazardous material management procedures for refuelling ○ Dedicated hazardous material management procedures for the storage of hazardous material ○ Dedicated emergency response procedures specific to the itemised hazardous materials • A training programme be provided for all personnel who handle hazardous material. • Standard Operating Procedures (SOPs) be put in place for the management of secondary containment structures, specifically in relation to the removal of any accumulated non-hazardous fluid to ensure that the intent of the system is not breached. • An inspection and maintenance program be implemented to verify the integrity of containment infrastructure.

Aspect	Mitigation Measures
General Handling and Storage	- Materials should be stored in accordance with their Material Safety Data Sheets (MSDS). - Containers must be designed, manufactured, and tested in accordance with internationally acceptable standards and affixed with approved labelling. - Areas storing hazardous material storage areas should possess the following features: - Impervious or resistant flooring constructed of combustible, chemically resistant material. - Separate fire-resistant compartments for storing substances that can react dangerously with one another. - Provide sufficient protection to stored hazardous materials from environmental exposure. - Areas storing hazardous liquids should, at a minimum, include the following features: - Possess liquid-tight secondary containment structures capable of containing up to 110 % of the largest tank or 25 % of the combined storage volume, whichever is greater. - Have secondary containment structures designed to prevent contact between substances which can react dangerously with one another. - No apertures directly connecting to the sewage system, surface drainage or water body. - Fill points for hazardous liquids should be located inside the secondary containment reservoir. - Possess readily accessible spill kits and firefighting equipment appropriate for use with inventoried hazardous material (e.g., oil only, chemical only, general use, etc.).
Transport	- It is required that hazardous material transportation methods are designed, constructed and maintained in accordance with the approved code of practice. - It is necessary to take adequate precautionary measures to prevent hazardous substances from exploding, catching fire, spilling, dropping, or being released during transportation. - It is required that suitable and efficient fire extinguishers be located on an easily accessible section of the vehicle transporting the hazardous material.
Equipment Cleaning and Maintenance	- Cleaning and maintenance activities that involve hazardous materials should be conducted over an impervious bunded surface. - Contaminated materials generated during cleaning and maintenance (e.g., oily rags, oil filters, spent oil, etc) should be segregated and disposed of according to the waste management plan.

Aspect	Mitigation Measures
Marine Refuelling Area	- The following physical measures are recommended for the refuelling area: - Refuelling area to be allocated and refuelling to be conducted away from sensitive areas and receptors (i.e., corals reefs, seagrass habitats, etc.) - Use of quick snap-back mechanism to minimize risk of spills and leaks.
Terrestrial Refuelling Area	- The following physical measures are recommended for the refuelling area: - Automatic shut-off bowser nozzles be used when refuelling to decrease the risk of overfilling. - The refuelling area should be located within a secondary containment area isolated from surface water drainage. - The surface of the refuelling area should be constructed of non-combustible, fuel-resistant liquid-tight material. - Readily accessible spill kits and firefighting equipment. - Should large volumes of spills happen, spills should be directed to the erosion control measure's holding pond. The water treatment system should be stopped and the contents in the holding pond be collected and disposed of by an NEA-approved toxic waste collector.
Security Measures	- It is recommended that enhanced security measures be implemented for facilities storing hazardous substances. Security measures include but are not limited to: - Monitoring and detection system such as CCTV cameras and human-based monitoring. - Security lighting to increase visibility at access points and sensitive locations (i.e., hazardous material storage). - Access control to limit access to hazardous materials (i.e., regulated key access, sign-in and sign-out procedures). - Documentation and reporting procedures for non-routine incidents.

The hazardous material impacts associated with this development are primarily associated with the risk of loss of containment (LOC) events. The application of industry best practices, EHS guidelines and national code of practices are required to ensure that the residual risks do not result in LOC events and subsequent impacts on ecological receptors. If diligently applied, the recommended mitigation measures can reduce the Magnitude of Change from spills and leaks arising from LOC events to “-1”, bringing out the impact significance to the various receptors to **Slight Negative Impact**.

5.8.6 Marine Ecology and Biodiversity Impact Summary

The Construction Phase impacts from the Project's construction work on marine ecology and biodiversity receptors have been summarised in Table 5.68.

Table 5.68 RIAM results for Construction Phase (short-term) impacts from the Project on marine ecology and biodiversity receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Intertidal areas and seagrass habitat (Keppel Island)	Marine construction activities	3	-1	2	2	3	-21	Slight Negative Impact	-1	-21	Slight Negative Impact
	Suspended sediments	3	0	2	2	3	0	No Impact	-	-	-
	Erosion/ Sedimentation	3	-3	2	2	3	-63	Minor Negative Impact	-2	-42	Minor Negative Impact
	Pollution release	3	0	2	2	3	0	No Impact	-	-	-
	Spills and leaks	3	-3	2	2	3	-63	Minor Negative Impact	-1	-21	Slight Negative Impact
Intertidal areas and seagrass habitat (Berlayer Creek)	Suspended sediments on seagrass	4	0	2	2	3	0	No Impact	-	-	-
	Erosion/ Sedimentation	4	0	2	2	3	0	No Impact	-	-	-
	Pollution release	4	0	2	2	3	0	No Impact	-	-	-
	Spills and leaks	4	-2	2	2	3	-56	Minor Negative Impact	-1	-28	Slight Negative Impact
Coral reefs and subtidal seagrass (Keppel Island)	Suspended sediments	4	0	2	2	3	0	No Impact	-	-	-
	Marine construction activities	4	-2	2	2	3	-56	Minor Negative Impact	-1	-28	Slight Negative Impact
	Pollution release	4	0	2	2	3	0	No Impact	-	-	-
	Spills and leaks	4	-3	2	2	3	-84	Moderate Negative Impact	-1	-28	Slight Negative Impact

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Coral reefs (Keppel Island)	Erosion/ Sedimentation	4	-2	2	2	3	-56	Minor Negative Impact	-1	-28	Slight Negative Impact
Subtidal seagrass	Erosion/ Sedimentation	4	-1	2	2	3	-28	Slight Negative Impact	-1	-28	Slight Negative Impact
Mangroves (Berlayer Creek)	Pollution release	4	0	2	2	3	0	No Impact	-	-	-
	Spills and leaks	4	-1	2	2	3	-28	Slight Negative Impact	-1	-28	Slight Negative Impact
	Erosion/ Sedimentation	4	0	2	2	3	0	No Impact	-	-	-
Macrobenthos	Erosion/ Sedimentation	1	0	2	2	3	0	No Impact	-	-	-
Marine fauna and megafauna	Marine construction activities (collision with fauna)	5	-2	2	2	2	-60	Minor Negative Impact	-1	-30	Slight Negative Impact
	Suspended sediments	5	-1	2	2	2	-30	Slight Negative Impact	-1	-30	Slight Negative Impact
	Underwater noise	5	-2	2	2	2	-60	Minor Negative Impact	-1	-30	Slight Negative Impact
	Pollution release	5	0	2	2	2	0	No Impact	-	-	-
	Spills and leaks	5	-2	2	2	2	-60	Minor Negative Impact	-1	-30	Slight Negative Impact

5.9 Terrestrial Ecology and Biodiversity

Temporary construction laydown and operating equipment on terrestrial grounds can produce varying levels of noise (from noisy human activities (e.g., excavation) and air pollution (from the resuspension of particulate matter into the air) that propagate towards adjacent terrestrial habitats and cause impacts to terrestrial flora and fauna. To ensure that the more sensitive forest ecology and biodiversity is not overlooked, terrestrial flora and fauna surveys were carried out as part of the baseline surveys for this Project.

5.9.1 Relevant Pressures

The environmental pressures from the works that are anticipated to be relevant to terrestrial ecology and biodiversity include:

- Physical disturbance due to construction activities (including avifauna);
- Air pollution (Section 5.4);
- Airborne noise (Section 5.5);
- Ground vibration (Section 5.6); and,
- Secondary impacts due to changes to terrestrial environmental quality as a result of accidental spills and leaks.

These pressures have been quantified and model results are presented in the earlier referenced sections where possible. This section benchmarks these changes against available ecological response thresholds to evaluate the significance of their impacts on terrestrial habitats and their inhabitants.

5.9.2 Baseline Features and Key Receptors

Relevant terrestrial ecology receptors in the Project area were identified using a combination of field surveys (primary data collection) and desktop studies (secondary data collection). The following subsections elaborate on notable receptors, particularly conservation-significant flora and avifauna species with higher ecological value in Singapore's context. On the whole, the broad grouping of key receptors for terrestrial ecology and biodiversity are:

- Terrestrial flora; and,
- Terrestrial fauna.

While impacts to overall terrestrial ecology and biodiversity will be considered within the assessment, Hillock Area has been identified to be of particular relevance to the Project due to its identified sensitive habitats, sensitive communities, and protected and threatened species which are adjacent to the site and within the Project's area of influence. For ease of understanding, each of the above receptors are separated by spatial distribution into the Hillock Area and within the Project Footprint. For example, Terrestrial flora within the Hillock Area will be assessed separately from Terrestrial flora within with Project Footprint.

5.9.2.1 Terrestrial Flora

Survey Methodology

The terrestrial flora baseline survey was conducted at the urban and forested areas within the flora survey area, as seen in Figure 5.100 below.

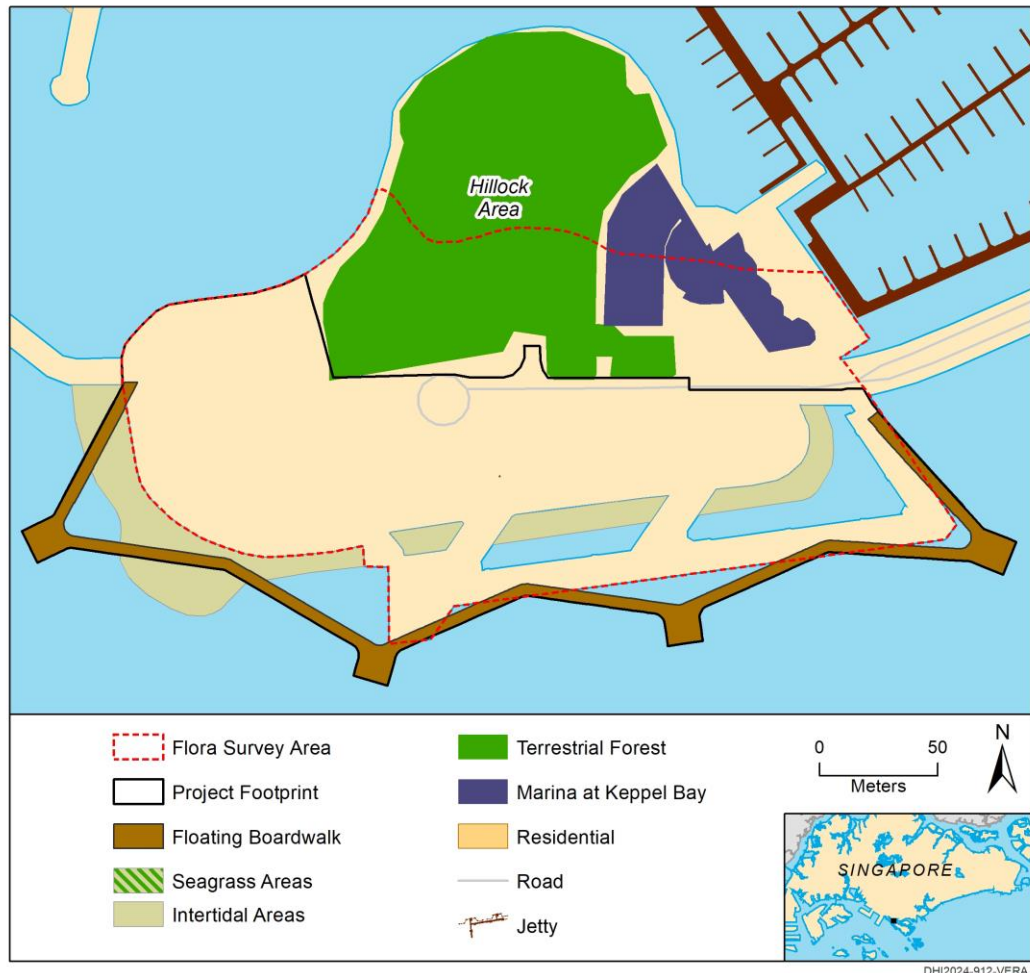


Figure 5.100 Terrestrial flora survey boundary

Flora surveys utilised a tiered census methodology, in which non-native woody flora species of ≥ 1 m girth, native woody flora species of ≥ 0.3 m girth, and all conservation-significant (CS) native vascular flora were recorded. Other flora species were recorded opportunistically where applicable.

Each two-person survey team consisted of at least one (1) flora specialist or ISA-certified arborist. The static parameters collected for each entry can be found in Table 5.69 below. Individuals not identified in the field were collected to facilitate species identification where required. The flora surveys were conducted on 12 March, 18 March, 27 March and 03 April 2024.

Table 5.69 Static parameters recorded during the survey

Static Parameters	Description
Coordinates	In SVY21 (EPSG:3414) Coordinate Reference System
Collection date	Date when the tree was geolocated
Tree Identification Number	Unique identification number for every surveyed tree
Flora Species	Scientific and common* names
Growth Form	Tree, shrub, palm, fern, climber/vine, etc.
Girth	Circumference of the tree (m) at 1.0 m height
Height	Height of the tree (m)
Canopy	Canopy width of the tree (m)
Surveyor's remarks	Any remarks about the tree, if applicable
Image [^]	At least one (1) colour image of every surveyed tree

* Some flora species within the Southeast Asian region have no common name

[^] To be provided as supplementary material

Native flora species followed the national status in the Red Data Book 3 (NParks, 2024a), while exotic flora species followed the Flora of Singapore – Checklist and bibliography (Table 5.70; Lindsay *et al.*, 2022). All other non-listed exotic species were labelled Cultivated Only. Table 5.70 provides definitions of the conservation status of flora species according to Lindsay *et al.* (2022).

Table 5.70 National conservation status definitions for flora species in Singapore (adapted from Lindsay *et al.* (2022))

National Status	Definition
Native Originated or arrived in Singapore without intentional or unintentional involvement of human activities.	
Extinct (EX)	Globally extinct.
Presumed Nationally Extinct (Nex)	Not recorded in Singapore within the last 30 years. Endemic species that are presumed nationally extinct will consequently also be presumed to be globally extinct.
Critically Endangered (CR)	Fewer than 50 mature individuals estimated to be in Singapore; or if more than 50 but fewer than 250 mature individuals, with evidence of rapid decline or decline and fragmentation of populations.

National Status	Definition
Endangered (EN)	Between 50 and 250 mature individuals estimated to be in Singapore, with no evidence of decline or fragmentation of populations.
Vulnerable (VU)	Between 250 to 1000 mature individuals estimated in Singapore.
Least Concern (LC)	More than 1000 mature individuals estimated in Singapore.
Data Deficient (DD)	Not enough information available to assess the risk of extinction.
Cryptogenic Uncertain whether presence in Singapore is from natural dispersal or as a result of human activities.	
Non-native (Exotic) Presence in Singapore is because of intentional or unintentional involvement of human activities.	
Naturalised	Species that have established self-sustaining wild (i.e., non-cultivated) populations such that long-term persistence in Singapore is likely without additional introduction of new individuals or propagules.
Casual	Species that occur in the wild in Singapore as escapes or relics of cultivation but do not form self-sustaining populations, such that their presence is ephemeral once the original individuals die or are removed without additional introduction of new individuals or propagules. This includes taxa that were formerly considered to be naturalised but have since died out. Those for which we have no record of occurrence in the wild for more than 30 years are still treated as casual but are further highlighted.
Cultivated Only	Only found in cultivation.
Not Evaluated (NE)	Not yet assessed for risk of extinction. This includes some species for which there are grounds for rejecting or questioning a previous assessment but for which a new assessment is pending.

Survey Results

The terrestrial flora baseline survey recorded a total of 95 flora entries identified at the species level. Of these, 72 (75.8 %) are native, 22 (23.5 %) are non-native, and a single (1.1 %) species was uncertain in origin. The summary of the local conservation status of these species can be found below in Table 5.71. The species list and full flora inventory containing all the static parameters (Table 5.69 above) can be found in **Appendix E**.

Table 5.71 Distribution of flora species found in the Study Area based on local conservation status

National Status	Number of Species	Percentage of Species (%)
Native	72	75.8
Least Concern	48	50.5
Vulnerable	9	9.5
Endangered	11	11.6

National Status	Number of Species	Percentage of Species (%)
Critically Endangered	4	4.2
Non-native	22	23.2
Cultivated Only	12	12.6
Casual	4	4.2
Naturalised	6	6.3
Uncertain	1	1.1
Cryptogenic	1	1.1
Total Number of Species	95	100

A high proportion of the species found within the Study Area (25.2 %) – 24 of all 95 species – were identified to be of conservation significance. Twenty-three (23) of the twenty-four (24) species of conservation significance were assessed to be of natural regeneration, where the plants were deemed to have grown spontaneously, without human management (Table 5.72; Figure 5.101).

Table 5.72 List of flora species encountered within the baseline study, including their local conservation significance and their likely source (e.g., native regeneration or cultivated stock)

S/N	Scientific Name	Common Name	National Status	Growth Form
Likely a result of Native Regeneration				
1	<i>Archidendron contortum</i>	Lesser grasshopper tree	Endangered	Tree, Shrub
2	<i>Bhesa robusta</i>	Red-flowered Malayan spindle tree	Vulnerable	Tree
3	<i>Calophyllum inophyllum</i>	Penaga laut	Endangered	Tree
4	<i>Campylospermum serratum</i>	-	Vulnerable	Tree
5	<i>Dibridsonia conferta</i>	Green coffee	Endangered	Tree
6	<i>Drypetes cf. longifolia</i>	-	Critically Endangered	Tree
7	<i>Erycibe leucoxyloides</i>	-	Vulnerable	Climber, Vine & Liana
8	<i>Ficus caulocarpa</i>	Stem-fruited fig	Endangered	Tree
9	<i>Ficus vasculosa</i>	White fig	Vulnerable	Tree
10	<i>Garcinia nigrolineata</i>	Beaked kandis	Critically Endangered	Tree
11	<i>Goniophlebium percussum</i>	-	Vulnerable	Epiphyte
12	<i>Hypserpa nitida</i>	-	Endangered	Climber, Vine & Liana

S/N	Scientific Name	Common Name	National Status	Growth Form
13	<i>Lasianthus hirsutus</i>	-	Endangered	Shrub
14	<i>Linostoma pauciflorum</i>	-	Endangered	Climber, Vine
15	<i>Memecylon edule</i>	-	Endangered	Shrub
16	<i>Myrsine capitellata</i>	Kicar	Endangered	Tree, Shrub
17	<i>Olea brachiata</i>	Sea olive	Vulnerable	Tree, Shrub
18	<i>Palaquium obovatum</i>	-	Vulnerable	Tree
19	<i>Rourea fulgens</i>	-	Endangered	Climber
20	<i>Symplocos adenophylla</i>	-	Endangered	Shrub
21	<i>Syzygium palembanicum</i>	-	Vulnerable	Tree
22	<i>Trema tomentosum</i>	Poison peach	Vulnerable	Tree, Shrub
23	<i>Trigonachras acuta</i>	Seremkan	Critically Endangered	Tree
Likely of Cultivated Stock				
1	<i>Syzygium myrtifolium</i>	Kelat oil	Critically Endangered	Tree, Shrub

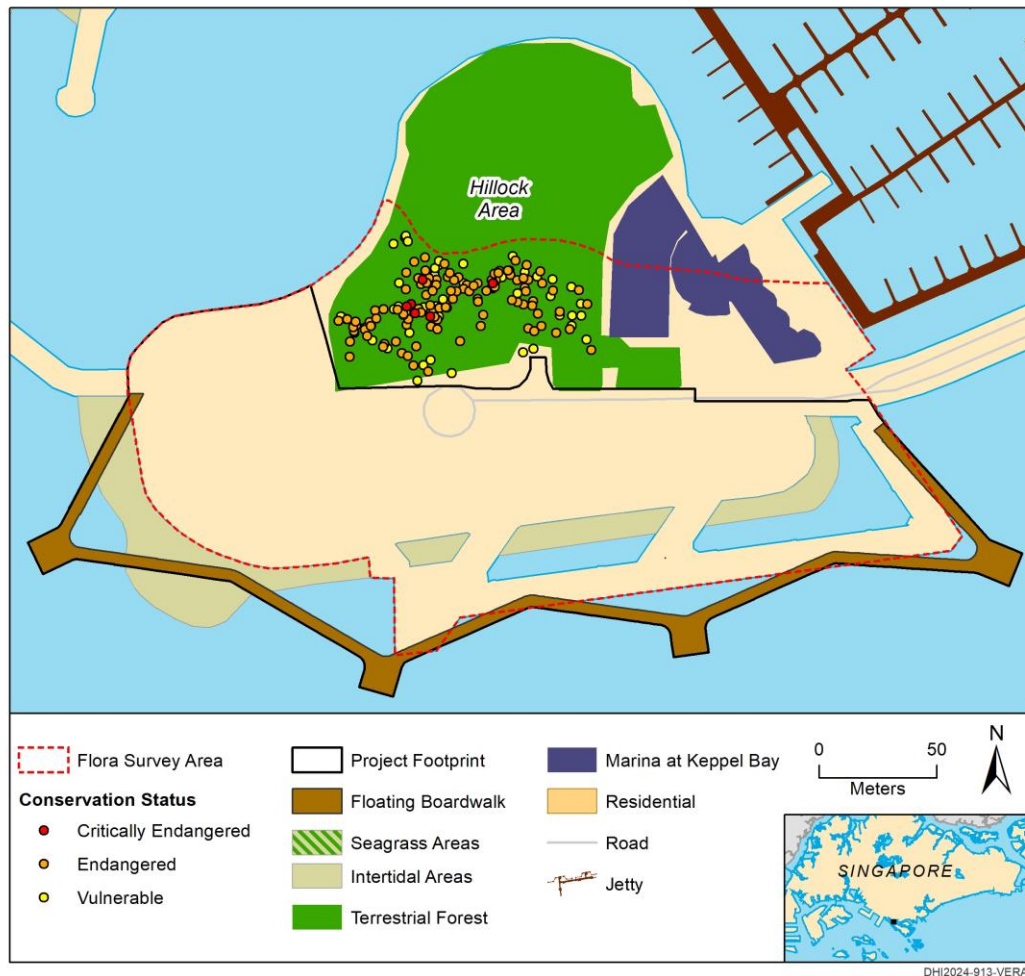


Figure 5.101 Flora of conservation significance found within the Study Area

The floristic ecological communities found in the Study Area varied based on habitat type. All areas outside the forested hillock consist of urban vegetation, while native-dominated old secondary forest and exotic-dominated secondary forest can be found on the northwestern and southern facing slopes of the hillock, respectively. Some of the most frequently recorded species in the native-dominated old secondary forest habitat in Study Area included tempinis (*Sloetia elongata*), sea apple (*Syzygium grande*), and wild cinnamon (*Cinnamomum iners*); while earleaf acacia (*Acacia auriculiformis*) and saga (*Adenanthera pavonina*) were commonly recorded in the exotic dominated secondary forest.

Apart from these species, all other frequently recorded (> 10 records) species within the forested area are species of national conservation significance. These include *Memecylon edule* (EN), sea olive (*Olea brachiata*) (VU), *Hypserpa nitida* (EN), kicar (*Myrsine capitellata*) (EN), and *Linostoma pauciflorum* (EN). These species were observed throughout the native-dominated old secondary forest, but also commonly in the understorey of the exotic-dominated secondary forest. The exotic-dominated secondary forest therefore aids the regeneration and dispersal of rare native species from the neighbouring native-dominated forest. The high density of species of conservation significance over the small 0.5 ha hillock area illustrates the high conservation and ecological value of this site. Some of the species of conservation significance found on the hillock can be found in Figure 5.102 below.

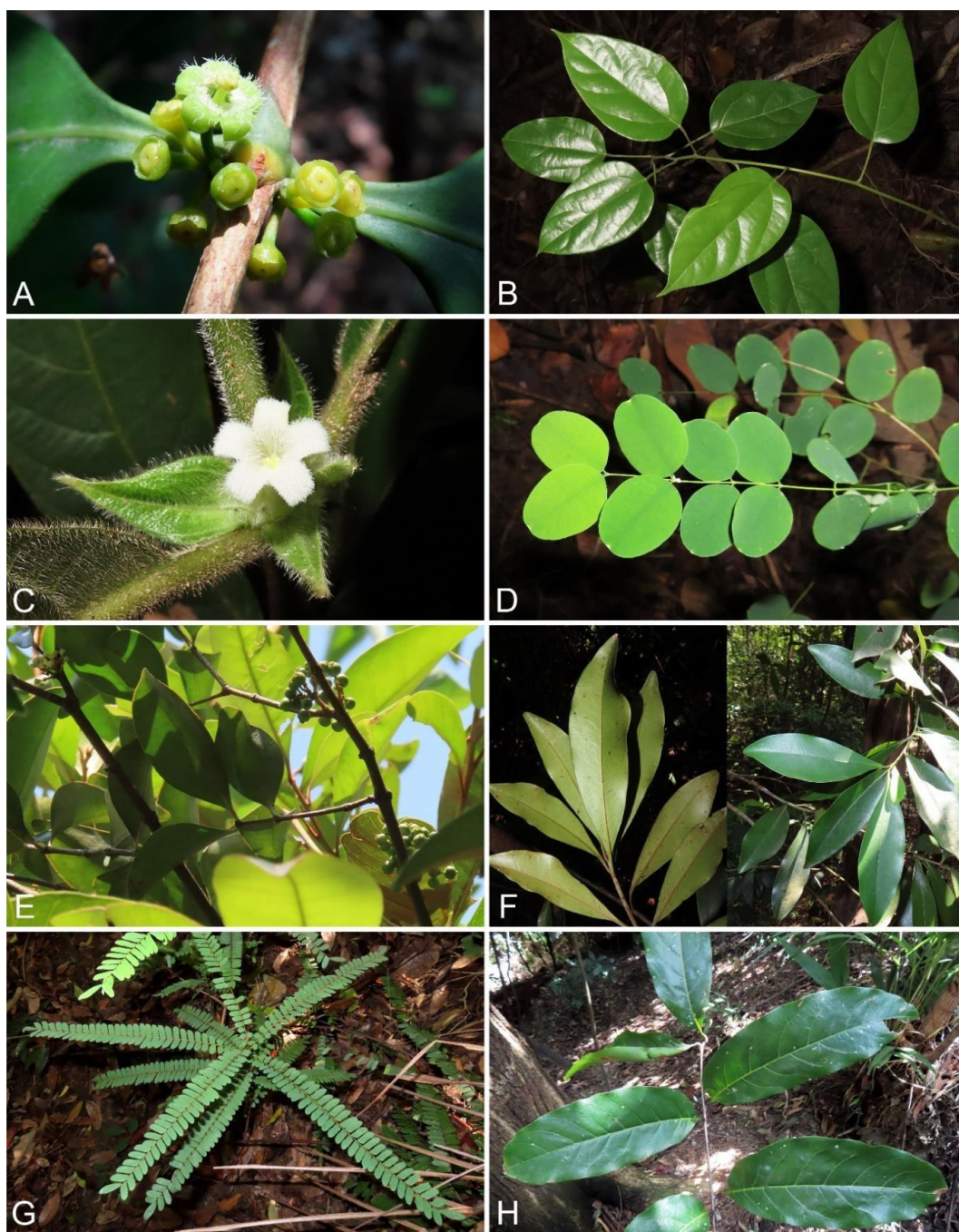


Figure 5.102 Species of conservation significance observed during the flora surveys. **A:** *Dibrindsonia conferta*; **B:** *Hypserpa nitida*; **C:** *Lasianthus hirsutus*; **D:** *Linostoma pauciflorum*; **E:** *Memecylon edule*; **F:** *Myrsine capitellata*; **G:** *Rourea fulgens*; **H:** *Trigonachras acuta*

Many flora species of conservation significance recorded in this terrestrial flora baseline survey corresponded with herbarium records. Over the last 30 years, *Memecylon edule*, sea olive (*Olea brachiata*), kicar (*Myrsine capitellata*), *Linostoma pauciflorum*, *Symplocos adenophylla*, beaked kandis (*Garcinia nigrolineata*) and *Syzygium palembanicum* have been recorded nearby at Labrador Park and Mount Imbiah (Singapore Herbarium Online, 2024). Slightly further north, the stem-fruited fig (*Ficus caulocarpa*) and *Goniophlebium percussum* were found at Alexandra Road and Mount Faber, respectively (Singapore Herbarium Online, 2024). Though not an official botanical record, the findings also largely corresponded to the species list of Keppel Island compiled by Lai (2012).

Other species which include Seremkan (*Trigonachras acuta*), *Rourea fulgens*, *Ixora cf. javanica* var. *retinervia*, *Dibridsonia conferta* and *Lasianthus hirsutus* have been collected at the Central Catchment, Western Catchment, Pulau Ubin, and other locations not in the southern region of Singapore (Singapore Herbarium Online, 2024). As Keppel Island represents a new locality record for these species, it might be worthwhile to consider collecting specimens from these individuals in due course.

Two potentially interesting findings are an *Ixora sp.* cluster and a *Cyperus sp.* cluster, as shown in Figure 5.103 below. The sterile characteristics of *Ixora sp.* matched that of *Ixora javanica* var. *retinervia*, where the plant has rather obscure or fine intermediate and tertiary veins that are not prominent on the lower leaf surface. The *Cyperus sp.* occurs in clusters at the top of the hillock with very dry soil, and the narrow, almost tubular leaf blade (width approximately 1 mm) does not match any common sedge species. It might be worthwhile to consider collecting fertile specimens of these two (2) flora entries to confirm the species further.



Figure 5.103 *Cyperus sp.* (top left and top right) and *Ixora sp.* (bottom left and bottom right) that are sterile but may potentially be of conservation interest

5.9.2.2 Terrestrial Fauna

Survey Methodology

Taking reference from the BIA guidelines (NParks, 2021 at the time of scoping), the terrestrial fauna baseline survey covered the following taxa of interest:

- Mammals (including bats);
- Avifauna;
- Herpetofauna (reptiles and amphibians);
- Butterflies; and,
- Odonates (dragonflies and damselflies).

Four (4) survey methods were utilised: 1) line transect surveys, 2) rapid survey points, 3) bat surveys and 4) camera trap surveys, taking reference from methodologies recommended in the BIA guidelines (NParks, 2021) and with the consideration that the BIA guidelines are meant to be non-prescriptive and non-exhaustive. Each survey methodology is elaborated upon in the subsequent sections. The data obtained and presented from the terrestrial fauna surveys include:

- Checklist of fauna, identified to species level where possible, or to the next lowest taxonomic rank possible, i.e., genus, family, order, or class level;
- Abundance (or independent detections for camera trap data);
- Local and global conservation status;
- Origin (native, introduced, invasive, migratory, resident etc.); and,
- Photographs of conservation-significant or notable/keystone species, or prominent fauna habitats (e.g., bird nests, tree burrows, beehives).



Figure 5.104 Locations of line transect, camera traps and rapid fauna surveys for terrestrial fauna surveys within the Study Area

Line Transect Survey

One (1) line transect of about 143 m in length was established within the Study Area shown above in Figure 5.104. The taxonomic groups of interest for line transect surveys include

bats, non-volant mammals, avifauna, herpetofauna (reptiles and amphibians), odonates (damselflies and dragonflies), and butterflies.

Surveys were conducted with surveyors walking along the line transects and documenting fauna encountered, either by visual sighting (with the aid of binoculars and/or telephoto lens if necessary) or by indirect evidence such as auditory calls (particularly for avifauna and amphibians) animal droppings or hoof marks. Both diurnal (morning and late morning) and nocturnal (dusk) surveys were conducted to account for the crepuscular activity pattern of many fauna species. The line transect surveys were replicated twice, with each sampling replicate minimally spaced a week apart to minimise temporal pseudoreplication and maximise sampling robustness. Any notable terrestrial fauna (e.g., conservation-significant, keystone, or charismatic species) observed beyond the line transects or stipulated survey window were recorded as opportunistic sightings and reported as such. The survey methods employed for each terrestrial fauna taxa of interest, including bats, are detailed in Table 5.73 below.

Table 5.73 Terrestrial fauna taxa of interest and the corresponding survey methodology for line transect surveys

Taxon of interest	Time of day	Additional details	Equipment
Mammals (Bats)	Dusk (1930hrs – 2200hrs)	Seen (frugivorous bats) and acoustically detected (insectivorous bats) along transect	Binoculars, torchlights, Echo Meter Touch 2 Pro Bat Detector (Wildlife Acoustics, Inc)
Mammals (Non-volant) and Avifauna	Morning (0700hrs – 0900hrs)	Minimally 30 mins sampling duration along entire transect	
	Dusk (1900hrs – 2100hrs)	Seen and heard within 50 m on either side and in front of transect	
Herpetofauna (Reptiles and Amphibians)	Morning (0800hrs – 1000hrs)	Minimally 30 mins sampling duration along transect	Binoculars, handheld GPS, camera with telephoto lens, torchlights, data sheet
	Dusk (1900hrs – 2100hrs)	- Seen and heard within 10 m on either side and in front of transect - Potential microhabitats (e.g., logs, crevices, hollows) may be surveyed as well	
Butterflies and Odonates	Late morning (1000hrs– 1200hrs)	- Minimally 30 mins sampling duration along transect - Within 10 m on either side and in front of transect - To aid identification, capture-and-release	Sweep nets, handheld GPS, binoculars, camera with telephoto lens, data sheet

Taxon of interest	Time of day	Additional details	Equipment
		of specimens may be carried out	

A total of four (4) line transect surveys and rapid survey replicates each were conducted across both diurnal and nocturnal replicates from February 2024 to April 2024 (Table 5.74).

Table 5.74 Details of terrestrial fauna surveys

Time of Survey	Type of Survey	Replicate	Survey Date
Diurnal survey	Line transect & rapid survey	Replicate 1	26 February 2024
		Replicate 2	16 April 2024
Nocturnal survey	Line transect & rapid survey	Replicate 1	7 March 2024
		Replicate 2	30 April 2024

Rapid Survey Points

In addition, two (2) rapid fauna surveys were carried out at the point locations shown in Figure 5.104 above. The surveys were carried out in open areas targeting all fauna groups (Figure 5.104, Table 5.73) detected around the point at both dawn and dusk. Surveyors stood at the specified points for 30 minutes, recording all fauna encountered via either direct visual sightings or auditory calls. These surveys were intended to detect birds and other fauna utilising the open areas (including birds of prey). RP01 was set to look over Berlayer Creek, while RP02 was focused on birds within the development plot.

Bat Surveys

Bat surveys consist of visual encounter surveys for frugivorous bats and acoustic sampling for insectivorous (echolocating) bats along the terrestrial fauna line transect, as well as at the two (2) rapid survey points (Figure 5.104). The surveys were conducted between 1930h and 2200h. The Echo Meter Touch 2 Pro Bat Detector (Wildlife Acoustics, Inc.) was used to record, stream, and attenuate ultrasonic calls between 18 and 192 kHz at a sampling frequency of 256 kHz. The bat sonograms were matched to a reference library of bat calls collected from species known to occur within Singapore and the region. Two (2) nocturnal replicates of visual encounter surveys and acoustic sampling were carried out.



Figure 5.105 A surveyor conducting bat sampling within the Study Area

Given the absence of bamboo clusters in the Study Area, roost emergence surveys were not carried out. All bats encountered through the various bat surveys were identified to species or the next lowest taxonomic level possible.

Camera Trapping

Camera trapping was carried out to supplement fauna surveying efforts by targeting uncommon or cryptic fauna species that may not have been recorded during line transect surveys or rapid point surveys. Camera trapping is a useful fauna survey approach because it is non-invasive (not requiring capture and handling of animals) and provides a 24-hour sampling regime that captures both diurnal and nocturnal species. While camera traps are appropriate for surveying a variety of fauna taxa, their main usage in this Environmental Study was to survey mammals, given the ease of identifying them readily through photographs or videos. Opportunistic captures of other fauna taxa, such as avifauna, reptiles, and amphibians, were also reported and analysed.

One camera trap (Model: SECACAM Pro Plus 60°, VenTrade GmbH) was deployed within the Study Area for a period of two (2) months – from 26 February 2024 to 30 April 2024, yielding a total of sixty-four (64) camera trap nights.

Deployment location was selected based on the presence of obvious animal trails or signs or where animal usage was deemed most likely according to habitat characteristics. The camera trap was mounted 30 cm to 50 cm off the ground and secured to a tree (Figure 5.106). The camera was programmed to record a 10-second window of video footage and a burst of three (3) photographs per motion trigger; colour photographs were taken during the day, while infrared photographs were taken at night. The camera traps were maintained every two (2) to four (4) weeks to ensure proper functioning and retrieved after the survey period.



Figure 5.106 Camera trap setup within Hillock Area

The recorded camera trap footage was manually screened to identify the species present. Wherever possible, individuals were identified at the species level, failing which, they were identified at the genera level and suffixed with *sp.*

Survey Results

The combined results from various terrestrial fauna survey methods and ad-hoc observations are collated and elaborated upon in subsequent taxa-specific sections.

Species Richness

A total of 55 fauna species were recorded via the transect, acoustic, rapid point counts, camera trap surveys and ad-hoc observations in the survey area. Birds were by far the most speciose taxa recorded for the Study Area, with the rest being far lower in observed species richness.

Three (3) species of local conservation significance (listed in SRDB3) and two (2) species of global conservation significance (listed in IUCN) were recorded. All recorded species of conservation significance were birds (Table 5.75). Details of all recorded fauna species and their conservation statuses are provided in the species checklist in the subsections that follow. A complete list of all terrestrial fauna species recorded by the baseline results may be found in **Appendix F**.

Table 5.75 Species richness of target terrestrial fauna groups recorded within the Study Area, sorted according to descending order of richness per taxon. The number of species of conservation significance (listed in Singapore Red Data Book version 3 (SRDB3) or International Union for Conservation of Nature (IUCN) Red List) is displayed as well.

Taxon	Total Number of Species	Conservation -significant (SRDB3)	Conservation -significant (IUCN 2021)	Distribution across survey locations		
				RP01	RP02	Transect
Bird	34	2	3	24	23	16
Mammal (non-volant)	4	0	0	0	1	0
Bat	3	0	0	2	3	2
Amphibian	3	0	0	1	1	2
Reptile	5	0	0	1	2	2
Butterfly	5	0	0	0	2	3
Odonate	1	0	0	0	0	1
Total	55	3	2	28	32	26

Avifauna

A checklist of all avian species recorded from the line transect and rapid point surveys is provided in Table 5.76. The avifauna recorded within the Study Area were mostly common generalist species primarily listed as Least Concern on the SRDB3 or IUCN red lists. These common species are typical of urban, parkland and coastal habitats, and include birds such as the Asian Koel (*Eudynamys scolopaceus*), Scarlet-backed Flowerpecker (*Dicaeum cruentatum*) and the White-bellied Sea Eagle (*Ichthyophaga leucogaster*) respectively.

Two bird species recorded for the Study Area were of local conservation significance. These are the Straw-headed Bulbul (*Pycnonotus zeylanicus*; Figure 5.107) and Oriental Magpie-Robin (*Copsychus saularis*), which are locally 'Endangered' and 'Vulnerable', respectively (Table 5.76, Figure 5.107). Three of the bird species recorded were of global conservation significance – the Straw-headed Bulbul, which is 'Critically Endangered', along with the Long-tailed Parakeet (*Psittacula longicauda*) and Javan Myna (*Acridotheres javanicus*), which are both are 'Vulnerable'. Of these species, the Javan Myna is non-native and, therefore, not considered to be of conservation significance in Singapore.

Table 5.76 Checklist of avifauna species recorded across the line transect and rapid survey points, along with local and global conservation statuses. Species of conservation significance globally or locally are indicated in bold.

Species		Survey Location			Conservation Status	
Scientific Name	Common Name	RP01	RP02	Transect	IUCN	SRDB3
<i>Acridotheres javanicus</i>	Javan Myna	✓	✓		VU	NA
<i>Aegithina tiphia</i>	Common Iora	✓			LC	LC
<i>Aerodramus sp.</i>	Swiftlet sp.	✓	✓		N.A.	N.A.
<i>Aplonis panayensis</i>	Asian Glossy Starling	✓		✓	LC	LC
<i>Cacomantis merulinus</i>	Plaintive Cuckoo		✓		LC	LC
<i>Caprimulgus macrurus</i>	Large-tailed Nightjar		✓	✓	LC	LC
<i>Cinnyris jugularis</i>	Olive-backed Sunbird	✓	✓		LC	LC
<i>Copsychus saularis</i>	Oriental Magpie-Robin	✓	✓	✓	LC	VU
<i>Corvus splendens</i>	House Crow	✓	✓	✓	LC	NA
<i>Dicaeum cruentatum</i>	Scarlet-backed Flowerpecker	✓	✓		LC	LC
<i>Dinopium javanense</i>	Common Flameback	✓			LC	LC
<i>Eudynamys scolopaceus</i>	Asian Koel		✓		LC	LC
<i>Gallus gallus</i>	Red Junglefowl	✓	✓	✓	LC	NT
<i>Geopelia striata</i>	Zebra Dove			✓	LC	LC
<i>Halcyon smyrnensis</i>	White-throated Kingfisher	✓			LC	LC
<i>Ichthyophaga leucogaster</i>	White-bellied Sea Eagle		✓		LC	LC
<i>Haliastur indus</i>	Brahminy Kite		✓		LC	LC
<i>Hirundo tahitica</i>	Pacific Swallow	✓			LC	LC
<i>Loriculus galgulus</i>	Blue-crowned Hanging Parrot	✓	✓		LC	LC
<i>Merops viridis</i>	Blue-throated Bee-eater	✓	✓	✓	LC	LC
<i>Mixornis gularis</i>	Pin-striped Tit-Babbler			✓	LC	LC
<i>Muscicapa dauurica</i>	Asian Brown Flycatcher	✓			LC	LC
N.A.	Tern sp.		✓		N.A.	N.A.

Species		Survey Location			Conservation Status	
Scientific Name	Common Name	RP01	RP02	Transect	IUCN	SRDB3
<i>Oriolus chinensis</i>	Black-naped Oriole	✓	✓	✓	LC	LC
<i>Orthotomus ruficeps</i>	Ashy Tailorbird		✓	✓	LC	LC
<i>Orthotomus sutorius</i>	Common Tailorbird	✓	✓	✓	LC	LC
<i>Psilopogon lineatus</i>	Lineated Barbet	✓	✓	✓	LC	NA
<i>Psittacula longicauda</i>	Long-tailed Parakeet	✓			VU	NT
<i>Psittacula sp.</i>	Parakeet sp.			✓	N.A.	N.A.
<i>Pycnonotus goiavier</i>	Yellow-vented Bulbul	✓	✓	✓	LC	LC
<i>Pycnonotus zeylanicus</i>	Straw-headed Bulbul	✓			CR	EN
<i>Spilopelia chinensis</i>	Spotted Dove	✓	✓	✓	LC	LC
<i>Todiramphus chloris</i>	Collared Kingfisher	✓	✓		LC	LC
<i>Treron vernans</i>	Pink-necked Green Pigeon	✓	✓	✓	LC	LC



Figure 5.107 Straw-headed Bulbul (*Pycnonotus zeylanicus*) and Oriental Magpie-Robin (*Copsychus saularis*) recorded within the Study Area.

Mammals (non-volant)

A checklist of all non-volant mammals recorded within the Study Area may be found in Table 5.77. All the species detected are urban-adapted and widespread human commensals, found island-wide. No species of conservation significance were observed. It was also noted that while macaques are often found around Labrador Park, they were not observed within the study area (e.g., Keppel Island and Caribbean at Keppel Bay) during baseline surveys.

Table 5.77 Checklist of non-volant mammal species recorded within the Study Area, along with local and global conservation statuses. Species of conservation significance globally or locally are indicated in bold

Species		Survey Location			Conservation Status	
Scientific Name	Common Name	RP01	RP02	Transect	IUCN	SRDB3
<i>Felis catus</i>	Domestic Cat	✓	✓	✓^	N.A.	N.A.
<i>Paradoxurus musangus</i>	Sumatran Palm Civet*				LC	LC
<i>Rattus sp.</i>	Rat sp.			✓^	N.A.	N.A.
<i>Suncus murinus</i>	House Shrew		✓		LC	LC

* Detected indirectly via droppings on pavement adjacent to Hillock Area patch (Figure 5.108, Figure 5.104Figure 5.104)

^ Detected within vicinity of transect by camera trap footage

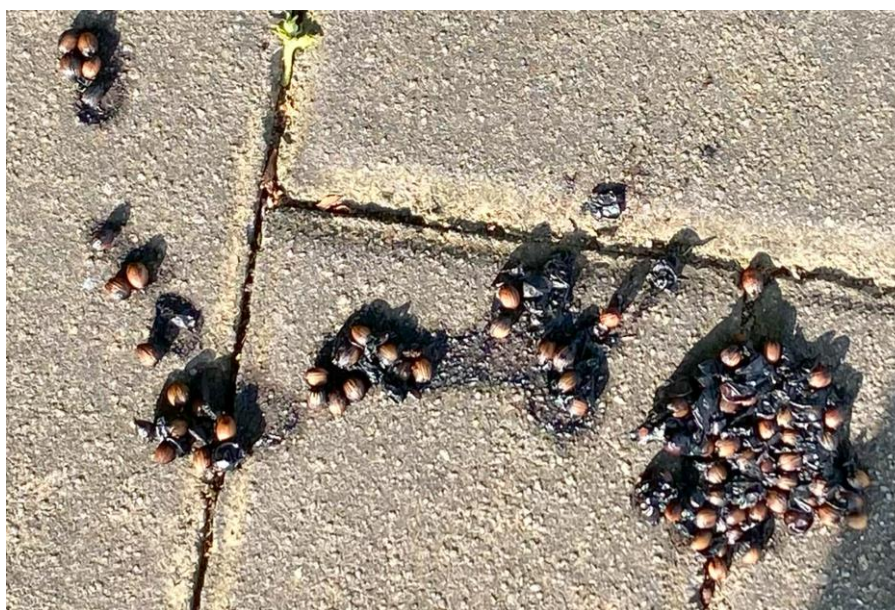


Figure 5.108 Droppings, presumably belonging to the Sumatran Palm Civet (*Paradoxurus musangus*) found along a pavement within the Study Area

Multiple free-roaming cats (*Felis catus*) were found loitering in the vicinity of RP01, RP02, and the line transect. As free-roaming cats are well-known predator of small mammals and birds (Murphy *et al.*, 2019), their presence across the Study Area and the island at large may be a possible explanation for the death of small mammal species detected by the Study.

Although not detected during the surveys, Smooth-coated Otters (*Lutrogale perspicillata*) is a globally Vulnerable and locally Endangered species that have been recorded in the vicinity of Keppel Island, such as the nearby Reflections at Keppel Bay Condominium. As such, they may also be a species of probable occurrence within the Study Area.

Bats

The field assessment recorded three bat species (Table 5.78). All three species were insectivorous bats identified using ultrasonic sonograms (Figure 5.109). The species recorded include the Pouched Tomb Bat (*Saccolaimus saccolaimus*), Lesser Asian House Bat (*Scotophilus kuhlii*), and Narrow-winged Pipistrelle (*Pipistrellus stenopterus*). All the species have a widespread distribution across Singapore and are not species of global or local conservation significance. No frugivorous bats were visually observed, and no bamboo bat clusters were encountered during the surveys.

Table 5.78 Number of independent audio detections for each bat species captured by the Echo Meter within the Study Area. The local (SRDB3) and global (IUCN) conservation status of each species is also shown (LC = Least Concern).

Scientific Name	Common Name	Conservation Status		Number of Audio Recordings		
		SRDB3	IUCN	RP01	RP02	Transect
<i>Pipistrellus stenopterus</i>	Narrow-winged Pipistrelle	LC	LC	0	2	0
<i>Saccolaimus saccolaimus</i>	Pouched Tomb Bat	LC	LC	6	62	18
<i>Scotophilus kuhlii</i>	Lesser Asian House Bat	LC	LC	23	54	2
Total				29	118	20

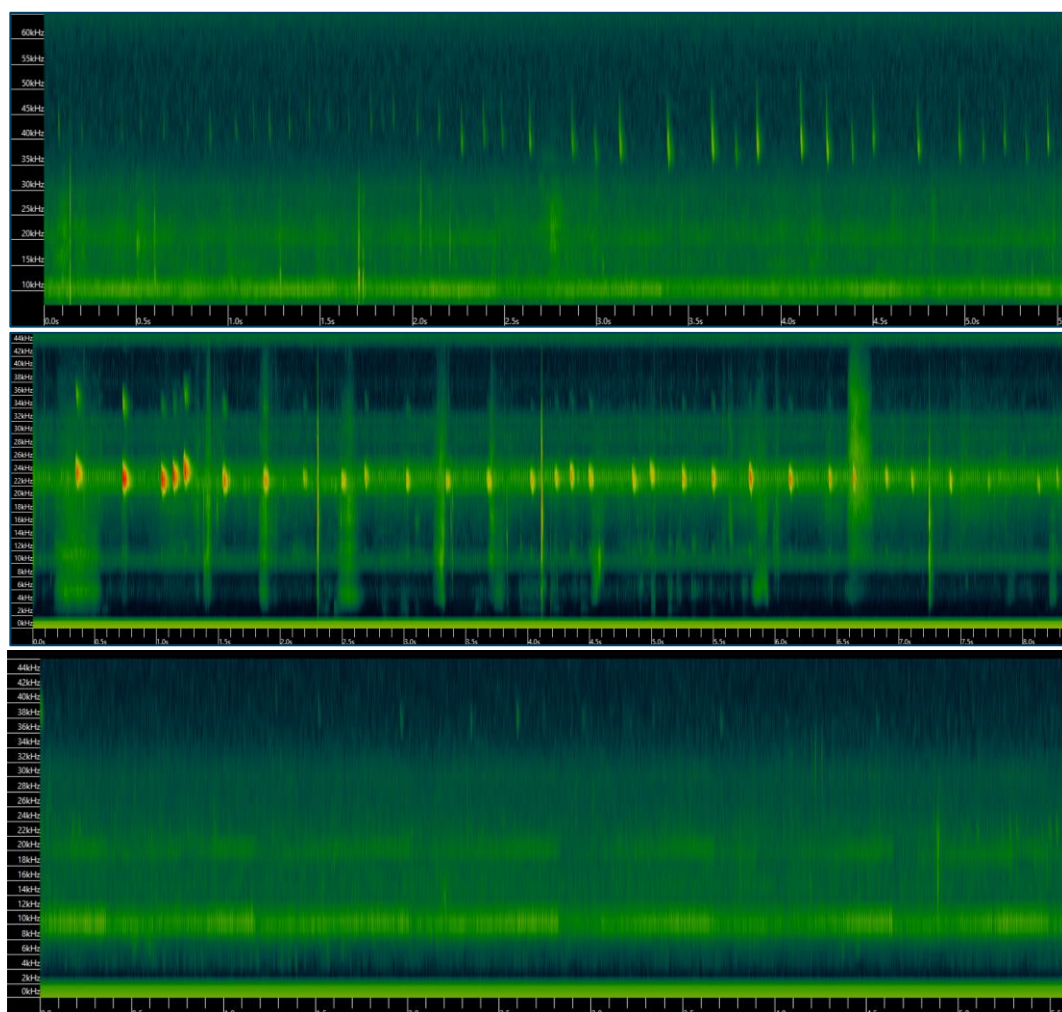


Figure 5.109 Sonograms of insectivorous bat calls recorded. (Top) *Scotophilus kuhlii*; (Middle) *Saccolaimus saccolaimus*; and (Bottom) *Pipistrelle stenopterus*. Sonograms for *Scotophilus kuhlii* and *Pipistrelle stenopterus* are differentiated by the length of the bat call

Amphibians

Table 5.79 provides a checklist of all amphibian species recorded within the Study Area is provided in. All detected species were widespread urban-adapted species, and none were of conservation significance globally or locally.

Table 5.79 Checklist of amphibian species recorded within the Study Area, along with local and global conservation statuses. Species of conservation significance globally or locally are indicated in bold

Species		Survey Location			Conservation Status	
Scientific Name	Common Name	RP01	RP02	Transect	IUCN	SRDB3
<i>Duttaphrynus bengalensis</i>	Asian Toad	✓		✓	LC	LC
<i>Eleutherodactylus planirostris</i>	Greenhouse Frog		✓	✓	LC	NA

Species		Survey Location			Conservation Status	
Scientific Name	Common Name	RP01	RP02	Transect	IUCN	SRDB3
<i>Polypedates leucomystax</i>	Common tree frog*				LC	LC

* Ad-hoc sighting outside official survey locations, but within Study Area

The paucity of amphibian species recorded by the surveys could potentially be attributed to a dearth of freshwater bodies occurring within the site. Amphibians rely heavily on permanent and sometimes ephemeral streams and puddles in order to reproduce and spawn aquatic larvae. In the general absence of such sources of freshwater, a significant drop in amphibian diversity is within expectations. The presence of the Greenhouse Frog (*Eleutherodactylus planirostris*) within both the forested Hillock and urban areas is thus also within expectations, as the species is known to undergo direct development (i.e., no tadpole stage), and would be able to reproduce successfully even in the absence of waterbodies.

Reptiles

A checklist of all reptile species recorded within the Study Area is provided in Table 5.80. All species detected were widespread urban-adapted species, and none of them were of conservation significance globally or locally.

Table 5.80 Checklist of reptile species recorded within the Study Area, along with local and global conservation statuses. Species of conservation significance globally or locally are indicated in bold.

Species		Survey Location			Conservation Status	
Scientific Name	Common Name	RP01	RP02	Transect	IUCN	SRDB3
<i>Calotes versicolor</i>	Changeable lizard*				LC	N.A.
<i>Dendrelaphis pictus</i>	Painted Bronzeback		✓		LC	LC
<i>Gekko monarchus</i>	Spotted house gecko			✓	LC	LC
<i>Hemidactylus frenatus</i>	Common House Gecko	✓	✓		LC	LC
<i>Lycodon capucinus</i>	Common House Snake			✓	LC	LC

* Ad-hoc sighting outside official survey locations, but within Study Area.

Butterflies

A checklist of all butterfly species recorded within the Study Area is provided in Table 5.81. All species found are widespread, urban and parkland-adapted, with a wide range of locally available host plants that are easily encountered. No species of global or local conservation significance were detected.

Table 5.81 Checklist of butterfly species recorded within the Study Area, along with local and global conservation statuses. Species of conservation significance globally or locally are indicated in bold.

Species		Survey Location			Conservation Status	
Scientific Name	Common Name	RP01	RP02	Transect	IUCN	SRDB3
<i>Acraea terpsicore</i>	Tawny Coster		✓		N.A.	LC
<i>Catopsilia scylla cornelia</i>	Orange Emigrant		✓		N.A.	LC
<i>Delias hyparete metarete</i>	Painted Jezebel		✓	✓	N.A.	LC
<i>Eurema sp.</i>	Grass Yellow sp.			✓	N.A.	N.A.
<i>Junonia hedonia ida</i>	Chocolate Pansy			✓	N.A.	LC

Odonates

A checklist of all odonate species recorded within the Study Area is provided in Table 5.82. The sole species found in the Study Area was the White-barred Duskhawk (*Thylomis tillarga*), which is a locally widespread and commonly encountered species, and of no global or local conservation significance.

Table 5.82 Checklist of odonate species recorded within the Study Area, along with local and global conservation statuses. Species of conservation significance globally or locally are indicated in bold.

Species		Survey Location			Conservation Status	
Scientific Name	Common Name	RP01	RP02	Transect	IUCN	SRDB3
<i>Thylomis tillarga</i>	White-barred Duskhawk			✓	LC	LC

Like amphibians, odonates rely on freshwater bodies to reproduce and spawn aquatic larvae as well. As such, the lack of suitable freshwater bodies on Keppel Island correlates strongly to the absence of most commonly encountered urban-adapted odonate species, such as the Common Parasol (*Neurothemis fluctuans*). The White-barred Duskhawk is a strong flier, and the individuals encountered during the line transect survey may have been using the island as a stopping point and is unlikely to be from a resident population.

Camera Trapping

The camera trapping survey within the Hillock Forest on Keppel Island detected a total of four (4) terrestrial fauna species, from a total of 64 camera trap nights. A checklist of all species detected by the sole camera trap (CT01) is provided in Table 5.83.

Table 5.83 Checklist of species detected by camera trap CT01, along with local and global conservation statuses. Species of conservation significance globally or locally are indicated in bold.

Species		Conservation Status	
Scientific Name	Common Name	IUCN	SRDB3
<i>Copsychus saularis</i>	Oriental Magpie-Robin	LC	VU
<i>Felis catus</i>	Domestic Cat	N.A.	N.A.
<i>Gallus gallus</i>	Red Junglefowl	LC	NT
<i>Rattus</i> sp.	Rat sp.	N.A.	N.A.

Nearly all the species detected are urban-adapted and widespread human commensals, which are found island wide, with the exception of the Oriental Magpie-Robin, which is a locally Endangered species. The presence of Domestic Cats within the Hillock Forest may likely be a contributing factor for the dearth of species detected by the camera trap, as free-roaming cats are a well-known predator of small mammals and birds (Murphy *et al.*, 2019).

5.9.3 Evaluation Framework

The generic criterion used to evaluate the Importance of ecological and biodiversity receptors, as stipulated in the BIA Guidelines (NParks, 2024b), is adapted following a customisation that considers the context-specificity of Singapore's ecological landscape, and its constituent biodiversity, habitat types, and conservation values.

The evaluation of the Importance of identified receptors here utilised findings from the baseline surveys, the team's expert judgement, available scientific literature, an experience from similar developments within Singapore. The evaluation of Importance scores also considers the sensitivity or susceptibility of ecological receptors to the environmental pressure being assessed (e.g., airborne noise and air pollution).

5.9.3.1 Evaluation of Receptor Importance

The evaluation of the Importance of identified receptors here utilised findings from the baseline surveys, the team's expert judgement, available scientific literature, and experience from similar developments within Singapore, using Table 4.11.

5.9.3.2 Evaluation of Magnitude of Change

The specific criteria used to evaluate impact magnitude on terrestrial ecology and biodiversity receptors are presented in Table 5.84 and is based on expert judgement of the local ecological context and with reference to other relevant scientific literature.

For terrestrial fauna receptors, there are no specific guidelines or thresholds stipulated globally or in Singapore, partly because the effects of noise on most fauna species are

poorly understood (Larkin *et al.*, 1996; Brown, 2001), hence guidance is taken from relevant organisations, literature, and expert judgement. For example, The Nature Conservancy (2015) recommends noise levels to be ideally as low as 55 dBA within 100 m from source to protect sensitive animal species. Other studies have suggested that higher noise levels of around 68 dBA may reduce birds' foraging ability and eventually lead them to avoid and abandon the habitat (Ortega, 2012). For acoustic pollution impacts specific to aquatic fauna and habitats, a noise level above 60 dBA is accepted to induce behavioural changes in freshwater fauna and temporary changes in population patterns (Kunc *et al.*, 2016). Given that different species have varied tolerance to anthropogenic noise and noise levels (Parris & Schneider, 2008) and taking into account the generally anthropogenic nature of the Study Area, a noise level of 60 dBA is taken as the threshold for fauna receptors in this Study, above which detectable changes are predicted.

Table 5.84 Criteria applied in the evaluation of Magnitude of Change for terrestrial ecology during the Construction Phase

Score	Generic Criteria	Specific Criteria		Noise-specific Criteria
		Loss of Flora/Fauna	Human-wildlife conflict	
-4	Major negative disadvantage or change	- Expected depletion of population beyond 75 % of current abundance or diversity - Loss of sufficient population numbers such that expected fecundity or recoverability of the population is negligible or unlikely - Affects species without the ability to respond and relocate rapidly and further away from the source of potential injurious activities, and thus are likely to experience significant mortality and/or injuries consequential to fitness	- Developed site is connected to at least three or more other natural sites that are at least translocatable through short-distance flight, terrestrial or aquatic locomotion - Developed site is keystone position for connectivity across global or regional ecological landscape	- Predicted noise level cause an increase of greater than 10 dBA as compared to baseline level - Predicted noise level exceeded 85 dBA, likely resulting in death or injury of fauna receptors
-3	Moderate negative disadvantage or change	- Expected depletion of the population between 50 – 75 % of current abundance or diversity - Loss of sufficient population numbers such that expected fecundity or recoverability of the population is possible only in the long term, and/or up to 50 % of current abundance or diversity - Affects species likely to respond quickly but lack the means to relocate rapidly and further away from the source of potential injurious activities. Species in this group are likely to be able to live amidst and evade deleterious activities/find alternative shelter (Urban adaptive mammals). Injuries/mortality likely to be occasional in nature.	- Increase to the rate of encounters with species that may result in injury in humans. - Species that are typically perceived as nuisances and possibly as threats by construction personnel and others, highly tolerant of human presence and urban environments, and frequently implicated in human-wildlife conflict	- Predicted noise level cause an increase of up to 10 dBA as compared to baseline level - Or predicted noise level of 80-85 dBA, resulting in evident physiological and anatomical changes, and low survivability and biological fitness of fauna populations

Score	Generic Criteria	Specific Criteria		Noise-specific Criteria
		Loss of Flora/Fauna	Human-wildlife conflict	
-2	Minor negative disadvantage or change	- Expected depletion of the population between 25 – 50 % of current abundance or diversity - Loss of sufficient population numbers such that expected fecundity or recoverability of the population is possible in the long term, and/or up to 75 % of current abundance or diversity - Affects species with a delayed response to disturbances, but with the means to relocate rapidly and further away from the source of potential injurious activities.	- Increase to the rate of encounters with species that may result in fear, revulsion, or concern in humans - Species that are possibly perceived as both nuisances and threats by construction personnel and others, less tolerant of human presence and urban environments	- Predicted noise level cause an increase of up to 8 dBA as compared to baseline level - Or predicted noise level of 70 – 80 dBA, resulting in significant behavioural changes in fauna (change in feeding patterns, predator-prey interactions, reduced ability to maintain territories and increased aggression between individuals)
-1	Slight negative disadvantage or change	- Expected depletion of the population between < 25 % of current abundance or diversity - Loss of sufficient population numbers such that expected fecundity or recoverability of the population is possible in the long term, and/or up to 90 % of current abundance or diversity - Affects species with the ability to respond and relocate rapidly and further away from the source of potential injurious activities, and thus are likely to experience limited to no mortality and/or mild injuries	- Increase to the rate of encounters with species that may result in annoyance in humans. - Species that may be perceived as a nuisance by construction personnel and others, face restricted to slight persecution in abundance, less tolerant of human presence and urban environments	- Predicted noise level cause an increase of up to 5 dBA as compared to baseline level - Or predicted noise level of 60 – 70 dBA, resulting in temporary/recoverable shifts in fauna behaviour (e.g., change in vocalisation pattern or avoidance of areas with acoustic pollution), which are not expected cause a substantial change in species population

Score	Generic Criteria	Specific Criteria		Noise-specific Criteria
		Loss of Flora/Fauna	Human-wildlife conflict	
0	No change	- No expected loss of flora and fauna - No increments to the expected rate of animal mortality and injury compared to the baseline level	- Increase to the rate of encounters with species likely to incite no negative responses in humans. - Species that are not perceived as nuisances or threats by construction personnel and others.	- No change in predicted noise level compared to baseline level - Or predicted noise level below 60 dBA, with no changes in fauna behaviour or populations expected

Ground Vibration

There are no other standards or guidance on the ground vibration impact to ecological and human receptors except for the guidance on the effect of vibration levels to human receptors in BS 5228-2 published by the British Standard Institute. A qualitative evaluation framework for fauna receptors have been developed and summarised below in Table 5.85 (BS, 2009b).

Table 5.85 Evaluation framework for Magnitude of Change in ground vibration

Score	Generic Criteria	Specific Criteria	
		Human Receptors	Fauna Receptors
-4	Major negative disadvantage or change	> 10 mm/s PPV	Affects entire population or a significant part of it causing a substantial decline in abundance or change in and recovery of the population (or another dependent on it) is not possible either at all or within several generations due to natural recruitment
-3	Moderate negative disadvantage or change	1 to 10 mm/s PPV	Effect causes a substantial change in abundance or reduction in distribution of a population over one or more generations but does not threaten the long-term viability or function of that population, or any population dependent on it
-2	Minor negative disadvantage or change	0.3 to 1 mm/s PPV	Effect does not cause a substantial change in the population of the species, or other species dependent on it
-1	Slight negative disadvantage or change	0.14 to 0.3 mm/s PPV	Effect is within the normal range of natural variation accustomed to by the population of the species
0	No change	< 0.14 mm/s PPV	Status quo

Accidental Spills and Leaks

The evaluation criteria for accidental spills and leaks are similar to that in marine ecology and biodiversity as outlined earlier in Table 5.65 under Section 5.8.3.

5.9.4 Impact Assessment

Similarly to marine ecology receptors, terrestrial ecology and biodiversity receptors are also allocated an Importance score based on a set criterion. Due to pronounced differences between the two types of ecological habitats, determining the importance scores of terrestrial ecology receptors is based on Table 4.11.

Due to a marked differences of flora and fauna within the Hillock and the urban area within the Project footprint, flora and fauna were split into each area as separate receptors. Flora within the Project footprint, which mainly comprised of urban managed vegetation along wide streets or carpark areas, hence the flora receptors there was given an Importance score of "1". In contrast, flora within the Hillock Area (Figure 5.101) was comprised of a high proportion of conservation significant species (25.2 %) within a native dominated old

secondary forest habitat, in a small 0.5 ha of area. It is also likely that this area will be a key stepping stone for the regeneration or dispersal of rare native species of flora from neighbouring native-dominated forests. Hence, the score of the flora within the Hillock Area is “4”.

For fauna within the Project footprint, two locally conservation significant species were found, namely, the Straw-headed Bulbul (*Pycnonotus zeylanicus*, locally “Endangered” and internationally “Critically Endangered”) and the Oriental Magpie-Robin (*Copsychus saularis*, locally “Vulnerable”). As such, an Importance score of “4” was allocated to this receptor. For fauna within the Hillock, the Straw-headed Bulbul was not detected during transect surveys within the forest. In fact, most of the bulbuls were detected at the survey point facing Berlayer Creek (RP01), and mostly flying past the point location, and it is suspected that they were mainly utilising the habitats at Labrador Park instead of the Hillock Area. As such, the Importance score for fauna in the Hillock area is “3”.

Similar to marine ecology and biodiversity receptors, the Permanence (P), Reversibility (R) and Cumulativity (C) of the pressure also needs to be determined. For terrestrial receptors, construction phase as short term and most of the pressures being able to be mitigated with proper construction SOPs, means that the Permanence and Reversibility score of “2” each. For Cumulativity, the loss of an area typically does not affect another terrestrial habitat. Since the Hillock forest is located to the far south of Singapore mainland, it is unlikely to be a habitat key to fauna or flora connectivity, hence this score for terrestrial receptors is typically “2” for this Project. Should there be exceptions to this scoring, for example, for a certain pressure-receptor combination, it will be elaborated upon in the text below.

5.9.4.1 Terrestrial Flora

Encroachment of construction machinery to plant root systems and/or tree canopy of Flora in the Hillock Area

These two impacts were raised by the National Parks Board (NParks) during the TA consultation scoping meeting. Due to the proximity of the construction work area to the Hillock area, there is a possibility that the construction equipment would physically damage the plant roots systems, or the cranes used could hit the tree canopy of flora in the hillock area.

From site visits and site topology drawings, the infringement into root systems is unlikely due to the presence of perimeter drain along the southern boundary of the Hillock Area, along with the gradient of the slope leading up to the Hillock Area (Figure 5.110). However, potential physical damage to the tree canopy is still a possibility. Should these events occur, these changes will cause localised disruption to the forest within a small area (around ~20m into the hillock forest), although the damage will be noticeable. It should also be noted that such an impact has cumulative effects on the flora, leading to a Cumulativity score of “3”. As such, the Magnitude of Change is assessed as “-2”, giving an impact significance of **Minor Negative Impact**.

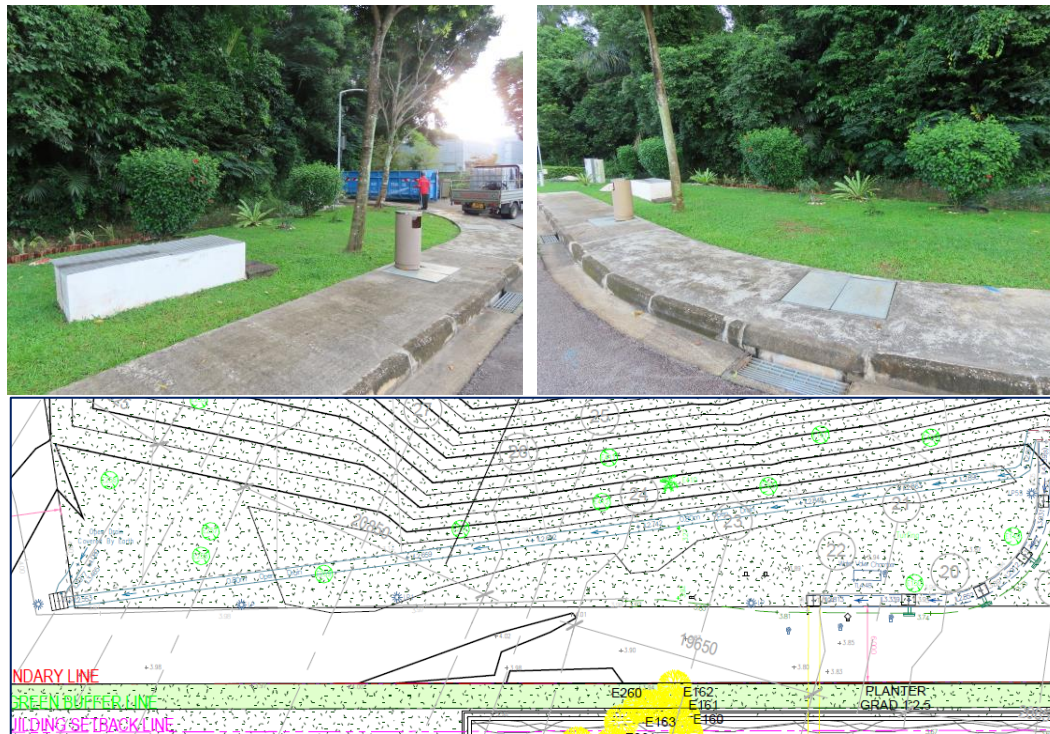


Figure 5.110 Images of the perimeter drain on site (top) and drawings of the drains on the site plan of Keppel Island (bottom)

Impact of Spills and Leaks on Flora in the Hillock Area

The containment of pollutive liquids and construction materials, and their potential negative impacts when accidentally released, outlined in Section 5.8.4.14, can also occur for terrestrial flora. However, in this case, due to the presence of the perimeter drain mentioned above, spills or leaks that occur are likely directed towards the perimeter drain and away from any forested habitat within the Hillock Area. Similar to above, such an impact has potential cumulative effects on the flora habitat in the Hillock Area, leading to a Cumulativity score of “3”. Hence, a “0” Magnitude of Change is expected, giving an impact significance of **No Impact**.

5.9.4.2 Terrestrial Fauna

Construction Activities Leading to Faunal Injury or Mortality for Fauna within the Project Footprint

Heavy machinery is expected to be involved in the site clearance and development construction. This machinery could lead to physical injury or mortality to fauna using the area. The Magnitude of Change for faunal injury or mortality during the Construction Phase has been assigned a score of “-1” as low biodiversity was observed within the Project footprint, and the species observed can respond and relocate quickly. Hence a **Slight Negative Impact** is expected from construction activities on faunal injury or mortality during construction.

Construction Space Potentially Increasing Human-Wildlife Conflict (Fauna in both Hillock Area and Project Footprint)

The construction works will be taking a plot of land that was previously used by certain fauna, displacing them towards urban areas, and increasing the potential for human-wildlife conflict to occur.

From our baseline surveys, it was found that there will not be any eviction of fauna species from the Hillock Area, meaning that the possibility of human-wildlife conflict remains low. However, the area is known to be home to a family of Smooth-coated Otters (*Lutrogale perspicillata*), which are globally “Vulnerable” and locally “Endangered”. They are well known to residents and travel around the area, such as at the nearby Reflections at Keppel Bay, despite them not being detected during baseline surveys. This family group could therefore be encountered during construction, or displaced slightly from their usual routines and attacks from these animals may result in bites, scratches or bruises.

Despite the severe consequences of potential human-wildlife conflict, the probability of such attacks is likely relatively low. In addition, the occurrence of human-wildlife conflict is likely to be transient and isolated. Thus, this pathway was assessed to have a Magnitude of Change score of “-1”. This score is the same for terrestrial fauna within the Project Footprint and in the Hillock area. Therefore, **Slight Negative Impact** is expected from the effects of human-wildlife conflict during construction.

Air Pollution Impact on Fauna within Hillock Area

However, fauna in the nearby habitat within the Hillock Area may be affected by dust generated from activities at the Project site. Construction activities, such as the demolition of the existing Wharf structure, grading, and earthmoving, will generate dust. Since the Project involves building a low-rise residential area, activities like asphalt road development can emit volatile organic compounds (VOCs) and other fumes from construction vehicles. Prolonged exposure to these emissions may adversely affect the health of nearby wildlife, particularly small mammals, birds, and insects.

However, since this exposure is expected to be short-term and at present, the fauna at the edge of the Hillock Area is exposed to vehicle emissions from the service road south of the Hillock Area. This suggests that these species may have adapted to these anthropogenic air quality conditions. A Magnitude of Change score of “-1” was therefore assigned because of the relatively localised exposure, and the fauna species are likely able to respond and relocate further away from the source of air pollution when construction begins. Hence, **Slight Negative Impact** from air pollution on terrestrial fauna in the hillock area is expected from the construction activities during construction.

Airborne Noise Impact on Fauna within Hillock Area

The potential effects of noise on terrestrial wildlife include physical damage to hearing organs, increased energy expenditure or physical injury from reacting to noise, and disruption of normal behaviours. Noise can also hinder communication, leading to long-term consequences like habitat loss due to avoidance, reduced reproductive success, and higher mortality rates. Some species may experience stress, which affects their foraging or breeding habits or causes them to leave an area. Others may seem unaffected or gradually adapt to the noise. Certain species have adapted to urban environments by changing the frequency of their vocalisations to avoid being drowned out by noise and have thrived in these settings. However, not all species can adjust their behaviour, and most are negatively impacted by human-generated noise, often avoiding noisy areas.

Construction activities are expected close to the Hillock Area (10 m from the Project boundary). The predicted noise levels at Hillock Area exceeded the threshold noise limit of 60 dBA by up to 12 dBA (refer to Section 5.5). The forest edge facing the construction site is expected to experience a slight increase in noise level perception during construction. However, the availability of space within the Hillock Area provides a refuge for fauna species to retreat away from the noise sources.

Terrestrial fauna was assigned a score of “-4” for Magnitude of Change due to the predicted noise level, which increased by over 10 dBA compared to the baseline level (Table 5.23). A **Minor Negative Impact** from airborne noise on fauna in the hillock area is expected during construction.

Ground Vibration Impact to Fauna within Hillock Area

The predicted ground vibration level from the vibratory piling rig at Hillock Area is 2.86 mm/s. A score of “-2” for Magnitude of Change was attributed for the vibration impact to terrestrial fauna as the effect will not cause a substantial change in the wild fauna population. This is due to relatively localised area of effect from the ground vibration caused by the piling works. Hence, a **Slight Negative Impact** is expected from ground construction vibration on the hillock area fauna during construction.

Impact of Spills and Leaks on Terrestrial Fauna within the Hillock Area

Similar to Section 5.9.4.1 for terrestrial flora, the presence of a perimeter drain along the southern boundary of the Hillock Area ensures that any spills or leaks that occur are directed towards the perimeter drain and away from any forested habitat within the Hillock Area. As such, “0” is assigned to the Magnitude of Change score for the impact of spills and leaks on the terrestrial fauna. Hence, **No Impact** is expected.

5.9.5 Mitigation Measures

As mentioned above, a dedicated Construction-specific EMMP (CEMMP) shall be designed and executed during the construction process and shall comprise of both marine and terrestrial aspects. The terrestrial aspects of the CEMMP are elaborated upon here.

5.9.5.1 Construction Phase Mitigation Measures

Minimum controls for each potential impact occurring from the Construction Phases are listed in Table 5.86. This reflects biodiversity-specific minimum controls commonly implemented in Singapore for similar construction activities. These are assumed to be implemented for the impact assessment. These measures should be proposed in tandem with other environmental receptors (e.g., air and noise).

Table 5.86 Description of minimum controls implemented during the Construction Phase

Work Activities	Minimum Controls
General	• Proper installation of hoardings to delineate work site, discourage wildlife entry into the site and prevent work and equipment encroachment outside the work site. • Avoid fogging by implementing preventive measures for mosquito to remove sources of stagnant water or water-bearing receptacles, e.g., providing well-maintained pitched roof, clearing discarded items daily, store materials appropriately, level up ground depression/uneven surfaces, ensure effective drainage flow. • Daily checks by Environmental Manager/Environmental Control Officer on site, including but not limited to: ○ Visual checks for animal entrapments on-site, particularly within tree protection zones (TPZ), Earth Control Measures (ECM) sedimentation tanks, erosion control blankets (ECBs) and among construction materials and equipment. ○ Gaps in hoarding. • Establish a Wildlife Response Plan in consultation with NParks Animal Management Centre to be executed during encounters with trapped, injured or dead wildlife, as well as incidents of human-wildlife conflicts, in accordance to Section 10 of Wildlife Act. • There are no night works implemented for the Project. However, in the event of an emergency where night works need to be conducted, a light management plan will need to be developed. • Adhere to regulations stipulated in the (1) Wildlife Act, (2) Parks and Trees Act, and (3) Animals and Birds Act. • Ensure that no construction equipment or material is to be found on land outside the Project boundary
Vegetation Clearance	• Set up TPZs around trees or other plant specimens to be retained (if any). This should be executed by certified arborists and in accordance with NParks' guidelines. • Conduct inspections of fauna prior to felling or removal of vegetation. This should be done by an ecologist who is able to identify wildlife and/or active nesting structures, such as bird nests, tree hollows and/or burrows, and bamboo clusters. • Implement soil erosion control measures as soon as vegetation has been removed and soil is exposed. • Engage a Qualified Erosion Control Professional (QECP) to formulate and implement an ECM plan in accordance with PUB requirements
Earthworks (Excavation, above and below ground construction)	• Implement soil erosion control measures. • Ensure proper storage of materials likely to leach harmful chemicals and fuel-powered equipment. Store them away from waterbodies and/or sensitive habitats. • Implement dust control measures. • Ensure noise levels are within approved limits, and to implement noise barriers where required.

Minimise

In addition to minimum controls, Table 5.87 includes a summary of the key recommended measures to avoid and minimise biodiversity impacts to habitats, flora and fauna species during the Construction Phase.

Table 5.87 Key recommended measures to minimise biodiversity impacts during the Construction Phase

Receptor	Impact Types	Mitigation Measures
Flora	Hillock Area Tree Canopy Infringement	A 20m “No-Infringement Zone” is to be established where no cranes and other elevated equipment can enter (Figure 5.111)
Fauna	- Faunal injury or mortality - Human-wildlife conflict	- Conduct regular site inspections to ensure contractor compliance to the EMMP - Install hoarding properly (no gaps, flushed to the ground) to prevent wildlife entry - Conduct biodiversity awareness trainings - Ensure good housekeeping - Conduct daily checks for roadkill and fauna entrapment within the worksite - Use only fully biodegradable wildlife-friendly erosion control blankets - Execute Wildlife Response Plan when a trapped/injured/dead/dangerous animal is encountered - Restrict entry of site personnel beyond the worksite
	Ground vibration from construction	- When technically feasible, use construction equipment with less vibration intensity or shorter duration (e.g., use a rotary pile driver in replacement of the vibratory pile driver; use dump trucks with higher loading capacity to reduce the duration of operation) - Low-power machinery of the same type should be considered to reduce the vibration strength at source (i.e., use vibration rollers and excavators with smaller capacity to reduce intensity of operation.) - A minimum distance of 20 m between heavy vibration-generating equipment and the edge of Hillock Area is recommended. - Ensure vehicles and equipment are well maintained. - Sequence construction activities to minimise cumulative impact from the vibration-generating equipment. - Maintain a complaints procedure to log and track response to complaints received from stakeholders.

Receptor	Impact Types	Mitigation Measures
	Dust and emissions from construction	• Comply with relevant environmental regulations, including the Environmental Protection and Management Act and any other regulations and guidelines come into effect when the time of construction works commencement. • Minimise the duration of bare earth exposure through careful planning of work sequence and schedule • Plants and machineries used on site shall be properly and regularly inspected and maintained to control dust and air pollutants emission. • Minimise dust emission from dusty activities, e.g., excavation and demolition, by water spraying and/or physical screening. • Installation and proper maintenance of dust screen, fencing or hoarding along construction site perimeters recommended to reduce dust deposition. • Avoid burning of waste or other materials.
	Airborne noise from construction	• Prior to commencement of construction works, install hoarding along Project boundary and noise barrier of 4.0 m along the Project boundary facing Hillock Area and Marina at Keppel Bay • Select equipment with low noise emissions • Keep compressor, generator and engine compartment doors close and plant turned off when not in use • Machines in intermittent use will be shut down or throttled down to a minimum during periods between works • Apply a speed limit (typically 20 km/h) to the access track and around the site which drivers will be required to adhere to • Construction personnel to be trained in noise-reduction behaviours such as reducing the drop height of materials. • Daily toolbox briefing should include reminders on the need to implement noise-reduction behaviours • All construction personnel should be educated about sensitive ecological nature of work areas before commencing the work

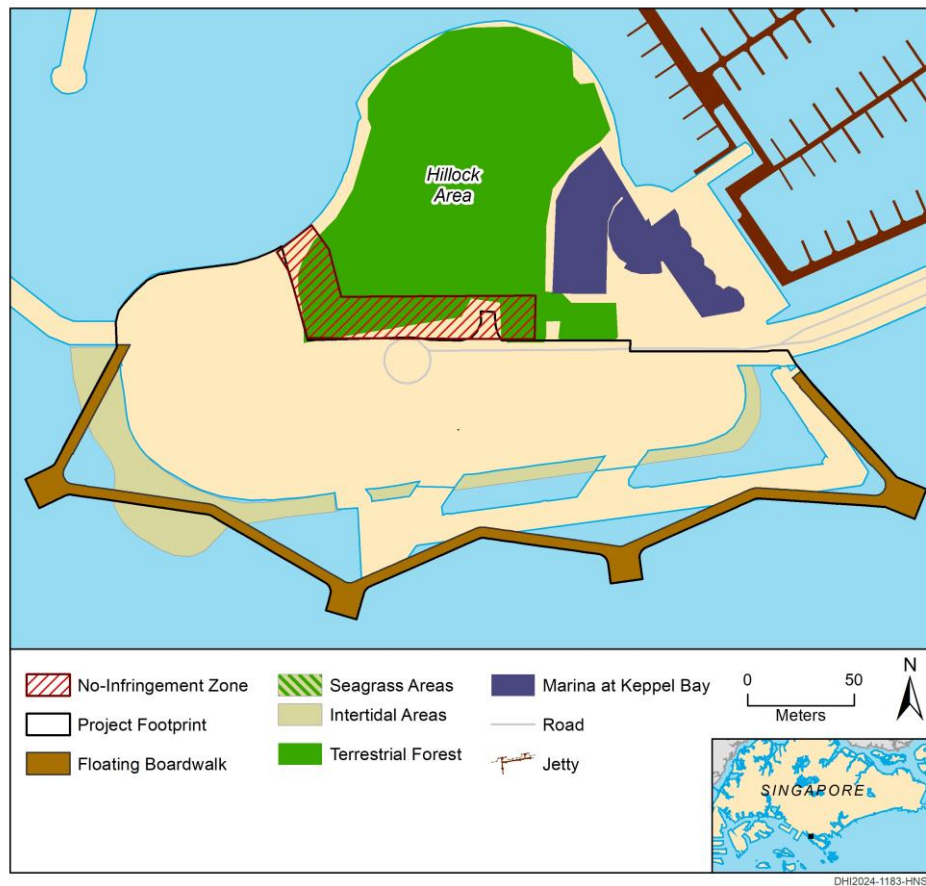


Figure 5.111 Map showing the “No-Infringement Zone” into the Hillock forest, a mitigation measure to prevent canopy destruction during the construction works

Pre-felling Fauna Inspections

Trees selected for imminent felling should be adequately marked and physically tagged in a clear and distinct manner. Pre-felling inspections should be performed on such trees with the assistance of a trained ecologist, to check for the presence of arboreal fauna, fledging avifauna and other pre-existing or erected microhabitats, such as bird nests, bee hives and tree burrows. Appropriate actions should then be undertaken in response to the findings. For example, planned works should be postponed if active bird nests are found on trees marked for felling, until further verification attempts ascertain that the nests are no longer occupied or utilised.

Wildlife Management, Protection and Monitoring Plan (including Wildlife Response and Rescue Plan)

A suitable Wildlife Management, Protection and Monitoring Plan is to be prepared prior to the commencement of construction or clearance activity. This plan should identify and flag out potential species of interest, including conservation-significant species, species likely to be able to move across established hoardings, and potentially injurious species. The plan should also encompass suitable Wildlife Response and Rescue protocols; these should dictate the procedures for the appropriate handling, trapping and relocation of errant wildlife, as well as contain relevant information for the employment of NParks Certified Animal Management Specialist to execute the aforementioned plan.

Planning and Installation of Hoarding

A suitable hoarding plan should be established prior to the commencement of construction or clearance activity. The placement of the hoarding should demarcate and define the planned construction area, and no modifications to the natural environment beyond the

hoarding should be undertaken. The hoarding should be well-marked. Hoarding lines should also be located at a distance from any retained trees to prevent damage to the major roots of trees during the installation process, which may destabilise trees and result in them falling accidentally. It shall also be noted that any construction equipment, including footings, should only be placed or used within the boundaries of the terrestrial working space.

Once the hoarding is satisfactorily installed, its structural integrity should be subject to regular inspections. This will ensure that no changes to the hoarding or earthen foundations occur throughout the Construction Phase, which may allow various fauna to enter the development area through gaps or by digging.

Flora Management

Clearance works should consider any vegetation immediately adjacent to the Project site, particularly for slope levelling works. Working areas should be marked out by physical boundaries in order to prevent excess vegetation clearance. Should there be any trees identified for retention, as well as trees along the boundary of the Project, appropriate TPZs should be implemented. These TPZs are to be recommended by an ISA-certified Arborist and installed prior to any vegetation clearance. The integrity of TPZs is to be monitored regularly by the ISA-certified Arborist, who is to maintain records of tree health and TPZ integrity.

Prevention of Fauna Entrapment

Erosion Control Blankets (ECBs) can prove to be hazardous – becoming traps for ground-dwelling fauna such as snakes and lizards. To minimise the impact from fauna entrapment, the selection of ECBs should be limited to those made of fully biodegradable material. In addition, all ECBs and pits should be checked daily by on-site personnel, to minimise the likelihood of entrapping fauna, which can result in increased rates of injury or mortality over prolonged periods.

Biodiversity Awareness Training

The potential presence Smooth-coated Otters and Reticulated Pythons may pose a threat to human health and safety. Conversely, aggressive animals and other fauna that generally repulse people may be subjected to persecution from people working on site. The implementation of Wildlife Awareness Training aims to provide an overview of the potentially injurious or distasteful species on site, an educated assessment of their potential threat and alternative solutions to violence for the management of such individuals. In addition, such training will also provide information on preventative measures intended to reduce the occurrence of negative human-wildlife encounters. For example, prevent wild animals from scavenging on construction site, areas for food consumption, storage, and waste disposal should be demarcated and managed. The personnel should also be briefed on what to do should they encounter specific wild animals. Particular attention should be paid to training content on the Smooth-Coated Otters.

Air Quality and Dust Reduction Measures

To address air quality and dust impacts during construction, several mitigation strategies will be implemented. These include regularly applying water to construction sites, covering stockpiles, and utilising dust suppression equipment to minimise dust emissions. Hoarding will be installed around the Project area to prevent dust from spreading. Additionally, all vehicles and machinery will be maintained in optimal working condition to reduce exhaust emissions. Air quality will be monitored continuously throughout the Construction Phase, allowing for timely adjustments to mitigation measures to protect nearby flora and fauna from potential pollutants.

Noise and Vibration Reduction Measures

To mitigate noise and vibration impacts on biodiversity during construction, it is essential to implement measures that reduce noise levels and minimise disturbances to wildlife. Construction activities should be scheduled during periods of low wildlife activity, such as outside breeding or nesting seasons, to avoid disrupting critical life stages. Utilising noise barriers, such as acoustic screens or natural vegetation buffers, can help dampen construction noise. Additionally, employing quieter machinery and regularly maintaining equipment to reduce noise output are important steps. Monitoring noise and vibration levels and adjusting activities as necessary to stay within acceptable thresholds can further protect sensitive species from harmful noise impacts.

5.9.6 Terrestrial Ecology and Biodiversity Impact Summary

The Construction Phase impacts from the Project's construction work on terrestrial ecology and biodiversity receptors have been summarised in Table 5.88.

Table 5.88 RIAM results for Construction Phase (short-term) impacts from the Project on terrestrial ecology and biodiversity receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Flora within Hillock Area	Encroachment of equipment to tree canopy only	4	-2	2	2	3	-28	Minor Negative Impact	-1	-28	Slight Negative Impact
	Spills and leaks	4	0	2	2	3	0	No Impact	-	-	-
Fauna within Project footprint	Fauna injury or mortality	4	-1	2	2	2	-24	Slight Negative Impact	-1	-24	Slight Negative Impact
	Human-wildlife conflict	4	-1	2	2	2	-24	Slight Negative Impact	-1	-24	Slight Negative Impact
Fauna within Hillock Area	Air pollution	3	-1	2	2	2	-18	Slight Negative Impact	-1	-18	Slight Negative Impact
	Airborne noise	3	-4	2	2	2	-72	Minor Negative Impact	-2	-36	Slight Negative Impact
	Ground vibration from construction	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
	Spills and leaks	3	0	2	2	2	0	No Impact	-	-	-

5.10 Marine Navigation and Infrastructure

The proposed Project site is located on Keppel Island – a private island situated within the Cruise Bay area in the HarbourFront district, under the jurisdiction of the new town of Bukit Merah. Situated near the HarbourFront Cruise Pier and Marina at Keppel Bay, the area is expected to experience high volumes of marine vessel traffic throughout the year. Consequently, construction works in the region could potentially affect existing vessel traffic that traverse Cruise Bay, jetties, piers and marine intakes. This section presents the existing navigational usage of waters around Keppel Island and an assessment of potential impacts on marine infrastructure and navigation receptors during Construction Phase.

5.10.1 Relevant Pressures

The relevant pressures to maritime infrastructure and navigation are:

- Erosion/Sedimentation and suspended sediments (Section 5.2);
- Construction vessel traffic; and,
- Secondary impacts due to changes in water quality as a result pollution release (Section 5.3) and accidental spills and leaks.

This section first discusses the present use of the waters around the Project site, after which the resulting sedimentation impacts on the maritime features in the Study Area will be assessed. Estimation of construction traffic and how it affects maritime receptors is also presented herein. Finally, the secondary impacts from changes in the water quality will be assessed.

5.10.2 Baseline Features and Key Receptors

The key maritime infrastructure and navigation receptors that might be affected by the construction activities are presented in Figure 5.112, with their respective labels described in Table 5.89. During the construction process, both the HarbourFront Cruise Pier and Marina at Keppel Bay will remain operational and are thus listed as maritime infrastructure and navigation receptors during the Project.

Relocation of the HarbourFront Ferry Terminal to a newly constructed ferry terminal at the same location is expected to occur during the project timeline and will be completed by 2025. As construction for this Project will begin in the first half of 2025, there will be some overlap between the construction phases. As such, the increased vessel traffic that will inevitably occur due to construction on Keppel Island is expected to affect the HarbourFront Cruise Pier as well.

While no developments at Marina at Keppel Bay are expected to occur during the proposed project timeline, increased vessel traffic as a result of construction is likely to affect the frequency and speeds of vessels travelling to and from the marina as well. Hence, Keppel Bay needs to be considered a key maritime infrastructure and navigation receptor for the Project as well.

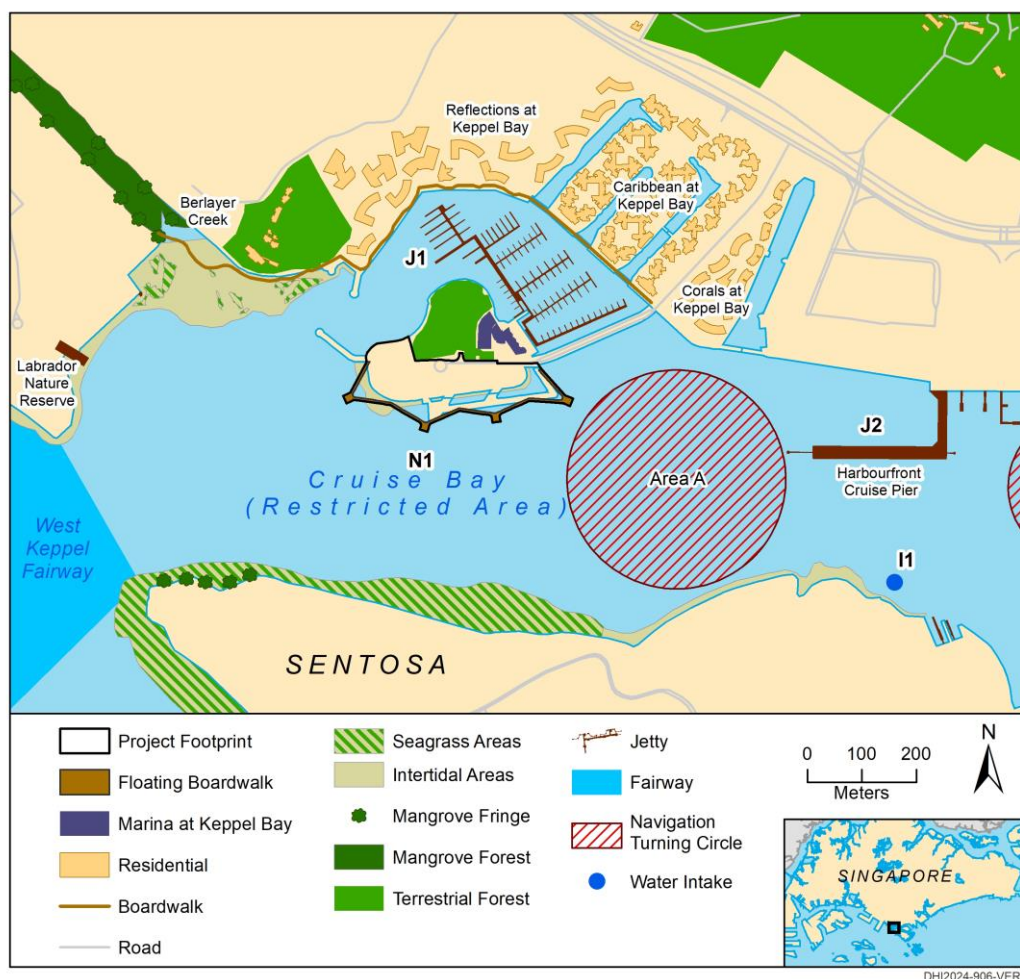


Figure 5.112 Overview of maritime infrastructure and navigation receptors and relevant labelled extraction points for assessment of impacts to maritime infrastructure and navigation

Table 5.89 Table of respective label IDs and description for maritime infrastructure and navigation receptors

ID	Description
J1	Marina at Keppel Bay
J2	HarbourFront Cruise Pier
I1	Marine Life Park Marine Intake
N1	Marine Navigation (Cruise Bay, West Keppel Fairway, Turning Circle)

Marina at Keppel Bay

Marina at Keppel Bay was developed as a world-class berthing dock for international luxury yachts. It is located in the waters between Keppel Island and mainland Singapore.

HarbourFront Cruise Pier

The HarbourFront Cruise Pier, located in the HarbourFront precinct of Singapore, serves as a premier gateway for international cruise travellers. It is situated adjacent to the

Sentosa Island and the VivoCity shopping mall. The pier is an integral part of Singapore's tourism and maritime industries.

Marine Life Park Marine Intake

The Marine Life Park is part of Resorts World Sentosa which is situated at the north of Sentosa Island. The park is home to two primary attractions – the Southeast Asia Aquarium (S.E.A. Aquarium) and Adventure Cove Waterpark. The marine intake ensures a supply of clean seawater to the Marine Life Park to support the health and well-being of its marine inhabitants in the aquarium. The quality and consistency of the seawater drawn into these facilities are critical for maintaining the delicate balance of the ecosystems they support.

Cruise Bay

Cruise Bay is a navigation channel between Keppel Island and Sentosa Island, primarily serving the needs of the maritime and cruise industries, such as the HarbourFront Cruise Centre and Resorts World Sentosa.

West Keppel Fairway

The West Keppel Fairway is a crucial navigation channel, serving as a key maritime route for vessels accessing the western parts of Singapore, including the industrial and port areas.

Turning Circle

The turning circle in Cruise Bay is an essential navigational feature in maritime operations, particularly in busy ports and harbours. It is a designated water area that allow vessels to turn around, change direction, or manoeuvre safely, especially when space is limited.

Vessel Traffic

The baseline data for maritime transport activities is obtained from the Automatic Identification System (AIS). AIS is an automatic tracking system used on ships to identify and locate vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites. Outputs from the AIS data include:

- Vessel identity (Maritime Mobile Service Identity [MMSI]);
- Vessel spatial properties (heading, position, speed);
- Vessel temporal properties (time);
- Vessel physical properties (length overall (LOA), beam, draught); and,
- Vessel class (general class type (e.g., tanker), hazard type).

AIS data from 2019 was utilised in this analysis as data obtained prior to the COVID-19 pandemic would be more representative of typical local vessel traffic than data from the post-pandemic period (2020 – 2023). The AIS data was extracted from an area that encompasses the entirety of Cruise Bay, which includes the waters of HarbourFront Cruise Pier and Keppel Bay (Figure 5.113).

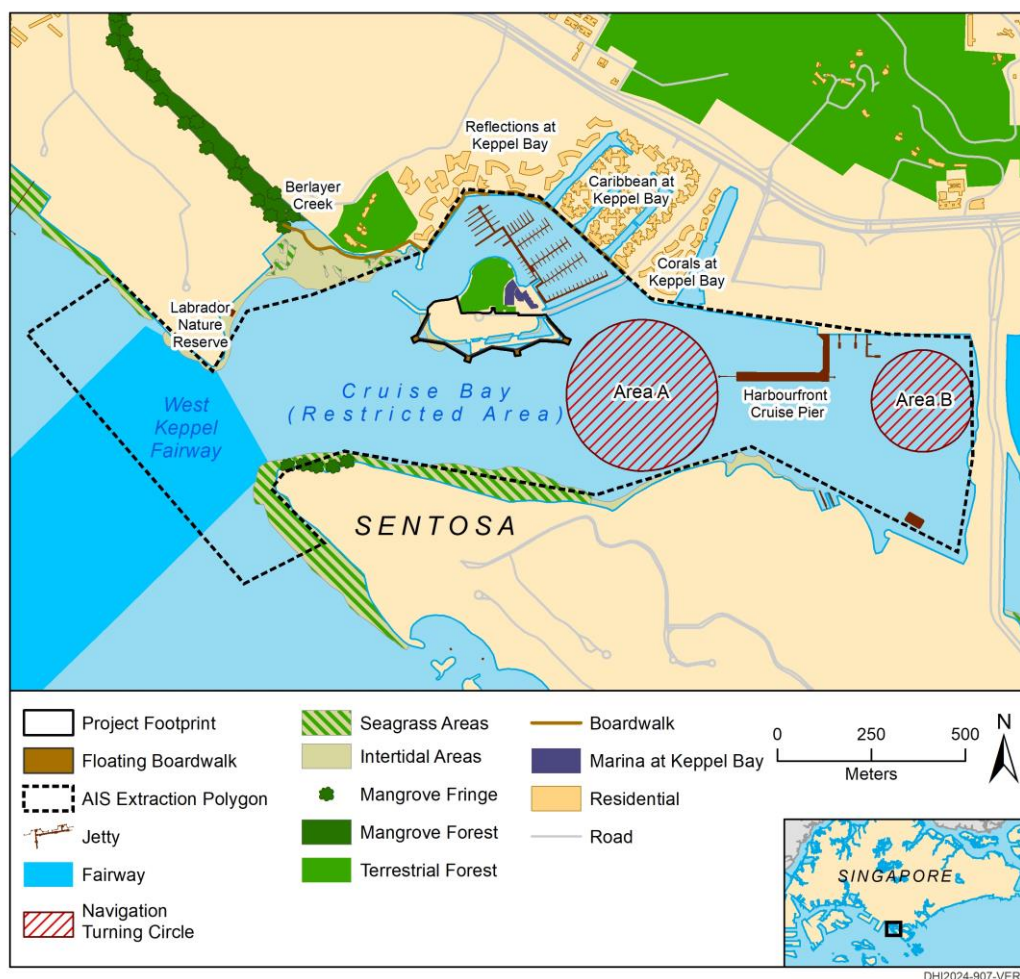


Figure 5.113 Map showing the area where AIS data in 2019 was extracted and analysed

Results of AIS data extracted from the 2019 period are presented in Figure 5.114 to Figure 5.121. Vessel movements within the vicinity of the proposed Projects are visualised in Figure 5.114 (according to LOA) and Figure 5.115 to Figure 5.116 (according to speed over ground [SOG]). The distribution of vessel type and LOA, as well as vessel type and SOG, are displayed in Figure 5.117 and Figure 5.118, respectively. Figure 5.119 and Figure 5.120 shows the distribution of vessel LOA by SOG and by passenger vessels respectively, while Figure 5.121 displays the total number of vessels' tracks every hour of the day in 2019 within the subset AIS data.

In Cruise Bay, vessel movements vary in LOA from <50 m to 300 m. The dominant vessel length within the Project area is <50 m in LOA, contributing to approximately 96 % of movements (see Figure 5.114). When considering SOG, vessels in Cruise Bay typically operate at mean SOG ranging from 2 to 14 knots (see Figure 5.115). The predominant mean SOG for vessels in the Project area mainly ranged between 2-4 kn, 4-6 kn, and 6-8 kn, representing approximately 10%, 23%, and 49% of movements in the region, respectively (see Figure 5.116). The vessel movements with mean SOG below 4 is primarily observed near the HarbourFront Cruise Pier (see Figure 5.116, top row).

Statistical analyses for the Project area were conducted in terms of vessel types, LOA, and SOG (see Figure 5.117 to Figure 5.120). Within the defined region, a significant majority of vessels were observed to be small vessels, with an LOA of less than 50 m and an SOG of less than 12 kn. These vessels mainly included passenger crafts, high-speed crafts, and pleasure crafts, accounting for 47 %, 32 %, and 9 % of the vessels within the area, respectively. For passenger vessels, the LOA distribution is primarily dominated by LOA

below 50 m, with only a few amounts of passenger vessels in the 50 to 100 m LOA range (see Figure 5.120).

The total daily and hourly vessel movements statistics in the Study Area are tabulated in Table 5.90. The median and the 95th percentile vessel counts in Cruise Bay are respectively reported to be 262 and 342 counts per day and 16 and 25 counts per hour. These figures indicate a relatively high level of vessel traffic, categorising Cruise Bay as a busy route compared to other channels across the country. Furthermore, AIS results show that there will be more vessel traffic around the Cruise Bay area between 0700hrs – 2100hrs as compared to the nighttime, as seen in Figure 5.121.

Table 5.90 Daily and hourly vessel movements in the Study Area, based on AIS data of 2019

Location	Daily Vessel Movements		Hourly Vessel Movements	
	Median	95 th percentile	Median	95 th percentile
Cruise Bay	262	342	16	25

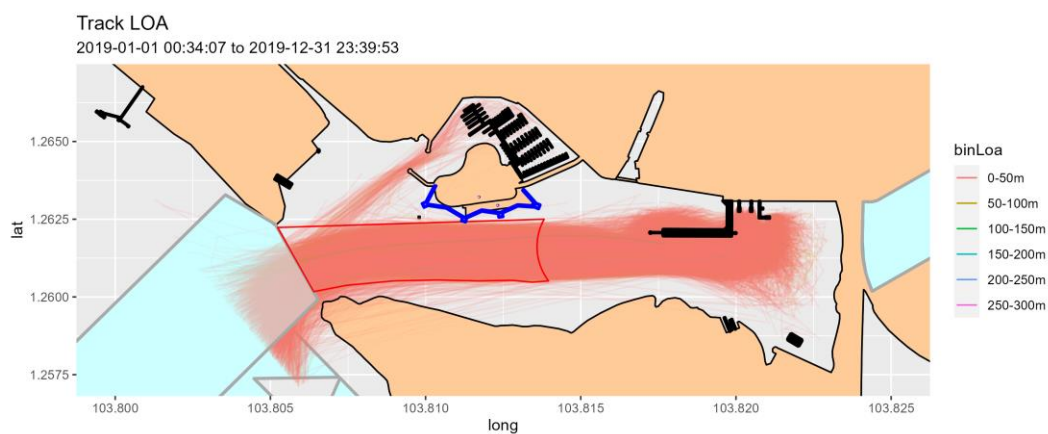


Figure 5.114 Vessel tracks in the Study Area based on AIS data in 2019, categorised according to Length Overall (LOA)

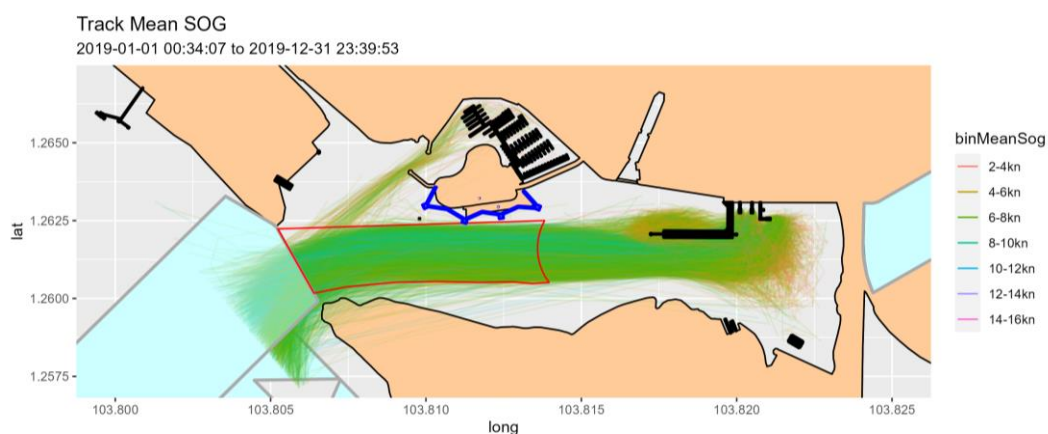
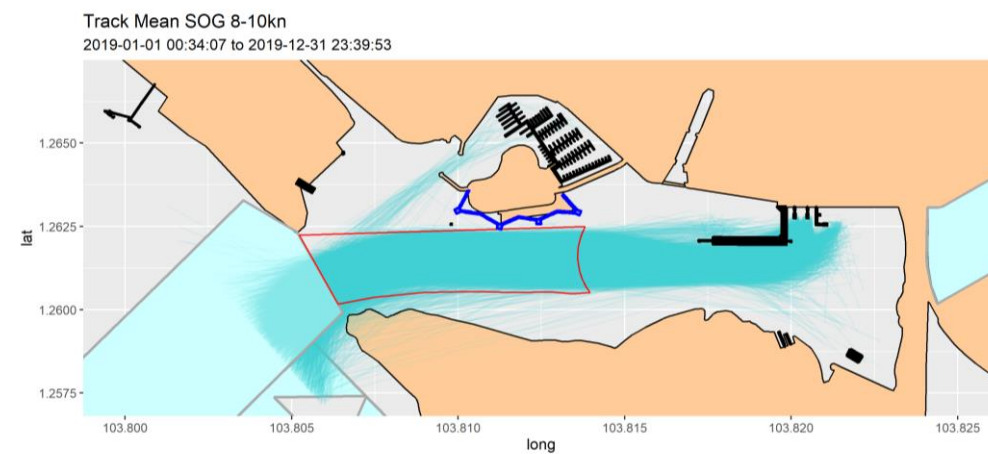
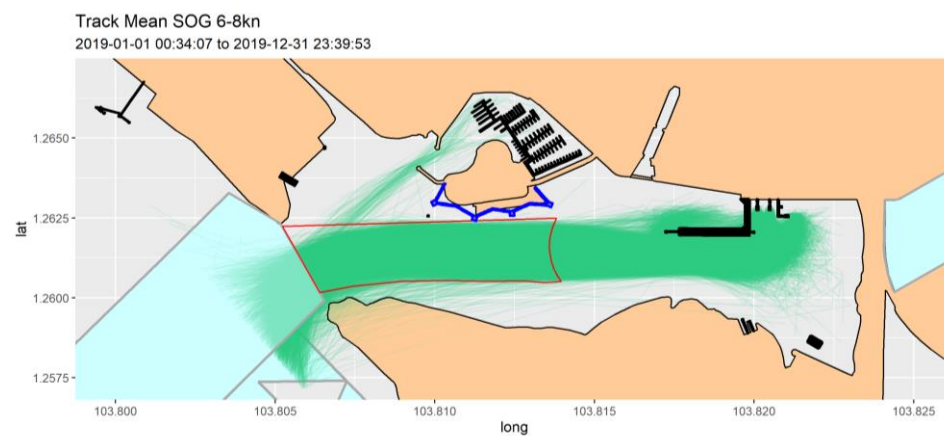
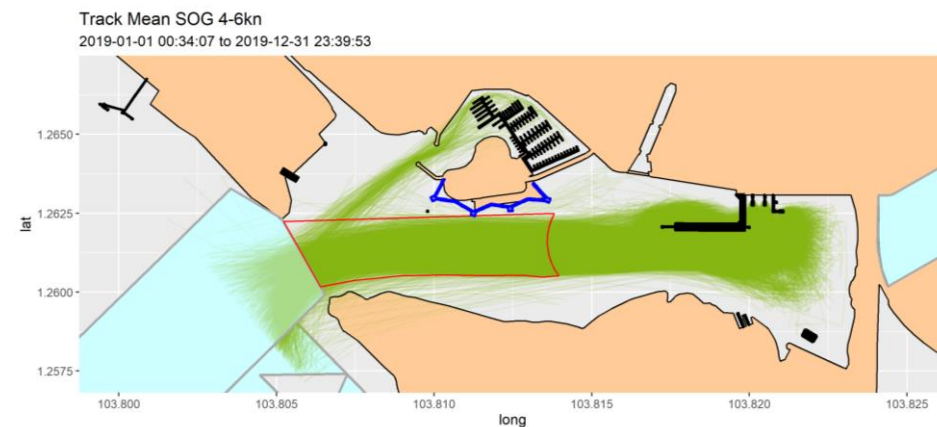
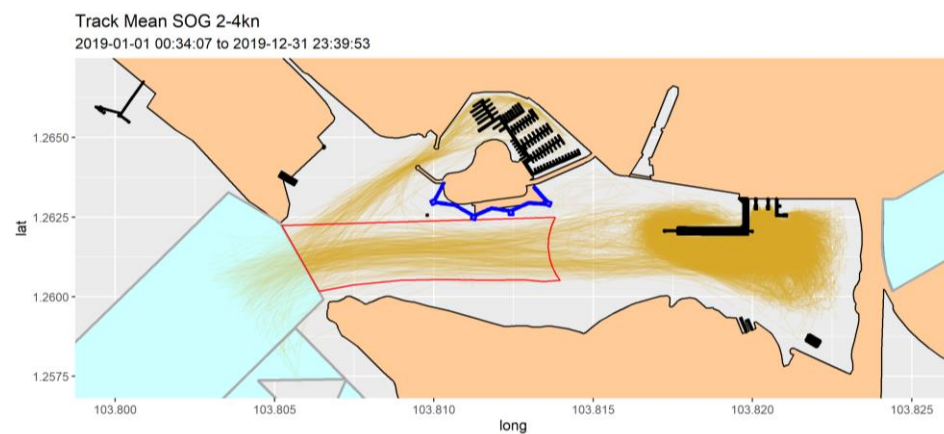


Figure 5.115 Vessel tracks in the Study Area based on AIS data in 2019, categorised according to Mean Speed Over Ground (SOG)

Construction Phase (Short-Term) Impacts



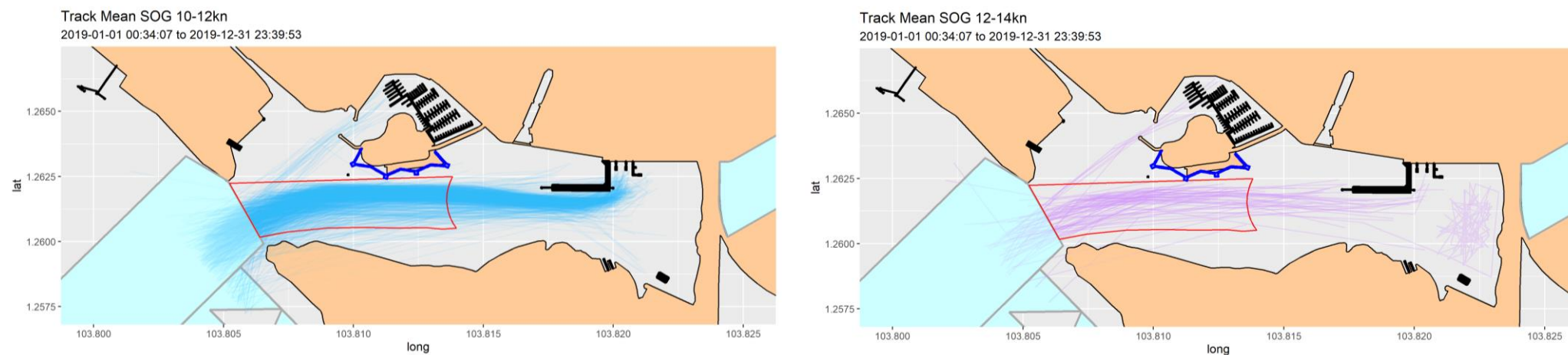


Figure 5.116 Vessel tracks in the Study Area categorised by mean Speed Over Ground (SOG): 2-4 knots (top-left); 4-6 knots (top-right); 6-8 knots (middle-left); 8-10 knots (middle right); 10-12 knots (bottom-left) and 12-14 knots (bottom-right), based on AIS data in 2019.

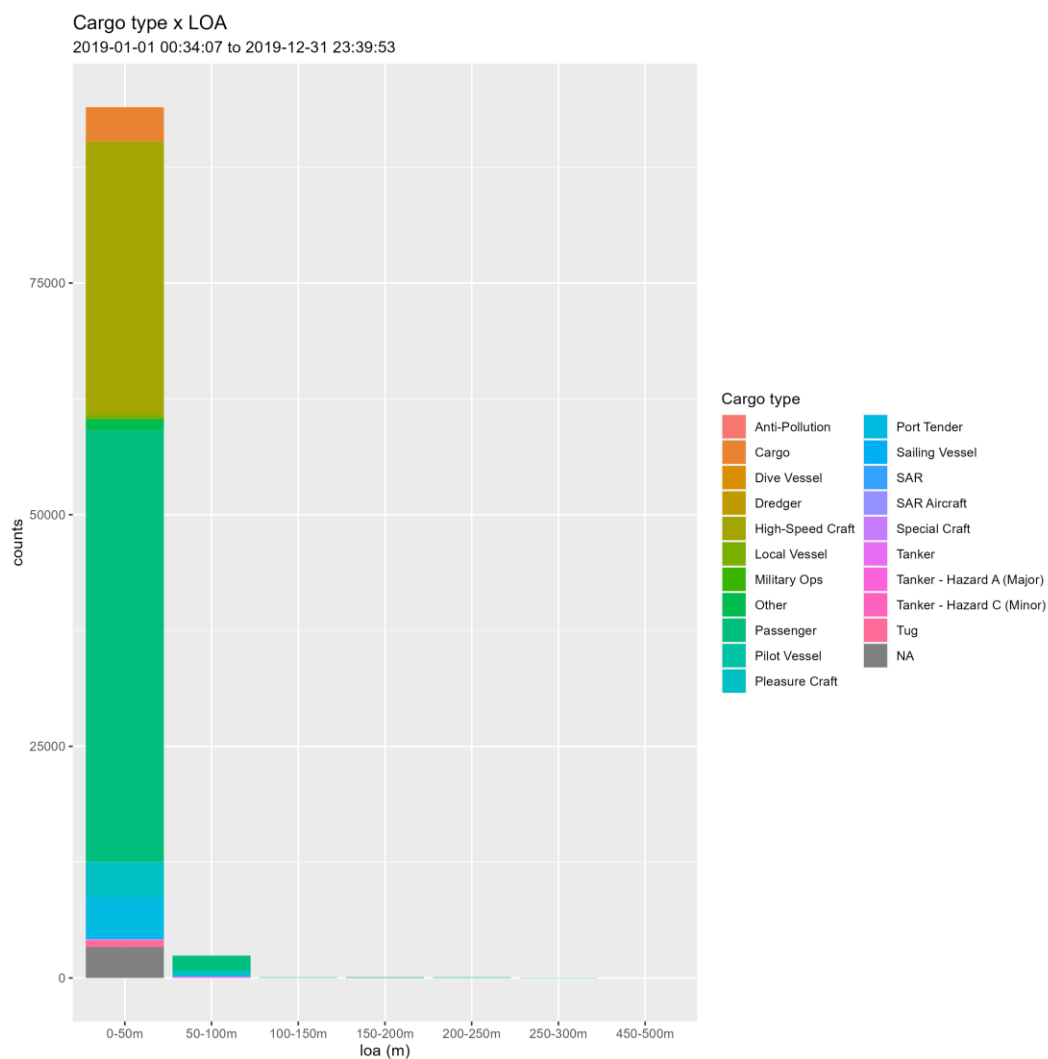


Figure 5.117 Length Overall (LOA) of vessels traversing through Cruise Bay categorised according to Cargo Type based on AIS data in 2019

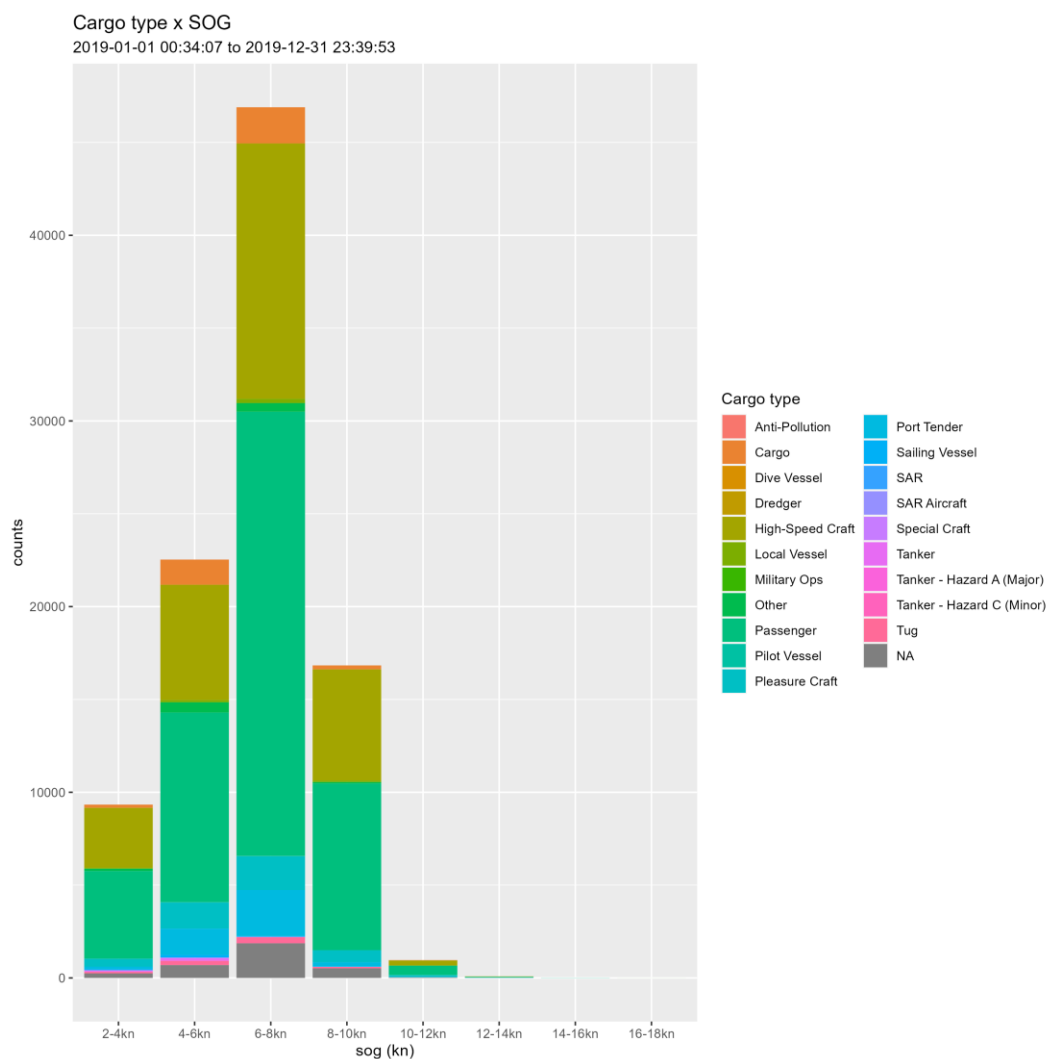


Figure 5.118 Mean Speed Over Ground (SOG) of vessels traversing through Cruise Bay categorised according to Cargo Type based on AIS data in 2019

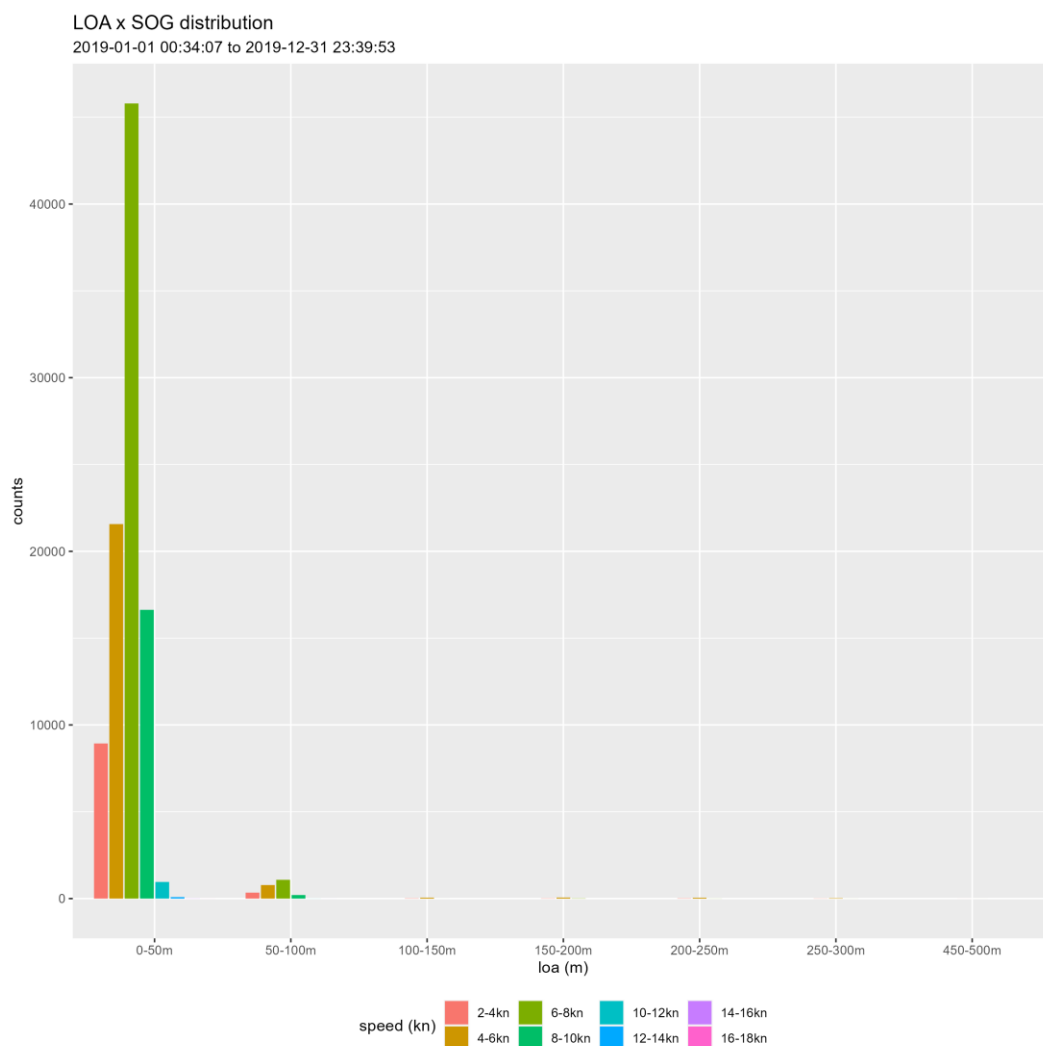


Figure 5.119 Mean Speed Over Ground (SOG) of vessels traversing through Cruise Bay categorised according to LOA based on AIS data in 2019

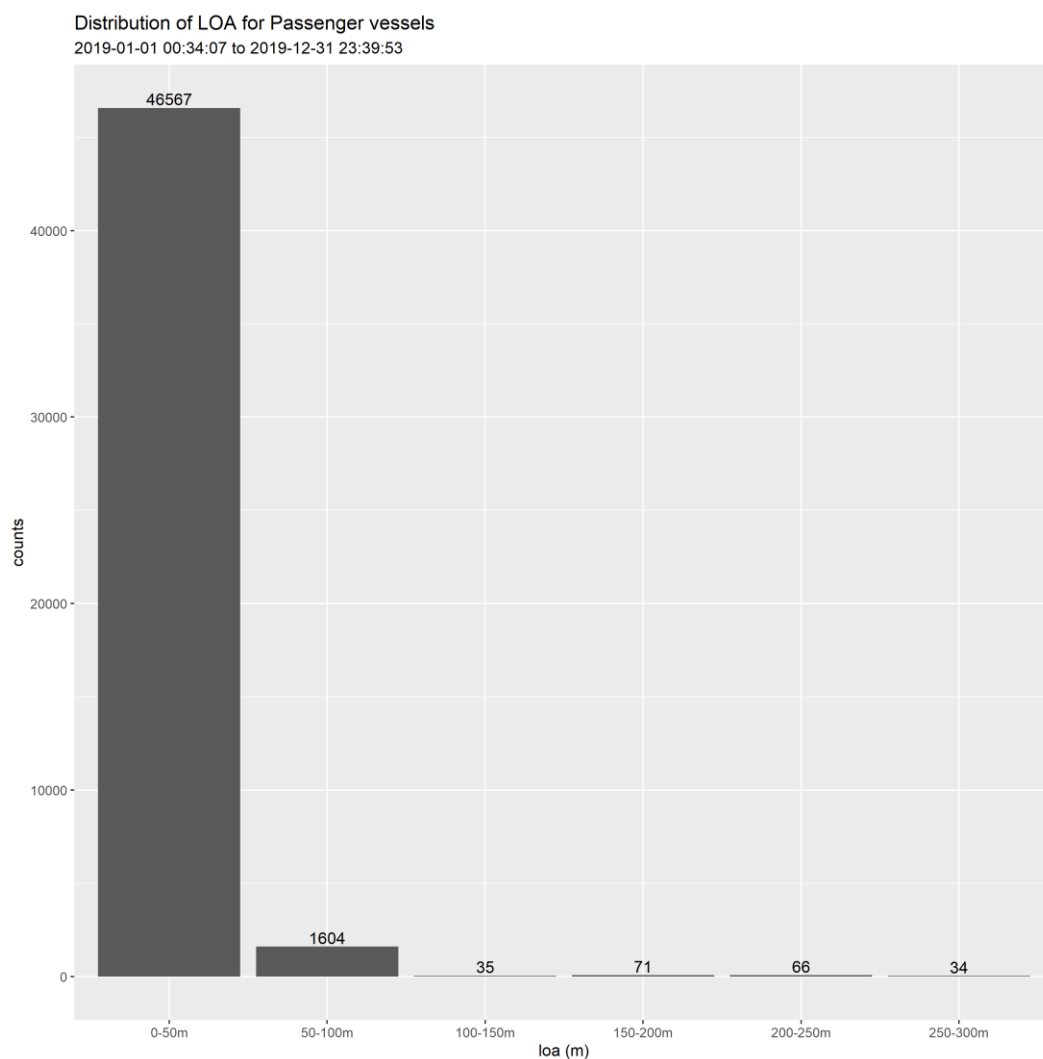


Figure 5.120 Passenger vessels traversing through Cruise Bay categorised according to LOA based on AIS data in 2019

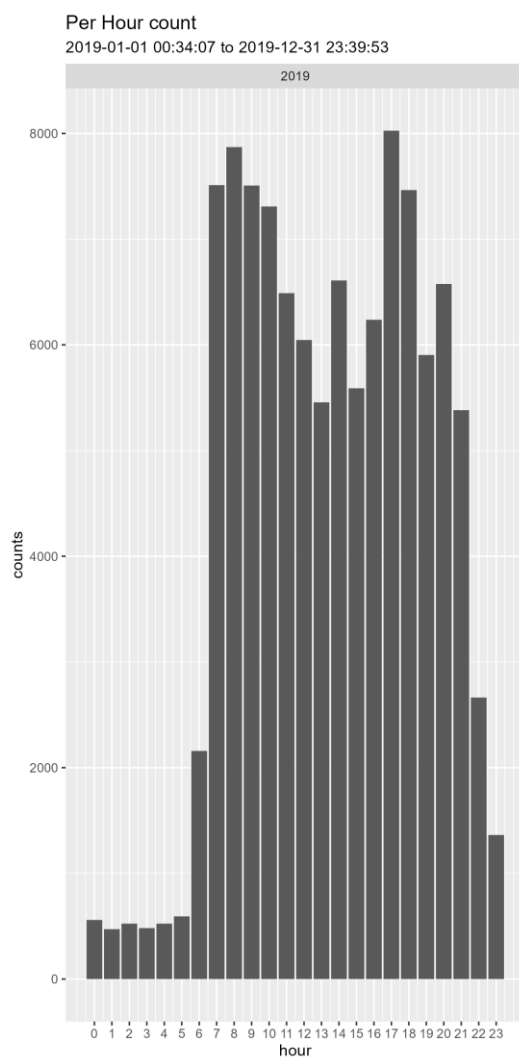


Figure 5.121 Hourly Total Vessel Count based on AIS data in 2019

5.10.3 Evaluation Framework

The assessment of impact on marine navigation and infrastructure requires a framework for ranking importance of this group of receptors. For this purpose, the standard definitions of Importance in the RIAM framework (Table 4.11) are adopted.

Marine Navigation and Infrastructure Tolerance to Sedimentation

Navigation channels and berthing areas are susceptible to incremental sedimentation, which may result in increased maintenance costs associated with maintenance dredging.

In the field, redistribution mechanisms such as the effect of propeller wash and the inherent accuracy limits of bathymetric surveys make detecting small incremental changes to sedimentation against background variability very difficult, with a potential measurable change typically being taken as about 150 mm. For this Environmental Study, 150 mm/year has thus been set as the lower limit for measurable change labelled as 'Minor Change,' and other limits set are presented in Table 5.91.

It is noted that there is presently a degree of uncertainty in the suitability of 50 mm/year reflecting 'No Impact'. Although this is well below the limit that can be reliably measured in the field, some facility operators claim realised impacts for changes in the order of 10 mm/year or less. Whilst standard practice cannot support such low limits, the fact that claims have been made on changes falling in the 'Slight' or 'No Impact' categories must be flagged as a risk factor in the application of the proposed tolerance limits for environmental study purposes.

Table 5.91 Tolerance limits for marine navigation and infrastructure to excess (i.e., in addition to background) sedimentation

Magnitude	Definition
No Change	Less than 50 mm/year
Slight Negative Change	Between 50 to 150 mm/year
Minor Negative Change	Between 150 to 300 mm/year
Moderate Negative Change	Between 300 to 500 mm/year
Major Negative Change	More than 500 mm/year

Marine Intakes Tolerance to Suspended Sediments

Increased suspended solids may affect marine intakes in terms of increased maintenance costs, for example, filter cleaning and risk of sedimentation of fine material within the water system. The tolerance limits of intakes are very site-specific. They are usually determined based on the statistical 'No Change' in suspended sediment concentrations compared to the background at the intake location. This value is normally calculated following an intensive baseline monitoring period during the EMMP before the start of work. The limits should also be agreed upon with the specific intake operators. For the present Study, monitoring data is available at some Singaporean intakes, but not all intakes affected by the Project. Therefore, a precautionary approach has been adopted: to take the strictest limits from the available well-validated data sets.

For suspended sediments, a distinction is drawn between power station (cooling water) intakes, which are relatively tolerant to suspended sediment, and process water intakes, which are relatively intolerant to changes in suspended sediments. No cooling water intakes are identified within the Project area; however, a process water intake is present in the Study Area associated with industrial activities.

Based on baseline monitoring data near Jurong Island collected in 2009 and 2010 and supported by consultation with the facility operator, Singapore Refining Company (SRC), an impact severity of 'No Change' has previously been defined as an excess suspended sediment concentration of less than 1.0 mg/l at process water intake locations. This limit has previously been successfully applied to manage SSC impacts on sensitive SRC process water intake. The full range of operational limits for the absolute suspended sediment reflecting the statistically 'No Change' situation for different time scales of exposure is presented in Table 5.92.

Table 5.92 Operational limit of 'No Change' situation for process water intakes based on previous case at Jurong Island

Control	Baseline Mean (mg/l)	Operational Mean Limit (mg/l)
10 min	25.6	28.6
1 hour	18.1	24.0
3 hour	15.8	19.7
1 day	11.3	13.0
3 day	11.0	11.7
7 day	9.2	11.1
14 day	8.9	9.9

The mode of management agreed with the operator that if the one-hour mean were exceeded, work on-site would be stopped. Table 5.92 clearly shows that an incremental change of the order of 5.9 mg/l, for the purposes of assessment, constitutes a 'Moderate Change' (i.e., with secondary consequences on linked processes in this case of development works). Adopting a precautionary approach to the interpretation of the operational limits presented above leads to the present Environmental Study tolerance limits, which are presented in Table 5.93.

Table 5.93 Tolerance limits for process water intakes to excess (i.e., in addition to background) SSC

Magnitude	Definitions
No Change	Excess mean SSC < 1 mg/l
Slight Negative Change	Excess mean SSC 1 mg/l to < 3 mg/l
Minor Negative Change	Excess mean SSC 3 mg/l to < 6 mg/l
Moderate Negative Change	Excess mean SSC 6 mg/l to < 20 mg/l
Major Negative Change	Excess mean SSC ≥ 20 mg/l

In 2005 and 2006, extensive monitoring of the Shell Bukom process water intakes was undertaken in relation to the management of reclamation impacts. These data broadly support the limits identified for the SRC intake, so it is considered appropriate to utilise the proven SRC intake tolerance limits to determine impacts on processing water intakes in the southern Singapore area.

Construction Vessels

Deployment of marine barges and construction equipment for construction works is expected to increase vessel traffic in the vicinity of the work area. No numerical tolerance limits exist for assessing severity of the resulting space congestion in relation to varying increase in local traffic. This assessment is primarily qualitative based on the construction vessels plan and the vessel traffic statistics from 2019 AIS data.

Evaluation of Magnitude of Change due to Accidental Spills and Leaks

The evaluation criteria for accidental spills and leaks in marine infrastructure are similar to that in marine ecology and biodiversity as outlined earlier in Section 5.8.3.

5.10.4 Impact Assessment

The evaluation of the Importance score in RIAM for socio-economic receptors adopts the framework presented in Table 4.11. Marina at Keppel Bay is assessed to have an Importance score of “3” as they are important to areas beyond the localised area of the Project. Marine navigation (consisting of Cruise Bay channel, West Keppel Fairway and the turning circle), HarbourFront Cruise Pier, and Marine Life Park Marine Intake are assigned an Importance score of “4” as they are of national importance for tourism activities. In addition, the Marine Life Park is a significant institution for multiple other purposes, including, but not limited to, education, conservation and scientific research.

5.10.4.1 Sedimentation Impacts

The sedimentation results presented in Section 5.2 indicate that changes are expected within the immediate Project footprint, with rates of more than 250 mm per year. However, sedimentation changes are minimal in areas where marine navigation and infrastructure are found, with less than 50 mm per year. According to Table 5.91, the Magnitude is assessed as “No Change”. Hence, **No Impact** from sedimentation is anticipated on marine navigation and infrastructure.

5.10.4.2 Reduction in Navigation Space due to Marine Work Area

During the Construction Phase, sea space beyond the pile deck and floating boardwalk footprint is required as a marine work area. No detailed construction work plan is available at the time of writing. For the purpose of this Study, the marine work area is estimated to extend approximately 60 m from the Project profile to accommodate marine construction vessels and equipment, such as piling rigs and/or barges for marine piling works, and towboats required for adjusting and securing the floating boardwalk onto the piles.

The key navigation receptors of concern are the navigation turning circle (MPA’s restriction area), the Cruise Bay channel, and the West Keppel Fairway, all of which are utilised by both smaller vessels (LOA < 50 m) and larger vessels (LOA > 50 m) for navigating within the area. Hence, the assessment of reduced navigation space due to the work area will focus on these navigation receptors.

The estimated marine work area is not expected to affect the West Keppel Fairway, as that location is far from the Project site. However, it encroaches on the turning circle southeast of Keppel Island and the navigation channel of Cruise Bay. Since MPA would not approve of the encroachment of marine working areas into the designated turning circle, the Contractor would be required to plan to work within a smaller sea space for the eastern section of the Project. Some mitigation measures are recommended in Section 5.10.5 to minimise the potential impact associated with this limitation.

The estimated marine work area also potentially affects marine transport and navigation along the Cruise Bay channel by reducing the available sea space for vessels to transit, anchor, or manoeuvre within the channel. This is because the traversable width of the Cruise Bay channel will be reduced near the Project site. MPA requires that the marine work area not extend beyond the sea space necessary for the Project's vessel's safe movements, using sea space with depth of more than 10 m as a reference for where existing marine traffic would be traversing. Figure 5.122 shows the encroachment into sea space with a depth of more than 10 m for an estimated 60 m marine work area, which suggests that the reduction in navigational space along Cruise Bay is expected to be felt by the existing vessels. However, the marine working area is not expected to be completely occupied 100 % of the time; hence, ample sea space for a vessel to navigate through remains available. In the worst case, when sections of the marine work area are occupied, vessels could still navigate along the channel by rerouting. This rerouting may cause minor delays or require vessels, especially larger vessels (LOA > 50 m), to adjust their typical navigation paths, potentially disrupting their operations.

Based on the above assessment of reduction in navigation space, the potential change to navigation space along Cruise Bay is considered to be the most significant and is assessed as a Moderate Negative Change. Consequently, the impact significance is anticipated to have a **Moderate Negative Impact**. Some mitigation measures are recommended in the later section to minimise this impact.

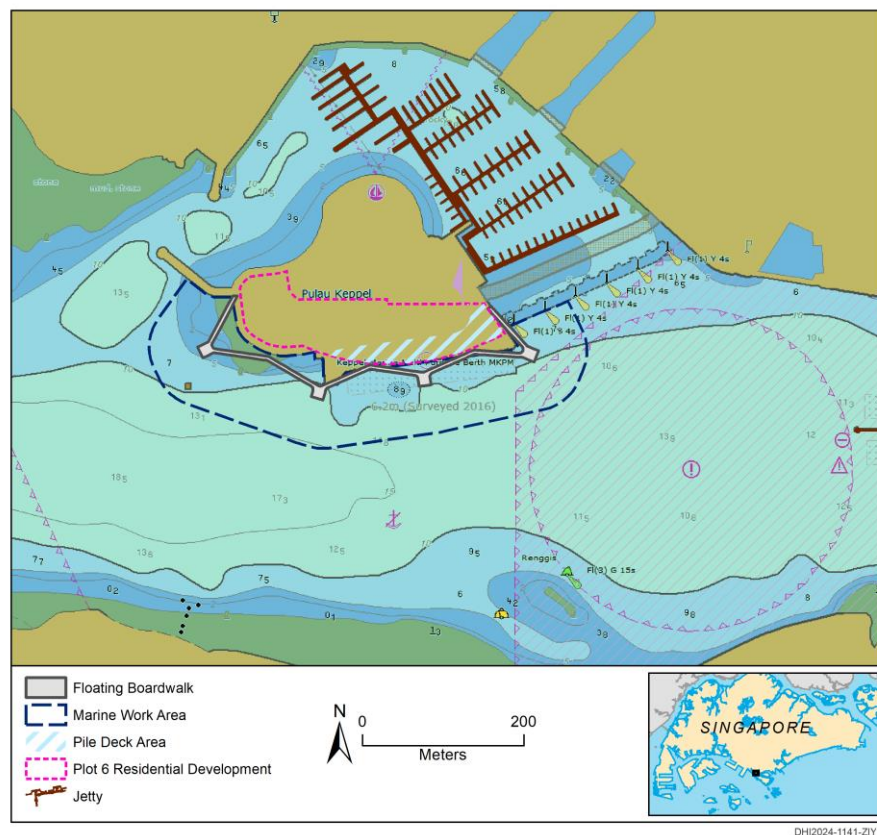


Figure 5.122 Contour map of the waters around Keppel Island, including the 10m contour line

5.10.4.3 Reduction in Navigation Space due to Marine Construction Vessels

The Construction Phase of the Project will inevitably introduce additional vessels into the Study Area, which could potentially increase the risk of collisions with existing vessel traffic as these new vessels transit to the work area. Based on the existing vessel traffic presented in Section 5.10.2, the key maritime transport of concern are (1) small vessels (LOA < 50 m), including passenger crafts, high-speed crafts, and pleasure crafts, which primarily use the entire of Cruise Bay navigation channel area due to their smaller size that making them easy to manoeuvre and flexible in their use of the channel; as well as (2) large vessels (LOA > 50 m), such as passenger (cruise) vessel, military ops, tanker, and cargo vessels, that utilise the middle of the Cruise Bay channel as they require more space for manoeuvring or deeper waters for safe transit. Hence, the assessment of the impact of construction vessels on navigational safety will focus on these two types of receptors.

Based on the preliminary construction plan at the time of writing, only two (2) barges will be deployed for the purpose of constructing pile deck and floating boardwalk, with these activities scheduled to take place over a thirty-two (32) weeks period near the end of Construction Phase. During the period of pile deck and floating boardwalk construction, these barges will transit within Cruise Bay, and berth and manoeuvre within the marine working area. The movements of these barges may increase the risk of collisions with existing vessel traffic in the area.

For smaller vessels (LOA < 50 m), the impact of construction vessels is expected to disrupt their routes while transiting, manoeuvring, and anchoring within the navigation area. The impact on larger vessels (LOA > 50 m) is anticipated to be similar but could be more severe due to their poor manoeuvrability compared to smaller vessels, making it more challenging for them to reroute within the restricted space. Given their size and the constraints of navigating through tighter areas, larger vessels might face increased risks of collision or grounding in the area. This is assessed as “Minor Negative Change”, considering the low frequency of construction vessels during the Construction Phase. Consequently, significance impact of construction vessels on marine navigation is anticipated to have a **Minor Negative Impact**. Some mitigation measures are recommended in Section 5.10.5 to minimise this impact.

5.10.4.4 Marine Intakes

Impact of Suspended Sediments on Marine Intakes

Suspended sediments can be taken into at marine intakes, which can increase maintenance costs and sedimentation within the system. Table 5.94 presents the mean excess SSC model results based on the extraction point located at the marine intake.

Table 5.94 Mean excess SSC at marine intake

Marine Intake receptor	Mean Excess SSC (mg/l)
I1	<1.0

The mean SSC at the Marine Life Park's marine intake (I1) is predicted to be < 1.0 mg/l. This change is equivalent to “No Change” according to the tolerance limits for marine intakes as presented in the Evaluation Framework section above (Section 5.10.3).

Impact of Pollution Release on Marine Intakes

The build-up of heavy metals in fish can cause health problems and disrupt their physical functions. The severity of metal toxicity varies based on factors such as the type of fish, the amount of toxins, and how long the exposure lasts. Aquatic creatures can get contaminated

by both water and sediment, harming their nervous systems and their ability to interact with other species and their environment (Ray & Vashishth, 2024).

In the context of the Project, heavy metals in the seabed can be suspended into the seawater due to construction activities and may get drawn into the marine intakes of the Marine Life Park. The mean excess SSC at the water intake was predicted to be < 1.0 mg/l; hence, the Project is expected to contribute negligible amounts of heavy metals to the waters near the water intake. Therefore, **No Impact** is expected.

Impact of Accidental Spills and Leaks on Marine Intakes

Should construction-related chemicals enter the marine intake system of an aquarium, potential harm to the marine life in the aquarium and damage to the aquarium's marine intake and circulation system may lead to downtime and maintenance of the facility's overall operations. The containment of pollutive liquids and construction materials and their potential negative impacts when accidentally split are outlined previously in Section 5.8.4.14. This would result in an impact Magnitude of “-2”.

Given the transient nature of spills and leaks, the permanence and reversibility scores are assigned at “2”. There are no known cumulative effects, hence a score of “2” is assigned.

This brings the Environmental Score of the impact of spills and leaks on marine intakes to “-64”, which is considered a **Minor Negative Impact**.

5.10.5 Mitigation Measures

The EQO for marine navigation and infrastructure has been set at “no more than Minor Impact”, in consultation with Technical Agencies during the scoping stage. The predicted impacts are in compliance with this EQO, except for the reduction in navigational space along Cruise Bay, due to the sea space required for the marine working area.

Based on the assessment, the following mitigation measures are recommended to minimise the navigation risks in the vicinity of the Project:

- Carry out a Formal Safety Assessment (FSA) for the Construction Phase to assess all potential marine risks covering not only the work sites but also the access routes.
- After consultation with MPA, it was mutually agreed that the Contractor shall liaise closely with MPA during the construction works, to adjust work plans and schedules, to ensure that sufficient navigational space is provided for the entry of large vessels that are scheduled to enter the Cruise Bay Channel.
- The Contractor shall ensure that sufficient manoeuvring space remains for vessels, during the construction works.
- The Contractor shall also note that no encroachment into the turning circle is permitted during the works. An updated map of the indicative marine working area is shown in Figure 5.123, subject to approval from MPA.
- Submit an application to MPA for a Port Marine Notice (PMN) and demarcate the marine working area according to MPA's requirements. The PMN would be published by MPA to inform operators and users of HarbourFront Cruise Pier, Marina at Keppel Bay, and the Cruise Bay channel about the Project's marine work area.
- Regarding accidental spills and leaks from construction material and equipment, the management guidelines are detailed out in Section 5.8.5.3, particularly with respect to oil spill incidents and responses.

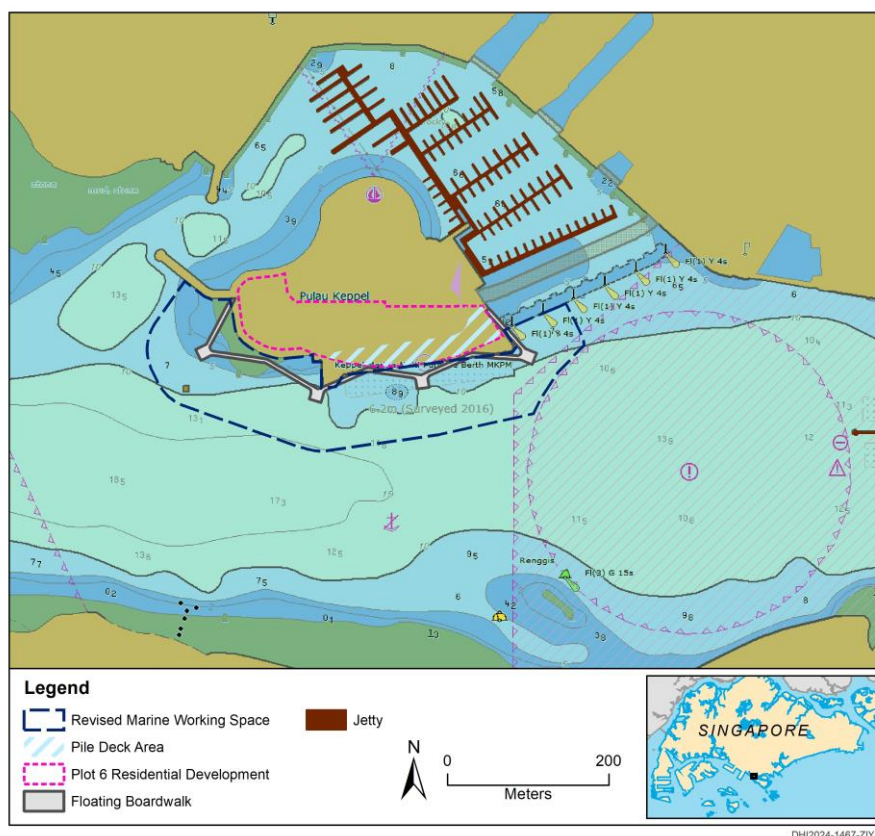


Figure 5.123 Map showing the finalised indicative marine work area after TA consultation with MPA

5.10.6 Marine Infrastructure and Navigation Impact Summary

The Construction Phase impacts from the Project's construction work on marine infrastructure and navigation receptors have been summarised in Table 5.95.

Table 5.95 RIAM results for Construction Phase (short-term) impacts from the Project on marine infrastructure and navigation receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Marine Navigation (Cruise Bay, West Keppel Fairway, Turning Circle)	Sedimentation	4	0	2	2	2	0	No Impact	-	-	-
	Reduction in navigational space	4	-3	2	2	3	-84	Moderate Negative Impact	-1	-28	Slight Negative Impact
Marina at Keppel Bay	Sedimentation	3	0	3	3	3	0	No Impact	-	-	-
HarbourFront Cruise Pier	Sedimentation	4	0	3	3	3	0	No Impact	-	-	-

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Marine intake at Marine Life Park	Excess suspended sediments	4	0	3	3	2	0	No Impact	-	-	-
	Change in water quality due to pollution release	4	0	3	3	2	0	No Impact	-	-	-
	Spills and leaks arising from vessel collision and other construction activities	4	-2	3	3	2	-64	Minor Negative Impact	-1	-32	Slight Negative Impact

5.11 Rivers and Canals

The presence of rivers and canals near construction areas may be subject to the risk of sedimentation, possibly inducing blockage of these water bodies. This section lists all the existing rivers and canals near the Project, presents the evaluation framework and discusses the Project's impacts on them.

5.11.1 Relevant Pressures

The main pressure to the assessment of impact on rivers and canals is from sedimentation, possibly causing blockage, impeding discharge to the sea.

This pressure has been quantified using MIKE 21 MT model as presented in Section 5.2. This section discusses and assesses the significance of the resulting blocking effects on the rivers and canals near the Project area.

5.11.2 Baseline Features and Key Receptors

Berlayer Creek is the only river near the Project (Figure 5.124 and Table 5.96), and it is located northwest of Keppel Island.

The location and delineation of the river are established through remote sensing techniques based on DHI's internal research and past project experience. No specific baseline condition about sedimentation (the pressure of interest) is discussed herein.

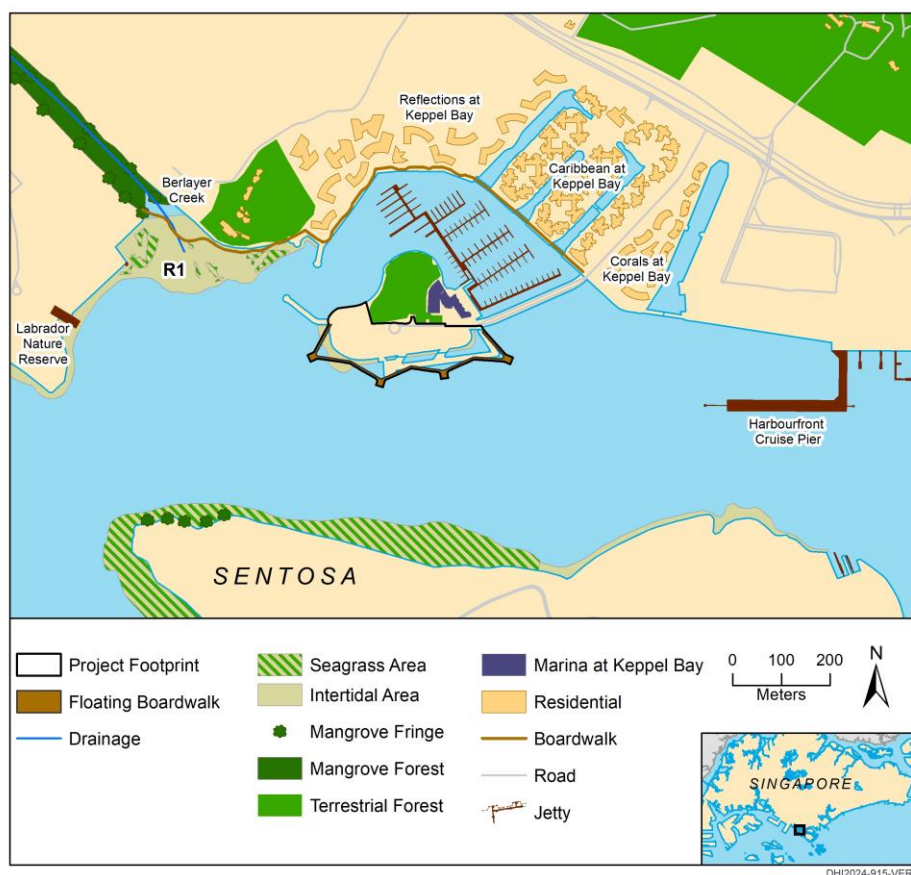


Figure 5.124 Overview of rivers and canals receptors and relevant labelled extraction points for assessment of impacts to rivers and canals

Table 5.96 Table of respective label ID and description for rivers and canals receptors

ID	Description
R1	Berlayer Creek

5.11.3 Evaluation Framework

Sedimentation is the calculated output from the sediment plume model. The tolerance limits of marine infrastructure and navigation (Section 5.10.3) are adopted for the sedimentation effect. The assessment of impact on rivers and canals also requires a framework for ranking importance of this group of receptors. For this purpose, the standard definitions of Importance in the RIAM framework (Section 4.2.2) are adopted.

5.11.4 Impact Assessment

The Importance score is allocated based on the criteria found in Table 4.11. Berlayer Creek is a natural waterway that houses various habitats – mudflats, mangroves, and coastal forests – and is part of the Labrador Nature Reserve. An Importance score of “4” is assigned to Berlayer Creek due to its rich fauna, flora biodiversity, and mangrove ecosystem.

The annual sedimentation rate at Berlayer Creek is predicted to be < 50 mm (Table 5.97). The incremental sedimentation induced by the construction at Berlayer Creek is assessed to be “No Change”, which translates to a Magnitude score of “0”.

Given the transient nature of the construction activities’ impacts, a Permanence score of “2” was assigned. A score of “2” was also assigned for Reversibility and Cumulativity. This results in an Environmental Score of “0”, which is assessed to have **No Impact**.

Table 5.97 Annual sedimentation rate (mm) at rivers

Receptor	Annual sedimentation rate (mm)
Berlayer Creek	< 50

5.11.5 Rivers and Canals Impact Summary

The Construction Phase impacts from the Project’s construction work on rivers and canals receptors are summarised in Table 5.98.

Table 5.98 RIAM results for Construction Phase (short-term) impacts from the Project on rivers and canals receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Berlayer Creek	Blockage of river outlet due to sedimentation	4	0	2	2	2	0	No Impact	-	-	-

5.12 Socio-economic

The Study Area is characterised by a diverse group of social and recreational receptors including commercial businesses, recreational activities, and public spaces. The Construction Phase impacts arising from the proposed residential development on social-economic receptors are assessed within this section.

5.12.1 Relevant Pressures

The relevant environmental pressures to the assessments presented in this section are:

- Visual impacts due to suspended sediments (Section 5.2), accidental spills and leaks, and construction site;
- Air pollution (Section 5.4);
- Airborne noise (Section 5.5);
- Ground vibration (Section 5.6);
- Construction vessel traffic (Section 5.10); and,
- Marine water quality change due to accidental spills and leaks on human health.

These environmental pressures have been quantified wherever possible, the methodology for which and the model results are presented in the respective sections referenced above. This section offers to evaluate those changes based on available tolerance limits relevant to the pressures and receptors.

5.12.2 Baseline Features and Key Receptors

The following receptors are considered as key to the analysis:

- Residents at Reflections at Keppel Bay, Caribbean at Keppel Bay, and Corals at Keppel Bay;
- Staff of businesses at Marina at Keppel Bay; and,
- Recreational users at Keppel Island, the Keppel Bay Promenade (in short, the “Promenade”) and passengers in the cruise ships that pass through the Project area.

Residential receptors

Three (3) condominium developments overlook the Project site. They are Reflections at Keppel Bay (~300 m away), Caribbean at Keppel Bay (~220 m away), and Corals at Keppel Bay (~250 m away). Reflections at Keppel Bay comprises 6 – 8 storey blocks along the Keppel Bay Promenade and Queen’s Dock, and 24 – 41 storey glass towers at the back. Similarly, housing units of Caribbean at Keppel Bay and Corals at Keppel Bay are low-rise along the seafront (~ 5 storeys) and higher further in (~10 storeys). The residents of these waterfront housing developments enjoy a stunning view of the Singapore skyline. Presence of the work site and pressures associated with the construction works such as noise, dust and sediment plume, might cause nuisances to these receptors.

Commercial receptors

Marina at Keppel Bay is a luxurious marina with a variety of amenities, including a swimming pool, gym, spa, restaurant, and bar and is also home to a number of yachts and

superyachts. Staff at these businesses might be adversely affected by noise, dust and sediment plume arising from Plot 6 construction works.

Recreational receptors

There are several recreational receptor sites in the Study Area. Keppel Island is a popular spot for outdoor activities among the locals. The marina provides berthing facilities and services for yachts and superyachts. Recreational diving activities are also noted to take place in the marina. The Promenade running along the marina connecting Labrador Nature Reserve with commercial premises in the southern water such as HarbourFront and Vivo City is also a popular walking track. Passengers of the passing cruise ships are also included in this receptor group.

The baseline recreational activities at Keppel Island and along the Promenade were recorded via field surveys. The subsections to follow describe the methodology of these surveys and discuss the survey results.

Survey Methodology

Socio-recreational surveys were conducted to capture the potential socio-recreational impacts of the project on the nature areas and coastal parks along the northeast shoreline of Keppel Island. On 14 March and 16 March 2024, surveys were carried out at Keppel Island and the promenade fringing the island which, consists of the Caribbean Promenade, Reflections Promenade, and Bukit Chermin Boardwalk (henceforth termed the “Promenade”).

The survey comprised of questionnaire-based interviews of recreational users encountered at six (6) designated survey stations and surveyor’s observations of socio-recreational aspects including types of recreational activities undertaken (e.g., running, walking, cycling, etc), the demographics of recreational users, and frequency and duration of recreational visits to these amenities.

Figure 5.125 Schedule of socio-recreational surveys

Date	Time & Duration		Survey Points	Methodology
14 March 2024	Daytime	0700H to 0900H	SR1-1 to SR1-3 (Keppel Island)	Visual observation & questionnaire- based interviews
	Evening	1700H to 1900H		
16 March 2024	Daytime	0700H to 0900H	SR2-1 to SR2-3 (Promenade)	
	Evening	1700H to 1900H		

Each survey was carried out by two (2) DHI staff who were stationed at six (6) designated survey point for 30 minutes. One (1) surveyor was responsible for interviewing random recreational users encountered, while the other surveyor recorded visitor counts and documented visual observations of socio-recreational activities in the area. Figure 5.126 shows the location of the stations.

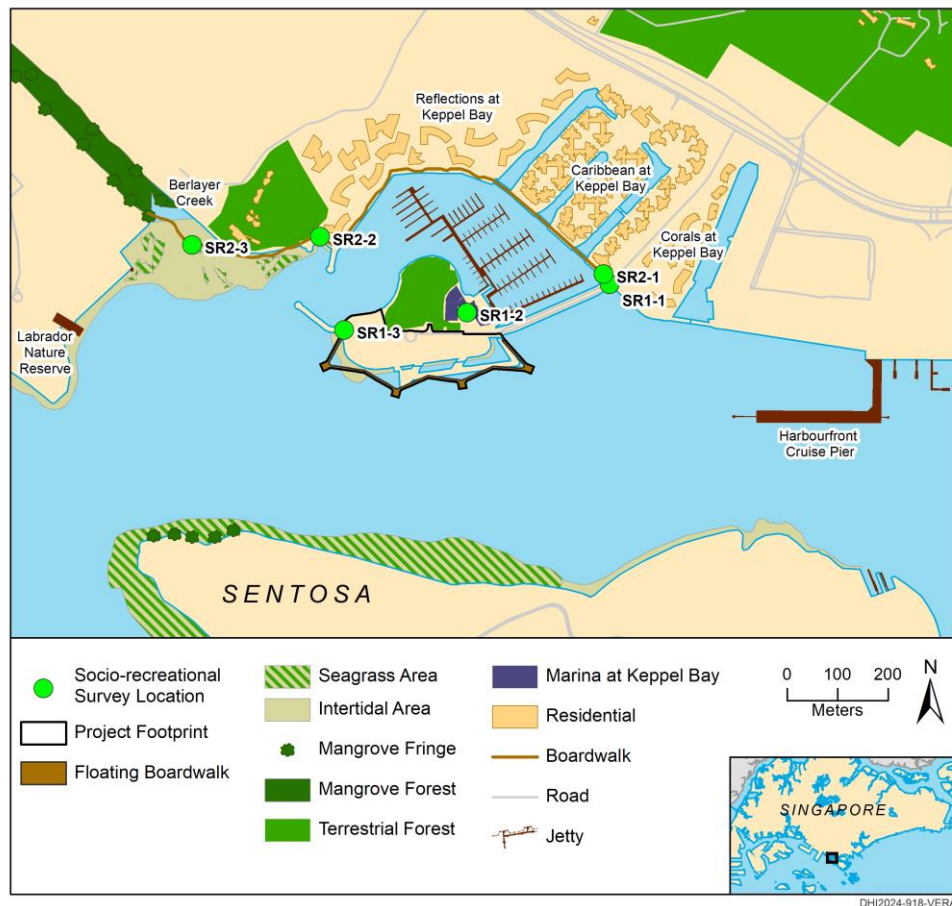


Figure 5.126 Locations of socio-recreational surveys carried out as part of baseline surveys for this Project

Survey Results and Discussion

The survey results are tabulated in Table 5.99 and presented in Figure 5.127. Overall, the Promenade is a more popular recreational area as compared to Keppel Island, with 1,117 versus 332 visitors during the survey days. Adults make up the largest number of visitors to both Keppel Island and the Promenade, followed by elderlies). For children and adults, the highest footfall was observed during the weekend evening survey at both Keppel Island and along the Promenade. Elderly activities at Keppel Island were highest during weekend evening, and those at the Promenade were highest during weekend morning.

Table 5.99 Total recreational users counted during DHI's socio-recreational surveys

Total Recreational Users Counted							
Location	Visitor	Weekday		Weekend		Sub Total	Grand Total
		Morning	Evening	Morning	Evening		
Keppel Island	Children	3	2	6	12	23	380
	Adult	63	53	82	111	309	
	Elderly	15	8	8	17	48	
Promenade	Children	2	4	4	19	29	1117
	Adult	208	178	190	308	884	
	Elderly	21	13	142	28	204	

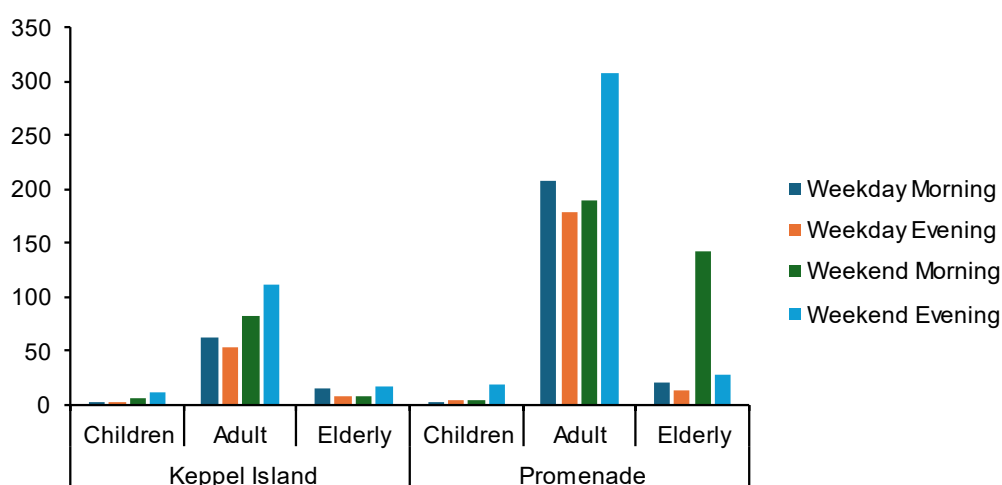


Figure 5.127 Total recreational users counted during DHI's socio-recreational surveys

Surveyors interviewed one hundred (100) visitors, of which ninety-one (91) responded to all questions in the questionnaire. Of the remaining nine (9), two (2) did not provide their age, and seven (7) did not provide their residential postal code.

The highest percentage of recreational users interviewed at both Keppel Island and the Promenade fall within the age range of forty-one (41) – sixty (60) years old (Figure 5.128), making it the largest demographic for the overall Project footprint. The largest proportion of respondents visit the area on a daily basis. The highest rate of visit is thrice daily, whereas the lowest is once a year (Figure 5.129). The majority of interviewed visitors on both Keppel Island and the Promenade are adults who engage in walking (Figure 5.130). Fifty-four (54) out of the one hundred (100) interviewed visitors to Keppel Island and the Promenade reside in the immediate and surrounding neighbourhood (South zone, District 04). Details of the zones and districts can be found in Table 5.100.

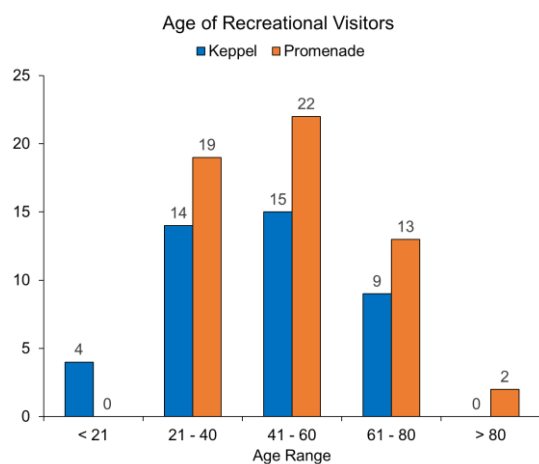


Figure 5.128 Age profile of interviewed visitors to Keppel Island and the Promenade

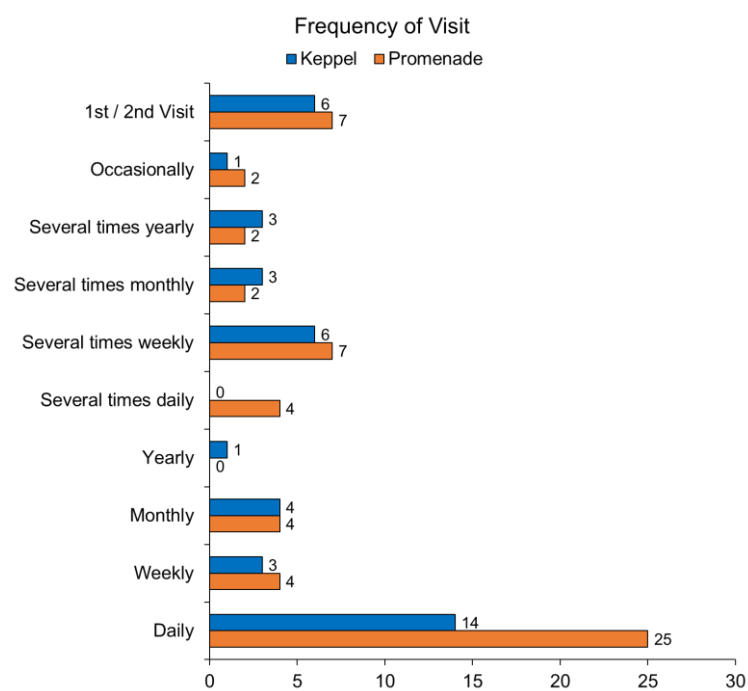


Figure 5.129 Frequency of visit of interviewed visitors to Keppel Island and the Promenade

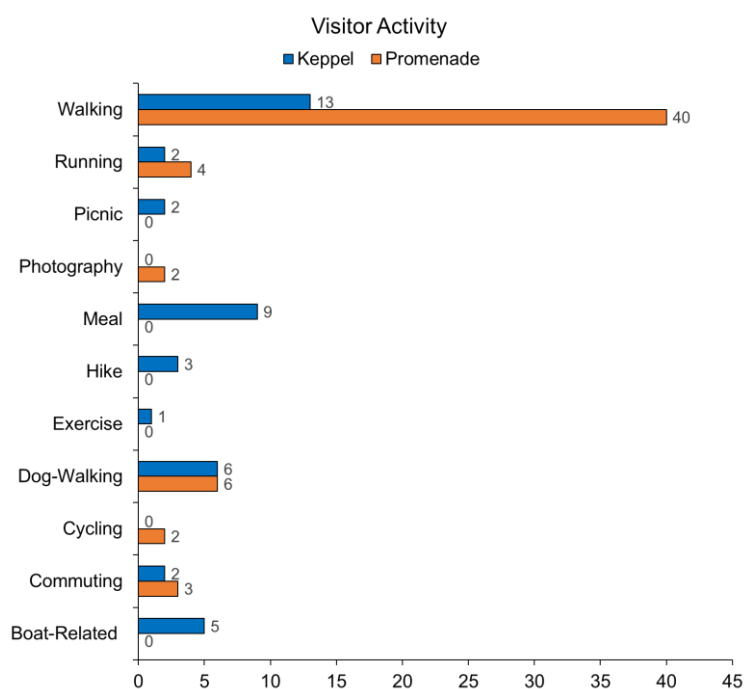


Figure 5.130 Activity of interviewed visitors to Keppel Island and the Promenade

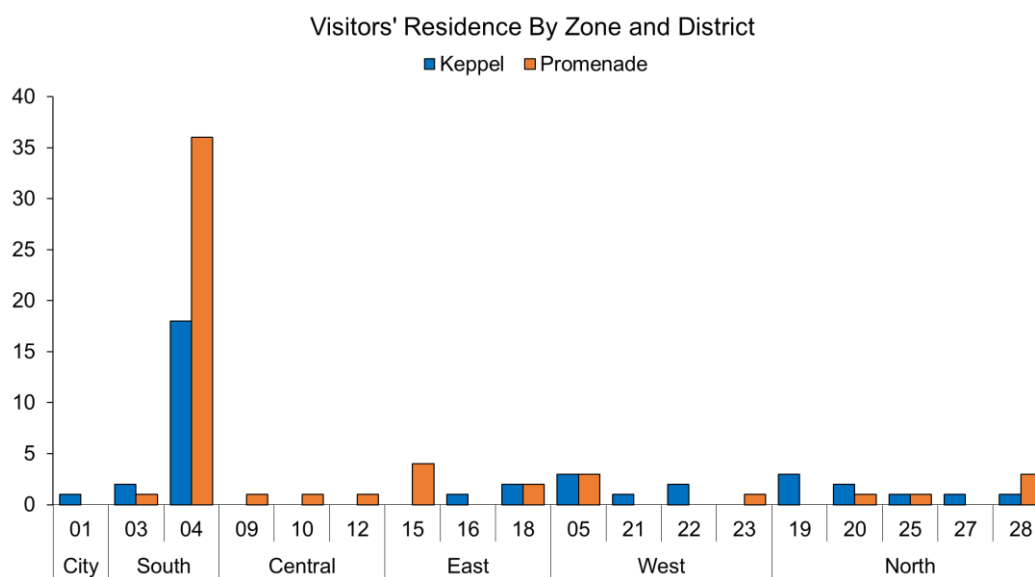


Figure 5.131 Residence of interviewed visitors (by Singapore's district and zone) to Keppel Island and the Promenade

Table 5.100 Singapore's zones and districts (URA)

Zone	District	General Location
City	01	Raffles Place, Cecil, Marina, People's Park
City	02	Anson, Tanjong Pagar
South	03	Queenstown, Tiong Bahru
South	04	Telok Blangah, Harbourfront
West	05	Pasir Panjang, Hong Leong Garden, Clementi New Town
City	06	High Street, Beach Road (part)
City	07	Middle Road, Golden Mile
Central	08	Little India
Central	09	Orchard, Cairnhill, River Valley
Central	10	Ardmore, Bukit Timah, Holland Road, Tanglin
Central	11	Watten Estate, Novena, Thomson
Central	12	Balestier, Toa Payoh, Serangoon
East	13	Macpherson, Braddell
East	14	Geylang, Eunos
East	15	Katong, Joo Chiat, Amber Road
East	16	Bedok, Upper East Coast, Eastwood, Kew Drive
East	17	Loyang, Changi
East	18	Tampines, Pasir Ris
North	19	Serangoon Garden, Hougang, Punggol
North	20	Bishan, Ang Mo Kio
West	21	Upper Bukit Timah, Clementi Park, Ulu Pandan
West	22	Jurong
West	23	Hillview, Dairy Farm, Bukit Panjang, Choa Chu Kang
West	24	Lim Chu Kang, Tengah
North	25	Kranji, Woodgrove
North	26	Upper Thomson, Springleaf
North	27	Yishun, Sembawang
North	28	Seletar

5.12.3 Evaluation Framework

Environmental changes that potentially affect social-economic receptors within the Study Area include generation of sediment plume (Section 5.2), water quality changes (Section 5.3), air quality pollution (Section 5.4), and ambient noise pollution (Section 5.5). Additionally, effects of spills and leaks from construction activities and vessels are also assessed qualitatively. This section describes the evaluation framework whereby significance of these impacts on the socio-economic receptors are assessed.

5.12.3.1 Evaluation of Receptor Importance

The evaluation of the Importance score in RIAM for socio-economic receptors adopts the framework presented in Table 4.11. In this Environmental Study, residential and recreational receptors are given an Importance score of "3" as they are important to areas

beyond the localised area of the Project. Staff of businesses is assessed to have an Importance score of “2” – they are important to the businesses affected only.

5.12.3.2 Evaluation of Magnitude of Change

To assess the impacts of the other socio-economic changes within the region as a result of the Construction Phase, analysis will follow the legal framework which governs Singapore. Where Singapore legislation is not available regarding aspects of the assessment, other evaluation criteria (e.g., DHI's airborne noise tolerance limits) are applied if applicable. Such tolerance limits are based on extensive experience within Southeast Asia, and specifically Singapore.

Visual Aesthetics for Sediment Plume

In the turbid water environments that are found around Singapore, low concentration sediment plumes in the surface of the water column are generally not visible if the excess concentration above background does not exceed 5 mg/l. This value, although potentially conservative during the rainy season when a change of 10 mg/l may not be visible, has been widely accepted by the Singapore authorities and is considered an appropriate limit.

In areas where there is a relatively high value or sensitivity associated with marine and shoreline usage, such as those with recreational beaches, high-level viewing, and/or hotel frontages, a more stringent tolerance limit of < 2.5 % exceedance of 5 mg/l is considered appropriate and has previously been successfully adopted (DHI, 1997; Driscoll *et al.*, 1997) when considering the potential impact on tourism. This is equivalent to a 5 mg/l plume being present for about 18 minutes per 12-hour daylight period. Based on this, the tolerance limits shown in Table 5.101 will be adopted for this Study, for residential and recreational receptors and businesses.

Table 5.101 Magnitude of Change matrix for visual impact from suspended sediments on residential and recreational receptors and businesses during daylight hours

Magnitude	Definition
No Change	Excess SSC > 5 mg/l for less than 2.5 % of the time
Slight Negative Change	Excess SSC > 5 mg/l for 2.5 % – 15 % of the time
Minor Negative Change	Excess SSC > 5 mg/l for 15 % – 30 % of the time
Moderate Negative Change	Excess SSC > 5 mg/l for more than 30 % of the time

Visual Aesthetics for Landscape Character

The assessment will be evaluating the visibility of the development's components. 'Visibility' refers to the degree to which specific activities can be seen from neighbouring areas, considering factors such as the number of viewers, the duration of visibility, viewing distance (proximity to construction/Project operations), type of view / landscape character, and the context of the view. In this Study, the general classifications of visibility are outlined broadly in accordance with the evaluation framework below.

Table 5.102 Evaluation framework for magnitude of change in visual impact

Score	Generic Definition	Customised Definition
-4	Major negative disadvantage or change	Extensive and transformative alterations that fundamentally reshape the landscape character, resulting in a significant and permanent deviation in nature from its original state.

Score	Generic Definition	Customised Definition
-3	Moderate negative disadvantage or change	Significant modifications that have a noticeable impact on the landscape, potentially leading to changes in its visual aesthetics and landscape character for a considerable area.
-2	Minor negative disadvantage or change	Noticeable alterations that may affect specific portions of the landscape, but the overall integrity and character are still largely preserved.
-1	Slight negative disadvantage or change	Small-scale modifications that are generally subtle and may not significantly alter the overall appearance or functionality of the landscape.
0	No change	Landscape character remains unchanged or change into comparable functionality. No noticeable change.

Air Quality

The evaluation framework for air quality impact on human receptors takes reference from the Guidance on the Assessment of Dust from Demolition and Construction by the Institute of Air Quality Management. This guidance suggests combining magnitude of emissions with sensitivity of receptors in order to evaluate the risk of air quality impact. The latter is influenced by exposure duration, sensitivity to exposure, number of receptors, distance from the source and lastly, the prevailing background concentration. IAQM's guidance for evaluating these parameters are summarised in Table 5.103 to Table 5.108.

This evaluation framework corresponds well with DHI's typical approach for deriving Magnitude score. For example, the tolerance limits of corals towards suspended sediment consider exposure duration and corals' sensitivity to this pressure and tolerance limit is an integral part of deriving Magnitude score. Number of receptors, distance from the source and prevailing background concentration are quantitatively predicted by DHI's marine models. No detailed description of IAQM's risk classifications (Negligible, Low, Medium and High) but these are deemed corresponding to RIAM's Magnitude definitions (Slight, Minor, Moderate and Major).

Table 5.103 Reference for defining the sensitivity of identified receptors

Sensitivity Classification	Reference Definitions
High	- Locations where members of the public are exposed over a time period relevant to the air quality objective for PM₁₀ (in the case of the 24-hour objective, a relevant location would be one where individuals may be exposed for eight hours or more in a day) - Indicative examples include residential properties. Hospitals, schools and residential care homes should also be considered as having equal sensitivity to residential areas for the purposes of this assessment.
Medium	- Locations where the people exposed are workers ¹, and exposure is over a time period relevant to the air quality objective for PM₁₀ (in the case of the 24-hour objective, a relevant location would be one where individuals may be exposed for eight hours or more in a day) - Indicative examples include office and shop workers but will generally not include workers occupationally exposed to PM₁₀, where protection is typically covered by Workplace Safety and Health regulations.
Low	- Locations where human exposure is transient ² - Indicative examples include public footpaths, playing fields, parks and shopping streets

Table 5.104 Sensitivity of the Area to Human Health Impacts (adapted to Singapore context)

Receptor Sensitivity	Annual Mean PM ₁₀ Concentration (µg/m ³)	Number of Receptors	Distance from the Source (m)				
			<20	<50	<100	<200	<350
High	>20	>100	High	High	High	Medium	Low
		10-100	High	High	Medium	Low	Low
		1-10	High	Medium	Low	Low	Low
	18-20	>100	High	High	Medium	Low	Low
		10-100	High	Medium	Low	Low	Low
		1-10	High	Medium	Low	Low	Low
	16-18	>100	High	Medium	Low	Low	Low
		10-100	High	Medium	Low	Low	Low
		1-10	Medium	Low	Low	Low	Low
	<16	>100	Medium	Low	Low	Low	Low
		10-100	Low	Low	Low	Low	Low
		1-10	Low	Low	Low	Low	Low
Medium	>20	>10	High	Medium	Low	Low	Low

¹ Workers are considered to be less sensitive than the general public as a whole because those most sensitive to the effects of air pollution, such as young children, are not normally workers. For this reason, workers have been included in the medium sensitivity category.

² There are no standards that apply to short-term exposure, e.g., one or two hours, but there is still a risk of health impacts, albeit less certain.

Receptor Sensitivity	Annual Mean PM ₁₀ Concentration (µg/m ³)	Number of Receptors	Distance from the Source (m)				
			<20	<50	<100	<200	<350
		1-10	Medium	Low	Low	Low	Low
	18-20	>10	Medium	Low	Low	Low	Low
		1-10	Low	Low	Low	Low	Low
	16-18	>10	Low	Low	Low	Low	Low
		1-10	Low	Low	Low	Low	Low
	<16	>10	Low	Low	Low	Low	Low
		1-10	Low	Low	Low	Low	Low
Low	-	≥1	Low	Low	Low	Low	Low

Table 5.105 Classification of risk of dust impacts for Demolition activities

Sensitivity of Area	Dust Emission Magnitude		
	Large	Medium	Small
High	High Risk	Medium Risk	Medium Risk
Medium	High Risk	Medium Risk	Low Risk
Low	Medium Risk	Low Risk	Negligible

Table 5.106 Classification of risk of dust impacts for Earthworks

Sensitivity of Area	Dust Emission Magnitude		
	Large	Medium	Small
High	High Risk	Medium Risk	Low Risk
Medium	Medium Risk	Medium Risk	Low Risk
Low	Low Risk	Low Risk	Negligible

Table 5.107 Classification of risk of dust impacts for Construction activities

Sensitivity of Area	Dust Emission Magnitude		
	Large	Medium	Small
High	High Risk	Medium Risk	Low Risk
Medium	Medium Risk	Medium Risk	Low Risk
Low	Low Risk	Low Risk	Negligible

Table 5.108 Classification of risk of dust impacts for Trackout

Sensitivity of Area	Dust Emission Magnitude		
	Large	Medium	Small
High	High Risk	Medium Risk	Low Risk
Medium	Medium Risk	Low Risk	Negligible
Low	Low Risk	Low Risk	Negligible

Airborne Noise

To assess the Magnitude of Change of noise impact to human receptors, the predicted noise levels are compared against the criteria stated in NEA's Environmental Protection and Management (Control of Noise at Construction Sites) Regulations as presented earlier in Table 5.20.

Assessment of noise levels against a noise limit merely requires comparison of the measured noise level against the permissible sound pressure levels. Assessment of the impact of a noise level in the environment, and the anticipated community response to the noise may require evaluation of the magnitude by which the noise level exceeds the existing ambient (baseline) sound level. The resulting exceedance is interpreted and categorised into different significance levels as described in Table 5.109. The thresholds presented takes guidance from the Fundamentals of Acoustics adopted by WHO which indicate a change in sound pressure level of 3 dB is just perceptible to the human ear and that of 5 dB is clearly noticeable (Hansen, 1951).

Table 5.109 Evaluation Framework for Magnitude of Change in noise level for human receptor. Where multiple criteria result in multiple possible scores, the more conservative score (higher Magnitude) is adopted in evaluating the Magnitude of Change.

Ordinal Score	Magnitude of Change	Criteria
-4	Major negative disadvantage or change	Predicted noise level at NSR exceeded the limit by more than 10 dBA
-3	Moderate negative disadvantage or change	- Predicted noise level at NSR exceeded the limit by between 5 to 10 dBA - Or predicted noise level at NSR cause an increase of greater than 10 dBA as compared to baseline level
-2	Minor negative disadvantage or change	- Predicted noise level at NSR exceeded the limit by between 3 to 5 dBA - Or predicted noise level at NSR cause an increase of up to 10 dBA as compared to baseline level
-1	Slight negative disadvantage or change	- Predicted noise level at NSR exceeded the limit by between 1 to 3 dBA - Or predicted noise level at NSR cause an increase of up to 5 dBA as compared to baseline level
0	No change	- Predicted noise level at NSR exceeded the limit by up to 1 dBA - Or predicted noise level at NSR cause an increase of up to 3 dBA as compared to baseline level

Ground Vibration

The evaluation criteria for ground construction vibration in socio-economic are similar to that in terrestrial ecology and biodiversity as outlined earlier in Section 5.9.3.2.

Underwater Noise

Elevated noise underwater could affect divers. A study was conducted with divers sitting in a diving tank where noise was induced, and diver drop-out rate was recorded as the noise increases. The effects of low frequency underwater sound on divers are summarised in Table 5.110 for the frequency range of 100 – 500 Hz. While there was also diver response information at the higher frequency range of 500 – 2500 Hz, there is a more sensitive

response at lower frequencies, hence this assessment is based on thresholds in the 100 – 500 Hz range only.

The tolerance limits proposed for the underwater noise impact on human receptors in this Environmental Study are shown in Table 5.111. They were based on benchmarking the study observations at varying sound level against the RIAM's definition for Magnitude of Change as per Table 4.10. 136 dB re.1 μ Pa is proposed as the threshold for measurable change (or Minor Change) as that was when the majority of the divers start to feel aversion from the sound pressure. At 148 dB re.1 μ Pa, the divers felt increasingly affected indicating higher stress level among a larger number of divers. This is set as the threshold for Moderate Change. 170 dB re.1 μ Pa is proposed as the limit for Major Change.

Table 5.110 Effects of low frequency underwater sound at frequency range of 100 – 500 Hz on divers (Source: SubAcoustech³)

SPL [dB re.1 μ Pa]	Effects
184	Based on animal models, liver haemorrhage and soft tissue damage are likely.
170	Tolerance limit for divers and swimmers. Sound causes lung and body vibration.
148 – 157	The loudness and vibration levels become increasingly aversive. Some divers will contemplate aborting an open water dive.
140 – 148	A small number of divers rate the sound as 'very severe'.
136 – 140	The sound is clearly audible. The majority of divers tolerate the sound well with only "Slight" aversion.
130	Divers and swimmers able to detect body vibration
80 – 100	Auditory threshold

Table 5.111 Proposed tolerance limits for evaluating Magnitude of Change for underwater noise effect on divers

SPL [dB re.1 μ Pa]	Magnitude of Change
≥ 170	Major Change
≥ 148	Moderate Change
≥ 136	Minor Change
≥ 130	Slight Change
< 130	No Change

Marine Navigation Impact

Deployment of marine barges and piling rigs for pilings and marine construction works is expected to increase vessel traffic in the vicinity of the work area. This might lead to

³ Limits for underwater noise exposure of human divers V2 (npl.co.uk)

potential congestion and travel inconveniences within the existing navigation channel. No numerical tolerance limits exist for assessing severity of the resulting space congestion in relation to varying increase in local traffic. This assessment is primarily qualitative based on the estimated marine work area and the vessel traffic statistics from 2019 AIS data.

Water Quality and Human Health

Pollution release or chemical spills from the Project construction activities to the waters may expose the recreational water users to elevated heavy metal concentrations to various degrees depending on the frequencies of contact and type of exposure. However, it is noteworthy that many chemical substances of potential concern have low water solubility and will tend to migrate to sediments, where they may accumulate (World Health Organization, 2021).

World Health Organization (WHO) Guidelines on Recreational Water Quality (World Health Organization, 2021) suggests that skin exposure may occur if the sediments are disturbed and resuspended, or where recreational water users are in direct contact with sediments. Direct contact with sediments is considered to make only a minor contribution to overall exposure. The evaluation framework for alteration of recreational water quality at Cruise Bay follows WHO's recreational water screening values for heavy metals. WHO recommended that a substance occurring in recreational water exceeded the guideline values should be investigated. The evaluation also considers the ASEAN MWQC for bacterial counts as shown in Table 5.112.

Table 5.112 Applied guideline values for heavy metals and bacteria in recreational waters

Parameter	
WHO Recreational Water Screening Value (µg/l)	
Arsenic (As)	200
Cadmium (Cd)	60
Chromium (Cr)	1,000
Copper (Cu)	40,000
Lead (Pb)	200
Nickel (Ni)	1,400
ASEAN MWQC for Human Health Protection	
Faecal Coliform	100 MPN/100ml
Enterococci	35 CFU/100ml

5.12.4 Impact Assessment

This section evaluates the potential impacts of various pressures on socio-economic receptors. A qualitative approach is used to assess the visual impact of accidental spills and leaks, the construction site, navigation impacts on water-based recreational users, and human health impacts resulting from spills and leaks associated with the Project's development. A quantitative approach is employed for the remaining identified pressures.

Passengers on cruise ships calling at HarbourFront Cruise Pier are considered as recreational receptors but have been scoped out from this assessment. They will likely have the full view of sediment plume, spills and leaks, construction area given their direct-

line-of-sight with the Project area and the water around it. Their exposure to these visual stressors is however influenced by the cruise speed. Based on the AIS data reported in Section 5.10.2, Figure 5.118, cruise ship speed ranges from 0 to 14 knots, with significant portion of them cruising between 2 and 8 knots. The total exposure is conservatively estimated to be 20 minutes considering 2 knots cruising speed. This is equivalent to 1.4 % of a day, too transient to warrant a concern of complaint.

5.12.4.1 Visual Impact due to Suspended Sediment Plumes

The mud transport modelling conducted for this Environmental Study (Section 5.2) has demonstrated that the sediment plume induced by the marine piling works is localised to the work area. Visibility of the plume to the residents varies depending on where the plume (or the piling work) is and whether the resident units are in the direct line-of-sight. It is likely that sediment plume from the marine works around the island will be visible to residents of the high-rise units at Reflections at Keppel Bay. The lower units at the seafront of this condominium are in the direct line-of-sight with only sediment plume on the western end of the island. The waterfront units of Caribbean at Keppel Bay and Corals at Keppel Bay will likely be able to see turbidity arising from marine piling works at the east and southeast of the island. The slightly higher units away from the Promenade are likely unaffected.

It is expected that staff of the businesses, users of the marina and recreational receptors at Keppel Island (at public spaces outside the Project's working area), along the Promenade and on the passing cruise ships will likely have a sight of the sediment plume when piling works is done at either eastern or western ends of the island.

In terms of suspended sediment concentration, DHI's mud transport model has predicted that the incremental SSC will exceed 5 mg/l for up to 23 % of the daylight hours. Based on the evaluation framework in Table 5.101, visual impact is assessed based on percentage time in exceedance of 5 mg/l during the 12-hour daylight period and this exceedance level is assessed to be Minor Negative Change. This change results in **Slight Negative Impact** on both the residents and the visitors in the Study Area.

5.12.4.2 Visual Impact due to Accidental Spills and Leaks

Marine vessel collisions, marine vessel groundings, and leaks onboard vessels can result in the uncontrolled release of oil, diesel, or oily wastes into the marine environment. While the likelihood of these events is relatively low, piling rigs and barges are expected in the Project area during construction, and the likelihood of these events is higher compared to the baseline situation. It is noted in Section 5.10 that the working area encroaches the turning circle southeast of Keppel Island and the navigation channel of Cruise Bay.

Similar to the discussion on sediment plume, visual impact due to spills and leaks happens when line-of-sight exists between oil slicks or oil sheens and the socio-recreational receptors. The nearby residents and recreational users with a closer distance from the seascape views are susceptible to the visual aesthetic appearance of the waters that could be compromised by the presence of oil slicks or oil sheens on the water's surface. For instance, residents living closer to the water's edge and recreational goers to Keppel Bay and the Promenade experience a sweeping vista of the waterfront. In the event of accidental spills and leaks, these receptors would experience a noticeable change in the appearance of the waterfront. Overall, this is assessed as a Minor Negative Change, giving a **Slight Negative Impact** to all the visual-sensitive receptors mention above.

5.12.4.3 Visual Impacts due to Construction Site

According to Guidelines for Landscape and Visual Impact Assessment (Landscape Institute and Institute of Environmental Management & Assessment, 2013), the visual effect of a development is greatly influenced by:

- The scale of the change in the view, including the proportion of the view occupied by the development;
- The degree of contrast to or integration with the existing condition; and,
- The nature of the view of the proposed development, i.e., whether the view will be full, partial or glimpse.

The landscape character of the Project area will be changed from serene area with manicured fields and small grass pastures (Figure 2.1) to active construction site comprising of works elaborated in Table 2.1. Presence of piling rigs and marine equipment has low degree of integration to the existing background landscape, i.e., view of the sea or the lush green of Sentosa and Labrador Nature Reserve.

The scale of the change in the view varies among the receptor groups of interest in this study. The proposed Project likely significantly occupies the view of the staff and visitors to the recreational facilities at Keppel Island and Marina at Keppel Bay, but only partially changes the seascape that the residents of higher-rise units at the nearby condominiums currently enjoy. It is noted that the visual effects on the residents at the seafront low-rise units and recreational receptors along the Promenade are limited due to the lack of line of sight.

Based on the definitions provided in Table 5.102, the Magnitude of Change is assessed as -2 for the nearby residents and for recreational receptors at the Promenade; and -3 for the recreational receptors and business at Keppel Island and Keppel Bay. These result in **Minor Negative Impact** on recreational receptors at Keppel Island and Keppel Bay and **Slight Negative Impact** on other socio-economic receptors.

5.12.4.4 Air Pollution Impact on Human Health

This assessment is carried in two steps. First, the sensitivity of the receptor and of the area is assessed based on the IAQM's evaluation framework presented in Table 5.103 and Table 5.104 and the information of the sensitive receptors in the area as discussed in Section 5.12.2. The outcome is documented in Table 5.113. The residential and recreational areas around the Project site are assessed to have Low sensitivity. The staff of businesses at Marina at Keppel Bay is with High sensitivity due to its close proximity to the construction area.

Second, the risk of air quality impacts is evaluated by combining receptor area sensitivity with dust emission magnitude according to the predefined matrices in Table 5.105 to Table 5.108. The residents at Reflections at Keppel Bay, Caribbean at Keppel Bay and Corals at Keppel Bay and recreational receptors at the Promenade are assessed to have Low Risk of human health impact due to dust emission from the Project. This is equivalent to Minor Negative Change in DHI's RIAM method, resulting in **Slight Negative Impact** when considering the Importance score of these receptors and Permanence, Reversibility and Cumulativity scores of the impact. The staff of businesses and recreational users at Keppel Island and Marina at Keppel Bay however are predicted to face Medium to High Risk, corresponding to Moderate to Major Negative Change, resulting in a **Minor Negative Impact**.

Table 5.113 Evaluation of sensitivity of residential, recreational and business receptors

Receptor Group	Receptor Sensitivity	Distance from Source	Annual Mean PM10 Level ⁴	Number of Receptors	Area Sensitivity
Residents at nearby condominiums	High	200 – 300 m	24 µg/m ³	> 100	Low
Recreational receptors at Keppel Bay	Low	< 20 m		81 – 140 ⁵	Low
Recreational receptors at the Promenade	Low	220 m		195 – 355 ⁴	Low
Staff of business	Medium	< 20 m		> 10	High

Table 5.114 Evaluation of risk of air quality impacts on residential, recreational and business receptors

Receptor group	Risk of Impact			
	Demolition	Earthworks	Construction	Trackout
Residents at nearby condominiums	Low Risk	Low Risk	Low Risk	Low Risk
Recreational receptors at Keppel Bay	Low Risk	Low Risk	Low Risk	Low Risk
Recreational receptors at the Promenade	Low Risk	Low Risk	Low Risk	Low Risk
Staff of business	Medium Risk	Medium Risk	High Risk	High Risk

5.12.4.5 Airborne Noise on Human Health

The Study Area has a low ambient noise level in general. Development works involve several noise-intensive activities (demolition and piling) that may alter the ambient noise in this area. DHI's 3D noise model shows that construction noise stays rather localised around the work area. The model results for the socio-economic receptors of interest along with the evaluation of Magnitude of Change in accordance with the framework presented in Table 5.109 are summarised in Table 5.115 below.

Residential and recreational receptors outside Keppel Island are predicted to experience 60-65 dBA Leq-5min. In relation to the baseline noise level at these places, the Magnitude of Change is assessed as Minor. The noise model also predicts > 10 dBA increase in noise exposure for the recreational receptors (in the area outside the Project footprint) and businesses (staff and visitors) at Keppel Island, resulting in a Moderate change.

⁴ Source: [Singapore: annual air pollution level PM10 2022 | Statista](#)

⁵ These are number of visitors recorded in each survey

Considering other RIAM attributes, the construction noise impact from the Project is assessed to be **Minor Negative Impact** on the visitors at Keppel Bay and Marina at Keppel Bay and **Slight Negative Impact** on the nearby residents, staff of businesses and the recreational receptors along the Promenades.

Table 5.115 Predicted pre-mitigation noise levels at the noise-sensitive receptors, comparison with the baseline levels and the relevant noise limits, and evaluation of Magnitude of Change.

NSR	Predicted noise level (dBA)	Baseline noise level (L10, dBA)	Adjusted Noise Limit (dBA)	Exceedance over Baseline	Exceedance over Noise Limit	Magnitude of Change
Marina at Keppel Bay	77	59	90	18	NA	Moderate
The Promenade	64	55	90	9	NA	Minor
Caribbean at Keppel Bay	62	55	90	7	NA	Minor
Reflections at Keppel Bay	64	55	90	9	NA	Minor
Corals at Keppel Bay	61	55	90	6	NA	Minor

Table 5.116 Predicted post-mitigation noise levels at the noise-sensitive receptors, comparison with the baseline levels and the relevant noise limits, and evaluation of Magnitude of Change.

NSR	Predicted noise level (dBA)	Baseline noise level (L10, dBA)	Adjusted Noise Limit (dBA)	Exceedance over Baseline	Exceedance over Noise Limit	Magnitude of Change
Marina at Keppel Bay	62	59	90	3	NA	No Change
The Promenade	64	55	90	9	NA	Minor
Caribbean at Keppel Bay	58	55	90	3	NA	No Change
Reflections at Keppel Bay	64	55	90	9	NA	Minor
Corals at Keppel Bay	60	55	90	5	NA	Slight

5.12.4.6 Underwater Noise Impact on Human Health

Piling works associated with the boardwalk construction will alter the underwater noise in the vicinity. Leisure diving activities at Marina at Keppel Bay take place between Keppel Bay bridge and the adjacent pontoon within Keppel Bay. This diving site is 20 m within the nearest piling operation and the divers may be adversely influenced by elevated noise level.

It was proposed earlier that 170 dB re.1 μ Pa the threshold for Major Change and 148 dB re.1 μ Pa the threshold for Moderate Change. Following the same method as for underwater noise impact on fish and megafauna, the distance to threshold is calculated. The distances to 170 dB re.1 μ Pa and to 148 dB re.1 μ Pa are 21.5 m and 631 m respectively. The dive site overlaps slightly with the Major Negative Change zone and is mostly within the Moderate Negative Change zone. For this assessment, Major Negative Change is conservatively used, resulting in a **Minor Negative Impact**.

5.12.4.7 Ground Vibration Impact on Human Health

The predicted ground vibration level at Marina at Keppel Bay due to vibratory piling is 2.60 mm/s (Section 5.6.3) which is above the threshold of 1.0 mm/s to cause complaints in a residential environment according to BS 5228-2. Based on the tolerance limits presented in Table 5.85, this vibration level is assessed as Moderate and the resulting impact levels are **Minor Negative Impact** on the recreational receptors on Keppel Island and **Slight Negative Impact** on businesses at Marina at Keppel Bay. There is no vibration impact on the nearby residents.

5.12.4.8 Marine Water Quality Impacts on Human Health

The construction Project may alter water quality around Keppel Island in several ways, i.e., release of pollutants from resuspended seabed sediment and accidental spills and leaks. This section discusses the human health impacts associated with these changes, in relation to the recreational divers at the marina.

It has been demonstrated in Section 5.3.5 that heavy metal release from suspended sediment is minute and the resultant heavy metal concentrations in the water around Plot 6 development will remain compliant with the ASEAN MWQC, and compliant with WHO Recreational Water Screening Values.

In the event of an accidental release, the spilled inventory will be carried away by the tidal current and may reach the recreational dive site. This could cause adverse effects on the divers (or temporary closure of the site until clean-up is completed). It is qualitatively assessed that the risk of oil spill impact on human health is Minor Negative Change since it is likely measurable. This assessment considers that oil spill risk presently exists in the study area due to vessel movement in Cruise Bay and that there will be only two (2) marine barges working at a time. Consequently, the risk of oil spill impact on human health is evaluated as a **Slight Negative Impact**.

5.12.4.9 Impact from Construction Vessel Traffic on Recreational Marine Traffic

Recreational marine traffic in the study area includes the cruise ships that depart from or approach HarbourFront Cruise Pier, as well as the recreational yachts and superyachts that enter and exit Marina at Keppel Bay. The navigation impact on cruise ships has been discussed in Section 5.10, this section focuses on impacts on the recreational boats at the marina.

The AIS data extracted within the study area (Figure 5.114) show that these yachts typically transit through the break waters west of Keppel Island and east of Bukit Chermin. The breakwaters shape the marina opening in a way that channel the yacht movement away

from the working area for Plot 6 development. Marine construction traffic for the Project is anticipated to cause **No Impact** on these movements.

5.12.5 Mitigation Measures

The impacts on socio-economic receptors in the vicinity of the proposed construction Project were predicted to range from **No Impact** to **Minor Negative Impact**, which are within the proposed EQO for this receptor group. The follow mitigation measures are recommended to improve environmental performance of the Project, through minimising the potential impacts on socio-economic receptors.

Table 5.117 Mitigation and management measures to impacts on socio-economic receptors during the Construction Phase

Aspect	Mitigation/Management Measures
Visual Impact	- Deploy silt curtain around marine works to contain sediment plume, reducing visual impacts arising from it. It is to note that this solution will only reduce impacts on the business and recreational receptors on the ground and will not mitigate visual impact on the residents. - Install visually appealing construction hoarding (e.g., pixelated tree design hoarding). It is to note that this solution will only reduce impacts on the business and recreational receptors on the ground and will not mitigate visual impact on the residents. - Proactively monitor and regularly maintain equipment to prevent accidental spills and leaks. It is a good practice to have a standby spill kit on site.
Air pollution	- Comply with relevant environmental regulations, including the Environmental Protection and Management Act and any other regulations and guidelines that come into effect when the time of construction works commences. - Erect barriers around dust-emitting activities or the site boundary that are at least as high as any stockpiles on site. - Fully enclose site or specific operations where high potential for dust emission is expected. - Stockpile, if any, should be covered using biodegradable erosion control mat to prevent wind erosion and wash off by rain. - Machinery used on-site shall be properly and regularly inspected and maintained to control dust and air pollutants emission. - Imposing speed limits on construction site to limit dust suspension, especially on un-surfaced roads and work areas. According to Washington State Department of Ecology, lowering the speed of a vehicle from 45 miles per hour (mph) to 35 mph can reduce dust emissions by up to 22 %. - Shutting down of equipment and vehicles when not in use to reduce emission and wastage. - Recommendation of mitigation measures assumes that no concrete batching would be carried out on site. In the event of concrete batching, mitigation measures should be recommended prior to construction to minimise dust impacts.

Aspect	Mitigation/Management Measures
Airborne Noise	- Comply with approved working hours, strict compliance for noise generating construction operations such as demolition and piling works. - Noise barrier of 4.0 m along the Project boundary Marina at Keppel Bay as mentioned in Section 5.5.6. - Shutting down of equipment and vehicles when not in use to reduce construction noise generated.
Underwater Noise	Temporary closure of the leisure dive operation at Marina at Keppel Bay during the marine construction period.
Ground Vibration	- When technically feasible, use construction equipment with less vibration intensity or shorter durations (e.g., use a rotary pile driver in replacement of the vibratory pile driver during driven cast-in-place piling; use dump trucks with higher loading capacity to reduce the duration of operation); use vibration rollers and excavators with smaller capacity to reduce intensity of operation. - Low-power machinery of the same type should be considered to reduce the vibration strength at source (i.e., use vibration rollers and excavators with smaller capacity to reduce intensity of operation.) - Sequence construction activities to minimise cumulative impact from the vibration generating equipment. - Maintain a complaints procedure to log and track response to complaints received from stakeholders.
Marine water quality	A spill emergency response plan and related equipment for the Project site to be developed to ensure a maximum response time of 60 minutes after detection of leak or spill while the slick is mostly localised to the release site.
Navigation impact	No mitigation needed.

5.12.6 Socio-economic Impact Summary

The Construction Phase impacts from the Project's construction work on socio-economic receptors have been summarised in Table 5.118.

Table 5.118 RIAM results for Construction Phase (short-term) impacts from the Project on socio-economic receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Residents	Air pollution	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Airborne noise	3	-2	2	2	2	-36	Slight Negative Impact	-2	-36	Slight Negative Impact
	Ground vibration from construction	3	0	2	2	2	0	No Impact	-	-	-
	Visual impact due to sediment plumes	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
	Visual impact of landscape changes	3	-2	2	2	2	-36	Slight Negative Impact	-	-	-
	Visual impacts of spills and leaks	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
Recreational users	Air pollution impact on recreational users at the Promenade	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
	Air pollution impact on recreational users at Keppel Island and Marina at Keppel Bay	3	-4	2	2	2	-72	Minor Negative Impact	-3	-54	Minor Negative Impact
	Airborne noise on recreational users at the Promenade	3	-2	2	2	2	-36	Slight Negative Impact	-2	-36	Slight Negative Impact
	Airborne noise on recreational users at Keppel Island and Marina at Keppel Bay	3	-3	2	2	2	-54	Minor Negative Impact	0	0	No Impact
	Ground vibration from construction on recreational receptor on Keppel Island	3	-3	2	2	2	-54	Minor Negative Impact	-2	-36	Slight Negative Impact
	Visual impact due to sediment plumes	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Visual impact of landscape changes (for recreational users at Keppel Island and at Marina at Keppel Bay)	3	-3	2	2	2	-54	Minor Negative Impact	-2	-36	Slight Negative Impact
	Visual impact of landscape changes (for recreational users at the Promenade)	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
	Visual impacts of spills and leaks	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
Recreational Users (Water users e.g., Divers)	Underwater noise	3	-4	2	2	2	-72	Minor Negative Impact	0	0	No Impact
	Health impacts of spills and leaks	3	-2	2	2	2	-36	Slight Negative Impact	0	0	No Impact
	Construction vessels and working area impacting movement of cruise ships	3	-1	2	2	2	-18	Slight Negative Impact	-	-	-
	Construction vessels and working area impacting movement of yachts	3	0	2	2	2	0	No Impact	-	-	-
Staff of Businesses	Air pollution	2	-4	2	2	2	-48	Minor Negative Impact	-3	-36	Slight Negative Impact
	Airborne noise	2	-3	2	2	2	-36	Slight Negative Impact	0	0	No Impact
	Ground vibration from construction	2	-3	2	2	2	-36	Slight Negative Impact	-2	-24	Slight Negative Impact

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Visual impact due to sediment plumes	2	-2	2	2	2	-24	Slight Negative Impact	-1	-12	Slight Negative Impact
	Visual impact of landscape changes	2	-3	2	2	2	-36	Slight Negative Impact	-2	-24	Slight Negative Impact
	Visual impacts of spills and leaks	2	-2	2	2	2	-24	Slight Negative Impact	-1	-12	Slight Negative Impact

6 Post-Construction Phase (Long-Term) Impacts

The assessment of impacts at the Post-Construction Phase is aimed at analysing the level of changes in the surrounding.

6.1 Hydrodynamics

This section presents the methodology for analysing changes to currents and morphology in the vicinity of the pile deck and floating boardwalk after the completion of the entire structure.

6.1.1 Relevant Receptors

Changes in hydrodynamic parameters may exert stresses on the following groups of receptors:

- Marine navigation and jetties; and,
- Recreational users

This section only discusses the pressure or stressor. The corresponding receptor chapters assess and discuss the resulting hydrodynamic effects on these receptors (Sections 6.4 and 6.6).

6.1.2 Baseline Conditions

The baseline conditions for hydrodynamics in the Study Area was described previously in Section 5.1.1.

6.1.3 Modelling Methodology

DHI's MIKE 21 Hydrodynamics (HD) FM was used to quantify the changes to the hydrodynamic conditions (current speeds, flow patterns) as a result of the Project. The calibrated and validated hydrodynamic model of the Singapore Strait (Figure 6.1) was used. The finest resolution of 8 m was applied to define features within the area of interest. The model was calibrated and validated with DHI's inhouse data. For the assessment in the Post-Construction Phase, a simplified morphological assessment was conducted to assess areas with expected erosion and sedimentation in the vicinity of the Study Area. The bed shear stress generated by the present current conditions was calculated and presented to identify the areas of relative erosion and sedimentation. A detailed description of HD model setup, assumption, and calibration is provided in **Appendix A**.

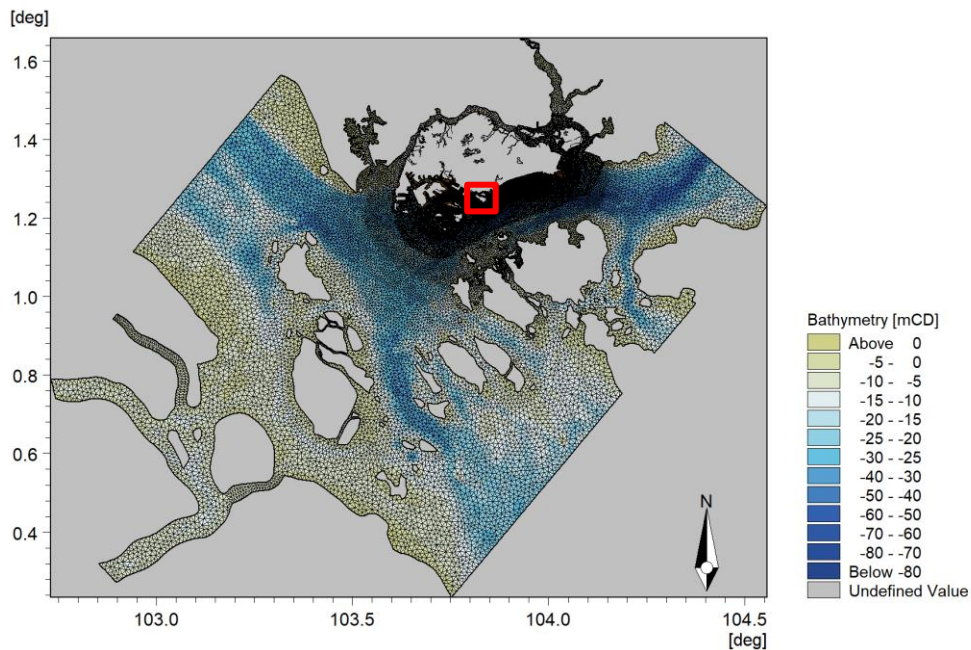


Figure 6.1 DHI's calibrated and validated Singapore Straits' model domain and bathymetry. The location of the Study Area with 8 m resolution in the model is indicated by the red box.

Modelling Scenarios

Due to concerns over the impact of seasonal variation, the modelling periods simulated were during NE monsoon and inter-monsoon to account for when the currents are at its strongest and its weakest, respectively. The Baseline and Post-Construction Phase scenarios were defined and simulated for fourteen (14) days, covering one spring-neap tidal cycle. This covered the range of seasonal variations in currents that might affect the model results.

Based on the chosen construction method provided (Section 2.3.2), piles will have to be installed in both the land and sea, to support the structures. However, only piles that are to be installed in the sea will be considered in this model as suspended sediment plumes will only be generated in the sea. In total, there are 355 piles to be installed – 133 piles for the floating boardwalk and 222 piles for the pile deck. The pontoons that are planned to be used in the floating boardwalk were designed to be submerged at least 1 m below the waterline. Therefore, both piles in the pile deck and floating boardwalk as well as floating boardwalk gate were simulated in the hydrodynamic model.

The baseline scenario will also be modelled over the same time period to assess changes between phases. In the baseline condition, there are marine structures near the Study Area that contribute to the hydrodynamic processes. These structures, including the caissons' structure, Marina Keppel Bay Jetties, Keppel Bay Bridge, breakwaters, and the existing Wharf, were incorporated into the baseline model (Figure 6.2). The same structures are considered in the post-construction scenario, except for the existing Wharf, as it will be demolished (Figure 6.3). Table 6.1 shows a summary of the modelled marine structures and land for the Post-Construction phase.

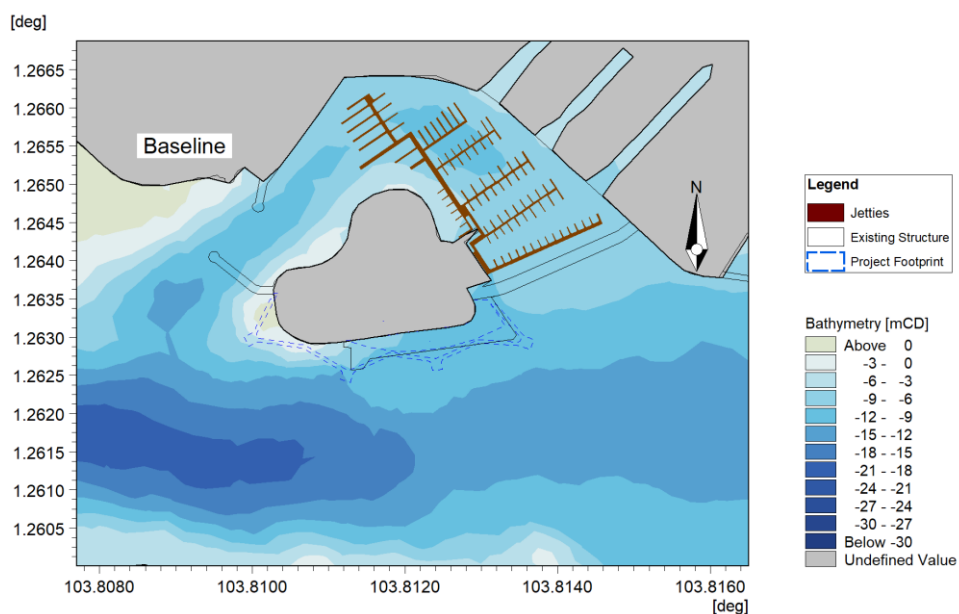


Figure 6.2 Baseline profile for assessment of hydrodynamic impacts. The baseline profiles include the existing structures, i.e., caissons, jetties in Marina at Keppel Bay, Keppel Bay Bridge, breakwaters, and existing Wharf.

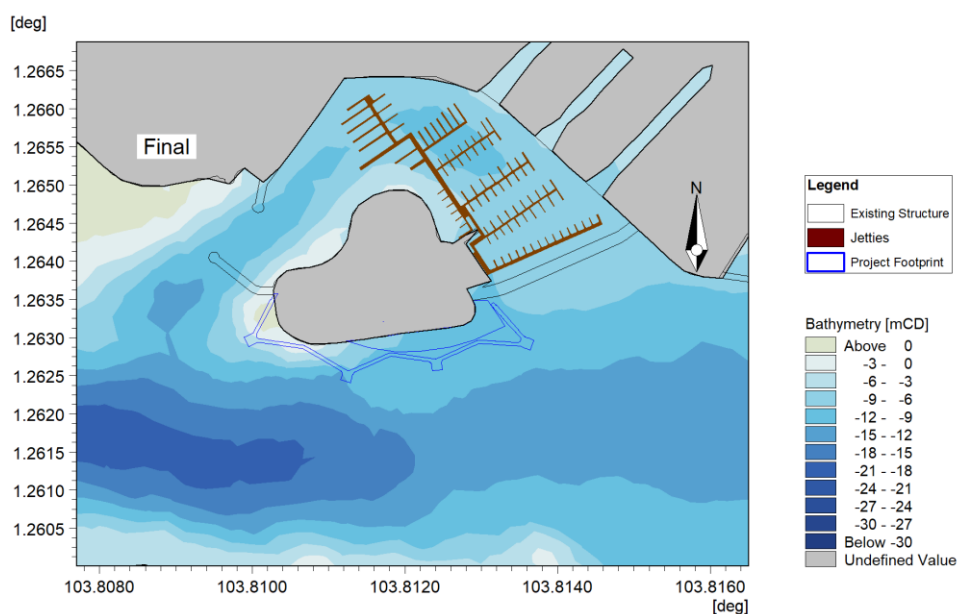


Figure 6.3 Post-Construction profile for assessment of hydrodynamic impacts. The Post-Construction profile include piles installed for the pile deck (222 piles) and floating boardwalk (133 piles), floating boardwalk's pontoons, and the existing structures, except existing Wharf (which will be demolished).

Table 6.1 Modelling scenarios for current impact assessment during Post-Construction Phase

Scenario	Phase	Monsoon Period
1	Baseline	NE
2		Inter-monsoon
3	Post-Construction	NE
4		Inter-monsoon

6.1.4 Evaluation Framework

Changes to currents as a result of final profile of the Project are primarily assessed through specific analysis of the following current characteristics:

- Mean current speeds;
- Maximum (95th percentile) current speeds; and,
- Representative current speeds such as exceedance of 2.0 knots, exceedance of 3.5 knots and slackwater (<0.5 knots) duration.

Assessment of statistical descriptors examining current conditions and current field time series are based on experience and generally accepted international practices in order to assess potential levels of change. These statistics help to focus and define the parameters and outputs for the modelling. Thresholds for the descriptors are related to navigational receptors. These tolerance limits are presented in the corresponding receptor chapters (Sections 6.4 and 6.6), along with the impact assessment.

As for the long-term sedimentation/erosion assessment, the following statistics describing erosion and sedimentation were extracted:

- Mean Bed Shear Stress (BSS); and
- Maximum (95th percentile) BSS.

6.1.5 Results and Discussions

The changes to currents around the Study Area are represented by changes to current statistics (mean and 95th percentile), representative current speeds, and BSS (mean and 95th percentile). Overall:

- Current speed in the surrounding Project area can reach up to 1.00 m/s during NE monsoon and 0.80 m/s during the inter-monsoon in the Cruise Bay Area, flowing from east (Brani Island) to west (Pandan Strait);
- The Project's footprint is predicted to have an impact on slackwater descriptor, while the impact on other current parameters is negligible. This observation holds for both NE and inter-monsoon periods; and
- The change in BSS due to the Project's footprint is relatively small in the Study Area for both NE and inter-monsoon periods.

These changes are described in the following subsections.

Change in Mean Current Speeds

Figure 6.4 illustrates the mean current speed during NE monsoon and inter-monsoon (on the left and right columns, respectively), and the top, middle, and bottom figures represent the Baseline, Post-Construction Phase; and finally, the predicted change in the mean current speeds (between Baseline and Post-Construction Phase) respectively.

The Project is expected to cause mean current speed changes of less than 0.10 m/s in the local Project area during the NE monsoon, and less than 0.05 m/s in both the local Project area and the vicinity during the inter-monsoon period.

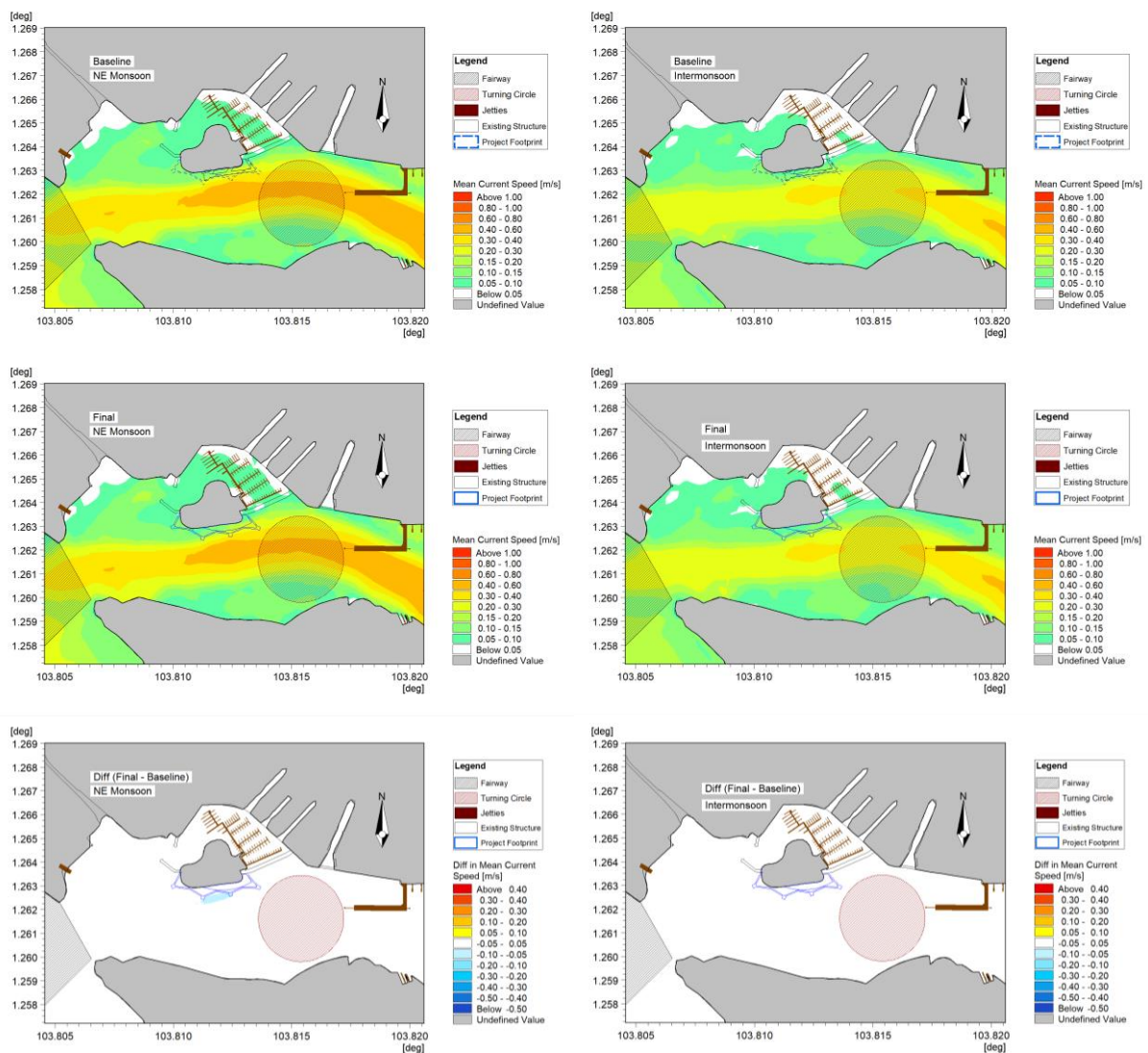


Figure 6.4 Mean current speed during NE monsoon (left column) and inter-monsoon (right column). Top row: Baseline during NE monsoon (left) and inter-monsoon (right). Middle row: Post-Construction phase during NE monsoon (left) and inter-monsoon (right). Bottom row: Difference between Post-Construction Phase and Baseline during NE monsoon (left) and inter-monsoon (right).

Change in 95th Percentile Current Speeds

Figure 6.5 illustrates 95th percentile current speed during NE monsoon and inter-monsoon (on the left and right columns, respectively), and the top, middle, and bottom figures represent the Baseline, Post-Construction Phase; and finally, the predicted change in the

95th percentile current speeds (between Baseline and Post-Construction Phase) respectively.

In general, the Project is predicted to cause changes in less than 0.1 m/s to 95th percentile current speed. However, there is a localised impact near the boardwalk area where the 95th percentile of current speed will decrease up to 0.2 m/s during NE Monsoon (see bottom row-left, Figure 6.5).

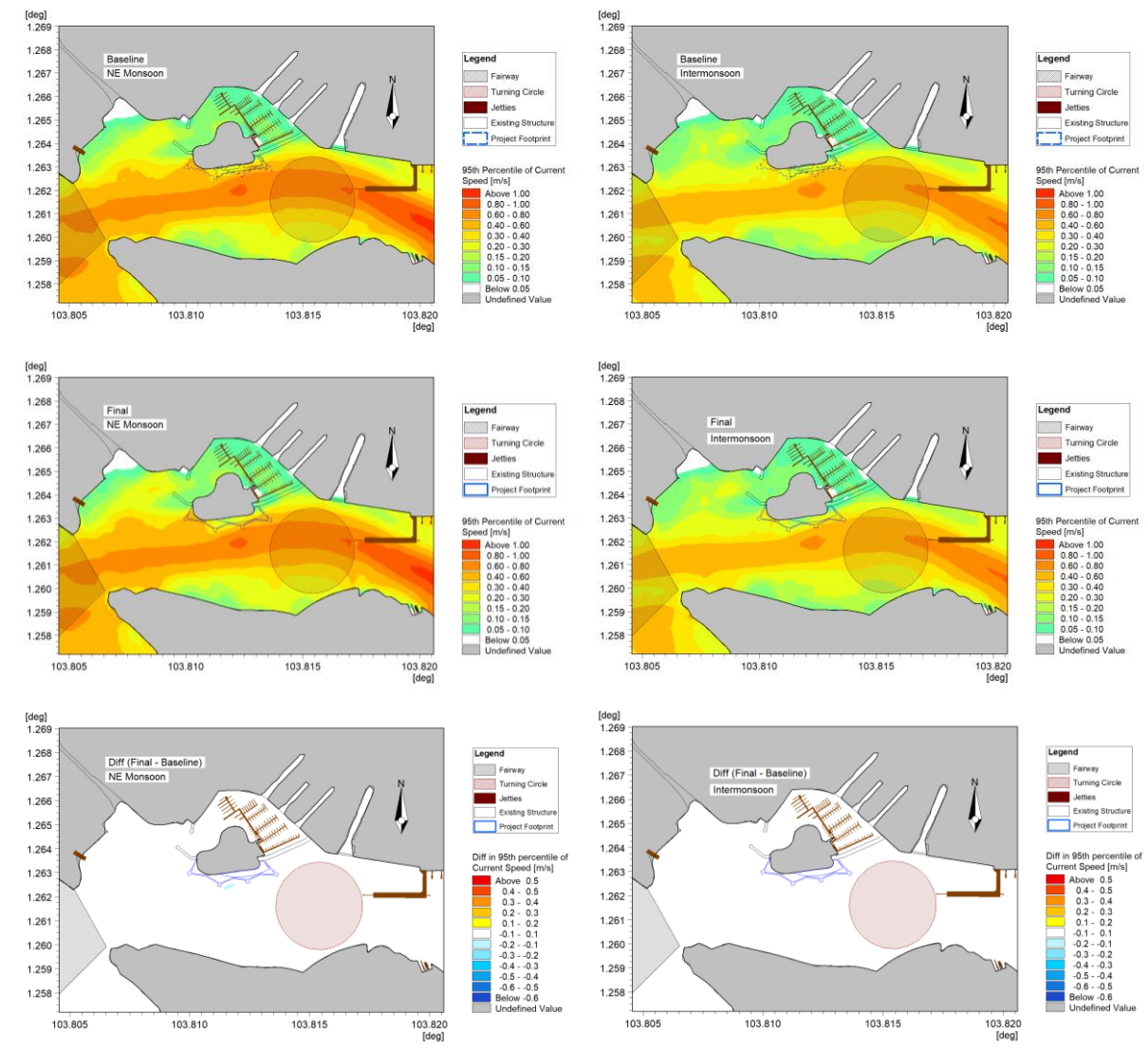


Figure 6.5 95th percentile current speed during NE monsoon (left) and inter-monsoon (right). Top row: Baseline during NE monsoon (left) and inter-monsoon (right). Middle row: Post-Construction phase during NE monsoon (left) and inter-monsoon (right). Bottom row: Difference between Post-Construction Phase and Baseline during NE monsoon (left) and inter-monsoon (right).

Representative Current Speeds: Slackwater (<0.5 knots), Exceedance of 2 knots and 3.5 knots

As an alternative to the analysis of mean and 95th percentile current speeds, a measure level of change to the exceedance of selected representative current speeds is provided in this section. This alternative is meant to provide additional understanding of the scale of change in current speeds, and for this purpose, the speed of 3.5 knots (1.8 m/s), 2.0 knots

(1 m/s) and below 0.5 knots (0.25 m/s) were used. A current speed lower than 0.5 knots is generally referred to as slackwater.

Figure 6.6 illustrates the duration of slackwater. The presence of the final structure is predicted to increase the duration of slackwater by up to 10 % near the Project site, which applies to both monsoon conditions, with the NE monsoon predicted to have a much wider area of increasing duration of slackwater (see bottom row-left of Figure 6.6). Meanwhile, a decrease in the duration of slackwater is predicted to occur in the vicinity of the Study Area by up to 10 % during the NE monsoon and 5 % during inter-monsoon (see bottom row-left and right of Figure 6.6).

In terms of exceedance of 2.0 knots and 3.5 knots in current speed, which can be seen in Figure 6.7 and Figure 6.8, the Project is predicted to cause changes in less than 1 % to the duration of current speed exceeding 2.0 knots and 3.5 knots in the vicinity of Project site in both monsoon conditions (see bottom row-left and right of Figure 6.7 and Figure 6.8).

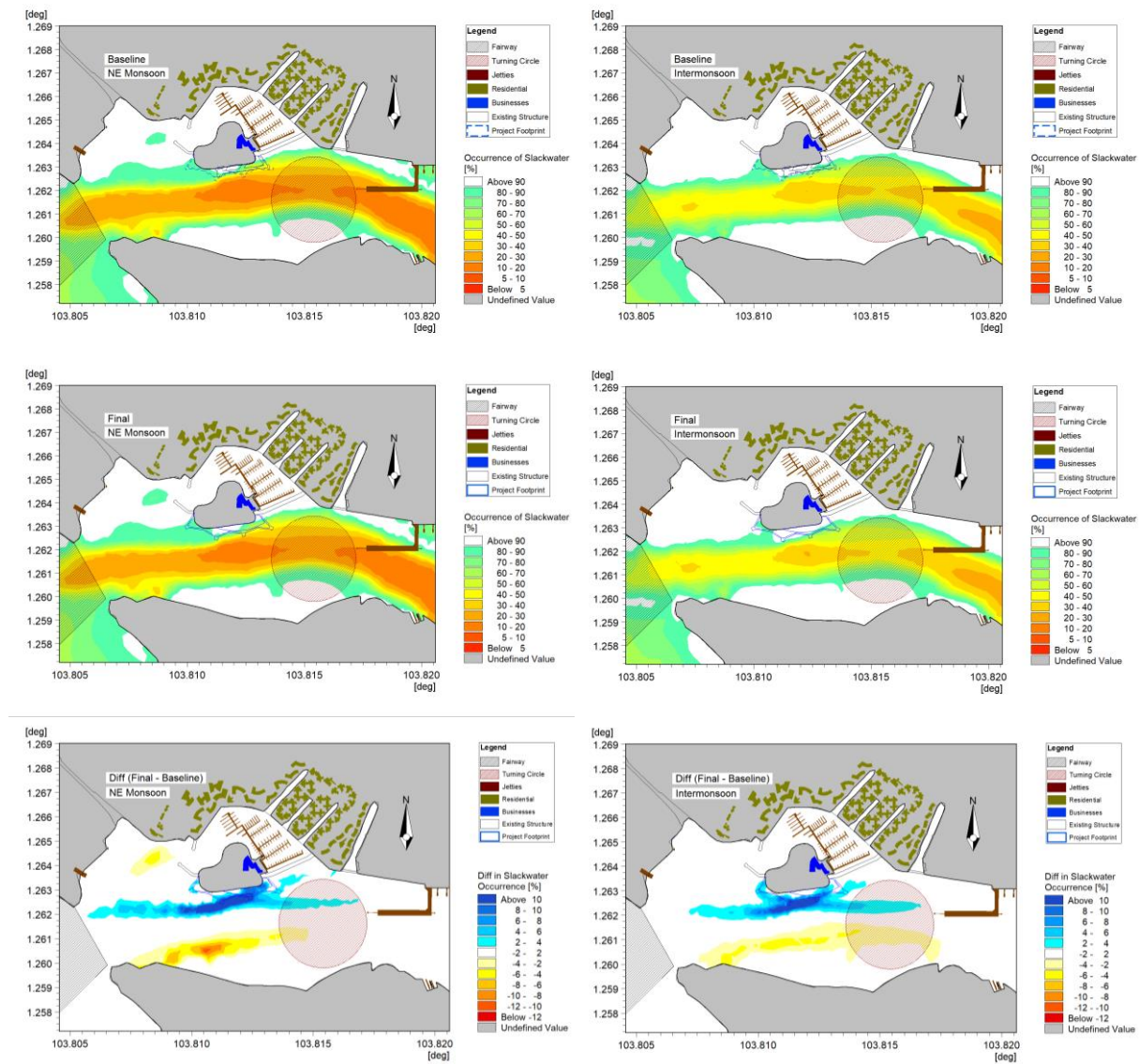


Figure 6.6 Slackwater duration (currents <0.5 knots) during NE monsoon (left) and inter-monsoon (right). Top row: Baseline during NE monsoon (left) and inter-monsoon (right). Middle row: Post-Construction phase during NE monsoon (left) and inter-monsoon (right).

Bottom row: Difference between Post-Construction Phase and Baseline during NE monsoon (left) and inter-monsoon (right).

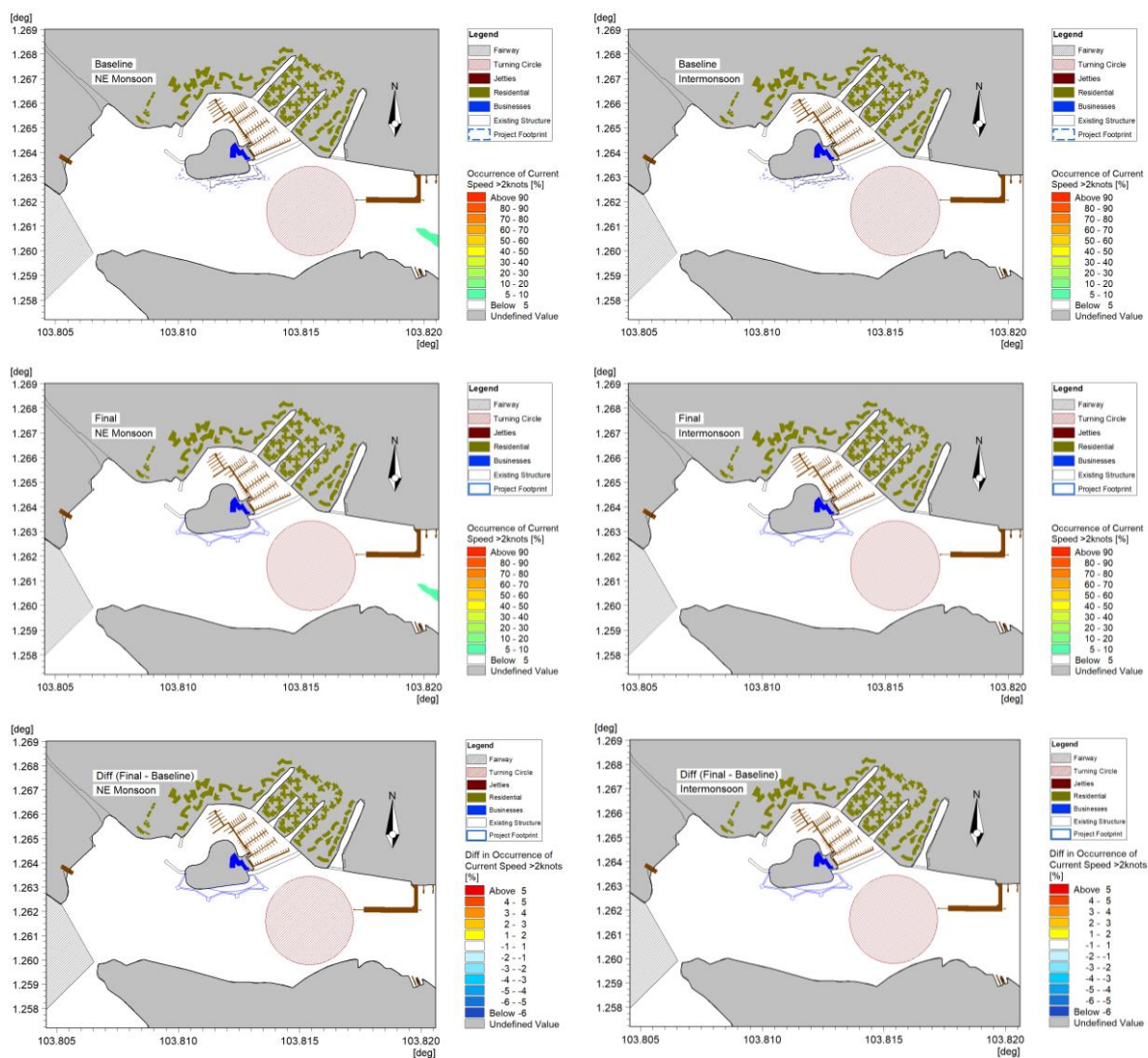


Figure 6.7 Percentage of time when current speed exceeded 2 knots during NE monsoon (left) and inter-monsoon (right). Top row: Baseline during NE monsoon (left) and inter-monsoon (right). Middle row: Post-Construction phase during NE monsoon (left) and inter-monsoon (right). Bottom row: Difference between Post-Construction Phase and Baseline during NE monsoon (left) and inter-monsoon (right).

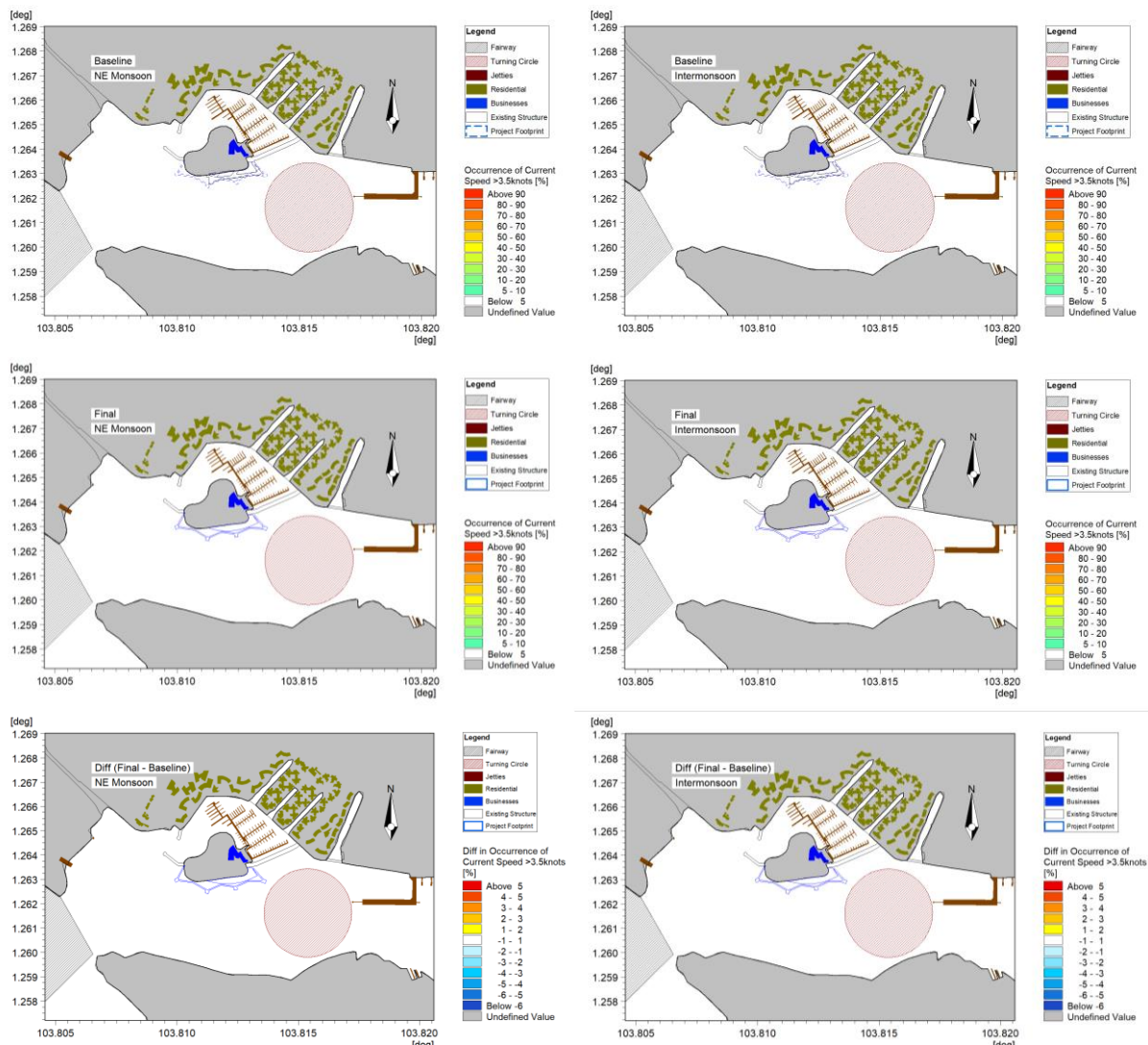


Figure 6.8 Percentage of time when current speed exceeded 3.5 knots during NE monsoon (left) and inter-monsoon (right). Top row: Baseline during NE monsoon (left) and inter-monsoon (right). Middle row: Post-Construction phase during NE monsoon (left) and inter-monsoon (right). Bottom row: Difference between Post-Construction Phase and Baseline during NE monsoon (left) and inter-monsoon (right).

Change in Mean Bed Shear Stress

Figure 6.9 illustrates the mean BSS during NE monsoon and inter-monsoon (on the left and right columns, respectively), and the top, middle, and bottom figures represent the Baseline, Post-Construction Phase; and finally, the predicted change in the mean BSS (between Baseline and Post-Construction Phases) respectively.

In general, the mean BSS in the Cruise Bay channel is predicted to have value up to 0.5 N/m² for NE monsoon, and up to 0.3 N/m² for inter-monsoon. The Project's footprint is predicted to cause changes of less than 0.1 N/m² to mean BSS across the Study Area. Nevertheless, during the NE monsoon, a slight decrease in mean BSS (less than 0.2 N/m²) is expected in a region near the Project footprint (see bottom row-left, Figure 6.9).

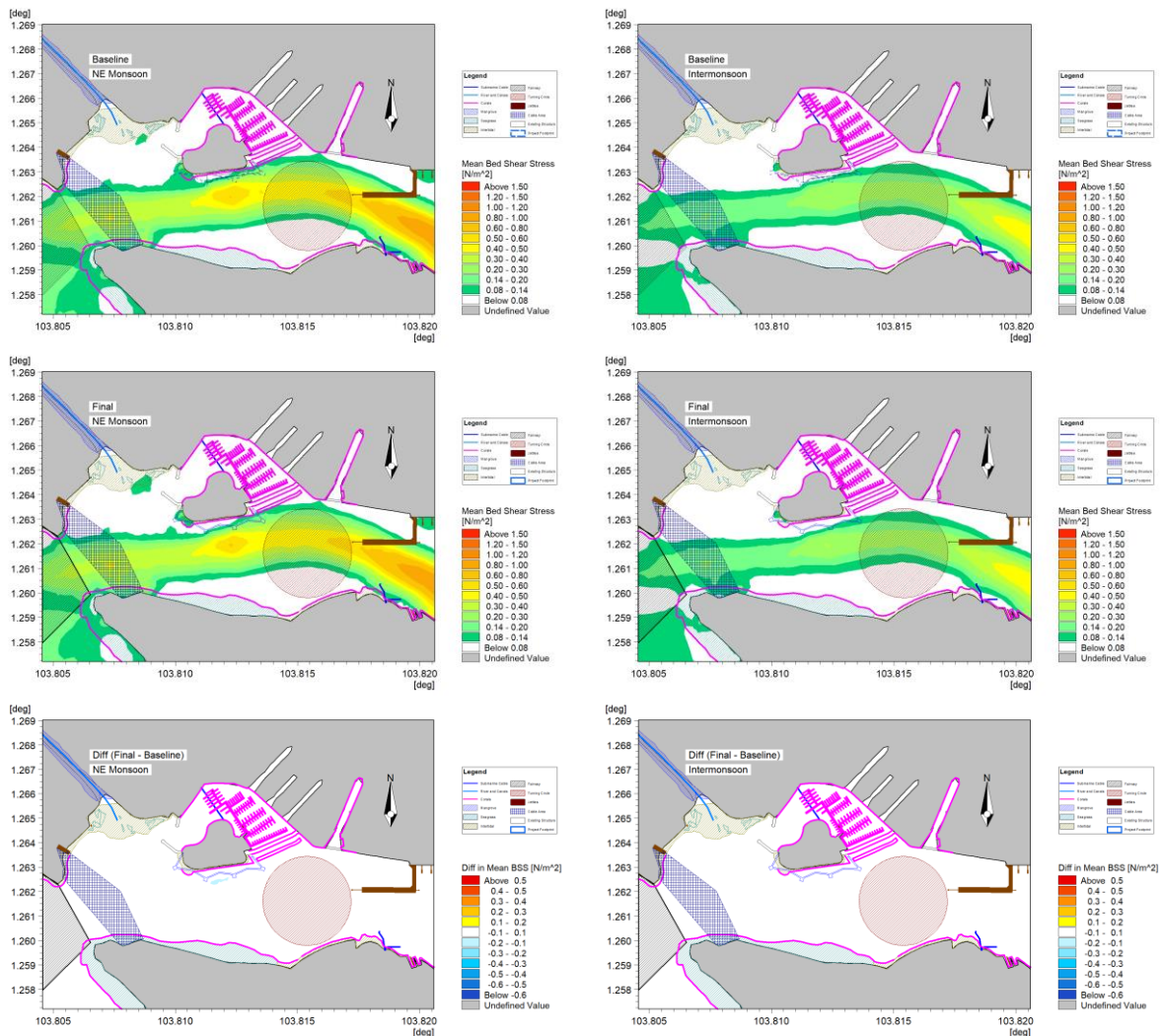


Figure 6.9 Mean BSS during NE monsoon (left) and inter-monsoon (right). Top row: Baseline during NE monsoon (left) and inter-monsoon (right). Middle row: Post-Construction phase during NE monsoon (left) and inter-monsoon (right). Bottom row: Difference between Post-Construction Phase and Baseline during NE monsoon (left) and inter-monsoon (right).

Change in 95th Percentile Bed Shear Stress

Figure 6.10 illustrates the 95th percentile BSS during NE monsoon and inter-monsoon (on the left and right columns, respectively), and the top, middle, and bottom figures represent the Baseline, Post-Construction Phase; and finally, the predicted change in the 95th percentile BSS (between Baseline and Post-Construction Phase) respectively.

In general, the 95th percentile of BSS in the Cruise Bay channel is predicted to have value up to 1.5 N/m² during NE monsoon, and up to 1.0 N/m² during inter-monsoon. The Project's footprint is predicted to cause changes in the 95th percentile BSS of up to 0.3 N/m² within the Project site, including Cruise Bay channel, and less than 0.1 N/m² in areas outside the Project site. This observation holds for both seasons, except during the inter-monsoon, where a slight decrease of less than 0.2 N/m² in 95th percentile BSS is expected to occur near the Project area.

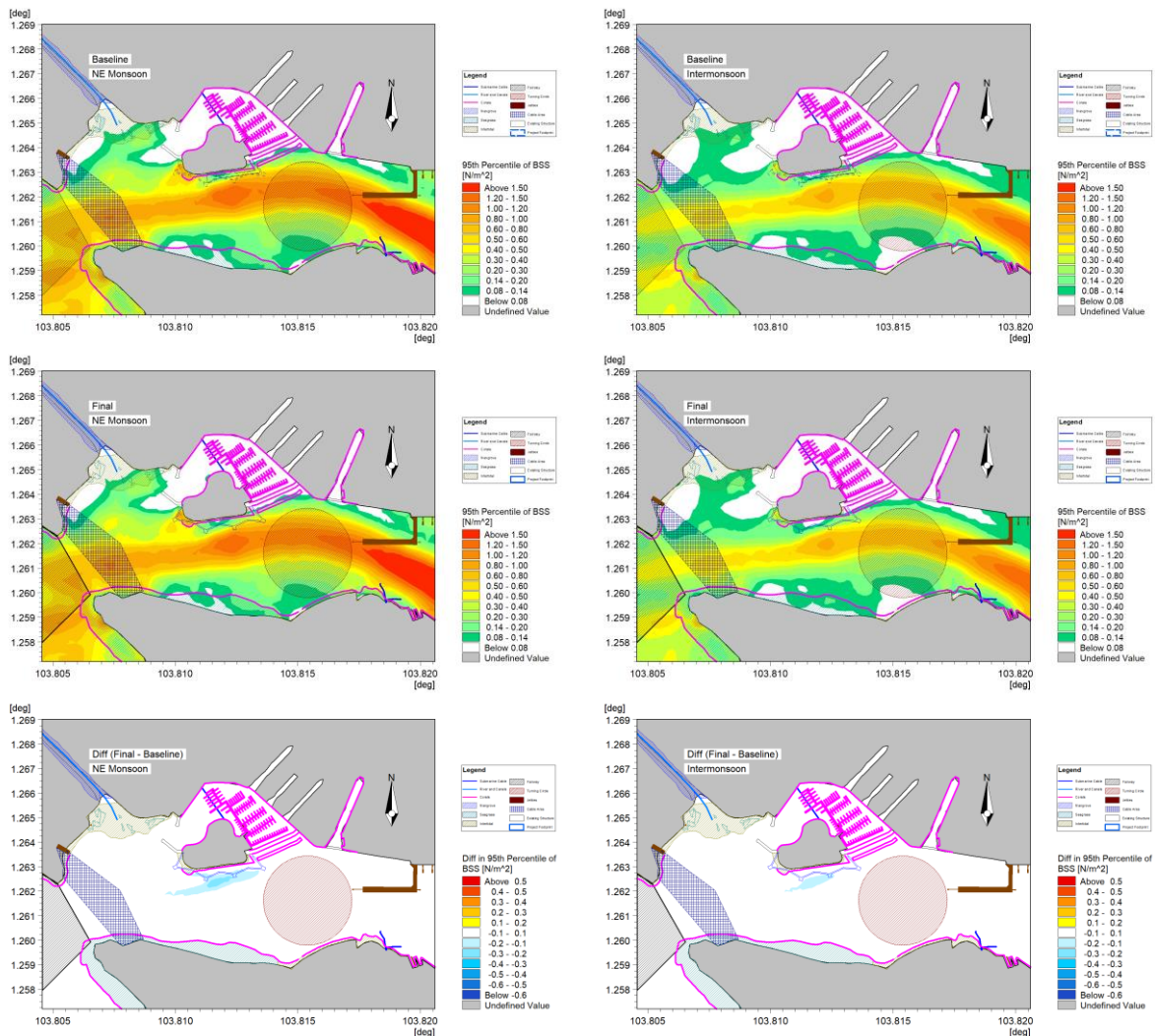


Figure 6.10 95th percentile BSS during NE monsoon (left) and inter-monsoon (right). Top row: Baseline during NE monsoon (left) and inter-monsoon (right). Middle row: Post-Construction phase during NE monsoon (left) and inter-monsoon (right). Bottom row: Difference between Post-Construction Phase and Baseline during NE monsoon (left) and inter-monsoon (right).

6.1.6 Hydrodynamics Impact Summary

The Project is located in a navigation channel where the current speed can reach up to 1.00 m/s during the NE monsoon and 0.80 m/s during the inter-monsoon, with currents predominantly moving in an east-west direction. DHI's MIKE 21 HD FM simulations predicted that the Post-Construction Phase will produce negligible changes to all current descriptors, except slackwater duration and 95th percentile BSS. Assessment of the impact arising from these changes in currents due to Project footprint is presented in the relevant receptors (Sections 6.4 and 6.6).

6.2 Marine Ecology and Biodiversity

6.2.1 Relevant Pressures

From the nature of the proposed construction, the following sources of environmental pressures and potential impact on sensitive receptors in the marine ecosystem have been assessed for long-term impacts:

- Direct loss of habitat due to the development footprint, including any anticipated changes to connectivity
- Long-term Erosion/Sedimentation impacts

6.2.2 Key Receptors

The key groups of receptors for the impact assessment are:

- Intertidal areas;
- Coral reef habitats;
- Mangrove habitats; and
- Macrobenthos.

6.2.3 Evaluation Framework

Evaluation frameworks for coral & subtidal seagrass and intertidal & seagrass receptors can be found in Section 5.8.3.

6.2.4 Impact Assessment

The receptor Importance and Cumulativity scores for the marine biology and ecology receptors follows the ones laid out in Section 5.8.4. The main difference lies in the Reversibility and Permanence scores. Reversibility score is generally a “3” as many of these habitat losses cannot be reversed or mitigated, unless in exceptional cases (e.g., coral relocation works). Permanence score will be a “3” as the impacts discussed in this section concern long-term impacts, after the Project has been completed. Similar to in the Construction Phase, should there be exceptions to this scoring, it will be elaborated upon in the text below.

6.2.4.1 Impact of Project Footprint on Intertidal Areas at Keppel Island

From DHI's maps, the estimated loss of intertidal area (i.e., which will be built over by the pile deck and the floating boardwalk) is about 0.5 ha. This results in loss of intertidal and coral area that was utilised by intertidal organisms and even some conservation significant species of fish (Table 5.43). These changes would be clearly detectable in the field and would constitute a significant loss of intertidal coral habitat, which is relatively rare around Singapore mainland. However, it should be noted that this habitat is at the base of a sea wall, indicating that it is secondary growth, of which many of these habitats are found along Singapore's southern shoreline. As such, the Magnitude of Change for this direct loss of intertidal habitats at Keppel Island is assessed as a moderate change, i.e., “-3”. This gives an impact significance score of **Minor Negative Impact**.

6.2.4.2 Impact of Project Footprint on Coral Reefs and Subtidal Seagrass Habitats

The Project will cause an estimated surface area loss of 0.8ha of coral reefs and subtidal seagrass habitats. Similar to the above, this results in a significant loss of subtidal coral habitat that is highly rich in diversity and abundance. Baseline surveys have found nearly two hundred coral colonies within 2 transects, and up to 27 genera of corals at each transect (Section 5.8.2.2). In addition, locally “Critically Endangered” seagrass, *Halophila decipiens*, was also found here during baseline surveys. Within the larger context of Singapore’s southern shore however, it shall be noted that these corals are regenerated on anthropogenic structures. In addition, the scale of loss is less than a hectare and there large areas of coral habitat in the area (e.g. around Sentosa Island). With these considerations, the loss is assessed to be a Magnitude of Change of “-3”, giving an impact significance of **Moderate Negative Impact**.

6.2.4.3 Impact of Project Footprint on Macrobenthos within the Project Footprint

The estimated loss in macrobenthos is about 0.3ha, mostly from the footprint of the floating boardwalk, which goes into deeper waters. Macrobenthos diversity was around 26 individuals/m², low especially compared to other parts of Singapore such as the Eastern Johor Straits (Muda et al., n.d.). It is a relatively small area of loss compared to the overall amount of microbenthic habitat available in the surrounding waters, hence the Magnitude of Change is assessed to be “-1”, giving an impact significant of **Slight Negative Impact**.

6.2.4.4 Impact of Project Footprint on Connectivity of Marine Biodiversity and Ecology Receptors

A qualitative assessment of connectivity will be carried out to assess for changes to connectivity for 1) intertidal and seagrass habitats at Berlayer Creek, 2) Coral habitats around Keppel Island and 3) Macrobenthos. From the modelled changes to the hydrodynamics in the waters in the Study Area (Figure 6.4), a small area of hydrodynamics change will only be observed south of Keppel island. This area is just a small proportion of the larger channel between Keppel Island and Sentosa, which the bulk of the fastest currents flow through (see snapshots of the ebb and flood currents in the waters in Figure 5.3 and Figure 5.4). As such, the anticipated connectivity changes for the above specified receptors are unlikely to experience a large change. The Magnitude of Change for intertidal and seagrass habitats at Berlayer Creek and Coral habitats around Keppel Island are assessed as “-1”. For macrobenthos, this Magnitude is assessed as “0” as this decrease in current in the area is unlikely to affect the microbenthic community at all, as it is disproportionately much larger than the affected area. Hence, the impact significance assessed are between **Slight Negative Impact to No Impact**.

6.2.4.5 Impact of Long-Term Erosion/Sedimentation on Intertidal/Seagrass and Mangroves at Berlayer Creek

As seen in Section 5.2.5 and 6.1.5 (Figure 6.9), the long-term sedimentation/erosion and any changes bed sheer stress (BSS) levels are not expected at Berlayer Creek. Neither are long-term sedimentation effects going to be observed in the area (Figure 5.23). This applies to both the mangrove habitats as well the seagrass and intertidal habitats in that area. As such, the Magnitude of Change is assigned at “0”, giving an impact significance of **No Impact** to both these receptors at Berlayer Creek.

6.2.4.6 Impact of Long-Term Erosion/Sedimentation on Intertidal and Coral Reefs and Subtidal Habitats at Keppel Island

As seen in Section 6.1.5, some subtidal habitats south of Keppel Island is anticipated to experience some change in mean and 95th percentile BSS (Figure 6.9 and Figure 6.10).

However, it should be noted that BSS acts as an indication erosion/sedimentation, as the exact BSS threshold value for actual erosion or sedimentation in an area varies with many factors such as local site conditions, sediment composition and sediment cohesion (Winterwerp et al., 2004). From Figure 6.10, it shows that there will be an area south of Keppel that will experience a decrease in mean BSS of up to -0.2 N/m^2 , yet most of the shipping channel appears to be in a state of constant erosion due to the high value of BSS within the Study Area. Hence, a decrease in BSS likely indicates a decrease erosion in the area, rather than a shift in state from eroding to sedimentation.

Hence, due to a notable change in the long-term erosion rate over the southern part of Keppel Island, the Magnitude of Change is for both intertidal and seagrass area and coral reefs and subtidal seagrass areas is assessed to be “-1”, giving an impact significance of **Slight Negative Impact** for both pathways.

6.2.4.7 Impact of Long-Term Erosion/Sedimentation on Macrobenthos

Similar to the assessment of long-term erosion/sedimentation on the coral reefs and subtidal habitat (see above), macrobenthos south of Keppel Island as well, are likely to experience a state of decrease of erosion. This indicates that they will experience some form of change, however, due to their nature, are biologically accustomed to sedimentary shifts in their environment. While there are not known thresholds as to the specific levels which macrobenthos are adapted to, the change in mean BSS value ($\sim 0.2 \text{ N/m}^2$) is low enough that it should not have a significant impact on the diversity and organisms found within. As such, the Magnitude of Change of this impact is assessed to be “-1”, giving an impact significance of **Slight Negative Impact**.

6.2.5 Mitigation Measures

Impact of Project Footprint on Marine Ecological Receptors

The total amount of loss for sensitive marine ecological receptors totals to about 1.5 ha. Of greatest concern are the corals reefs, subtidal seagrass and intertidal areas, which have high species diversity, high coral coverage and the presence of conservation significant species (see Section 5.8.2).

As such, DHI proposes coral and seagrass relocation works within a 100 m buffer around the pile deck footprint as well as the estimated marine working space. This area will also encompass areas affected by the floating boardwalk (Figure 6.11). The sensitive marine biodiversity receptors proposed to be relocated include:

- Corals and seagrass (if any) at the Intertidal and Seagrass area south and southwest of Keppel Island;
- Subtidal corals and seagrass found between the existing Wharf and Keppel Island, on the Wharf; and,
- Corals at the nearest caisson structure, just east of Keppel Island

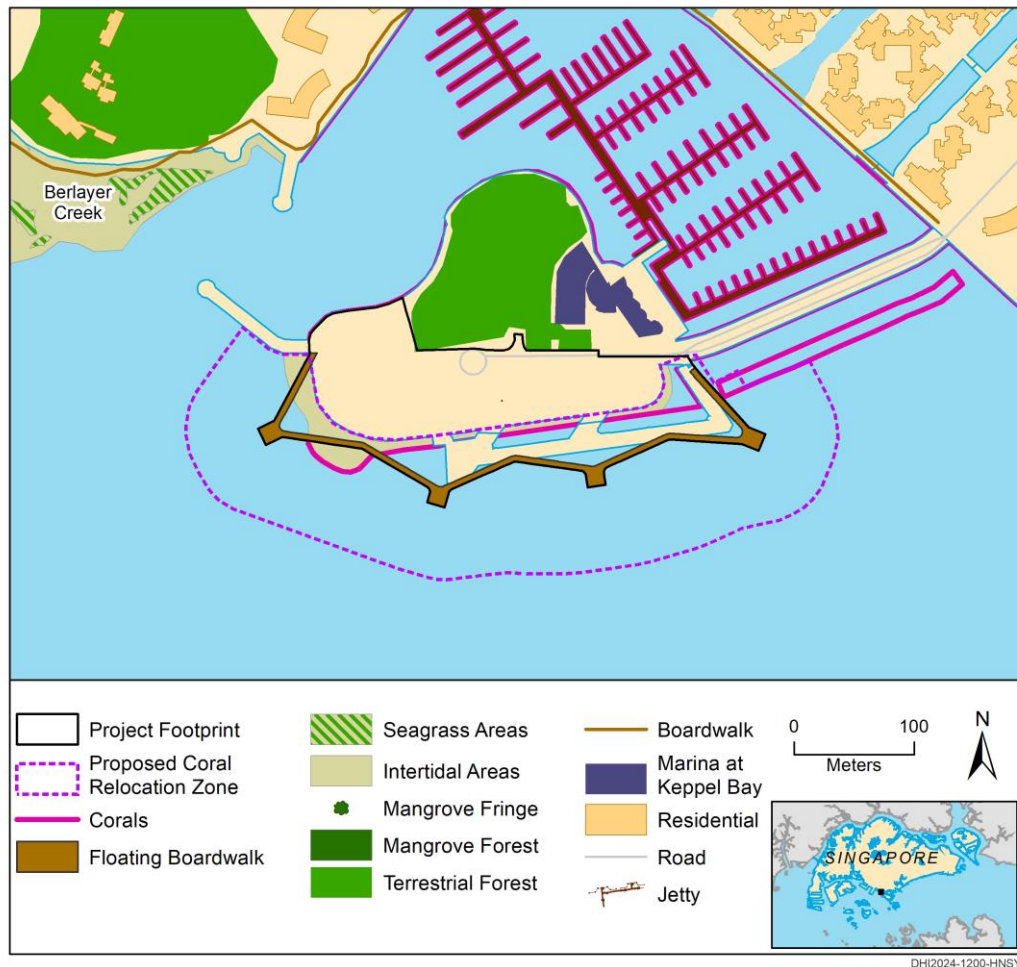


Figure 6.11 Map showing the proposed extent of coral and/or seagrass relocation area

These mitigation measures are still highly disruptive to natural ecosystem functions. In addition, seagrass transplantation is a difficult process that might not necessarily yield successful results. Thus, the Magnitude of change decreases slightly to “-2” for intertidal and seagrass areas and coral reef and subtidal seagrass areas at Keppel Island, adjusting the post mitigation impact significance to **Minor Negative Impact** to both receptors.

In addition, due to strong historical record of this location being suitable for coral growth (e.g. at Keppel Marina), it is recommended that the floating boardwalk design be adjusted to facilitate the growth of coral colonies to support marine biodiversity, as a type of Nature-based Solution (NbS).

After the nature group engagement for this study, the following additional recommendations shall be considered for coral transplantation:

- It was suggested that previous coral relocation survival rates at a site could be being considered during the selection of recipient sites. This consideration can be addressed during the coral relocation feasibility study.
- The release of this report coincides with the announcement of the National Parks Board's (NParks) 100k Coral Initiative, a habitat enhancement effort for coral in Singapore's waters (NParks, 2024c). It is recommended that the list of coral species prioritised for the initiative (e.g. specific endangered *Acropora* and *Euphylla* species) should be checked against the detected species list during the pre-transplantation surveys. These individuals should then be prioritised for relocation when executing the transplantation.

6.2.6 Marine Ecology and Biodiversity Impact Summary

The Post-Construction Phase impacts from the completed Project on marine ecology and biodiversity receptors have been summarised in Table 6.2

Table 6.2 RIAM results for Post-Construction Phase (long-term) impacts from the Project on marine ecology and biodiversity receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Intertidal areas and seagrass habitat (Keppel Island)	Project footprint	3	-3	3	2	3	-72	Minor Negative Impact	-2	-48	Minor Negative Impact
	Long-term Erosion/ Sedimentation	4	-1	3	3	3	-36	Slight Negative Impact	-	-	-
Intertidal areas and seagrass habitat (Berlayer Creek)	Long-term Erosion/ Sedimentation	4	0	3	3	3	0	No Impact	-	-	-
	Connectivity	4	-1	3	3	3	-36	Slight Negative Impact	-	-	-
Coral reefs and subtidal seagrass (Keppel Island)	Project footprint	4	-3	3	2	3	-96	Moderate Negative Impact	-2	-64	Minor Negative Impact
	Long-term Erosion/ Sedimentation	4	-1	3	3	3	-36	Slight Negative Impact	-	-	-
Coral Reefs around Keppel Island (remaining)	Connectivity	4	-1	3	3	3	-36	Slight Negative Impact	-	-	-
Mangroves (Berlayer Creek)	Long-term Erosion/ Sedimentation	4	0	3	3	3	0	No Impact	-	-	-
Macrobenthos	Project footprint	1	-1	3	3	3	-9	Slight Negative Impact	-	-	-
	Long-term Erosion/ Sedimentation	1	-1	3	3	3	0	Slight Negative Impact	-	-	-
	Connectivity	1	0	3	3	3	0	No Impact	-	-	-

6.3 Terrestrial Ecology and Biodiversity

6.3.1 Relevant Pressures

From the nature of the proposed construction, the following sources of environmental pressures and potential impact on sensitive receptors in the terrestrial ecosystem have been assessed for long-term impacts:

- Direct loss of habitat due to the development footprint, including any anticipated changes to connectivity;
- Reduced photosynthetic activity due to edge effects from building shade;
- Wildlife strike from glass facades on buildings; and,
- Human-wildlife conflict.

6.3.2 Key Receptors

As elaborated upon in Section 5.9.2, the key groups of receptors for the impact assessment are:

- Terrestrial flora; and
- Terrestrial fauna.

6.3.3 Evaluation Framework

The evaluation frameworks used for assessment of terrestrial flora and fauna are found in Section 5.9.3.

6.3.4 Impact Assessment

Similarly to the post-construction impact assessment for marine ecology and biodiversity, the Permanence score is a “3” for this stage, while the other scores remain the same.

6.3.4.1 Impacts to Terrestrial Flora

Direct Loss of Flora Habitat within the Project Footprint

Vegetation clearance is expected within the physical land footprint of the Project, leading to the loss of flora within the Project Footprint. It should be noted that this footprint is not anticipated to affect flora within the Hillock. Hence, the loss of flora within the Project footprint mainly involves losses of urban and managed streetscape vegetation, none of which are conservation significant. These changes will still be detected by people who are on site, however, it is at a small spatial scale and be easily reinstated. Hence, the Magnitude of Change is assigned a “-2”, giving an impact significance of **Slight Negative Impact**.

Reduced Photosynthetic Activity from Edge Effects (Building Shade)

The existence of a high-rise development may potentially create shade over the Hillock Area, potentially negatively affecting the photosynthetic activity of the trees and shrubs within the area. From the Project’s design, which face east to west lengthwise (Figure 2.3)

and follows the direction of the sun's movement in the sky, the shading effect on the flora in the Hillock Area is likely minimal. Studies suggest that high-rise buildings reduce Photosynthetically Active Radiation (PAR) received by plants by up to 50 % (Tan & Ismail, 2014); however, due to the low proposed height of the development, the Hillock Forest is still expected to receive a significant amount of PAR daily. Since this effect cannot be mitigated, the Recoverability score is given a "3". Hence, the Magnitude of Change assessed for the shading impact on flora in the Hillock Area is assessed to be "-1", giving an impact significance of **Slight Negative Impact**.

6.3.4.2 Impacts to Terrestrial Fauna

Direct Loss of Habitat Used by Terrestrial Fauna

The loss of flora within the Project Footprint in turn results in the loss of area that can be utilised by terrestrial fauna, majority of which are avifauna (birds), totalling up to 23 species. While the area is not large, it interestingly harbours more species than the Hillock Area, hence the loss of the area would result be a noticeable change in a significant number of species. Hence, the Magnitude of Change is assessed to be "-2", giving an impact significance of **Minor Negative Impact**.

Potential Avifauna Mortality from Strikes Against Glass Facades

Bird strikes are caused when tall, reflective buildings with extensive glass facades cast large reflections, that may confuse the spatial perception of birds and cause them to fly straight into these buildings. Such collisions frequently result in mortality.

The nationally "Endangered" and IUCN red listed "Critically Endangered" Straw-headed Bulbul (*Pycnonotus zeylanicus*), and nationally "Vulnerable" Oriental Magpie-robin (*Copsychus saularis*) are potential birds that could get affected by mortality from strikes to the glass facades. Such a population depletion could cause significant stress on the already threatened population of birds from these two species. Hence, the Magnitude of Change is assigned a score of "-3", giving an impact significance of **Minor Negative Impact**.

Loss of Ecological Connectivity due to Development

The presence of a large building façade in the middle of Keppel Island may potentially act as a barrier to terrestrial faunal dispersion, both on the ground and in the air. Such impedance may detrimentally affect the natural gene flow between faunal populations, depending on the nature and spatial arrangement of the development.

Due to the low height of the buildings (up to a maximum of 7 storeys), it is anticipated at the movement of birds and other avifauna will be unlikely to be affected by the Project Footprint. This is because birds are expected to easily circumvent the barrier to dispersal posed by the development. Ground-dwelling fauna will also likely not be affected by the development, as the Hillock forest will remain intact and any faunal dispersal in and out of this area from the mainland is unlikely to be hindered, given the location of the development. Hence, the Magnitude of Change for the impact of the Project Footprint on terrestrial fauna connectivity is assessed to be "0", giving an impact significance of **No Impact**.

Potential Human-Wildlife Conflict

The eviction of fauna species from the within the Project Footprint as well as the presence of the new development might potentially cause an increase in human-wildlife conflict as the normal human-avoidance behaviour of certain larger fauna might be disrupted, causing them to form new habitats that require them to come into increasing contact with human beings and anthropogenic areas.

From the Project Footprint as well as the baseline studies, the two likely species that might come into contact with humans and cause human-wildlife conflict at the Sumatran palm

civets (*Paradoxurus musangus*) (whose scat was observed during the baseline surveys), and the Smooth Otters (*Lutrogale perspicillata*), a globally “Vulnerable” and locally “Endangered” species that has been recorded in the vicinity.

It is likely that the probability of any animal attacks on humans is relatively low. Where Smooth-coated Otter only show aggression in groups, and Sumatran palm civets are nocturnal animals that are known to readily shy away from human contact. On the whole, the occurrence of human-wildlife conflicts from the new development are likely to be transient and isolated, but should they occur, an effect will be felt by the affected parties. Hence, the Magnitude of Change for potential human-wildlife conflict from the works is “-1”, giving an impact significance of **Slight Negative Impact**.

6.3.5 Mitigation Measures

This section provides a summary of the key recommended measures to minimise and rehabilitate biodiversity-related long-term impacts to habitats, flora and fauna species during the Post-Construction Phase.

6.3.5.1 Post-construction Phase Mitigation Measures

Minimise

The key mitigation measures to minimise biodiversity impacts during the Post-Construction Phase have been summarised below in Table 6.3.

Table 6.3 Key recommended measures to minimise biodiversity impacts during the Post-Construction Phase

Receptor	Impact Types	Mitigation Measures
Flora/Habitats	- Loss of flora within Project footprint - Degradation of Hillock habitat - Edge effects	- Verify and review footprints for hoarding, worksite boundaries, and access roads - Ensure good housekeeping - Put up signages to deter residents/public from entering Hillock Area - Restrict entry of residents/public into the Hillock Area by installing fences - Incorporate wildlife-friendly lighting
	Reduced photosynthetic activity from building shade	Include increased sunlight permeability in building design considerations, in order to minimise duration and level of shade casted on Hillock Area

Receptor	Impact Types	Mitigation Measures
Fauna	• Avifauna mortality from building strikes • Human-wildlife conflict • Faunal injury/mortality	• Implement bird-safe building interior and exterior design • Develop programme to monitor bird strike events during the Post-Construction Phase, identify hotspots for collisions and implement further measures to minimise future bird strike events • Prevent non-volant fauna incursions into development by installing fences • Educate residents and public that feeding of wildlife is strictly prohibited

Flora Management

The perimeter of the development area within the Project footprint should be clearly marked out by physical boundaries in order to prevent excess vegetation clearance. Any TPZs within the Project footprint and along the Project boundary that were erected during the construction phase should continue to be monitored during the Post-Construction Phase. The integrity of TPZs is to be monitored regularly by the ISA-certified Arborist, who is to maintain records of tree health and TPZ integrity.

Installation of Fences

The installation of adequate, wildlife-safe fences between the development's compound and the Hillock Area will prevent non-volant fauna from entering the development, thereby reducing the chance of human-wildlife conflict. Likewise, these fences will also deter residents and members of the public from entering the Hillock Area needlessly, ultimately safeguarding the forest from habitat degradation and human disturbances to resident fauna inhabiting the area. These wildlife-proof fences should be minimally 1.8m high, and constructed from sturdy materials, such as roll-top bottom fences. The fences should also be embedded into the ground to prevent burrowing animals from bypassing the fence underground.

Erection of Signages

Adequate signages should be erected around the development in order to educate residents and members of the public on appropriate behaviours and safety measures to undertake when encountering wildlife in the area, thereby reducing the chance of human-wildlife conflict occurring.

Good Housekeeping

Proper waste-management can minimise wildlife incursions into the development and reduce the chances of human-wildlife conflict occurring. Anthropogenic sources of food tend to attract fauna towards human dwellings; thus, proper waste management protocols such as wildlife-proof bins and timely waste removal would reduce the chances of wildlife seeking these areas for food.

Sunlight Permeable Buildings

The building design of the development should take into consideration the amount of sunlight it allows to fall onto the Hillock Forest. Examples of sunlight-permeability include the potential use of transparent-concrete panels, glass fixtures and structural designs such as cutouts and alcoves that allow sunlight to pass through.

Bird-safe Buildings

The building design of the development should be in line with NParks' Bird-safe Building Guidelines (NParks, 2024d). Bird-safe buildings incorporate exterior and interior design elements to increase the ability of birds to detect buildings in their flight paths visually, thereby reducing the chances of fatal building collisions significantly. Given the open and low-rise nature of the area surrounding Keppel Island (with the exception of the Reflections at Keppel Bay Condominium), implementing bird-safe design is paramount to minimise the potential for such occurrences.

As further recommended by NParks (2024), a bird-strike hotspot identification programme can also be implemented for the development during the Post-Construction Phase, to identify gaps in bird-safe design and implement further measures at these hotspots in order to further reduce the chances of building collisions occurring around the development.

Rehabilitation

Infill Planting

For any streetscape vegetation and turfing lost due to the development of the Project, infill planting of pollinator-attracting vegetation should be implemented as a replacement for the loss in flora. These will serve as pollinator-attracting plants for native wildlife, such as butterflies and bees. Examples of pollinator-attracting species include blue snakeweed (*Stachytarpheta indica*) and coral vine (*Antigonon leptopus*).

6.3.6 Terrestrial Ecology and Biodiversity Impact Summary

The Post-Construction Phase impacts from the completed Project on terrestrial ecology and biodiversity receptors have been summarised in Table 6.4.

Table 6.4 RIAM results for Post-Construction Phase (long-term) impacts from the Project on terrestrial ecology and biodiversity receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Flora within Project footprint	Project footprint	1	-2	3	3	3	-18	Slight Negative Impact	-	-	-
Flora within Hillock Area	Shading effect	4	-1	3	3	3	-36	Slight Negative Impact	-1	-36	Slight Negative Impact
Fauna within Project footprint	Project footprint	4	-2	3	2	2	-56	Minor Negative Impact	-	-	-
Fauna within Hillock Area	Mortality due to building strikes	3	-3	3	2	2	-63	Minor Negative Impact	-1	-21	Slight Negative Impact
	Loss of ecological connectivity	3	0	3	2	2	0	No Impact	-	-	-

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Human-wildlife conflict	3	-1	3	2	2	-21	Slight Negative Impact	-1	-21	Slight Negative Impact

6.4 Marine Infrastructure and Navigation

6.4.1 Relevant Pressures

The relevant pressures to maritime infrastructure and navigation are:

- Hydrodynamic changes (Section 6.1); and,
- Erosion/Sedimentation (Section 6.1).

6.4.2 Key Receptors

The following receptors are key receptors for marine infrastructure and navigation:

- Marine navigation and jetties; and
- Submarine cables

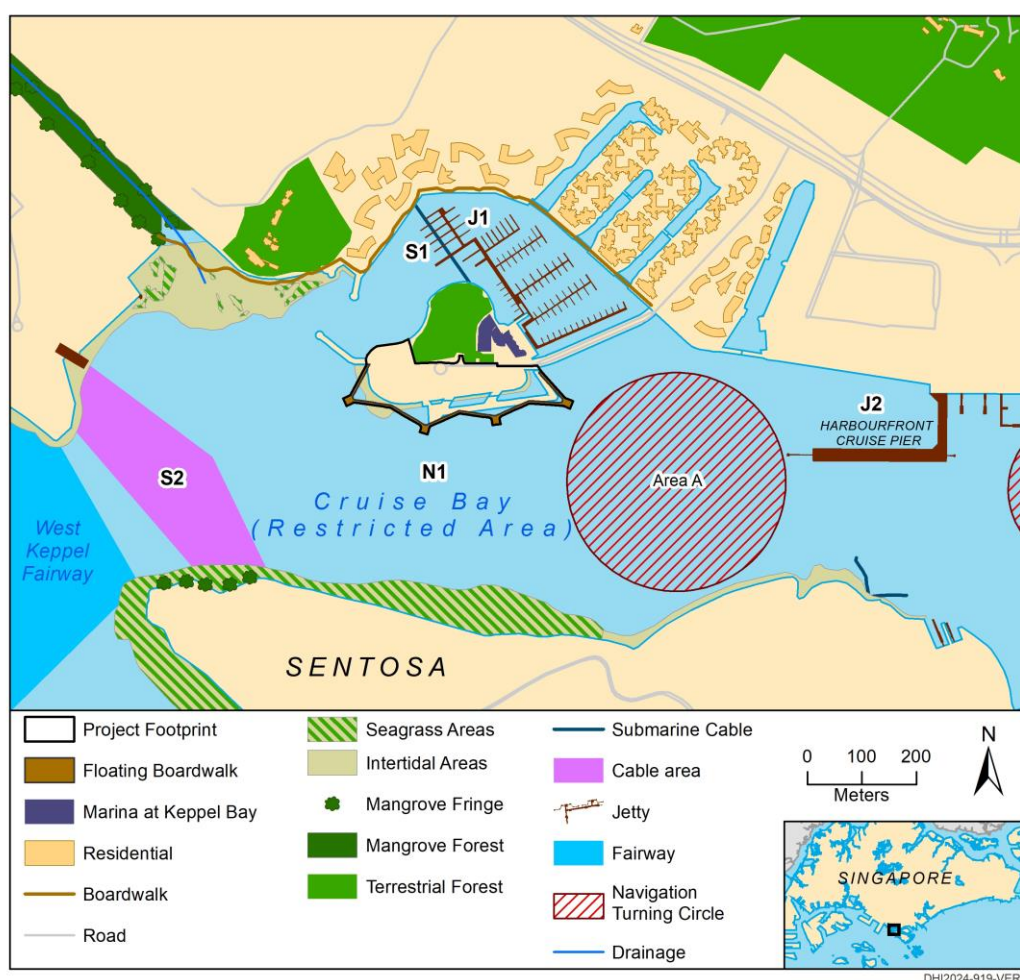


Figure 6.12 Overview of maritime infrastructure and navigation receptors and relevant labelled extraction points for assessment of impacts to maritime infrastructure and navigation

Table 6.5 Table of respective label IDs and description for maritime infrastructure and navigation receptors

ID	Description
J1	Marina at Keppel Bay
J2	HarbourFront Cruise Pier
N1	Marine Navigation (Cruise Bay, West Keppel Fairways, Turning Circle)
S1	Submarine Cable
S2	Cable Area

6.4.3 Evaluation Framework

The assessment of impact on marine navigation and infrastructure also requires a framework for ranking importance of this group of receptors. For this purpose, the standard definitions of Importance in the RIAM framework (Section 4.2.2) are adopted.

Hydrodynamic Changes

The main environmental changes affecting navigation and their thresholds indicating significant impact are presented in Table 6.6. Changes in current conditions can affect the safe passage and manoeuvring of vessels.

Table 6.6 Environmental changes affecting navigation

Environmental change	Thresholds and objectives for navigation
Changes to mean current speeds	Changes in mean current speed less than 0.05 m/s are typically considered as “No Change”
Changes to maximum current speeds	Changes in 95 th percentile current speed less than 0.1 m/s are typically considered as “No Change”
Exceedance of 2.0 and 3.5 knots	Minimal increases in current speeds. Changes in exceedance of these representative current statistics of less than 2 % to 4 % are typically considered as “No Change.”
Slackwater duration	Maintenance of berthing and unberthing windows. Changes of less than 2 % to 4 % are typically considered as “No Change.”
Shear Zones and eddy currents	Their presence may indicate an impact

Long-term Erosion/Sedimentation Changes

The change in hydrodynamic conditions anticipated as consequence of proposed Project may lead to morphological changes around the Study Area. These morphological changes may be characterised as increased erosion in more exposed areas and/or increased sedimentation in more sheltered waters. While calculating the actual magnitude of erosion and sedimentation is complex, bed shear stress (BSS) is often used to assess areas prone to relative erosion and accretion/sedimentation. This approach is considered a reliable preliminary assessment of potential erosion or accretion due to the changes in

hydrodynamic conditions. In this Study, a critical BSS threshold for erosion risk (τ_c) of 0.14 N/m^2 (Shi *et al.*, 2015) was used to estimate potential erosion occurrences. Exceeding this critical BSS value indicates a potential risk for erosion. The impact on morphological changes related to marine navigation and submarine cables is primarily assessed qualitatively based on the evaluation of bed shear stress result model and determining whether they exceed the critical threshold, which indicates potential erosion risk or not.

6.4.4 Impact Assessment

6.4.4.1 Reduction of Navigational Space due to Project Footprint

The navigation concerns with the presence of the Project, i.e., pile deck and floating boardwalk, are similar to those discussed during the construction phase. It takes up navigational space in Cruise Bay channel that could otherwise be used by smaller vessels (LOA < 50 m), such as high-speed crafts and pleasure crafts, as well as larger vessels such as passenger (cruise) ships, tankers, and cargo vessels. Nevertheless, even though only small portion of the space ($\sim 3.3 \text{ m}^2$) is affected by the floating boardwalk, vessel movements will likely need to be adjusted in the future to follow a safe navigation passage. This change is assessed as Slight Negative Change as it is observable in the field and affect the rerouting or adjusting passage. Hence, the impact significant is anticipated to be **Slight Negative Impact**. Some management measures are recommended in the later section to minimise this impact.

6.4.4.2 Hydrodynamic Changes affecting Vessel Manoeuvrability

Model results presented in Section 6.1 show minimal changes to the current field induced by the Project. Changes to other hydrodynamic statistical parameters are tabulated in Table 6.7.

Table 6.7 Changes in mean and 95th percentile current speeds, and in representative current speeds arising from Post-Construction Phase impacts during NE and inter-monsoon at marine navigation and infrastructure receptors

Monsoon	Parameters	Receptor IDs				
		J1	J2	N1	S1	S2
NE Monsoon	Change in mean current speed (m/s)	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
	Change in 95 th percentile current speed (m/s)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Change in exceedance of 3.5 knot (% time)	< 1	< 1	< 1	< 1	< 1
	Change in exceedance of 2 knot (% time)	< 1	< 1	< 1	< 1	< 1
	Change in slackwater duration (% time)	< 2	< 2	-4.71	< 2	-2.56
Inter-monsoon	Change in mean current speed (m/s)	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Monsoon	Parameters	Receptor IDs				
		J1	J2	N1	S1	S2
	Change in 95 th percentile current speed (m/s)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Change in exceedance of 3.5 knot (% time)	< 1	< 1	< 1	< 1	< 1
	Change in exceedance of 2 knot (% time)	< 1	< 1	< 1	< 1	< 1
	Change in slackwater duration (% time)	< 2	< 2	-4.36	< 2	-3.30

Based on the evaluation framework presented in Section 6.4.3 above, the magnitude of change for the mean and 95th percentile current speeds, as well as the percentage of time that current speeds exceed 2.5 knots and 3.5 knots, are all assessed as “No Change”. The slackwater duration in the navigation area (N1), particularly within the restricted turning circle, decreases by 4.71 % during the Northeast monsoon and 4.36 % during the intermonsoon period. Additionally, a reduction of less than 3.3 % is anticipated in the cable area for both monsoons period. The predicted reduction to slackwater duration in the marine restricted area is assessed to be “Slight Negative Change” based on the tolerance limits presented in Section 6.4.3. As such, the final impact significance of hydrodynamic changes to marine navigation and infrastructure is anticipated to be **Slight Negative Impact**.

6.4.4.3 Long-term Erosion/Sedimentation Change Impacts

Marine Navigation

According to BSS model results in Figure 6.9, the marine navigation channel in the Cruise Bay area is expected to face potential erosion risks under both baseline and final profile conditions, during either the NE or inter-monsoon periods. This is indicated by the mean and 95th percentile BSS results in the area, which can reach up to 0.6 N/m² and 1.5 N/m², respectively – exceeding the critical BSS threshold for erosion ($\tau_c = 0.14$ N/m²). The Project’s footprint is predicted to cause changes of up to -0.2 N/m² to mean BSS and -0.3 N/m² to 95th percentile BSS, which would result in the reduction of potential erosion risk in the channel. This reduction of potential erosion risk from the baseline conditions is assessed to be “Slight Negative Change” as it could potentially alter the morphology around the navigation channel. Although these morphological changes are noticeable in the model, they may not be measurable in the field, as such, the impact changes to marine navigation are anticipated to be **Slight Negative Impact**.

Submarine Cables

From the BSS model results in Figure 6.9, the submarine cables area is expected to experience potential erosion risks under both baseline and final profile conditions, during either the NE or inter-monsoon periods. This is evident from the mean and 95th percentile BSS results, which can reach up to 0.5 N/m² and 1.2 N/m², respectively – exceeding the critical BSS threshold for erosion ($\tau_c = 0.14$ N/m²). The predicted change in mean and 95th percentile BSS due to Project footprint is less than 0.03 N/m² and 0.08 N/m² respectively, suggesting no significant alteration to morphology in terms of increasing or reducing potential erosion risk in the submarine cables area. Therefore, the impact changes to submarine cables area are anticipated to be **No Impact**.

6.4.5 Mitigation Measures

It has been assessed that there are various environmental changes with the impacts ranging from No Impact to Minor Impact on marine navigation and infrastructure within the Study Area due to the Post-Construction Phase. The EQO for marine navigation and infrastructure has been set at “no more than Minor Impact”, in consultation with Technical Agencies during scoping stage. The predicted impacts are in compliance with this EQO.

The following mitigation measures are however recommended to minimise the navigation risks in the vicinity of the Project:

- Carry out a Formal Safety Assessment (FSA) for the Post-Construction Phase to assess all potential marine risks covering not only the work sites but also the access routes.

6.4.6 Marine Infrastructure and Navigation Impact Summary

The Post-Construction Phase impacts from the completed Project on marine infrastructure and navigation receptors have been summarised in Table 6.8.

Table 6.8 RIAM results for Post-Construction Phase (long-term) impacts from the Project on marine infrastructure and navigation receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
HarbourFront Cruise Pier	Hydrodynamic changes	4	0	3	3	2	0	No Impact	-	-	-
Marina at Keppel Bay	Hydrodynamic changes	3	0	3	3	2	0	No Impact	-	-	-
Marine Navigation (Cruise Bay, West Keppel Fairway, Turning Circle)	Hydrodynamic changes	4	-1	3	2	2	-28	Slight Negative Impact	-1	-28	Slight Negative Impact
	Long-term erosion/ sedimentation	4	-1	3	3	2	-32	Slight Negative Impact	-	-	-
	Project footprint	4	-1	3	3	2	-32	Slight Negative Impact	-	-	-
Submarine cables	Long-term erosion/ sedimentation	4	0	3	3	2	0	No Impact	-	-	-

6.5 Rivers and Canals

Shoreline changes in may potentially lead to changes in the hydrodynamics in the vicinity of the development. This resultant change may affect the seabed morphology at the mouth of rivers and canals, which may be subject to the risk of sedimentation and possibly inducing a blockage of these water bodies. This section presents the evaluation framework and discusses the Project's impacts on them.

6.5.1 Relevant Pressures

The relevant pressure to the assessment of the impact on rivers and canals is sedimentation caused by the Project's development, possibly causing blockage and impeding discharge to the sea.

These pressures have been quantified using MIKE 21 HD model, as presented in Section 6.1. This section discusses and assesses the significance of the blocking effects on the rivers and canals near the Project.

6.5.2 Key Receptors

The relevant baseline features and key receptors for changes are described in Section 5.11.2.

6.5.3 Evaluation Framework

Bed shear stress is the calculated output from the hydrodynamic model. The tolerance limits of marine navigation and infrastructure to sedimentation (Section 0) were adopted for assessing the impact on rivers and canals.

6.5.4 Impact Assessment

6.5.4.1 Long-term Erosion/Sedimentation Impacts on Rivers and Canals

An Importance score of "4" was assigned to this receptor; a detailed explanation of the assessment can be found in Section 5.11.4

With reference to BSS model results in Figure 6.9, Berlayer Creek is not expected to experience sedimentation induced by the Project's development. Therefore, **No Impact** is expected.

6.5.5 Rivers and Canals Impact Summary

The Post-Construction Phase impacts from the completed Project on rivers and canals receptors have been summarised in Table 6.9.

Table 6.9 RIAM results for Post-Construction Phase (long-term) impacts from the Project on rivers and canals receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Berlayer Creek	Blockage of river outlets due to sedimentation	4	0	2	2	2	0	No Impact	-	-	-

6.6 Socio-economic

Socio-economic receptors within the Study Area are diverse, including residential, recreational and commercial receptors. This section presents the long-term environmental pressures arising from the Project relevant to this receptor group and assesses the resulting impacts on them.

6.6.1 Relevant Pressures

The relevant environmental pressures to the assessments presented in this section are:

- Hydrodynamic changes (Section 6.1) affecting ability to enjoy water-based recreational activities;
- Loss of recreational space; and,
- Visual impact to landscape changes.

6.6.2 Key Receptors

The relevant baseline features and key receptors for changes are described in Section 5.12.2.

6.6.3 Evaluation Framework

6.6.3.1 Evaluation of Receptor Importance

The evaluation of the Importance is described in Section 5.12.3.1.

6.6.3.2 Evaluation of Magnitude of Change

Hydrodynamics

The evaluation for the changes to hydrodynamics as a result of the development work is as described in Section 6.4.3.

Visual Impact to Landscape Change

The evaluation for the changes to landscape as a result of the development work is as described in Section 5.12.3.2.

There is no evaluation framework for loss of recreational spaces and DHI therefore takes guidance from the standard RIAM's definitions for Magnitude of Change.

6.6.4 Impact Assessment

6.6.4.1 Hydrodynamics Changes Affecting Safety of Water-Based Recreational Activities

The Project's design, particularly the columns supporting the boardwalk, is expected to induce changes in current speed. DHI's hydrodynamic model predicted that 0.1 m/s and 0.2 m/s reduction in mean and 95th percentile current speed in a small area along the boardwalk. Changes in mean and 95th percentile current speed in the rest of the study area

were predicted to be less than 0.05 m/s and 0.1 m/s which are the upper limit for No Change. It is therefore considered there is **No Impact** on the marina's berthing area and movement of leisure yachts around the Project site.

6.6.4.2 Loss of Recreational Space

Keppel Island is currently a public recreational space. During DHI's socio-recreational surveys on 14 and 16 March 2024, eighty-one (81) – one hundred and forty (140) people in total were in the area enjoying leisure activities. Specifically, at SR1-3, which is at the open space, there were fourteen (14) – fifty-nine (59) people during the surveys. In the future, when the Plot 6 development is completed, this outdoor leisure space will be closed from public.

There is no evaluation framework for this impact and DHI therefore takes guidance from the standard RIAM's definitions for Magnitude of Change. This loss of recreational space is measurable to the local community. The development Project includes floating boardwalks that will allow recreational users to continue enjoying the waterfront scenery south of Keppel Island. Further, other recreational spaces are available and easily accessible in the area, such as Labrador Nature Reserve, Bukit Chermin boardwalk and the Promenade nearby and Mount Faber Park and Telok Blangah Hill Park further away. The Magnitude of Change is therefore assessed as Minor. Although this change will be permanent (P=3), public sentiment will recover over time and there is likely no secondary effect (R=2, C=2). Consequently, this impact is **Minor Negative Impact**.

6.6.4.3 Visual Impacts to Landscape Change

The landscape character of the Project area will change after the construction, transitioning from manicured fields and small grass pastures to low-rise residential development and floating boardwalk. While the once-tranquil open area will experience some movement and visual restrictions, the inclusion of floating boardwalks in the design will allow visitors and recreational users to continue enjoying the waterfront scenery south of Keppel Island. This is assessed as a Slight Negative Change.

From the perspective of the residents at nearby condominiums and the visitors at the Promenade, the housing development will blend in with the Marina at Keppel Bay building and the yachts at the marina, against the backdrop of Sentosa's lush greenery (Figure 6.13). The alteration of the visual landscape will occupy only a small portion of sea view, and the overall appearance of the landscape will not be significantly impacted. This is assessed to be a Slight Negative Change. For staff of businesses as well as recreational receptors at Keppel Island, the Project will considerably alter their view of greenery and seascape which is considered as a Minor Negative Change.

Consequently, the visual landscape impact from Plot 6 development is **Slight Negative Impact** on all residential, recreational and business receptors in the Study Area.



Figure 6.13 View of Keppel Island and Marina at Keppel Bay from the Promenade (Source: Google). Plot 6 development in the future will partially alter this view.



Figure 6.14 View of Keppel Island from Keppel Bay bridge (Source: Google). This view of greenery will be replaced by residential building blocks of Plot 6 development and buildings in the future.

6.6.5 Mitigation Measures

Visual Impacts to Landscape Change

The Post-Construction Phase presents opportunities to restore the visual appeal of disturbed areas, effectively minimising the impact. Key actions include carefully planned landscaping, compensatory tree planting, and the introduction of buffer vegetation, all aimed at blending the development with the surroundings. These approaches contribute to the broader objective of establishing a sustainable and visually attractive community as part of the final built environment.

6.6.6 Socio-economic Impact Summary

After completion, Plot 6 development will bring changes to the hydrodynamic conditions and the visual landscape in the area. The public recreational space on the island will also be lost to give space to Plot 6 housing blocks and amenities. These impacts have been assessed to range from **Slight** to **Minor Negative Impact** as summarised in Table 6.10.

Table 6.10 RIAM results for Post-Construction Phase (long-term) impacts from the Project on socio-economic receptors

Sensitive Receptor	Predicted Impact	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Residents	Visual impact of landscape changes	3	-1	3	2	2	-21	Slight Negative Impact	-	-	-
Recreational users	Loss of recreational space	3	-2	3	2	2	-42	Minor Negative Impact	-	-	-
	Visual impact of landscape changes on recreational users at Keppel Island and Marina at Keppel Bay	3	-1	3	2	2	-21	Slight Negative Impact	-	-	-
	Visual impact of landscape changes on recreational users at the Promenade	3	-1	3	2	2	-21	Slight Negative Impact	-	-	-
Recreational users (marina's berthing area, movement of leisure yachts)	Hydrodynamic changes	3	0	3	3	2	0	No Impact	-	-	-
Staff of businesses	Visual impact of landscape changes	2	-2	3	2	2	-28	Slight Negative Impact	-	-	-

7 RIAM Impact Significance Summary

7.1 Construction Phase

A summary of the predicted impacts from the Project's Construction Phase before and after mitigation for each of the main receptors is presented in Table 7.1. The proposed EQOs for the Project are presented in Section 8.1.

Table 7.1 RIAM table for Construction (short-term) impacts from the Project without mitigation and after implementation of the recommended mitigation measures

Environmental Study Section	Sensitive Receptor	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures			Details on mitigation measures
			I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance	
Marine Ecology and Biodiversity													
Section 5.8	Intertidal areas and seagrass habitat (Keppel Island)	Marine construction activities	3	-1	2	2	3	-21	Slight Negative Impact	-1	-21	Slight Negative Impact	Section 5.8.5.1 mapping of intertidal areas prior to works
		Suspended sediments	3	0	2	2	3	0	No Impact	-	-	-	
		Erosion/ Sedimentation	3	-3	2	2	3	-63	Minor Negative Impact	-2	-42	Minor Negative Impact	Section 5.8.5.2 deployment of silt curtains
		Pollution release	3	0	2	2	3	0	No Impact	-	-	-	
		Spills and leaks	3	-3	2	2	3	-63	Minor Negative Impact	-1	-21	Slight Negative Impact	Section 5.8.5.3 specifically spills and leaks management measures

Environmental Study Section	Sensitive Receptor	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures			Details on mitigation measures
			I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance	
	Intertidal areas and seagrass habitat (Berlayer Creek)	Suspended sediments on seagrass	4	0	2	2	3	0	No Impact	-	-	-	
		Erosion/ Sedimentation	4	0	2	2	3	0	No Impact	-	-	-	
		Pollution release	4	0	2	2	3	0	No Impact	-	-	-	
		Spills and leaks	4	-2	2	2	3	-56	Minor Negative Impact	-1	-28	Slight Negative Impact	Section 5.8.5.3 specifically spills and leaks management measures
	Coral reefs and subtidal seagrass (Keppel Island)	Suspended sediments	4	0	2	2	3	0	No Impact	-	-	-	
		Marine construction activities	4	-2	2	2	3	-56	Minor Negative Impact	-1	-28	Slight Negative Impact	Section 5.8.5.1 for mapping of intertidal areas prior to works and no anchor zones
		Pollution release	4	0	2	2	3	0	No Impact	-	-	-	
		Spills and leaks	4	-3	2	2	3	-84	Moderate Negative Impact	-1	-28	Slight Negative Impact	Section 5.8.5.3 specifically spills and leaks management measures
	Coral reefs (Keppel Island)	Erosion/ Sedimentation	4	-2	2	2	3	-56	Minor Negative Impact	-1	-28	Slight Negative Impact	Section 5.8.5.1 for the deployment of silt curtains

Environmental Study Section	Sensitive Receptor	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures			Details on mitigation measures
			I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance	
	Subtidal seagrass	Erosion/ Sedimentation	4	-1	2	2	3	-28	Slight Negative Impact	-1	-28	Slight Negative Impact	
	Mangroves (Berlayer Creek)	Pollution release	4	0	2	2	3	0	No Impact	-	-	-	
		Spills and leaks	4	-1	2	2	3	-28	Slight Negative Impact	-1	-28	Slight Negative Impact	Section 5.8.5.3 specifically spills and leaks management measures
		Erosion/ Sedimentation	4	0	2	2	3	0	No Impact				
	Macrobenthos	Erosion/ Sedimentation	1	0	2	2	3	0	No Impact	-	-	-	
	Marine fauna and megafauna	Marine construction activities (collision with fauna)	5	-2	2	2	2	-60	Minor Negative Impact	-1	-30	Slight Negative Impact	Section 5.8.5.1, such as silt curtains and a Marine Megafauna Action Plan
		Suspended sediments	5	-1	2	2	2	-30	Slight Negative Impact	-1	-30	Slight Negative Impact	
		Underwater noise	5	-2	2	2	2	-60	Minor Negative Impact	-1	-30	Slight Negative Impact	
		Pollution release	5	0	2	2	2	0	No Impact	-	-	-	
		Spills and leaks	5	-2	2	2	2	-60	Minor Negative Impact	-1	-30	Slight Negative Impact	Section 5.8.5.3 specifically spills and leaks management measures

Terrestrial Ecology and Biodiversity													
Section 5.9	Flora within Hillock Area	Encroachment of equipment to root system or tree canopy	4	-2	2	2	3	-56	Minor Negative Impact	-1	-28	Slight Negative Impact	Section 5.9.5.1 Implementation of a “No-Infringement Zone”
		Spills and leaks	4	0	2	2	3	0	No Impact	-	-	-	
	Fauna within Project footprint	Fauna injury or mortality	4	-1	2	2	2	-24	Slight Negative Impact	-1	-24	Slight Negative Impact	Section 5.9.5.1 frequent site inspections, proper hoardings and biodiversity awareness trainings
		Human-wildlife conflict	4	-1	2	2	2	-24	Slight Negative Impact	-1	-24	Slight Negative Impact	
	Fauna within Hillock Area	Air pollution	3	-1	2	2	2	-18	Slight Negative Impact	-1	-18	Slight Negative Impact	Section 5.9.5.1 EMMP management measures such as dust screens and noise barriers
		Airborne noise	3	-4	2	2	2	-72	Minor Negative Impact	-2	-36	Slight Negative Impact	
		Ground vibration from construction	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact	
		Spills and leaks	3	0	2	2	2	0	No Impact	-	-	-	
Marine Infrastructure and Navigation													
Section 5.10	Marine Navigation (Cruise Bay, West Keppel Fairway, Turning Circle)	Sedimentation	4	0	2	2	2	0	No Impact	-	-	-	
		Reduction in navigational space	4	-3	2	2	3	-84	Moderate Negative Impact	-1	-28	Slight Negative Impact	Section 5.10.5 on the conductance of Formal Safety Assessment (FSA) prior to works

	Marina at Keppel Bay	Sedimentation	3	0	3	3	3	0	No Impact	-	-	-	
	HarbourFront Cruise Pier	Sedimentation	4	0	3	3	3	0	No Impact	-	-	-	
	Marine intake at Marine Life Park	Excess suspended sediments	4	0	3	3	2	0	No Impact	-	-	-	
		Change in water quality due to pollution release	4	0	3	3	2	0	No Impact	-	-	-	
		Spills and leaks arising from vessel collision and other construction activities	4	-2	3	3	2	-64	Minor Negative Impact	-1	-32	Slight Negative Impact	Section 5.8.5.3 specifically spills and leaks management measures
Rivers and Canals													
Section 5.11	Berlayer Creek	Blockage of river outlet due to sedimentation	4	0	2	2	2	0	No Impact	-	-	-	
Socio-economic													
Section 5.12	Residents	Air pollution	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact	Section 5.12.5 construction measures to minimise dust and noise emissions, including erecting noise barriers
		Airborne noise	3	-2	2	2	2	-36	Slight Negative Impact	-2	-36	Slight Negative Impact	

		Ground vibration from construction	3	0	2	2	2	0	No Impact	-	-	-	
		Visual impact due to sediment plumes	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact	Section 5.12.5 deployment of silt curtains to minimise plume extent
		Visual impact of landscape changes	3	-2	2	2	2	-36	Slight Negative Impact	-	-	-	
		Visual impacts of spills and leaks	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact	Section 5.8.5.3 and 5.12.5 on spills and leaks management measures
	Recreational users	Air pollution impact on recreational users at the Promenade	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact	Section 5.12.5 construction measures to minimise dust and noise emissions, including erecting noise barriers
		Air pollution impact on recreational users at Keppel Island and Marina at Keppel Bay	3	-4	2	2	2	-72	Minor Negative Impact	-3	-54	Minor Negative Impact	
		Airborne noise on recreational users at the Promenade	3	-2	2	2	2	-36	Slight Negative Impact	-2	-36	Slight Negative Impact	

		Airborne noise on recreational users at Keppel Island and Marina at Keppel Bay	3	-3	2	2	2	-54	Minor Negative Impact	0	0	No Impact	
		Ground vibration from construction	3	-3	2	2	2	-54	Minor Negative Impact	-2	-36	Slight Negative Impact	
		Visual impact due to sediment plumes	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact	Section 5.12.5 deployment of silt curtains to minimise plume extent
		Visual impact of landscape changes (for recreational users at Keppel Island and at Marina at Keppel Bay)	3	-3	2	2	2	-54	Minor Negative Impact	-2	-36	Slight Negative Impact	Section 5.12.5 on installing visually appealing hoarding
		Visual impact of landscape changes (for recreational users at the Promenade)	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact	
		Visual impacts of spills and leaks	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact	Section 5.8.5.3 and 5.12.5 on spills and leaks management measures

	Recreational Users (Water users e.g., Divers)	Underwater noise	3	-4	2	2	2	-72	Minor Negative Impact	0	0	No Impact	Section 5.12.5 on temporarily suspending dive operations during marine piling works
		Health impacts of spills and leaks	3	-2	2	2	2	-36	Slight Negative Impact	0	0	No Impact	
		Construction vessels and working area impacting movement of cruise ships	3	-1	2	2	2	-18	Slight Negative Impact	-	-	-	
		Construction vessels and working area impacting movement of yachts	3	0	2	2	2	0	No Impact	-	-	-	
	Staff of Businesses	Air pollution	2	-4	2	2	2	-48	Minor Negative Impact	-3	-36	Slight Negative Impact	Section 5.12.5 construction measures to minimise dust and noise emissions, including erecting noise barriers
		Airborne noise	2	-3	2	2	2	-36	Slight Negative Impact	0	0	No Impact	
		Ground vibration from construction	2	-3	2	2	2	-36	Slight Negative Impact	-2	-24	Slight Negative Impact	
		Visual impact due to sediment plumes	2	-2	2	2	2	-36	Slight Negative Impact	-1	-12	Slight Negative Impact	Section 5.12.5 deployment of silt curtains to minimise plume extent
		Visual impact of landscape changes	2	-3	2	2	2	-36	Slight Negative Impact	-2	-24	Slight Negative Impact	Section 5.12.5 on installing visually appealing hoarding

		Visual impacts of spills and leaks	2	-2	2	2	2	-24	Slight Negative Impact	-1	-12	Slight Negative Impact	Section 5.8.5.3 and 5.12.5 on spills and leaks management measures
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7.2 Post-Construction Phase

A summary of the predicted impacts from the Project's Post-Construction Phase before and after mitigation for each of the main receptors is presented in Table 7.2. The proposed EQOs for the Project are presented in Section 8.1.

Table 7.2 RIAM table for the Post-Construction (long-term) impacts from the Project without mitigation and after implementation of the recommended mitigation measures

Environment al Study Section	Sensitive Receptor	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures			Details on mitigation measures
			I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance	
Marine Ecology and Biodiversity													
Section 6.2	Intertidal areas and seagrass habitat (Keppel Island)	Project footprint	3	-3	3	2	3	-72	Minor Negative Impact	-2	-48	Minor Negative Impact	Section 6.2.5 describing coral and seagrass relocation mitigation measures
		Erosion/Sedimentation	4	-1	3	3	3	-36	Slight Negative Impact	-	-	-	
	Intertidal areas and seagrass habitat (Berlayer Creek)	Long-term Erosion/ Sedimentation	4	0	3	3	3	0	No Impact	-	-	-	
		Connectivity	4	-1	3	3	3	-36	Slight Negative Impact	-	-	-	
	Coral reefs and subtidal seagrass (Keppel Island)	Project footprint	4	-3	3	2	3	-96	Moderate Negative Impact	-2	-64	Minor Negative Impact	Section 6.2.5 describing coral and seagrass relocation mitigation measures
		Long-term Erosion/ Sedimentation	4	-1	3	3	3	-36	Slight Negative Impact	-	-	-	

Environmental Study Section	Sensitive Receptor	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures			Details on mitigation measures
			I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance	
	Coral Reefs around Keppel Island (remaining)	Connectivity	4	-1	3	3	3	-36	Slight Negative Impact	-	-	-	
	Mangroves (Berlayer Creek)	Long-term Erosion/ Sedimentation	4	0	3	3	3	0	No Impact	-	-	-	
	Macrobenthos	Project footprint	1	-1	3	3	3	-9	Slight Negative Impact	-	-	-	
		Long-term Erosion/ Sedimentation	1	-1	3	3	3	0	Slight Negative Impact	-	-	-	
		Connectivity	1	0	3	3	3	0	No Impact	-	-	-	
Terrestrial Ecology and Biodiversity													
Section 6.3	Flora within Project footprint	Project footprint	1	-2	3	3	3	-18	Slight Negative Impact	-	-	-	
	Flora within Hillock Area	Shading effect	4	-1	3	3	3	-36	Slight Negative Impact	-1	-36	Slight Negative Impact	Section 6.3.5.1 suggesting building design tweaks to allow sunlight to filter through
	Fauna within Project footprint	Project footprint	4	-2	3	2	2	-56	Minor Negative Impact	-	-	-	

Environmental Study Section	Sensitive Receptor	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures			Details on mitigation measures
			I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance	
	Fauna within Hillock Area	Mortality due to building strikes	3	-3	3	2	2	-63	Minor Negative Impact	-1	-21	Slight Negative Impact	Section 6.3.5.1 suggesting building design tweaks to minimise bird strikes and mortality
		Loss of ecological connectivity	3	0	3	2	2	0	No Impact	-	-	-	
		Human-wildlife conflict	3	-1	3	2	2	-21	Slight Negative Impact	-1	-21	Slight Negative Impact	Section 6.3.5.1 suggesting good housekeeping practices and signages to minimise human-wildlife conflict
Marine Infrastructure and Navigation													
Section 6.4	HarbourFront Cruise Pier	Hydrodynamic changes	4	0	3	3	2	0	No Impact	-	-	-	
	Marina at Keppel Bay	Hydrodynamic changes	3	0	3	3	2	0	No Impact	-	-	-	
	Marine Navigation (Cruise Bay, West Keppel Fairway, Turning Circle)	Hydrodynamic changes	4	-1	3	2	2	-28	Slight Negative Impact	-1	-28	Slight Negative Impact	
		Long-term Erosion/Sedimentation	4	-1	3	3	2	-32	Slight Negative Impact	-	-	-	
		Project footprint	4	-1	3	3	2	-32	Slight Negative Impact	-	-	-	

Environment al Study Section	Sensitive Receptor	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures			Details on mitigation measures
			I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance	
	Submarine cables	Long-term Erosion/Sediment ation	4	0	3	3	2	0	No Impact	-	-	-	
Rivers and Canals													
Section 6.5	Berlayer Creek	Blockage of river outlets due to sedimentation	4	0	2	2	2	0	No Impact	-	-	-	
Socio-economic													
Section 6.6	Residents	Visual impact of landscape changes	3	-1	3	3	2	-24	Slight Negative Impact	-	-	-	
	Recreational users	Loss of recreational space	3	-2	3	2	2	-42	Minor Negative Impact	-	-	-	
		Visual impact of landscape changes on recreational users at Keppel Island and Marina at Keppel Bay	3	-1	3	2	2	-21	Slight Negative Impact	-	-	-	
		Visual impact of landscape changes on recreational users at the Promenade	3	-1	3	2	2	-21	Slight Negative Impact	-	-	-	

Environmental Study Section	Sensitive Receptor	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures			Details on mitigation measures
			I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance	
	Recreational users (marina's berthing area, movement of leisure yachts)	Hydrodynamic changes	3	0	3	3	2	0	No Impact	-	-	-	
	Staff of businesses	Visual impact of landscape changes	2	-2	3	2	2	-28	Slight Negative Impact	-	-	-	

8 Environmental Management Framework

The Environmental Management Framework presented herein is proposed for the Technical Agencies' review and feedback. It has been developed to focus efforts on implementing measures for impacts which have been assessed and identified during the Environmental Study as requiring mitigation, management, or monitoring to ensure compliance with the proposed EQOs.

The present Environmental Management Framework has been structured according to measures to be implemented during the Pre-Construction Phase and Construction Phase, to guide the Client in planning for its implementation.

8.1 Environmental Quality Objectives

Preliminary EQOs were proposed and presented at the Scoping Meeting with Technical Agencies on 21 December 2023. These EQOs are recommended to guide the implementation of the Environmental Management Framework for the Project and are subject to the Technical Agencies' review and feedback during the Environmental Study consultation.

The EQOs recommended for the Project are as follows:

- No more than **Minor Impact** on the following receptors:
 - Maritime infrastructure and navigation
 - Marine and terrestrial ecology and biodiversity
 - Socio-economic
- No more than **Slight Impact** on rivers and canals
- **No Impact** on receptors outside of the Study Area

8.2 Pre-Construction Phase

8.2.1 Formal Safety Assessment

A Formal Safety Assessment (FSA) is recommended for the Construction Phase to assess all potential marine risks covering not only the work sites but also the access routes.

An application shall also be made to MPA for a Port Marine Notice (PMN), and demarcation of the marine working area shall be made according to MPA's requirements. The PMN would be published by MPA to inform operators and users of HarbourFront Cruise Pier, Marina at Keppel Bay, and the Cruise Bay channel about the Project's marine work area.

8.2.2 Coral and Seagrass Relocation

Coral and seagrass relocation has been proposed (Section 6.2.5) to mitigate the loss of habitats within the direct footprint of the Project, as well as any potential physical damage from construction activities (e.g., demolition, anchoring) within the marine working area.

Consultation with NParks shall be carried out to determine the specifics of the Biodiversity Transplantation Plan, and the coral and seagrass relocation shall be completed prior to any marine works on site.

8.2.3 Finalisation and Implementation of the EMMP

An Environmental Management and Monitoring Plan (EMMP) is recommended to ensure that there would be compliance with the Project EQOs during the construction of the Project, and it is recommended for an EMMP Consultant to oversee the implementation of the management and monitoring plans.

Consultation with NParks shall be completed for the review and finalisation of the Environmental Management and Monitoring Plan. This process includes the submission of the Construction-specific Environmental Management and Monitoring Plan (CEMMP) document to NParks. The CEMMP document shall be prepared based on the actual construction design and work plans, the latest NParks BIA Guidelines, and shall comprise the management plans listed in Section 8.4, and the monitoring plans described in Section 8.5.

The EMMP tasks for the Pre-Construction Phase shall be completed prior to any works on site.

8.3 Construction Phase and Post-Construction Phase

The EMMP tasks for the Construction Phase and Post-Construction Phase shall be carried out for the respective terrestrial and marine construction phases. In general, all aspects of the management plans listed in Section 8.4 and the monitoring plans described in Section 8.5 shall be in place throughout the construction of the development. The marine environmental and habitat monitoring plans shall be in place during the marine construction phase only.

Fortnightly site inspections by the EMMP consultant and ad-hoc site inspections by the Client are recommended to ensure and document that the management plans are in place throughout the Construction Phase. Monthly reporting shall be carried out to document the findings of the fortnightly site inspections, as well as results and assessment of the environmental and habitat monitoring, and summary of compliance with EQOs.

In the event that elevated turbidity is detected, investigations should be conducted to identify and assess the source. Appropriate mitigation measures should be implemented to address the issue. Should the origin of the elevated turbidity be traced to external source(s) (i.e., other construction sites), it is recommended that the EMMP consultant provides feedback to the responsible party/parties.

A post-construction EMMP report shall be prepared to summarise the results for the entire EMMP, and the overall compliance with EQOs.

8.4 Management Plans

Management plans shall be drawn up for review include the following below. Details have been provided in Sections 5.8.5 and 5.9.5.

- Wildlife Management Plan, including plans for biodiversity awareness training, pre-felling fauna inspection, and wildlife encounter response.

- Flora Management Plan,
- Site Hoarding Plan, Tree Felling Plan and Method Statement
- Site Management Plan;
- Vector Control Plan;
- Earth Control Measures Plan;
- Water Pollution Management Plan;
- Waste Handling and Management Plan;
- Chemical and Hazardous Material Management Plan, including Emergency Spill Response Plan;
- Air Pollution and Dust Management Plan;
- Noise Management Plan;
- Environmental Incident Contingency Plan; and,
- Grievance and Complaint Handling Plan.

8.5 Environmental and Habitat Monitoring

Environmental and habitat monitoring is recommended to measure and document actual impacts due to the construction, and to ensure prompt response in the event of non-compliance with any of the Project EQOs. An overview is provided in Table 8.1 below, and further details are provided in the following sub-sections.

Table 8.1 Overview of environmental monitoring for the EMMP

Monitoring Aspect	Frequency	Monitoring Period		
		Baseline	Construction	Post-Construction
Sediment flux surveys for turbidity monitoring	Twice a week during marine construction	Not applicable	Marine construction period	Not applicable
Marine water quality monitoring	Monthly	Three months	Entire construction period	Three months
Airborne noise monitoring	Continuous	One week	Entire construction period	One week
Air quality monitoring	Continuous	One week	Entire construction period	One week

Monitoring Aspect	Frequency	Monitoring Period		
		Baseline	Construction	Post-Construction
Vibration monitoring	Continuous	One week	Land piling period	Not applicable
Underwater noise monitoring	Continuous	One week	Marine piling period	Not applicable
Terrestrial flora and arboricultural monitoring	Once every quarter	Not applicable	Entire construction period	Not applicable
Terrestrial fauna monitoring	Throughout	Not applicable	Entire construction period	Not applicable
Intertidal and seagrass habitat monitoring	Once every quarter	One survey	Entire construction period	One survey
Coral reef habitat monitoring	Once every quarter	One survey	Entire construction period	One survey
Sedimentation monitoring	Monthly	Three months	Entire construction period	One month

8.5.1 Sediment Flux Surveys

In order to monitor suspended sediment concentrations and the presence/absence of sediment plumes during the demolition and marine construction works, sediment flux transects with a vessel-mounted acoustic doppler current profiler are recommended in the immediate area of the targeted construction works. The purpose of the sediment flux transects is to confirm the absence or presence of any sediment plume from the demolition and marine construction works and provide spatial information on the generated sediment plumes during the progress of the Project's demolition and marine construction works, if any.

The sediment flux transects should be carried out perpendicular to the current flow. At least two (2) sediment flux surveys should be carried out in a week. A minimum of ten (10) transects should be taken during each survey, including transects upstream and downstream to capture background concentrations, as well as sediment plume generated by the marine construction activities.

8.5.2 Marine Water Quality Monitoring

Monthly monitoring of marine water quality is recommended. For each monthly survey, water samples shall be taken at each survey point on spring flood and ebb tides (i.e., two (2) repeats per campaign), with samples collect at surface and near seabed for both repeats. The parameters to be measured are shown in Table 8.3. The parameters are the

typical water quality monitoring parameters in marine EMMP projects in Singapore. They are key water quality parameters that indicate status/condition of a water body (turbidity, nutrient, biological (chlorophyll-a and bacteria) and heavy metals) and at the same time could be directly (such as TSS) or indirectly (such as chlorophyll-a) influenced by the Project.

The water quality monitoring should be undertaken for a minimum baseline period of three (3) months prior to start of works, monthly during construction and continue for three (3) months after the completion of construction.

The locations of the proposed water quality monitoring stations are shown in Figure 8.1, with the rationale for each station provided in Table 8.2.

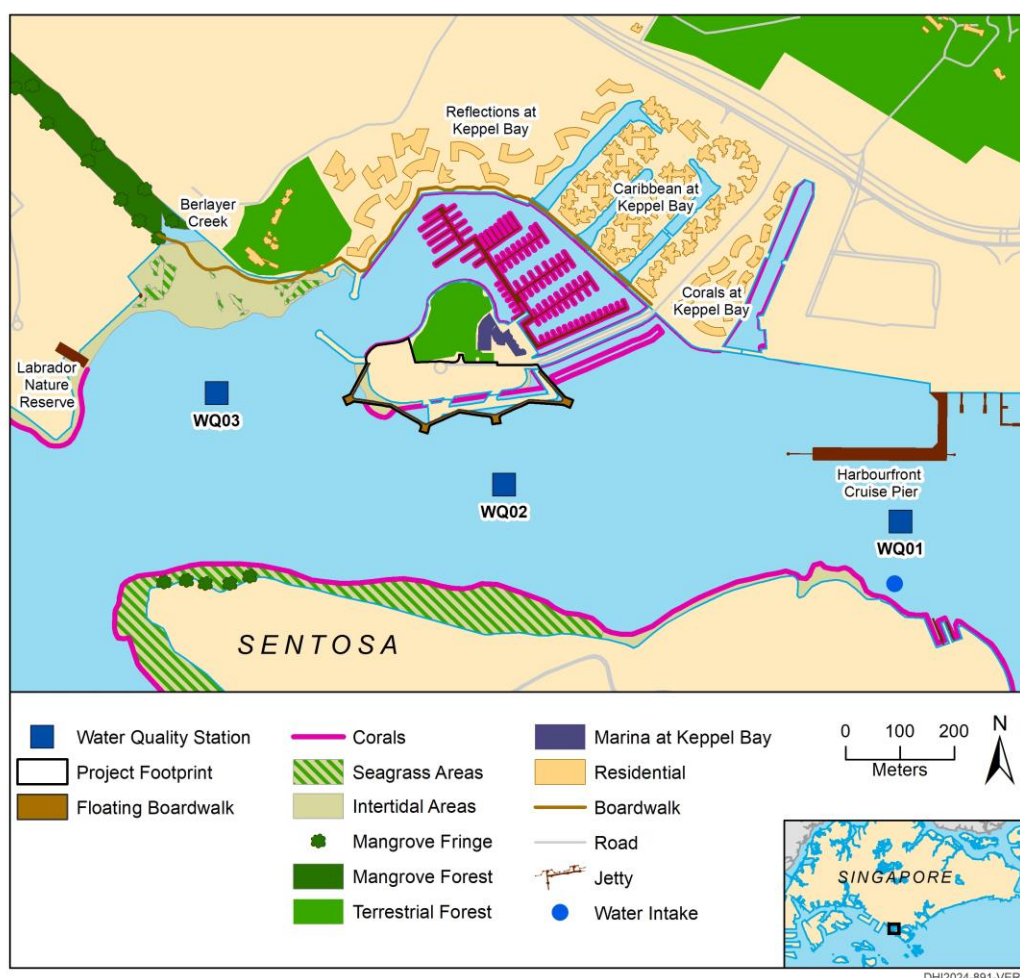


Figure 8.1 Proposed water quality monitoring stations for the Project's EMMP

Table 8.2 Rationale for proposed water quality monitoring locations for the residential development's construction EMMP

Station ID	Rationale
WQ01	Monitoring water quality changes along the main flow path south-east from the marine work area towards the marine intake along Sentosa coastline and HarbourFront Cruise Pier

Station ID	Rationale
WQ02	Monitoring water quality changes at the Cruise Bay channel
WQ03	Monitoring water quality changes along the main flow path west from the marine work area towards the mouth of Berlayer Creek

Table 8.3 Parameters for water quality surveys

Parameter	Detection Limit	Depth
<i>In Situ Measurements</i>		
Salinity	N/A	Profile at 1 m intervals
pH	N/A	Profile at 1 m intervals
Dissolved Oxygen (DO)	N/A	Profile at 1 m intervals
Temperature	N/A	Profile at 1 m intervals
Turbidity	N/A	Profile at 1 m intervals
Secchi Disc Depth	N/A	N/A
<i>Laboratory Analyses</i>		
Total Suspended Solid (TSS)	1 mg/l	Surface and near seabed ¹
Total Nitrogen	0.01 mg/l	Surface and near seabed ¹
Nitrate (as NO ₃ -N)	0.01 mg/l	Surface and near seabed ¹
Nitrite (as NO ₂ -N)	0.01 mg/l	Surface and near seabed ¹
Total Ammonia Nitrogen (TAN) ²	0.01 mg/l	Surface and near seabed ¹
Total Phosphorus	0.01 mg/l	Surface and near seabed ¹
Phosphate (as PO ₄ -P)	0.01 mg/l	Surface and near seabed ¹
BOD ₅ (Five-day Biochemical Oxygen Demand) at 20 °C	1 mg/l	Surface and near seabed ¹
Chlorophyll-a	0.5 µg/l	Surface and near seabed ¹
Oil & Grease	0.1 mg/l	Surface and near seabed ¹
Heavy Metals (Al, As, Cd, Cr, Cu, Pb, Hg, Ni, Zn)	5 µg/l	Surface and near seabed ¹
Heavy Metals (Hg)	0.1 µg/l	Surface and near seabed ¹
Escherichia coli (E. coli)	2 MPN/100ml	Surface and near seabed ¹
Enterococci	2 MPN/100ml	Surface and near seabed ¹
Faecal Coliforms	2 MPN/100ml	Surface and near seabed ¹

¹ 1 m below surface and 1 m above seabed

² Ammonia as NH₃-N will be calculated based on TAN level using temperature, salinity and pH measurements

8.5.3 Airborne Noise Monitoring

Three (3) airborne noise monitoring stations (all continuous monitoring and, preferably online) are recommended to be deployed. The locations are proposed to provide data on the noise levels at Marina at Keppel Bay and Hillock Area, and a strategic location in the vicinity to monitor noise levels in the residential and recreational areas. The noise sensors should be Type 1.

The monitoring should comprise one (1) week baseline monitoring prior to construction works commencing, continuous monitoring throughout construction, and one (1) week post-construction monitoring after the end of construction works.

The Construction Phase monitoring data should be compared as a minimum against baseline noise level (e.g., 95th percentile Leq 5 mins, 1 hr and 12 hrs) but also Singapore permissible noise levels, in the case of residential receptors, or any other potential thresholds established for protection of terrestrial fauna. Note additional noise monitoring may also be required at the boundary of the construction work area in accordance with NEA requirements.

The locations of the proposed airborne noise monitoring stations are shown in Figure 8.2, with the rationale for each station provided in Table 8.4.

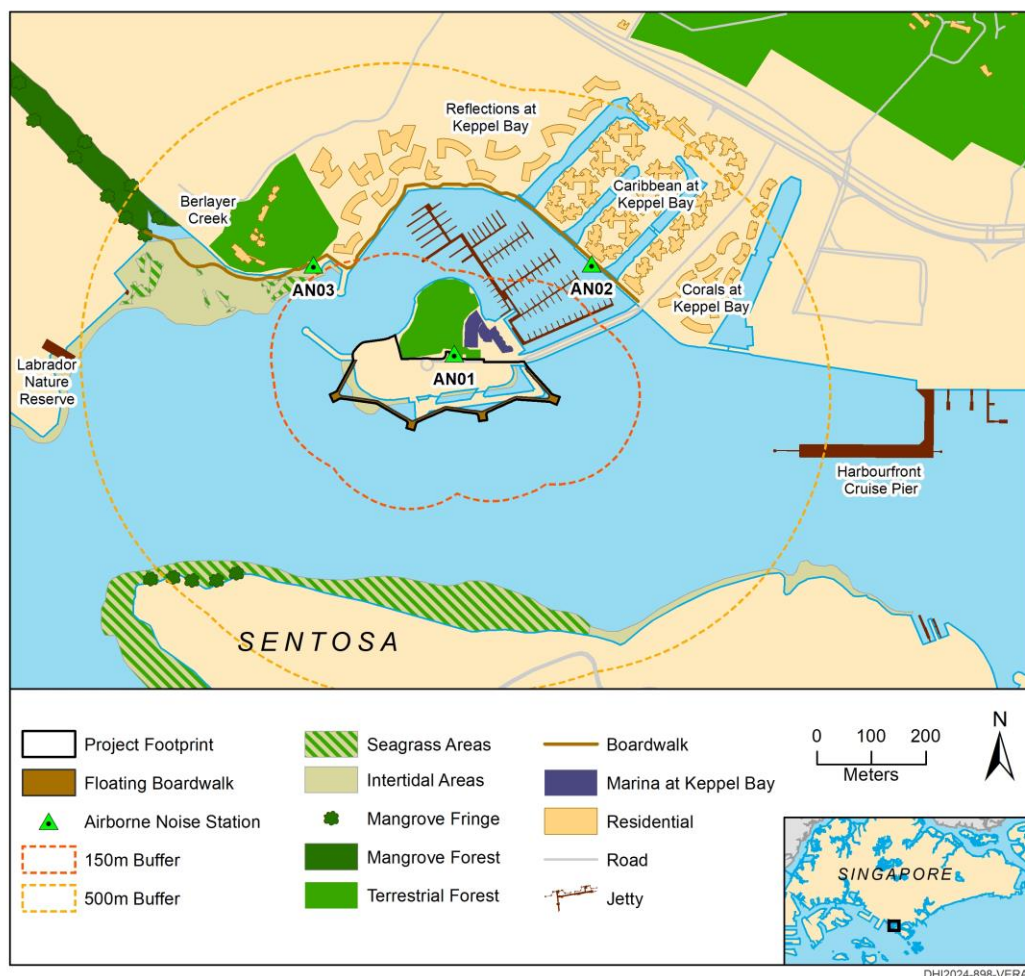


Figure 8.2 Proposed locations for airborne noise monitoring for the Project's EEMP

Table 8.4 Rationale for proposed online airborne noise monitoring stations for the residential development's construction EMMP

Station ID	Rationale
AN01	Monitoring airborne noise changes on Keppel Island where recreational users (Marina at Keppel Bay) and terrestrial fauna (Hillock Area) are present.
AN02	Monitoring airborne noise changes along Caribbean Promenade where residential buildings and recreational users are present.
AN03	Monitor airborne noise changes at the entrance of Bukit Chermin Boardwalk where residential buildings (Reflections at Keppel Bay) and recreational users are present.

8.5.4 Air Quality Monitoring

Three continuous, and preferably online, air quality monitoring stations are recommended to be deployed. The locations are proposed to provide data on the air quality conditions at Marina at Keppel Bay and Hillock Area, and some strategic locations in the vicinity to represent the residential and recreational areas.

The air quality monitoring sensor type employed should be capable of collecting timeseries of PM_{2.5} and PM₁₀. The instrument shall be calibrated based on laboratory results of gas samples collected by a passive air quality sampler. Meteorological data (e.g., wind speed, wind direction and rainfall) shall also be collected at each of the air quality monitoring stations. It is noted that NEA recommends USEPA FRM/FEM equipment for ambient air quality monitoring. As such, DHI proposes to conduct a co-location test for a week with the USEPA FRM/FEM air monitoring equipment prior to the planned monitoring period to ensure the performance of the non-USEPA FRM/FEM equipment. After the co-location test is completed, the validated non-USEPA equipment will be utilised for the ambient air quality monitoring at the proposed locations as part of the EMMP monitoring.

Monitoring should commence one (1) week prior to construction works commencing and one (1) week after the end of construction works. The results of Construction Phase monitoring shall be compared against SG AQT or, should the baseline data already show exceedance over SG AQT, against a threshold to be established based on the baseline survey data. Additional retrofitting shall be considered when monitoring data shows exceedance over the pre-defined limit.

The locations of the proposed air quality monitoring stations are shown in Figure 8.3, with the rationale for each station provided in Table 8.5.

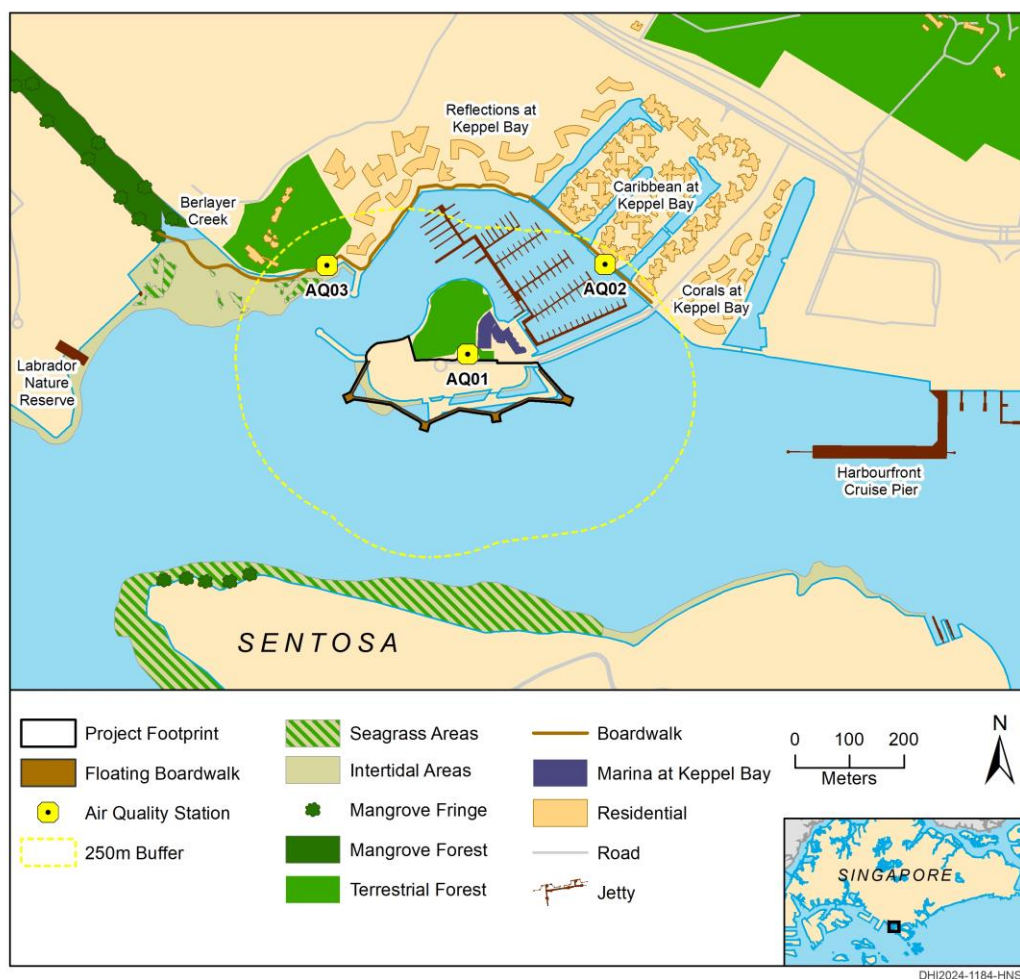


Figure 8.3 Proposed locations for air quality monitoring for the Project's EMMP

Table 8.5 Rationale for proposed air quality monitoring stations for the Project's EMMP

Station ID	Rationale
AQ01	Monitor air quality changes at Keppel Island where recreational users (Marina at Keppel Bay) and terrestrial fauna (Hillock Area) are present.
AQ02	Monitor air quality changes along Caribbean Promenade where residential buildings and recreational users are present.
AQ03	Monitor air quality changes at the entrance of Bukit Chermin Boardwalk where residential buildings (Reflections at Keppel Bay) and recreational users are present.

8.5.5 Vibration Monitoring

One (1) continuous vibration monitoring station is recommended to be deployed. The proposed monitoring location will provide data on the vibration levels at the Marina at Keppel Bay and Hillock Area during construction. Baseline vibration levels should be recorded for one (1) week before construction works, and subsequently throughout the duration of the land piling works. No monitoring is required after the piling works.

The location of the proposed vibration monitoring station is shown in Figure 8.4.

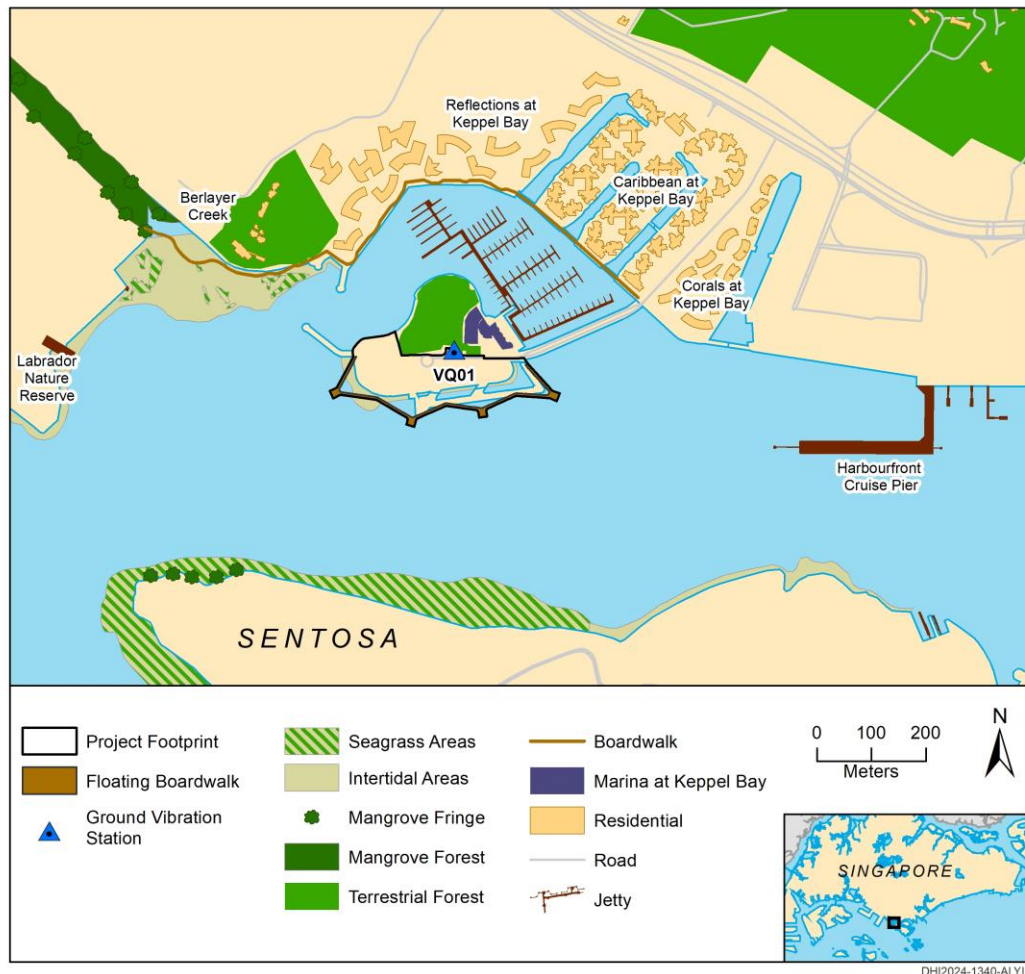


Figure 8.4 Proposed location for vibration monitoring for the Project's EMMP

8.5.6 Underwater Noise Monitoring

One (1) hydrophone should be installed to monitor underwater noise during piling (one in the vicinity of marine construction works located approximately 300 m away from the floating board walk profile). The hydrophone should be deployed at least one (1) week prior to the start of piling works, in order to record a minimum of 1 week of baseline underwater noise data before the start of piling works, and then throughout the duration of the marine piling works. No monitoring is required after the piling works. The hydrophone should be at least 5.0 m below the sea surface, and record at a high sampling rate. The hydrophones should be serviced regularly. However, to ensure the safety of the divers, no piling works should be carried out if diving is required to service or retrieve the hydrophones.

8.5.7 Terrestrial Habitat Monitoring

Applicable terrestrial habitat EMMP monitoring includes terrestrial flora, arboriculture, and terrestrial fauna.

Terrestrial Flora and Arboriculture

Terrestrial flora and arboricultural monitoring are to be conducted quarterly within development footprint and adjacent to the boundary of the Project site. No baseline and post-construction monitoring is required. The objective of the terrestrial flora monitoring is to ensure that construction activities do not affect flora and habitats adjacent to the Project site. The arboricultural monitoring serves as a check of tree physiological health, vigour, and structural stability. The visual arboricultural inspections serve as a safeguard to ensure that tree conditions have not deteriorated, verify no mechanical damage to trees has occurred, monitor for any potential edge effects, and check that the structural integrity of Tree Protection Zones on site (if any) has not been compromised. In the event of tree canopies encroaching into the worksite, the appointed ISA-certified arborist shall assess and provide recommendations for pruning or felling of affected trees.

The quarterly terrestrial flora and arboricultural monitoring reports to be submitted should also include a review of construction practices and method statements, recommendations, and a photolog.

Terrestrial Fauna

Monthly fauna inspections shall be conducted throughout the Construction Phase of the Project to prevent/minimise potential human-wildlife conflict and faunal injury or mortality. The appointed ecologist shall visually inspect the site for the following:

- Structural integrity and presence of gaps in perimeter hoardings
- Presence of roadkill along construction access roads and within the development footprint
- Potential fauna entrapments in areas such as erosion control blankets (ECBs), erosion control measure (ECM) tanks, storage areas, and equipment and machinery, etc.

Findings from the inspection should be reported to the ECO for rectification and follow-up, and subsequently documented in the EMMP.

8.5.8 Marine Habitat Monitoring

Marine habitat monitoring should be carried out at the coral reefs, and intertidal and seagrass areas marked out in Figure 8.5.

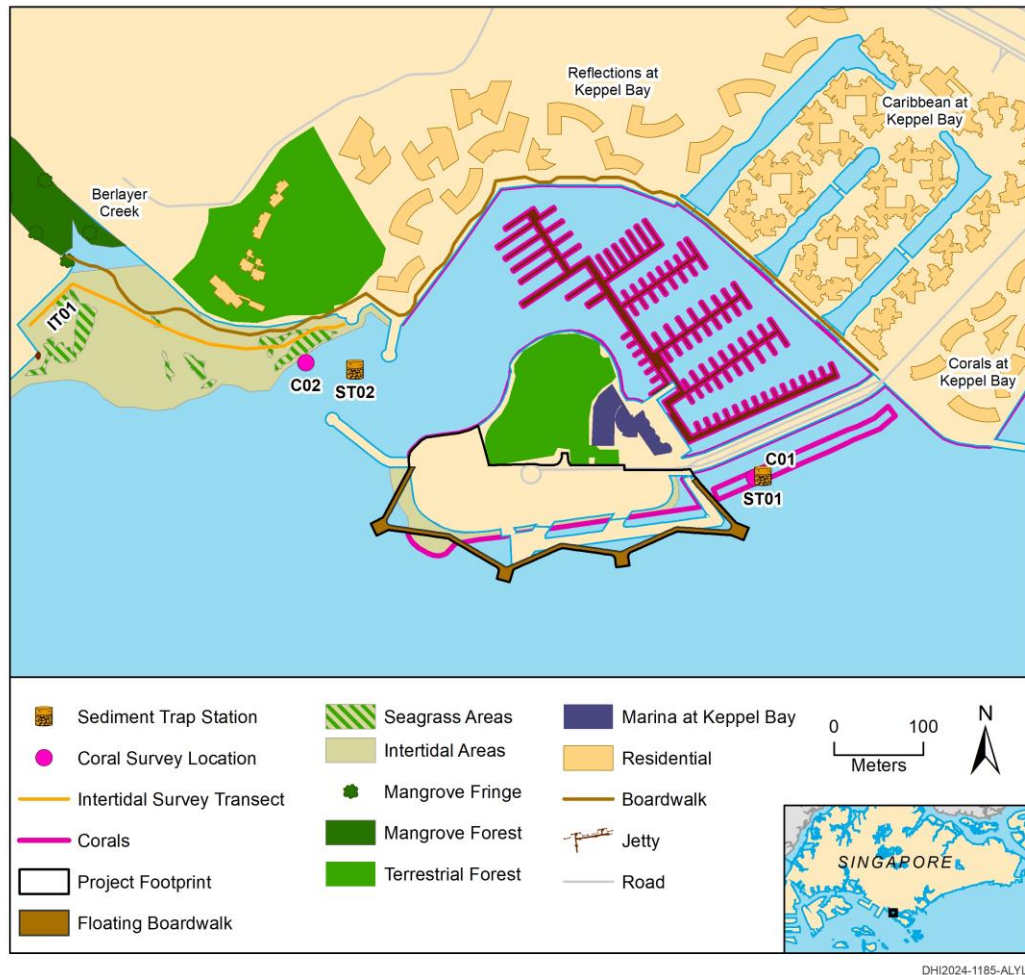


Figure 8.5 Proposed intertidal and coral monitoring stations (with includes coral sediment traps) for the Project's CEMMP

Intertidal and Seagrass Habitat

The intertidal mudflat and seagrass habitat monitoring surveys would be carried out quarterly throughout the baseline, construction phase and post-construction phase. Baseline and post-construction monitoring is proposed to be carried out for a minimum of one (1) quarter each and quarterly during the construction phase.

Surveys can be carried out using two methods depending on the size and extent of the intertidal areas, namely Visual Quadrat Transect (VQT) method or the Visual Quadrat Point (VQP) sampling method. The VQT method developed by Duarte and Kirkman (2001) can be adopted for large intertidal reef flats, while the Visual Quadrat Point (VQP) method can be adopted for small intertidal patch reef flats or narrow fringing reef flats. Surveys will be conducted during periods of spring low tide, between 0.0 m CD to 0.2 m CD.

In the VQT method, replicate transect lines will be laid across the reef flat/entire intertidal habitat at intervals at least 50 m apart (Figure 8.7). The lines will be laid perpendicular to the shore within the extent of the intertidal zone, which will be exposed during the survey. Along each transect, six (6) randomly distributed replicates of a 0.25 m² (0.5 m by 0.5 m) quadrat will be sampled at 10 m intervals along the transect lines (Figure 8.6). The

percentage cover of a predetermined list of flora and fauna within the quadrat, including seagrass, algae, other major sessile invertebrates, and abiotic substrate, will be documented (Table 8.6). In addition, individual motile organisms from a list of major taxonomic classes observed within the quadrats will be enumerated (Table 8.7). Where possible, all organisms will be identified to the lowest taxonomic level or grouped into taxa/functional groups for subsequent analyses. Species of conservation significance will be identified in accordance with published lists (e.g., IUCN Red List, the Singapore Red Data Book version 3 (NParks, 2024a); and Lindsay *et al.* (2022) and highlighted.

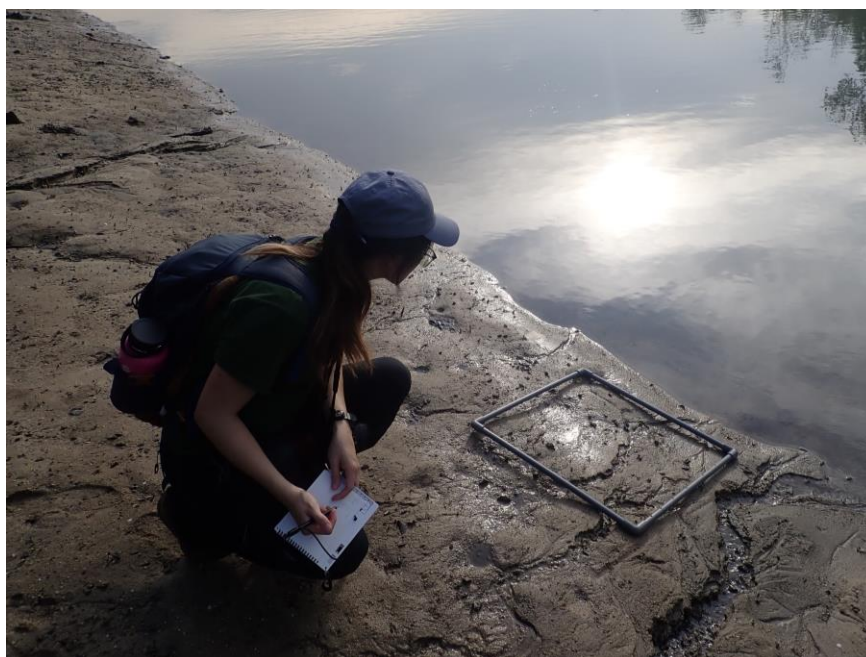


Figure 8.6 Intertidal survey using a 0.25 m² quadrat

Table 8.6 Major benthic categories used in the intertidal surveys

Major Benthic Category	Description
Hard Coral	Reef building scleractinian and non-scleractinian stony corals, e.g., <i>Favia spp.</i>
Seagrass	Marine flowering plants e.g., <i>Thalassia hemprichii</i>
Soft coral	Non-reef building fleshy corals without a supporting axis of horny and/or calcareous material e.g., <i>Sinularia spp.</i>
Sponge	Sessile multi-celled animals of the phylum Porifera that have many water intake and outlet openings connected by chambers e.g., <i>Xestospongia spp.</i>
Zoanthid	Colonial or solitary anthozoans, e.g., <i>Platythoa</i> , <i>Protopalythoa</i>
Other Fauna	Ascidians, anemones, gorgonians, giant clams etc.
Algae	Turf algae, coralline algae, all macroalgae (green, brown, red), algal assemblages, <i>Halimeda</i>
Abiotic	Non-living material such as dead coral, rubble, rock, soft benthos (sand/silt) and debris

Table 8.7 Fauna grouped according to taxonomic level of Phylum and Class and its corresponding components (Adapted from Allen and Steene, 2007)

Phylum	Class	Description
Annelida	Polychaeta	Segmented worms
Arthropoda	Crustacea	Barnacles, shrimps, crabs etc.
Echinodermata	Ophiuroidea	Brittle stars and basket stars
Echinodermata	Holothuroidea	Sea cucumbers
Echinodermata	Asteroidea	Sea stars
Echinodermata	Echinoidea	Sand dollars and sea urchins
Hemichordata	Enteropneusta	Acorn worms, live in sand or silt bottoms
Mollusca	Bivalvia	Clams, oysters, mussels etc.
Mollusca	Gastropoda	Cowries, cone shells, nudibranch etc.
Nemertea	Anopla	Unsegmented, ribbon worms
Platyhelminthes	Turbellaria	Flatworms
Sipuncula	Sipunculidea	Peanut worms

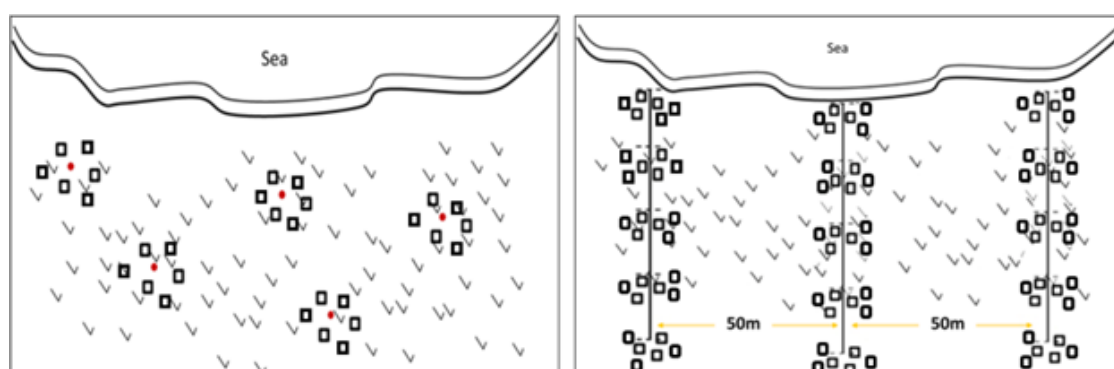


Figure 8.7 Placement of 0.25 m² quadrats (black squares) within the irregular intertidal area based on the VQP method. Red dots are survey locations marked by GPS (left). Placement of 0.25 m² quadrats within the intertidal area based on the VQT method. Lines represent the transect tapes laid perpendicularly to shore (right).

Where seagrass beds are small or patchy, the VQP sampling method will be employed, comprising replicate 0.25 m² quadrats placed randomly at appropriate predetermined points distributed across the site to ensure adequate representation of the intertidal area. (Figure 8.7). The VQP surveys will document and characterise the seagrass and intertidal communities, including:

- Benthic percentage cover of seagrass, macroalgae, and abiotic substrate (Table 8.6)
- Counts of individual motile organisms from major fauna classes
- Biodiversity of major intertidal flora and fauna, identified to the lowest taxonomic level possible (Table 8.7).

Coral Reef Habitat

Monitoring of corals on the caissons to the east of Keppel Island (i.e., outside the marine work area where physical damage from barge anchoring or direct collision is expected) and at Berlayer Creek to confirm compliance with the EQO for this area (Figure 8.5). Monitoring should be carried out on a quarterly basis, with one (1) survey to be carried out prior to the start of construction to establish the EMMP baseline conditions and one (1) survey to be carried out after the end of construction. However, to ensure the safety of the divers, no piling works should be carried out during the diving surveys.

Surveys can be carried out using two methods depending on the size and extent of the coral reefs. As mentioned in Section 5.8.2.2, the Line Intercept Transect (LIT), and Horizontal Visual Quadrat Transect (HVQT) methods can be adopted.

Sedimentation

Sediment traps function as measuring devices for sedimentation rate at the monitoring sites and serve to provide feedback and validation for the other monitoring parameters. At each station, the sediment traps would be deployed along the reef crest (0 mCD), where coral cover is typically the highest in Singapore, as three (3) replicates; each consisting of three small cylindrical tubes attached together (Figure 8.8). The replicates would be placed approximately 2 m to 5 m apart to capture local spatial variability. This follows the methods outlined in the Survey Manual for Tropical Marine Resources (English *et al.*, 1997).

The height of the trap opening from the reef substrate would be about 35 cm, held vertical by an angle-bar hammered into a denuded part of the reef (Figure 8.8). Baffles would also be placed in the top of the trap to reduce re-suspension within and exclude any animals that might otherwise enter the trap and affect the results. The sediment traps would also be painted with non-toxic anti-fouling paint to minimise bio-fouling between repeats. These sediment traps would not float, hence, even if any trap gets dislodged from the angle-bar, it will remain on the seabed.

In order to establish the baseline sedimentation rates, at least three (3) months should be monitored prior to the start of construction works. During the construction phase, the surveys are proposed to continue monthly. One (1) month of survey should be monitored post-construction. Servicing of the sediment traps would be carried out monthly, and the sediment trap samples would be recovered. The sediments collected in each replicate set over the deployment period would be recovered, sent to a laboratory for dry weight analysis, and used to derive sedimentation rate in terms of kg/m²/day. The indicative survey stations for this survey are presented in Figure 8.5.



Figure 8.8 Examples of one set of sediment trap deployed along the reef crest

9 Conclusion

The construction of the residential development and the floating boardwalk has a range of environmental impacts both during construction (short-term) and post-construction (long-term).

During construction, short term impacts may arise due to changes by construction activities (construction site, physical disturbance and inconvenience, and construction vessel traffic), suspended sediments, sedimentation, pollution release, spills and leaks, underwater noise, airborne noise, ground vibration, and air quality. These changes may result in impacts to marine and terrestrial ecology and biodiversity, marine infrastructure and navigation, rivers and canals, and social-economic receptors. The assessment focused on the pathways and potential consequences of the impact, rating the level predicted.

- **Hydrodynamics:** Hydrodynamic conditions at the baseline stage were ascertained via a calibrated and validated MIKE 21 HD model. These baseline characteristics are presented in Section 5.1.1. No construction phase modelling was carried out as no significant impacts to hydrodynamics were anticipated.
- **Sediment Plume:** Sediment plumes from demolition and piling works were simulated using the MIKE 21 MT model based on the construction methodology specified by the Client. Worst-case scenarios were assessed for the receptors on the east and west of Keppel Island, and the intermonsoon season was also assessed to examine the potential impact when the flushing rate was minimal (as requested by NEA). Model results show sediment plumes will be generated from the works, with a bigger plume on the eastern side of the works, with slight differences between the chosen monsoon seasons. Generally, the plumes were localised around the Study Area.
- **Pollutant Release:** With respect to water quality, the potential release of heavy metals from suspended sediment due to piling activities was studied. Calculations using conservative inputs from baseline sediment and water quality data, along with maximum amounts of suspended sediments generated, yielded a negligible increase in heavy metal concentrations. When compared against the ASEAN MWQC for the protection of aquatic life, the analysis shows that there were no exceedances of the ASEAN MWQC, and the risk of heavy metal contamination in the water due to suspended sediment is very low.
- **Air Quality:** Dust-emitting activities such as Demolition, Earthworks, Construction, and Trackout were qualitatively assessed to be contributing a “Medium” to “Large” magnitude of dust emission based on the Institute of Air Quality Management (IAQM)’s Guidance on the Assessment of Dust from Demolition and Construction.
- **Airborne Noise:** Ambient noise levels in the Study Area in two (2) construction scenarios were established via the SoundPlan 3D noise propagation model. It is predicted that noise generated from the demolition and piling work phase was rather localised around Keppel Island. Only receptors at Marina at Keppel Bay and terrestrial faunae in the Hillock Area were exposed to excessive noise. It has been demonstrated that a noise barrier of 4.0 m high will reduce the noise levels to 61 dBA and 62 dBA at the Hillock Area and Marina at Keppel Bay, respectively. In both modelled scenarios, other receptors are predicted to experience no more than 64 dBA.
- **Ground Vibration:** The vibratory piling rig used for piling works is expected to result in significant ground vibrations on Keppel Island only. The predicted ground vibration levels show that Hillock Area will be exposed to up to 2.86 mm/s of PPV, while staff of businesses and recreational land users will be exposed to 2.60 mm/s of PPV. The expected human responses to expected vibrations can be tolerated if warnings and explanations have been given to affected people in advance, though it may likely cause

complaints. Faunal responses to the expected ground vibrations will likely be similar or more intense in stress than humans.

- **Underwater Noise:** Piling works for the construction of the residential development and the floating boardwalk can potentially cause physiological stress on marine ecology and biodiversity, particularly for marine fauna (fish) and megafauna observed in the Study Area. Baseline underwater noise is primarily comprised of natural, anthropogenic and tonal noises. Potential impacts were then calculated using the National Marine Fisheries Service (NMFS) Multi-Species Pile Driving Calculator. The results show that the onset of behavioural changes in sea turtles and fish can be up to a maximum distance of 10 m and 464 m, respectively, from the piling location.
- **Marine Ecology and Biodiversity:** Significant marine habitats are found within the study area, most notably, intertidal (coral and seagrass), coral reefs, subtidal seagrass, and the presence of significant marine fauna and megafauna. A number of impacts to this receptor were assessed, resulting in impact levels ranging from **No Impact** to **Moderate Negative Impact** prior to mitigation. The effects were assessed using a combination of model, calculation results, and qualitative assessments. The most significant impacts during the construction phase are spills/leaks, marine construction and erosion/sedimentation impacts, particularly to the marine habitats around Keppel Island. Underwater Noise also has significant anticipated impacts on marine fauna/megafauna. These impacts should be managed to meet the EQOs via a CEMMP and to potential accidental spills, which can be avoided if adequate controls are in place. Mitigation measures for underwater noise impacts should also be put in place.
- **Terrestrial Ecology and Biodiversity:** Notable terrestrial biodiversity receptors include flora within the Hillock Area and fauna within the Study Area. The impacts assessed on terrestrial biodiversity receptors range from **No Impact** to **Minor Negative Impact**. The most significant impacts are the potential encroachment of construction equipment to the tree canopy of the Hillock Area and the effects of changes to airborne noise on terrestrial fauna. Do note that no flora within the Hillock Area is expected to be lost as a result of the construction of the residential development and the floating boardwalk. Terrestrial EMMP measures should be implemented to manage the anticipated impacts of the works on terrestrial flora and fauna, including “No infringement zones” in the Hillock Area.
- **Marine Infrastructure and Navigation:** The construction of the residential development and the floating boardwalk is expected to cause impacts ranging from **No Impact** to **Slight Negative Impact** on marine navigation, marine jetties and piers, and marine intake in the Study Area with proposed mitigation measures such as the Formal Safety Assessment (FSA).
- **Rivers and Canals:** Berlayer Creek was found to be in the vicinity of the Project and could potentially be impacted. The construction of the residential development and the floating boardwalk has potential to induce sedimentation at their outlets, reducing their ability to discharge to the sea. Sediment plume model results have shown no significant sedimentation at the river’s outlet, causing no concern related to the blockage of this water body.
- **Socio-economic:** From the baseline surveys, most socio-recreational receptors that visit Keppel Island its surrounding boardwalks live around the general area and engage in walking as a main recreational activity (from Labrador Park to Keppel Island). It was assessed that the construction works result in assessed impacts between **No Impact** and **Minor Negative Impact**. Notably, the most serious anticipated impacts are underwater noise impacts to divers and construction associated impacts to recreational users (e.g., air pollution, changes to airborne noise, ground vibration and visual landscape impacts) and occasionally to staff of businesses. Appropriate mitigation

measures are recommended to minimise potential negative impacts to health and safety of recreational users.

During post-construction, impacts may arise due long-term changes in Project footprint and landscape, currents and erosion/sedimentation. These changes may result in impacts to marine and terrestrial ecology and biodiversity, marine infrastructure and navigation, rivers and canals, and socio-economic receptors. The assessment focused on the pathways and potential consequences of the impact, assessing the impact level predicted.

- **Hydrodynamics:** Changes to the Study Area's hydrodynamics are assessed using DHI's MIKE 21 HD model. Results show changes to the slackwater duration and 95th percentile BSS (for long-term sedimentation and erosion assessment) within the Study Area, mainly in the waters just south of Keppel Island and the newly built boardwalk.
- **Marine Ecology and Biodiversity:** Impact levels ranging from **No Impact** to **Moderate Negative Impact** are predicted. Habitat loss within the pile deck and floating boardwalk footprint are anticipated to significantly impact the identified marine ecological receptors. Given such habitat loss of coral reefs, intertidal habitat and subtidal seagrass, coral and seagrass relocation works are proposed within a 100m buffer around the pile deck footprint and the estimated marine working space.
- **Terrestrial Ecology and Biodiversity:** The limited spatial overlap in the Project footprint on terrestrial habitats avoids impact on species within the Hillock area. The anticipated impacts on terrestrial flora and fauna were assessed to range between **No Impact** and **Minor Negative Impact**, with the most significant impact being the Project footprint impact on fauna within the Project footprint.
- **Marine Infrastructure and Navigation:** The footprint of the residential development and the floating boardwalk are expected to cause impacts ranging from **No Impact** to **Slight Negative Impact** on marine infrastructure and navigation in the Study Area.
- **Rivers and Canals:** Based on the bed shear stress results, the residential development and the floating boardwalk are unlikely to experience sedimentation at Berlayer Creek's river mouth. Hence, **No Impact** on rivers and canals is expected.
- **Socio-economic:** Potential impacts on social-economic receptors in the Study Area mainly result from changes in the landscape, ranging from **No Impact** to **Minor Negative Impact**. The marine-based recreational users are not expected to be impacted by current changes; however, significant impacts can be expected from loss of recreational spaces when the Project is completed.

After appropriate mitigation measures are implemented, all construction and post-construction impacts can be reduced to acceptable levels, except Project footprint impact on coral reefs and subtidal seagrass near Keppel Island, for which coral and seagrass relocation mitigation measures have been proposed. Hence, the Project is considered feasible from an environmental perspective.

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APPENDICES

APPENDIX A – Hydrodynamics Model

Model Setup and Results

A Hydrodynamics Model

Tide is the principal force that drives the dynamics of Singapore's waters, generated by the combination of tides propagating from the South China Sea and those produced in the Indian Ocean. The rising tide moves westward and the falling tide eastward.

In the Singapore Straits, the tide is dominated by four semi-diurnal and diurnal components: M2, S2, O1 and K1. The semi-diurnal tides mainly originate from the Andaman Sea, while the diurnal components mainly originate from the South China Sea, though with a contribution from the Java Sea. The tide in Singapore is generally semi-diurnal with two high tides and two low tides occurring each day.

During the northeast monsoon, the prevailing winds pile-up water at the south-western portion of the South China Sea, thus setting up a steric gradient between the eastern and western ends of the Singapore Strait. This phenomenon produces a slight seasonal increase in the local mean sea level, which, in combination with direct wind forcing from the prevailing monsoon, produces a slow net westward current in the Singapore Strait. Conversely, during the southwest monsoon, water mass is forced out into the South China Sea, producing a slight depression in the local mean sea level between April and September and a net current that travels west to east.

Currents around the areas of interest are complicated by a number of factors including tides, storm surge, seasonal surge, and local eddy formation, and therefore a two-dimensional hydrodynamic (HD) MIKE 21 Flexible Mesh (FM) model was set up and forced by tides, seasonal surge, and wind data extracted from East Coast Parkway NEA wind station.

A.1 MIKE 21 Flow Model FM

The MIKE 21 Flow Model is a modelling system for 2D free-surface depth-integrated flows that is developed and maintained by DHI and offered as part of MIKE Powered by DHI. The model system is based on the numerical solution of the two-dimensional (2D) incompressible Reynolds-averaged Navier-Stokes equations subject to the assumptions of Boussinesq and of hydrostatic pressure. The model is applicable for the simulation of hydraulic and environmental phenomena in lakes, estuaries, bays, coastal areas, and seas wherever stratification can be neglected. The model can be used to simulate a wide range of hydraulic and related items, including tidal exchange and currents and storm surges. For further details, see DHI's Hydrodynamic Module User Guide (2022).

The hydrodynamic (HD) module is the basic module in the MIKE 21 Flow Model FM. The HD module simulates water level variations and flows in response to a variety of forcing functions in lakes, estuaries, and coastal regions. The effects and facilities include:

- Barometric pressure gradients;
- Sources and sinks (e.g. rivers, intake and outlets from power plants);
- Flooding and drying;
- Momentum dispersion;
- Tidal potential;
- Coriolis force;
- Precipitation/Evaporation;
- Ice coverage; and
- Wave radiation stresses.

The model uses a flexible mesh (FM) based on unstructured triangular or quadrangular elements and applies a finite volume numerical solution technique.

A.2 Regional Hydrodynamic Model

A.2.1 Setup and Parameters

The model domain covers the Singapore Straits, and its resolution increases towards the project area, reaching approximately 8 m. the overall flexible mesh set up for the study area is shown in Figure A.1.

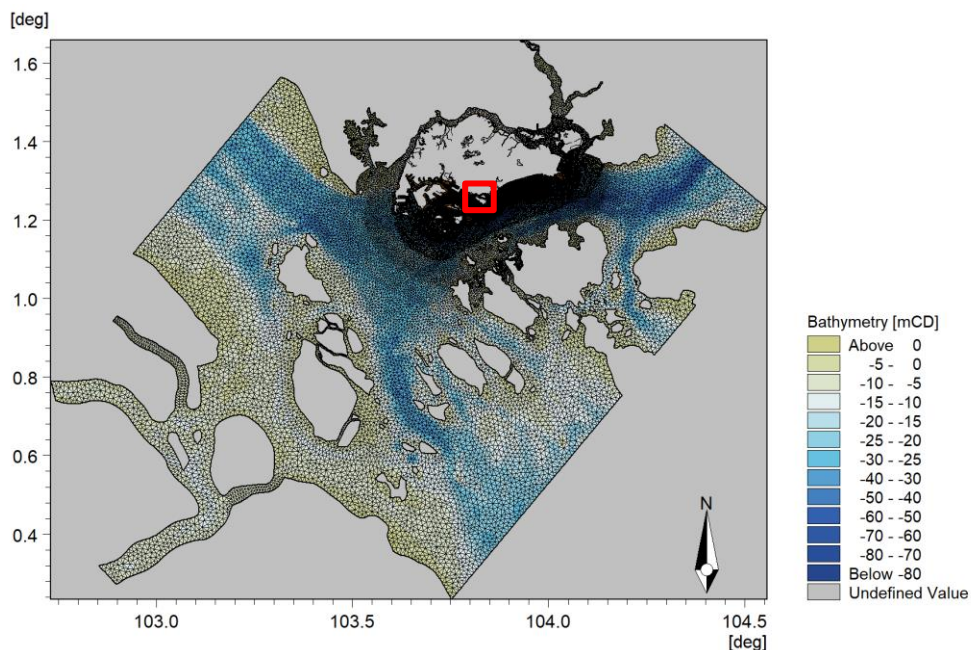


Figure A.1 Singapore Straits model domain and mesh. Location of the study site is indicated by red box

The bathymetry data set applied in the model is supplemented by MIKE C-MAP and DHI's bathymetry database. MIKE C-MAP provides access to digital nautical charts from Jeppesen Norway. In order to obtain a consistent dataset, a vertical reference relative to local chart datum (CD) was applied for all bathymetry data.

The boundaries of the hydrodynamic model were configured to align with the tidal phase of the study area. Setting the boundary line parallel to the tidal phase is preferred for a uniform description of the flow across the boundary line.

Water level predictions were imposed at the open boundaries to generate the tidal stream in the hydrodynamic model. The water level predictions are available from the following sources:

- 1979 Four Nation Joint Hydrographic Survey (JHS) water level constituents. This study utilised water level measurement taken from 1978 to 1979 at a number of tidal stations along the Malacca Straits and Singapore Straits. Fifty-four constituents are used to specify the water level variation using the IOS method.
- Admiralty Tide Table (ATT) water level constituents, which is published by the UK Hydrographic Office for tidal stations around the world. Water level variations are specified using six main constituents using the ATT method.

Additional boundary condition included in the model are the residual water level (SSH) extracted from Global Ocean Physics Reanalysis (GLORYS12V1), see below. Local storm

surge was accommodated by applying wind force based on the wind data from East Coast Parkway wind station.

Global Ocean Physics Reanalysis (GLORYS12V1)

The GLORYS12V1 product is the CMEMS global ocean eddy-resolving ($1/12^\circ$ horizontal resolution, 50 vertical levels) reanalysis covering the altimetry. The reanalysis is generated using the 'Nucleus for European Modelling of the Ocean' (NEMO) ocean model driven at the surface by the ECMWF ERA-Interim reanalysis. It assimilates along track altimeter observations (sea level anomaly), satellite sea surface temperature (SST), sea ice concentration and in situ temperature and salinity vertical profiles from the 'Coriolis Ocean database ReAnalysis' (CORA) dataset using a reduced-order Kalman Filter scheme. In addition, it uses a 3D-Var scheme for the correction of large-scale biases in temperature and salinity. The reanalysis covers the satellite era from 1993 to present. More details on GLORYS can be found in product page at the [CMEMS website](#).

GLORYS12V1 (Lellouche et. al., 2021) provides non-tidal water levels and other ocean-related parameters at $1/12^\circ$ resolution global coverage from 1993 to present at a timestep of one day. Output items of relevance to the present application include non-tidal water level, which also includes the contribution of the steric gradient between west and east of Singapore as well as the seasonal variations in water level.

A.2.2 Model Setup

Summary of model setup applied for production run is summarised in Table A.1

Table A.1 Summary of the HD model settings applied for the production period

Setting	Value
Mesh resolution	Element face size around the project site ~8 m
Simulation period	14 days during Northeast Monsoon and Intermonsoon (with 10-min timestep)
Eddy viscosity	Smagorinsky formulation with constant = 0.28
Wind forcing	East Coast Parkway wind data. Wind friction: constant friction 0.0042 for all wind speed
Bed resistance	Spatially varying
Boundary conditions	Water level boundary condition: Predicted tidal water level time-series superimposed with GLORYS12V1

A.2.3 Model Validation

A.2.3.1 Performance Criteria

The evaluation of whether an established model provides a sufficiently accurate description of the environment depends, in general, on the specific objective of the individual model. Traditionally, performance evaluation has been based on visual comparisons, e.g., time series plots or instantaneous plan/ transect plots of modelling results and monitoring data. An appropriate internationally accepted standard for validating hydrodynamic model performance can be found in the UK Foundation for Water Research publication Ref FR0374, "A framework for marine and estuarine model specification in the UK".

In broad terms, this can be categorised by the following performance limits:

- Tidal elevations: RMS (error) < 15% on spring tide and 20% on neap tide ranges;
- Current speed deviation RMS (error) < 10 to 20% (maximum deviation 0.2 m/s); and

Prior to the comparisons, the model data were synchronised to the time stamps of the observations so that both time series had equal length and overlapping time stamps. The comparisons of the synchronised observed and modelled data are illustrated the following format:

- Time series plot for visual comparison with general statistics of Mean, Maximum, Standard Deviation, and
- Scatter plot including quantiles, QQ-fit and QIs (dots coloured according to density).

A.2.3.2 Validation of Hydrodynamic Model

Our regional HD model used in the study is a pre-calibrated model and, in this study, it is validated against ADCP data located on the east side of the Project. The ADCP data was from DHI previous project and due to confidentiality, the exact location cannot be disclosed.

A.2.3.3 Validation of Water Level

The time series and scatter validation for water level parameter are presented in Figure A.2 and Figure A.3, respectively, and the model performance is tabulated in Table A.2. The plots show good quantile alignments and RMSE's value fulfil the criteria outlined in Section A.2.3.1.

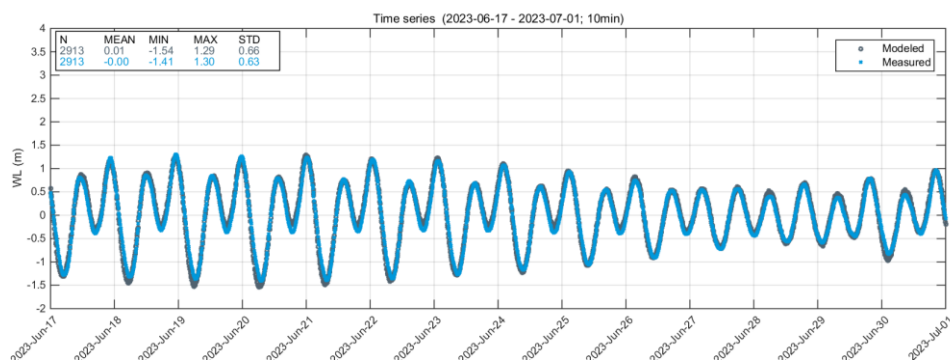


Figure A.2 Time series comparison of modelled and measured water level

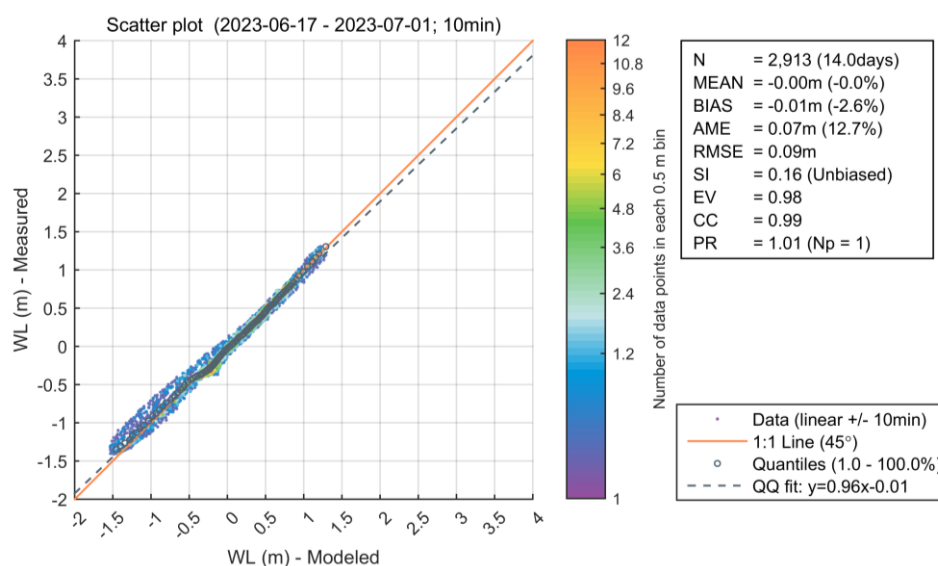


Figure A.3 Scatter comparison of modelled and measured water level.

Table A.2 Statistical analyses of water level

Station	RMSE (m) Water Level	RMSE (%) Water Level
DHI's inhouse data	0.09	3.3

A.2.3.4 Validation of Current Speed

The time series and scatter validation for current speed parameter are presented in Figure A.4 and Figure A.5, respectively, and the model performance is tabulated in Table A.3. Overall, the current speed is well represented. The scatter plots show good quantile alignment and low scatter index. The statistical analysis shows that the model has fulfilled the criteria as outlined in Section A.2.3.1.

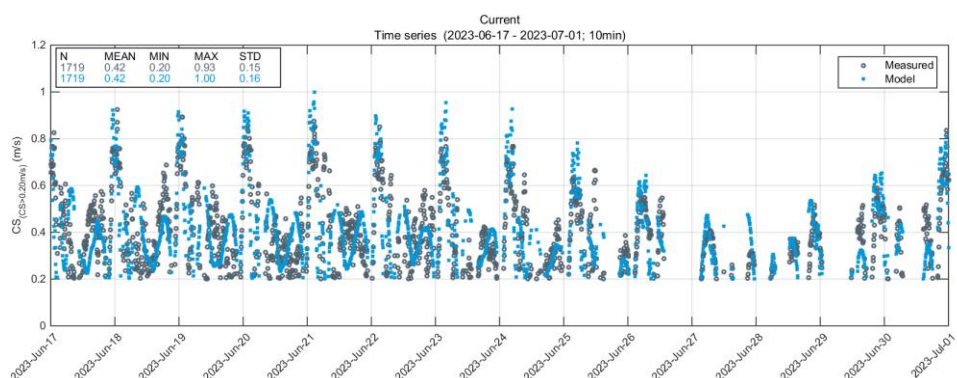


Figure A.4 Time series comparison of modelled and measured current speed

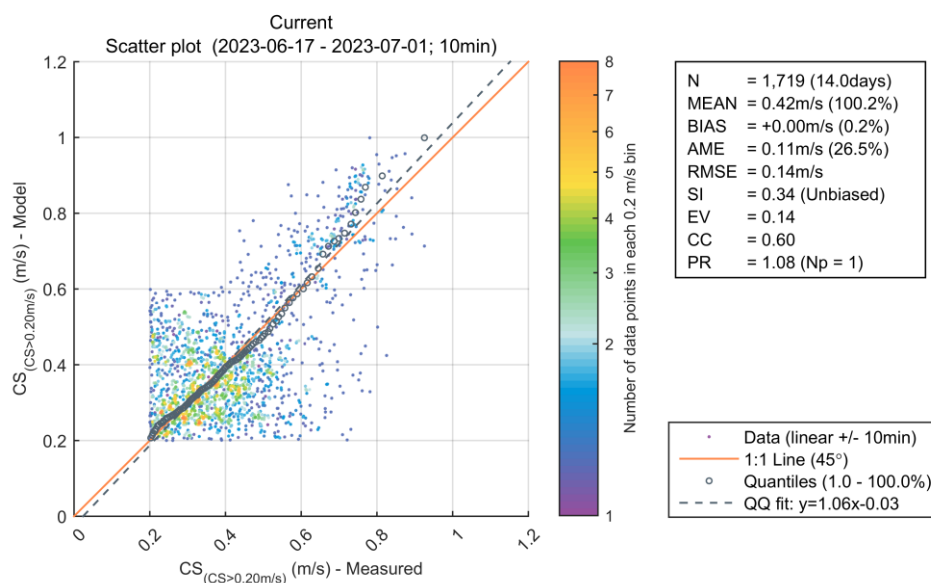


Figure A.5 Scatter comparison of modelled and measured current speed

Table A.3 Statistical analyses of current speed (RMSE)

Station	RMSE (m) Current Speed	RMSE (%) Current Speed
DHI's inhouse data	0.14	15

A.2.4 Output Specifications

The output of the hydrodynamic model included depth-integrated current components covering the entire model area (all grid cells), and water level at 10-minute intervals.

Table A.4 Specifications of current parameters

Abbreviation	Unit	Description
CS	m/s	Depth-integrated current speed
CD	°N (going to)	Depth-integrated current direction

A.2.5 Model Scenarios

For the Environmental Study, the models were simulated during NE monsoon and inter-monsoon to account for when the currents are at its strongest and its weakest, respectively. Two scenario profiles were used, Baseline and Post-Construction, and each profile were simulated for fourteen (14) days, covering one spring-neap tidal cycle. This covered the range of seasonal variations in currents that might affect the model results. The selected production periods are as follows (exclude 1-day warm-up period):

- NE monsoon (strongest current condition): 15/01/2023, 00:00 – 29/01/2023, 00:00
- Inter-monsoon (weakest current condition): 26/03/2023, 00:00 – 09/04/2023, 00:00

The construction will involve the demolition of existing promenade structure and the installation of 355 piles in the sea, with 133 piles for the floating boardwalk and 222 piles for the pile deck. The floating boardwalk will use a pontoon structure and designed to be submerged at least 1 m below the waterline. Other than the construction structures, various marine structures exist in the surrounding Project Site such as Caisson structure, Marina Keppel Bay Jetties, Keppel Bay Bridge, and breakwaters. These marine structures were included in the model in both Post-Construction and Baseline profiles. The Baseline profile refer to the existing land profile with promenade structure still intact. The Baseline and Post-Construction profiles are displayed in Figure A.6 and Figure A.7 respectively.

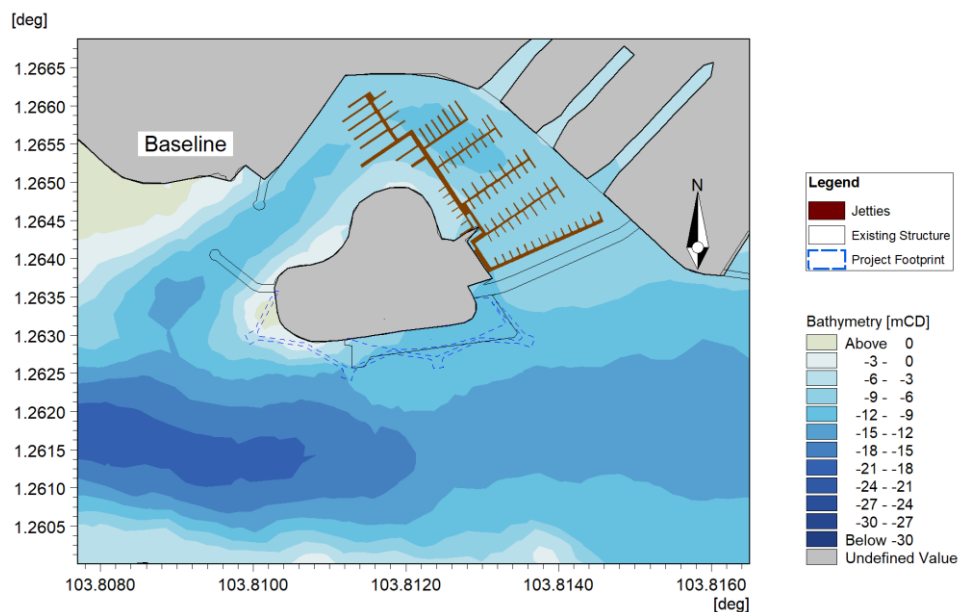


Figure A.6 Baseline profile for assessment of hydrodynamic impacts. The baseline profiles include the existing structures, i.e., caissons, jetties in Marina at Keppel Bay, Keppel Bay Bridge, breakwaters, and existing Wharf.

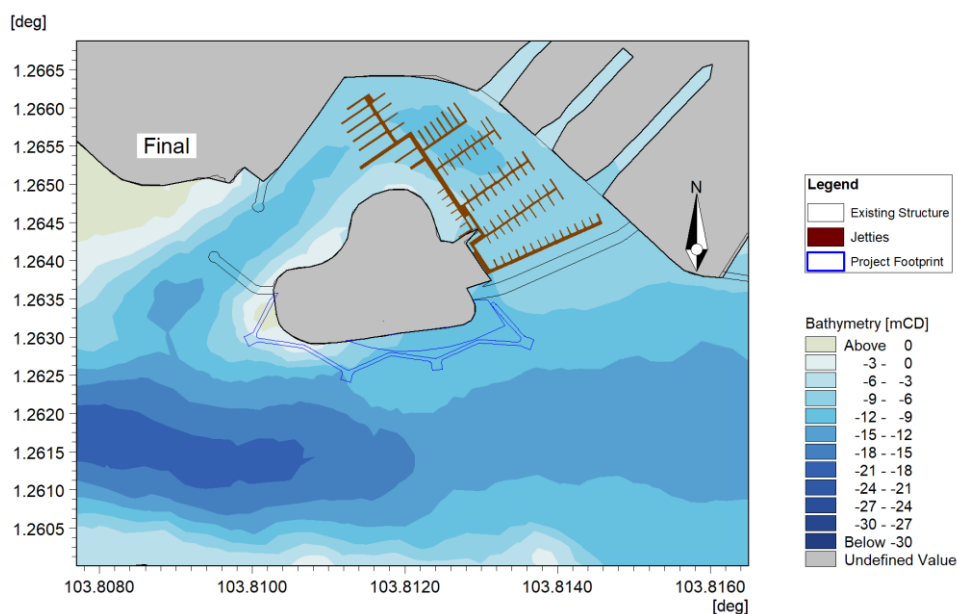


Figure A.7 Post-Construction profile for assessment of hydrodynamic impacts. The Post-Construction profile include piles installed for the pile deck (222 piles) and floating boardwalk (133 piles), floating boardwalk's pontoons, and the existing structures, except existing Wharf (which will be demolished).

Table A.5 Modelling scenarios for current impact assessment during Post-Construction Phase

Scenario	Phase	Monsoon Period
1	Baseline	NE
2		Inter-monsoon
3	Post-Construction	NE
4		Inter-monsoon

A.3 Model Results

The results from the hydrodynamic model include:

- 2D maps for mean current speeds,
- 2D maps for maximum (95th percentile) current speeds; and
- 2D maps for representative current speeds (<0.5 knots, >2.0 knots, and >3.5 knots).

The hydrodynamic model results mentioned above are presented in the Environmental Study report.

A.4 References

- /1/ DHI. 2022. "MIKE 21 FLOW MODEL FM, Hydrodynamic Module User Guide."
- /2/ Lellouche, J.-M., Bourdalle-Badie, R., Greiner, E., Garric, G., Melet, A., Bricaud, C., Legalloudec, O., Hamon, M., Candela, T., Regnier, C., and Drevillon, M.: The Copernicus global 1/12° oceanic and sea ice reanalysis, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14961, <https://doi.org/10.5194/egusphere-egu21-14961>, 2021.
- /3/ UK Foundation for Water Research publication Ref FR0374 "A framework for marine and estuarine model specification in the UK".

APPENDIX B – Sediment Plume Model

Model Setup and Results

B Sediment Plume Model

B.1 Model Description

Sediment plume model is based upon DHI's MIKE 21 MT (Mud Transport) multi-fraction cohesive sediment transport model (DHI, 2022), which is applied in a decoupled mode with the MIKE 21 Hydrodynamic Flow Model (DHI, 2022). The model simulates the spatial and temporal variation in suspended sediment concentrations subject to hydrodynamic transport and settling, deposition and re-suspension processes. In the present model, the sediment plume model will assess the impact from the construction activities (i.e., marine piling work).

B.2 Construction Sediment Plume

B.2.1 Model Setup

The 2D hydrodynamics model result which include decoupled mode was used as a base for the sediment plume modelling. The simulations period for the sediment plume modelling was twenty-eight (28) days, covering the spring-neap tidal cycle during the Northeast (NE) monsoon and inter-monsoon, with the last fourteen (14) days used for the assessment to consider the accumulation of suspended sediments.

B.2.2 Spill Properties

The sediment plume model has three fractions and a single bed layer. Fraction 1 to 3 represents the composition of the silt and clay seabed material. The spill is modelled as a point source with constant or time varying spill spread over a period of time.

Fraction 1	29 % contribution from spilled material due to piling penetration work
	Settling velocity coefficient = 349.8
	Coarse fines: settles quickly outside the work area
Fraction 2	20 % contribution from spilled material due to piling penetration work
	Settling velocity coefficient = 21.9
	Medium fines: can be transported large distances during spring tide, prime cause of remote sedimentation
Fraction 3	51 % contribution from spilled material due to piling penetration work
	Settling velocity coefficient = 2.6
	Fine fines: Regularly transported large distances, generally will not settle out and is only contributing to suspended sediment impacts

B.2.3 Initial Conditions

The background concentration was set to be zero and so the initial concentration is zero for all the fractions. Since the spill is modelled, initial bed layer thickness is set to zero.

B.2.4 Boundary Conditions

Suspended sediment concentrations along the boundaries are set to zero for all the fractions.

B.2.5 Bed Roughness

Constant bed roughness of 0.0687 m was assumed based on DHI past experience.

B.2.6 Settling Characteristics

The settling velocity is a parameter that has a strong bearing on the model simulations. Flocculation is an important process which enhances the settling velocity of suspended matter by allowing the individual particles to stick together and form larger aggregates. Therefore, it is considered relevant to include flocculation as a parameter influencing the settling velocity of the suspended matter.

The formulation for settling velocity in MIKE 21 MT is as described below, whereby w_s is a settling velocity, w_0 is a settling velocity coefficient, C_{floc} is a concentration at which flocculation begins, $\rho_{sediment}$ is sediment density (2,650 kg/m³) and γ is a constant equal to 1. $C_{hindered}$ is a minimum concentration at which hindered settling occurs. Hindered settling and consolidation are not included in the settling model. The settling velocity is assumed to be constant for $C < C_{floc}$ and $C > C_{hindered}$, and it is a function of concentration as long as $C_{floc} < C < C_{hindered}$, as shown below.

Using the MIKE 21 MT formulation under no flocculation condition, settling velocity coefficient (w_0) for each fraction was calculated based on the settling velocity (w_s) derived from Stoke law based on the sediment size representing different fraction of sediment. The settling velocity coefficient for each fraction is shown in Table B.1

The sediment density (2650 kg/m³) used in the formulation is referring to the seabed sediment and it is based on the literature (14).

$$\begin{aligned}
 w_s &= w_0 \left(\frac{C_{floc}}{\rho_{sediment}} \right)^\gamma & C < C_{floc} \\
 w_s &= w_0 \left(\frac{C}{\rho_{sediment}} \right)^\gamma & C_{floc} < C < C_{hindered} \\
 w_s &= w_0 \left(\frac{C_{hindered}}{\rho_{sediment}} \right)^\gamma & C > C_{hindered}
 \end{aligned}$$

Table B.1 Settling characteristics

Parameter	F1	F2	F3
C_{floc} (kg/m ³)	0.01	0.01	0.01
$C_{hindered}$ (kg/m ³)	10	10	10
$\rho_{sediment}$ (kg/m ³)	2,650	2,650	2,650
w_0 (m/s)	349.8	21.9	2.6
γ (-)	1	1	1

B.2.7 Model Scenario

Four (4) representative scenarios were simulated for the Construction Phase (Table B.2). The construction of the marine piles comprises piling, cage insertion, and infilling. However, only the piling is considered in the model, as the other activities were determined to contribute relatively minimal amounts of sediment plume. According to the construction schedule, two (2) piles will be installed per day, with the assumption that construction hours are eight (8) hours per day and six (6) days per week. The model also conservatively assumes that two piles will be installed concurrently, using two different barges, within a 30-minute time duration. Finally, the piles for the pile deck and the floating boardwalk were simulated separately. Hence, Scenario 1 and Scenario 2 were simulated for piles in the pile deck (Figure B.1), and Scenario 3 and Scenario 4 were simulated for piles for the floating boardwalk (Figure B.2). The detailed sizes of the piles and the number of piles simulated per day in each scenario are presented in Table B.3 and Table B.4.

Table B.2 Sediment plume modelling scenario

Scenario	Location	Monsoon Period	Simulated of Piles Simulated per Day
1	Pile Deck	NE monsoon	2
2	Pile Deck	Inter-monsoon 1	2
3	Floating Boardwalk	NE monsoon	2
4	Floating Boardwalk	Inter-monsoon 1	2

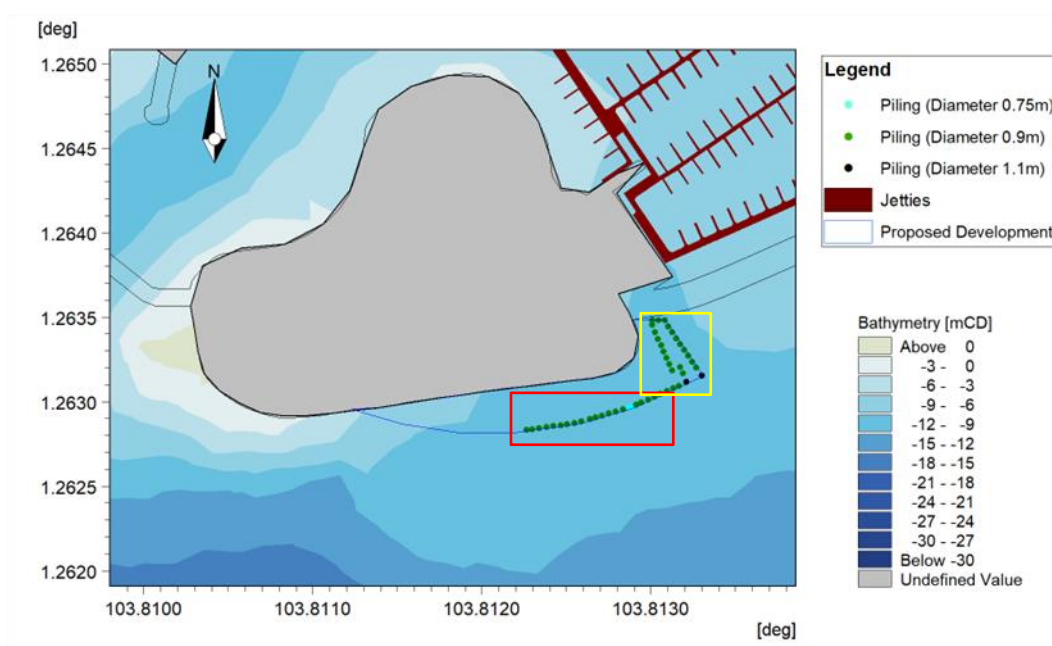


Figure B.1 Piles selected at the pile deck for Scenarios 1 and 2. Red and yellow boxes indicate piling works for the 1st and 2nd fourteen (14) days, respectively.

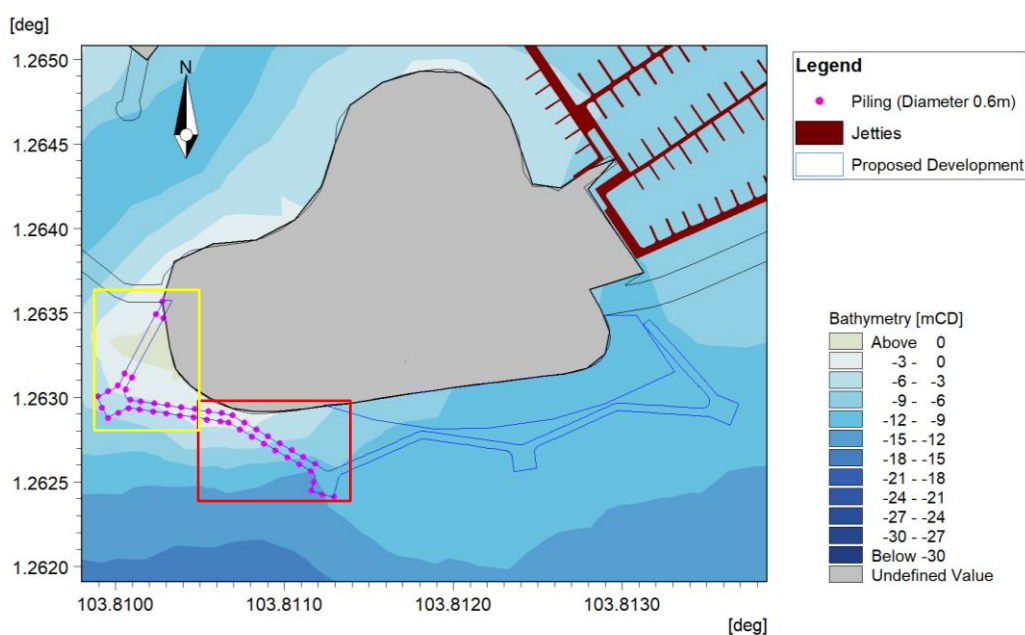


Figure B.2 Piles selected at the floating boardwalk for Scenarios 3 and 4. Red and yellow boxes indicate piling works for the 1st and 2nd fourteen (14) days, respectively.

Table B.3 Pile sizes and number of piles simulated per day for Scenarios 1 and 2

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Pile Size	Number of Piles Simulated in each Day																											
1.10 m															1												1	
1.00 m																												
0.90 m	2	2	2	2	2	2		2	1	1	2	2	2		1	2	2	2	2	2		2	2	2	2	2	1	
0.75 m									1	1																		
0.60 m																												

Table B.4 Piles sizes and number of piles simulated per day for Scenarios 3 and 4

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Pile Size	Number of Piles Simulated in each Day																											
1.10 m																												
1.00 m																												
0.90 m																												
0.75 m																												
0.60 m	2	2	2	2	2	2		2	2	2	2	2	2		2	2	2	2	2	2		2	2	2	2	2	2	

B.2.8 Spill Rate

Based on the spill rate information provided by Bridges et al. (2008), a typical escape rate from drilling operations is between 0.1 to 5%. Hence, for fairly conservative assumption, a 15% fine sediment will escape and will be transported to other areas for typical piling work activities which are presumed to have a more adverse impact compared to drilling operations.

B.2.9 Example Spill Rate Calculation

B.2.9.1 Piling Spill Rate (1.10 m diameter)

For the present assessment, piling work was done two (2) piles per day with each pile is modelled in terms of cycle time (i.e., time to complete the installation), working hour and location, with the material being introduced as a suspended sediment source distributed uniformly over depth (MIKE 21 MT being a depth-integrated model).

The spill rate is calculated based upon the following methodology:

Pile diameter, D	1.1 m
Penetration depth, L	18 m (based on Client's information)
Average penetration speed	36 m/hour (based on the example in the Method Statement)
Volume (cylindric)	$(\frac{\pi D^2}{4} \times L) = 17.11 \text{ m}^3$
Cycle time	2 pile per day (assuming 30 minutes of operation per day)
Percentage of fines	99% (from survey results)
Escape rate	15% (conservative assumption based on more adverse impact than drilling operations presented by Bridge et. al., (2008))
Dry bulk density	1250 kg/m ³ (from survey results)
Spill rate of fines	$= \text{Dry bulk density (kg/m}^3) \times \text{pile area (m}^2) \times \text{piling rate (m/hour)}$ $\times \% \text{ fines} \times \% \text{ escape rate} \times (1 \text{ hour} / 3600 \text{ s})$ $= 1250 \text{ kg/m}^3 \times (\pi \times 0.813^2 / 4 \text{ m}^2) \times 36 \text{ m/hour} \times 99\% \text{ fines} \times$ $15\% \text{ escape rate} \times (1 \text{ hour} / 3600 \text{ s})$ $= 1.76 \text{ kg/s}$
Spill rate of fines per day	$= \text{Spill rate of fines} \times 1800 \text{ s} \times 2 \text{ (assuming 2 piles per day and 30 minutes operation)}$ $= 6,350.6 \text{ kg/day}$

The spill rate is served as model inputs for twenty-eight (28) days based on the piling work assumption discussed in Section B.2.7. The source rate is subsequently distributed over the three representative sediment fractions (Fraction 1 to 3).

B.2.9.2 Piling Spill Rate (0.90 m diameter)

For the present assessment, piling work was done for two (2) piles per day with each pile is modelled in terms of cycle time (i.e., time to complete the installation), working hour and location, with the material being introduced as a suspended sediment source distributed uniformly over depth (as MIKE 21 MT is a depth-integrated model).

The spill rate is calculated based upon the following methodology:

Pile diameter, D	0.9 m (assumed including casing)
Penetration depth, L	16 m (based on the Client's information)
Average penetration speed	32 m/hour (based on the example in the Method Statement)
Volume (cylindric)	$(\frac{\pi D^2}{4} \times L) = 10.18 \text{ m}^3$
Cycle time	2 piles per day (assuming 30 minutes of operation per day)

Percentage of fines	99% (from survey results)
Escape rate	15% (conservative assumption based on more adverse impact than drilling operations presented by Bridge et. al. (2008))
Dry bulk density	1,250 kg/m ³ (from survey results)
Spill rate of fines	$= \text{Dry bulk density (kg/m}^3\text{)} \times \text{pile area (m}^2\text{)} \times \text{piling rate (m/hour)} \\ \times \% \text{ fines} \times \% \text{ escape rate} \times (1 \text{ hour} / 3600 \text{ s})$ $= 1,250 \text{ kg/m}^3 \times (\pi \times 0.813^2 / 4 \text{ m}^2) \times 32 \text{ m/hour} \times 99\% \text{ fines} \times 15\% \text{ escape rate} \times (1 \text{ hour} / 3600 \text{ s})$ $= 1.05 \text{ kg/s (1 pile)}$
Spill rate of fines per day	$= \text{Spill rate of fines} \times 1800 \text{ s} \times 2 \text{ (assuming 2 piles per day and 30 minutes operation)}$ $= 3,778.86 \text{ kg/day}$

The spill rate is served as model inputs for twenty-eight (28) days based on the piling work assumption discussed in Section B.2.7. The source rate is subsequently distributed over the three representative sediment fractions (Fraction 1 to 3).

B.2.9.3 Piling Spill Rate (0.75 m diameter)

For the present assessment, piling work was done two (2) piles per day with each pile is modelled in terms of cycle time (i.e., time to complete the installation), working hour and location, with the material being introduced as a suspended sediment source distributed uniformly over depth (MIKE 21 MT being a depth-integrated model).

The spill rate is calculated based upon the following methodology:

Pile diameter, D	0.75 m (assumed including casing)
Penetration depth, L	14 m (based on the Client's information)
Average penetration speed	28 m/hour (based on the example in the Method Statement)
Volume (cylindric)	$(\frac{\pi D^2}{4} \times L) = 6.2 \text{ m}^3$
Cycle time	2 piles per day (assuming 30 minutes of operation per day)
Percentage of fines	99% (from survey results)
Escape rate	15% (conservative assumption based on more adverse impact than drilling operations presented by Bridge et. al. (2008))
Dry bulk density	1,250 kg/m ³ (from survey results)
Spill rate of fines	$= \text{Dry bulk density (kg/m}^3\text{)} \times \text{pile area (m}^2\text{)} \times \text{piling rate (m/hour)} \\ \times \% \text{ fines} \times \% \text{ escape rate} \times (1 \text{ hour} / 3600 \text{ s})$ $= 1,250 \text{ kg/m}^3 \times (\pi \times 0.813^2 / 4 \text{ m}^2) \times 28 \text{ m/hour} \times 99\% \text{ fines} \times 15\% \text{ escape rate} \times (1 \text{ hour} / 3600 \text{ s})$ $= 0.64 \text{ kg/s (1 pile)}$
Spill rate of fines per day	$= \text{Spill rate of fines} \times 1800 \text{ s} \times 2 \text{ (assuming 2 piles per day and 30 minutes operation)}$ $= 2,296.19 \text{ kg/day}$

The spill rate is served as model inputs for twenty-eight (28) days based on the piling work assumption discussed in Section B.2.7. The source rate is subsequently distributed over the three representative sediment fractions (Fraction 1 to 3).

B.2.9.4 Piling Spill Rate (0.60 m diameter)

For the present assessment, piling work was done two (2) piles per day with each pile is modelled in terms of cycle time (i.e., time to complete the installation), working hour and location, with the material being introduced as a suspended sediment source distributed uniformly over depth (MIKE 21 MT being a depth-integrated model).

The spill rate is calculated based upon the following methodology:

Pile diameter, D	0.9 m (assumed including casing)
Penetration depth, L	13 m (based on the Client's information)
Average penetration speed	26 m/hour (based on the example in the Method Statement)
Volume (cylindric)	$(\frac{\pi D^2}{4} \times L) = 3.68 \text{ m}^3$
Cycle time	2 piles per day (assuming 30 minutes of operation per day)
Percentage of fines	99% (from survey results)
Escape rate	15% (conservative assumption based on more adverse impact than drilling operations presented by Bridge et. al. (2008))
Dry bulk density	1,250 kg/m ³ (from survey results)
Spill rate of fines	$= \text{Dry bulk density (kg/m}^3) \times \text{pile area (m}^2) \times \text{piling rate (m/hour)}$ $\times \% \text{ fines} \times \% \text{ escape rate} \times (1 \text{ hour} / 3600 \text{ s})$ $= 1,250 \text{ kg/m}^3 \times (\pi \times 0.813^2 / 4 \text{ m}^2) \times 26 \text{ m/hour} \times 99\% \text{ fines} \times$ $15\% \text{ escape rate} \times (1 \text{ hour} / 3600 \text{ s})$ $= 0.38 \text{ kg/s (1 pile)}$
Spill rate of fines per day	$= \text{Spill rate of fines} \times 1800 \text{ s} \times 2 \text{ (assuming 2 piles per day and 30 minutes operation)}$ $= 1,364.59 \text{ kg/day}$

The spill rate is served as model inputs for twenty-eight (28) days based on the piling work assumption discussed in Section B.2.7. The source rate is subsequently distributed over the three representative sediment fractions (Fraction 1 to 3).

B.2.10 Model Calibration and Validation

For obvious reasons, calibration or validation of a sediment plume model against data measured in the field cannot be carried out for a future spill situation. However, the robustness of the model has been proven for earlier studies carried out at other sites in Singapore and other regions, where specific validation against ongoing dredging and reclamation works has been possible. Figure B.3 shows the example of sediment plume validation for dredging operation in Singapore.

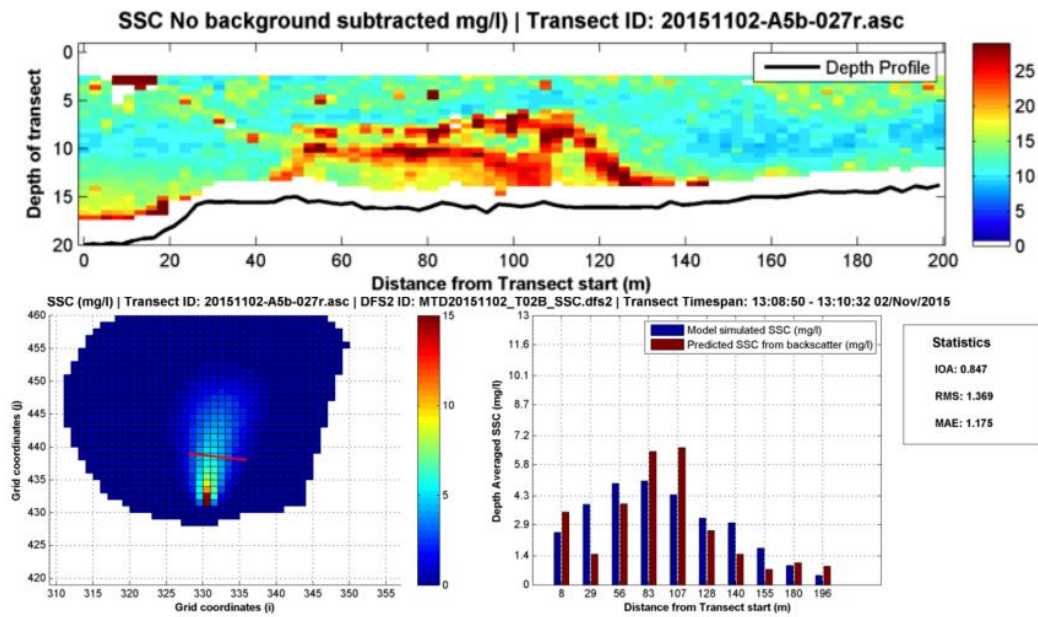


Figure B.3 Example of sediment plume validation in Singapore carried out by DHI. Top: measured SSC profile from ADCP; Bottom: comparison of depth averaged incremental SSC (blue bars represent simulation, and red bars represent measurement) (Zhao et. al., 2017).

Of particular relevance in the calibration exercise is the choice of dispersion coefficient, which is a critical parameter with respect to the spatial distribution of the sediment plume.

The critical shear stress for deposition and erosion are set as 0.1 N/m^2 and 0.3 N/m^2 , respectively, over the entire domain.

B.2.11 Model Results

The results from the sediment plume model include:

- 2D maps for incremental mean SSC
- 2D maps for 95th percentile incremental SSC
- 2D maps of time percentage incremental SSC exceeds 5 mg/l, 10 mg/l and 25 mg/l
- 2D maps of sedimentation over periods of 14-days.

The model results are presented in the Environmental Study report.

B.3 References

- /1/ Bridges TS, Ells S, Hayes D, Mount D, Nadeau SC, Palermo MR, Patmont C, Schroeder P. 2008. The four Rs of environmental dredging: resuspension, release, residual, and risk. January 2005. US Army Engineer Research and Development Center, Vicksburg, MS. ERDC/EL TR-08-4.
- /2/ DHI. 2022. "MIKE 21 FLOW MODEL FM, Hydrodynamic Module User Guide."
- /3/ DHI. 2022. "MIKE 21 FLOW MODEL FM, Mud Transport Module User Guide."
- /4/ Markussen, T. N., & Andersen, T. J. (2013). A simple method for calculating in situ floc settling velocities based on effective density functions. *Marine Geology*, 344, 10-18.
- /5/ Zhao, B., Jensen, J. H., Tan, L. H., Tan, C. A. 2017. Determination of settling velocities of cohesive sediments: from field measurements to numerical modelling. 36th IAHR World Congress, Kuala Lumpur, Malaysia, August 13-18, 2017.

APPENDIX C – Laboratory Results

C Laboratory Results

TEST REPORT

Our Reference No. : **R240 1413**
Project Code / Ref. : Keppel Island

Date Received : 21/02/2024
Date Commenced : 21/02/2024
Date Reported : 29/02/2024

Customer Ref. No. : 61803576
Customer Name : DHI Water & Environment (S) Pte Ltd
Customer Address : 2 Venture Drive
#18-18 Vision Exchange
Singapore 608526

Attention To : Mr. Andre Low

Sample Description : 1 Sediment sample as per received.

RESULTS : Refer to Page 2 to Page 4



Tan Thuan Piang
Senior Technical Manager

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- 2) The results in this report only apply to the sample received/analysed.
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Branch (Site and Laboratory):
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Co. Reg No. : 201422686C
116 Tuas South Ave 2, West Point Bizhub Singapore 637163
216 Tuas South Ave 2, West Point Bizhub Singapore 637213
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 : +65 6790 0118
 : +65 6262 3736 (Lab)

 : +65 6790 0091
 : +65 6262 3726 / 3776 (Site)

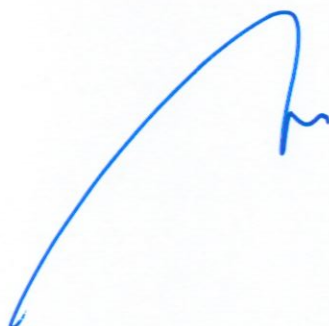
R240 1413

RESULTS

Test Parameter	Unit	Test Method	Sample 1	LOR
			SQ01	
			20/02/2024	
Total Nitrogen, TN	mg/kg	APHA 4500Norg (D) / APHA 4500-NO3 (I)	1,533	1
Total Phosphorus, TP	mg/kg	APHA 4500-P (J)	6.97	1
Arsenic as As	mg/kg	USEPA 3051A/ APHA 3120B	10.7	0.5
Cadmium as Cd	mg/kg	USEPA 3051A/ APHA 3120B	0.57	0.05
Chromium as Cr	mg/kg	USEPA 3051A/ APHA 3120B	28.5	0.02
Copper as Cu	mg/kg	USEPA 3051A/ APHA 3120B	29.0	0.1
Lead as Pb	mg/kg	USEPA 3051A/ APHA 3120B	30.3	0.5
Nickel as Ni	mg/kg	USEPA 3051A/ APHA 3120B	15.5	0.1
Zinc as Zn	mg/kg	USEPA 3051A/ APHA 3120B	103	0.05
Mercury as Hg	mg/kg	USEPA 3051A/ USEPA 245.1 (FIMS) (1994)	0.16	0.01
Bulk Density	Mg/m ³	BS EN ISO 17892-2 : 2014 Section 5.1	1.25	0.01

Note:

1. APHA is a standard method for Determination of Water and Waste Water (APHA 24th Edition, 2023).
2. LOR = Limit of Reporting. This value may also represent Detection Limit required for the project.
3. "ND" = Not detected. The data reported is less than the LOR.



R240 1413

RESULTS

Test Parameter : Falling Velocity Test (Owen Tube Method)
 Test Method : In-house Method MLS-SOP-SED-001. Total Suspended solids, TSS by APHA 2540D.

Sample Description	SQ01, 20/02/2024	TSS Result, mg/L
1 min		2,830
2 min		2,845
4 min		3,495
8 min		8,035
16 min		3,425
24 min		1,985
32 min		558
48 min		342
64A min		233
64B min		194
LOR		10

Note:

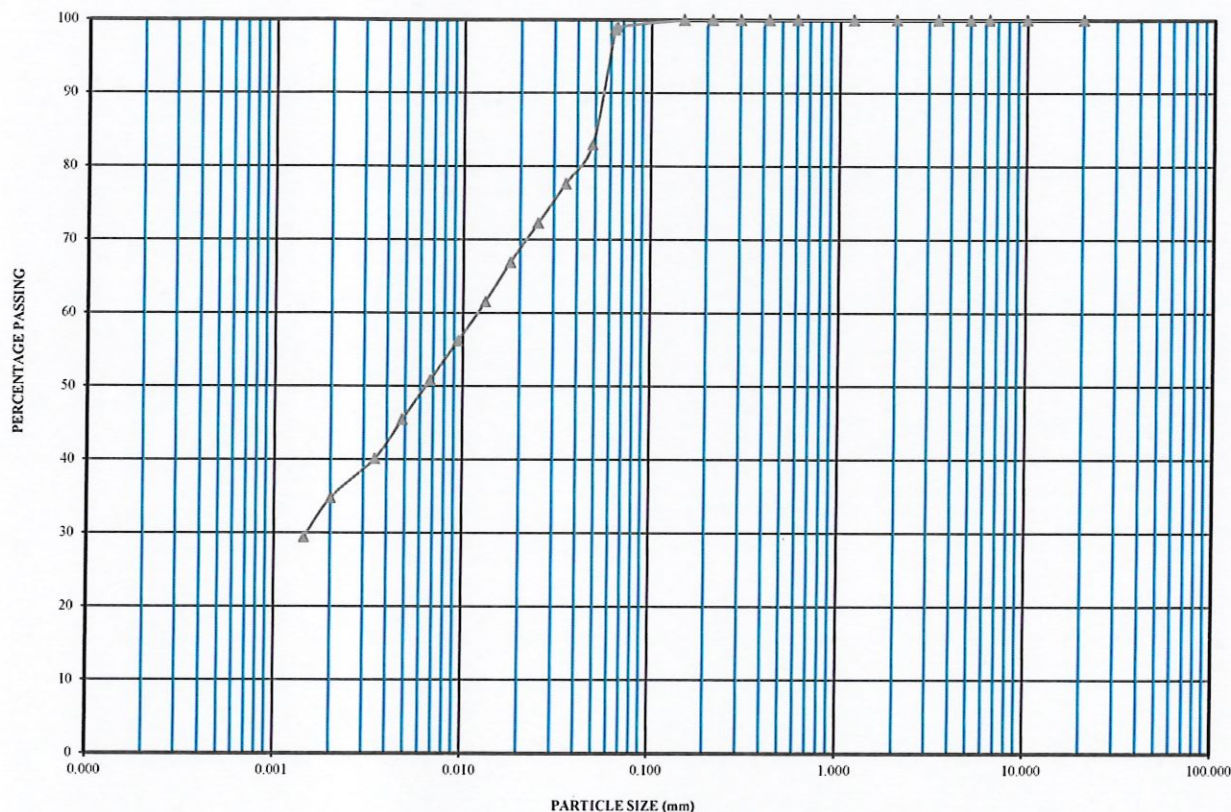
1. APHA is a standard method for Determination of Water and Waste Water (APHA 24th Edition, 2023).
2. LOR = Limit of Reporting. This value may also represent Detection Limit required for the project.



R240 1413

RESULTS FOR PARTICLE SIZE DISTRIBUTION

Test Method : BS 1377: Part 2: 2022
 Project Code / Ref. : Keppel Island
 SN : Sample 1
 Sample ID : SQ01
 Sampling Date : 20/02/2024



CLAY	SILT	SAND	GRAVEL
------	------	------	--------

Percentage	CLAY	SILT	SAND	GRAVEL
	35	64	1	0

Diameter (mm)	20.00	10.00	6.30	5.00	3.35	2.00	1.18	0.600	0.425	0.300	0.212	0.150	0.063	0.002
% passing	100	100	100	100	100	100	100	100	100	100	100	100	99	35

Note:

- The above test was sub-contracted to external lab.



CHAIN OF CUSTODY DOCUMENT / ANALYSIS REQUEST

Priority Queue / Urgent / Report Needed by: 5 working day

21 FEB 2024

CLIENT : DHI Water & Environment (S) Pte Ltd
 CONTACT (Name / Tel / email) : Andre Low / 9118 5838 / aly@dhigroup.com
 ADDRESS / COUNTRY : Z Venture Drive, #18-18 Vision Exchange, S(608526)
 PROJECT Code / Ref. : 61803576
 SITE : Pulau Ubin
 QUOTATION / JOB REQUEST / PO No. : 20230808-01R3(DHI)
 SEND REPORT TO : aly@dhigroup.com / ziyu@dhigroup.com / vera@d
 COMMENT / SPECIAL INSTRUCTION : 61803576_Sediment Quality
 STORAGE / DISPOSAL : as per Lab's practice

ANALYSIS PARAMETER (Enter "X" below to indicate Request)		STORAGE CONDITION**		TOTAL NOS OF CONTAINERS* / SAMPLING MEDIA ⁵		Sample Seal (Y / N) ☐ Tick if all sealed		ANALYSIS PARAMETER (Enter "X" below to indicate Request)		REMARKS / OBSERVATION		SAMPLE CONDITION	
Job No.:	Job No.:	Job No.:	Job No.:	Job No.:	Job No.:	Job No.:	Job No.:	Job No.:	Job No.:	Job No.:	Job No.:	Job No.:	Job No.:
1	SQ01												
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
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19													
20													

RELINQUISHED BY:		DATE / TIME		RECEIVED BY:		DATE / TIME		RELINQUISHED BY:		DATE / TIME		RECEIVED BY:		DATE / TIME	
Name:	SANN		2/21/2024	Name:				Name:				Name:			
Sign:	SANN			Sign:				Sign:				Sign:			

SHIPMENT BY COURIER:	
Courier Co. / Carrier Name:	
Consignment Note/Airway Bill	



MARCHWOOD LABORATORY SERVICES PTE LTD

116 Tuas South Ave 2
West Point Bizhub
Singapore 637163
Tel: 6790 0118
Fax: 6790 0091
Co Reg. No. 201422686C

SALES QUOTATION

To:	DHI Water & Environment (S) Pte Ltd 2 Venture Drive #18-18 Vision Exchange Singapore 608526	From:	Ang Kok Keong
Attn.:	Ms Vera Lim	Date:	07/02/2024
Tel:	6777 6330	Our Ref:	20230808-01R3(DHI)
Fax:	-	No. of pages:	3
Email:	vera@dhigroup.com		

Subject: Quotation on Ambient Air Monitoring & Sediment Analysis
Project Reference: 61803576

Dear Vera,

We are pleased to furnish our quotation for the following analysis:

Table B – Sediment Quality Surveys

Test Parameter	Test Method	Client's Detection Limit	
Physical			
Particle Size Distribution*	BS 1377-2:2022	0.01 %	
Bulk Density	BS EN ISO 17892-2:2014 Section 5.1	N/A	
Settling Velocity	Accredited In-house Method MLS-SOP-SED-001	N/A	
Chemical			
Total Phosphorus as TP	APHA 4500-P (J)	1 mg/kg	
Total Nitrogen as TN	APHA 4500Norg (D) / APHA 4500-NO3 (I)	1 mg/kg	
Arsenic as As	USEPA 3051 / APHA 3120B / APHA 3125B (Hg) / USEPA 245.1 (FIMS) (1994) (Hg)	0.50 mg/kg	
Cadmium as Cd		0.05 mg/kg	
Chromium as Cr		0.02 mg/kg	
Copper as Cu		0.10 mg/kg	
Lead as Pb		0.50 mg/kg	
Mercury as Hg		0.01 mg/kg	
Nickel as Ni		0.10 mg/kg	
Zinc as Zn		0.05 mg/kg	

*Subcontracted to external Laboratory

Sample Quantity: 1kg
Turnaround Time for Analysis: 5 – 7 Working Days

Note: Marchwood Laboratory Services is accredited by SAC-SINGLAS under ISO 17025.

TEST REPORT

Our Reference No. : **R240 1790**
Project Code / Ref. : Keppel Island

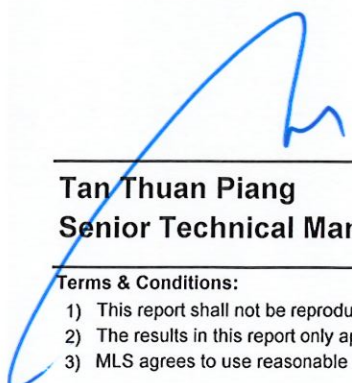
Date Received : 05/03/2024
Date Commenced : 05/03/2024
Date Reported : 15/03/2024

Customer Ref. No. : 61803576
Customer Name : DHI Water & Environment (S) Pte Ltd
Customer Address : 2 Venture Drive
#18-18 Vision Exchange
Singapore 608526

Attention To : Mr. Andre Low

Sample Description : 2 Sediment samples as per received.

RESULTS : Refer to Page 2 to Page 5



Tan Thuan Piang
Senior Technical Manager

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R240 1790

RESULTS

Test Parameter	Unit	Test Method	Sample 1	Sample 2	LOR
			SQ02	SQ03	
			05/03/2024	05/03/2024	
Total Nitrogen, TN	mg/kg	APHA 4500Norg (D) / APHA 4500-NO3 (I)	1,296	950	1
Total Phosphorus, TP	mg/kg	APHA 4500-P (J)	10.8	6.37	1
Arsenic as As	mg/kg	USEPA 3051A/ APHA 3120B	7.88	11.0	0.5
Cadmium as Cd	mg/kg	USEPA 3051A/ APHA 3120B	0.31	0.33	0.05
Chromium as Cr	mg/kg	USEPA 3051A/ APHA 3120B	19.8	19.2	0.02
Copper as Cu	mg/kg	USEPA 3051A/ APHA 3120B	25.2	21.6	0.1
Lead as Pb	mg/kg	USEPA 3051A/ APHA 3120B	25.8	26.8	0.5
Nickel as Ni	mg/kg	USEPA 3051A/ APHA 3120B	11.2	11.5	0.1
Zinc as Zn	mg/kg	USEPA 3051A/ APHA 3120B	88.2	87.9	0.05
Mercury as Hg	mg/kg	USEPA 3051A/ USEPA 245.1 (FIMS) (1994)	ND	ND	0.01
Bulk Density	Mg/m ³	BS EN ISO 17892-2 : 2014 Section 5.1	1.22	1.33	0.01

Note:

1. APHA is a standard method for Determination of Water and Waste Water (APHA 24th Edition, 2023).
2. LOR = Limit of Reporting. This value may also represent Detection Limit required for the project.
3. "ND" = Not detected. The data reported is less than the LOR.

R240 1790

RESULTS

Test Parameter by Falling Velocity Test (Owen Tube Method)

Test Method by In-house Method MLS-SOP-SED-001. Total Suspended solids, TSS by APHA 2540D.

Unit in mg/L

Sample Description	Sample 1	Sample 2
	SQ02	SQ03
	05/03/2024	05/03/2024
1 min	2,495	2,735
2 min	2,220	2,680
4 min	2,335	2,970
8 min	4,160	4,425
16 min	6,955	7,370
24 min	2,345	3,025
32 min	436	519
48 min	194	221
64A min	117	126
64B min	79.0	78.6
LOR	10	

Note:

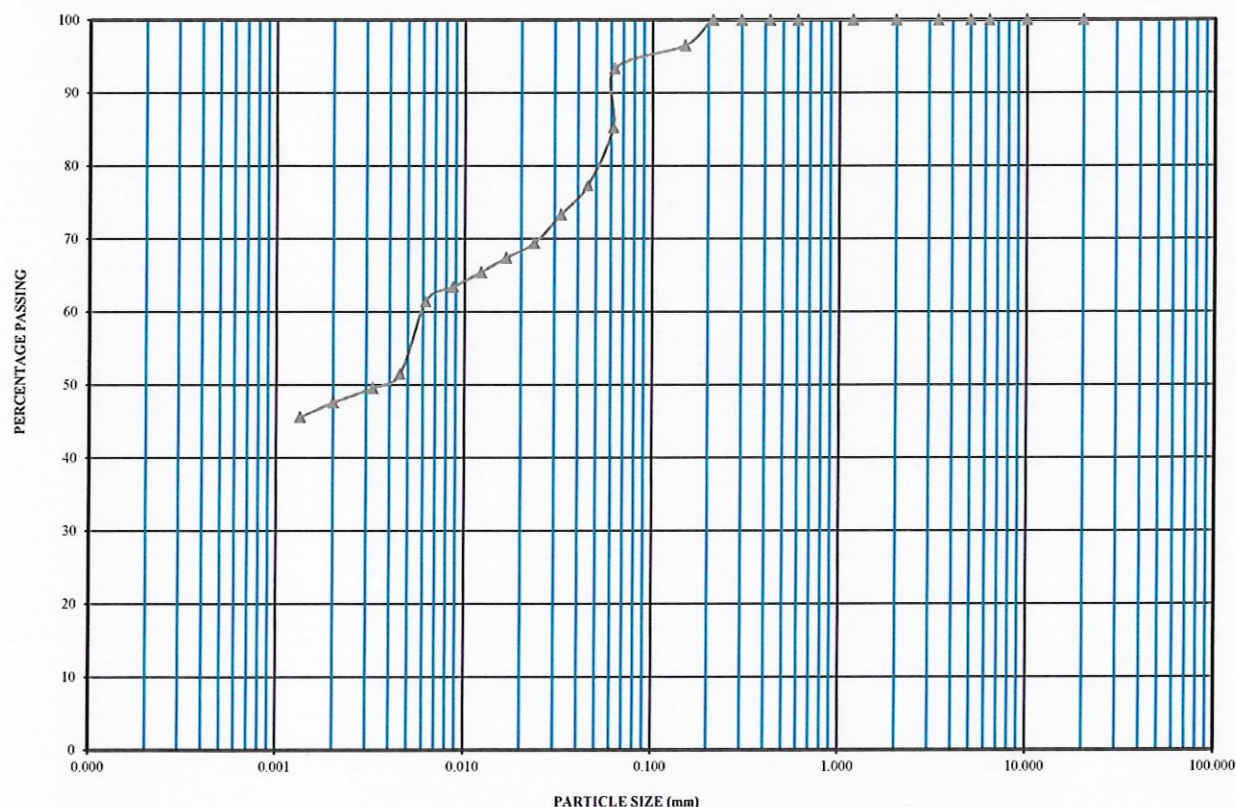
1. APHA is a standard method for Determination of Water and Waste Water (APHA 24th Edition, 2023).
2. LOR = Limit of Reporting. This value may also represent Detection Limit required for the project.



R240 1790

RESULTS FOR PARTICLE SIZE DISTRIBUTION

Test Method : BS 1377: Part 2: 2022
 Project Code / Ref. : Keppel Island
 SN : Sample 1
 Sample ID : SQ02
 Sampling Date : 05/03/2024



CLAY	SILT	SAND	GRAVEL
------	------	------	--------

Percentage	CLAY	SILT	SAND	GRAVEL
	48	45	7	0

Diameter (mm)	20.00	10.00	6.30	5.00	3.35	2.00	1.18	0.600	0.425	0.300	0.212	0.150	0.063	0.002
% passing	100	100	100	100	100	100	100	100	100	100	100	96	93	48

Note:

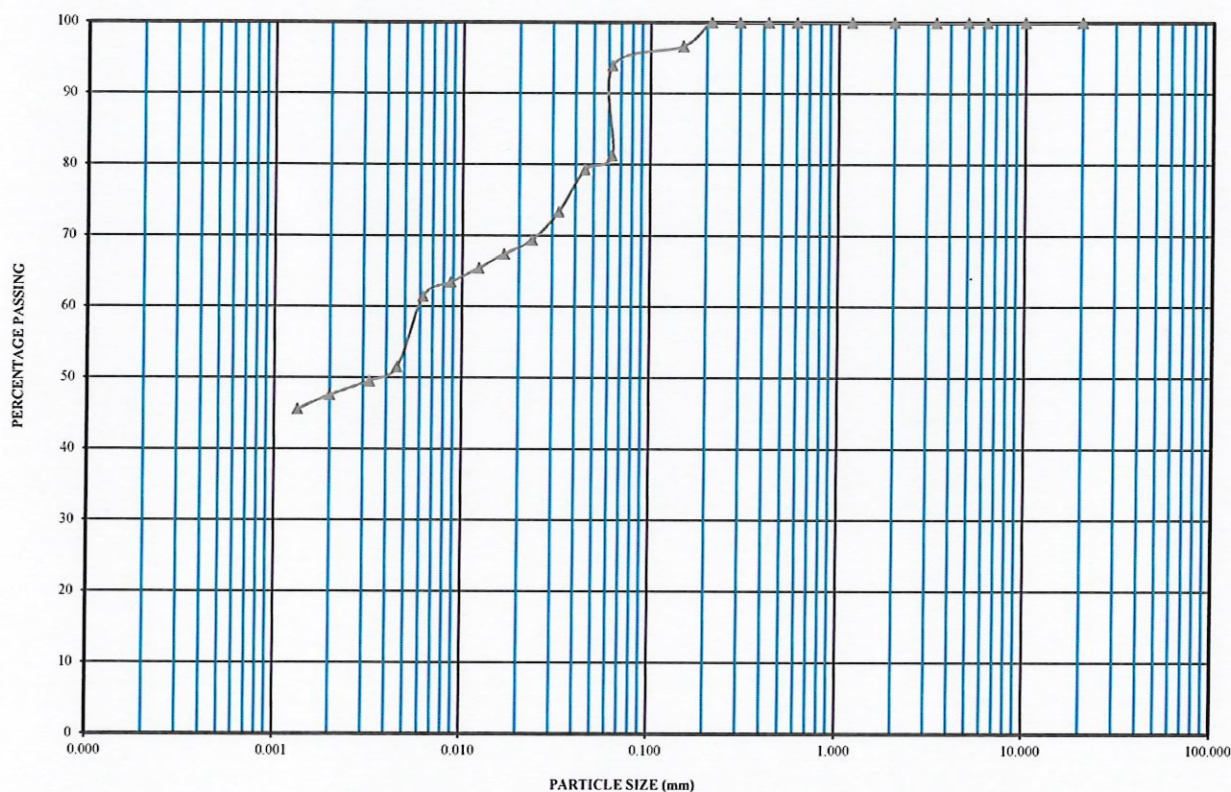
1. The above test was sub-contracted to external lab.



R240 1790

RESULTS FOR PARTICLE SIZE DISTRIBUTION

Test Method : BS 1377: Part 2: 2022
 Project Code / Ref. : Keppel Island
 SN : Sample 2
 Sample ID : SQ03
 Sampling Date : 05/03/2024



CLAY	SILT	SAND	GRAVEL
------	------	------	--------

Percentage	CLAY	SILT	SAND	GRAVEL
	48	46	6	0

Diameter (mm)	20.00	10.00	6.30	5.00	3.35	2.00	1.18	0.600	0.425	0.300	0.212	0.150	0.063	0.002
% passing	100	100	100	100	100	100	100	100	100	100	100	97	94	48

Note:

1. The above test was sub-contracted to external lab.



Priority Queue / Urgent / Report Needed by: 5 working day

05 MAR 2024

CHAIN OF CUSTODY DOCUMENT / ANALYSIS REQUEST

CLIENT

CONTACT (Name / Tel / email)

ADDRESS / COUNTRY

PROJECT Code / Ref.

SITE

QUOTATION / JOB REQUEST / PO No.

SEND REPORT TO

COMMENT / SPECIAL INSTRUCTION

STORAGE / DISPOSAL

: DHI Water & Environment (S) Pte Ltd

: Andre Low / 9118 5838 / aly@dhigroup.com

: 2 Venture Drive, #18-18 Vision Exchange, S(608526)

: 61803576

: Pulau Ubin

: 20230808-01R3(DHI)

: aly@dhigroup.com / ziyu@dhigroup.com / vera@dhigroup.com

: 61803576_Sediment Quality

: as per Lab's practice

S/N

SAMPLE ID / LOCATION

SAMPLING DEPTH (m)

MATRIX*
(Water/Soil/Sand/
Sed/Sludge/Air)

DATE
(DD/MM/YY)

TIME
(HRS)

1

SQ02

-

Sed

5-Mar-24

2

SQ03

Sed

5-Mar-24

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

TOTAL NOS OF CONTAINERS[#] /
SAMPLING MEDIA⁵

STORAGE CONDITION**

☐ Tick if all sealed

ANALYSIS PARAMETER (Enter "x" below to indicate Request)

Particle size distribution

[D_L 0.01 %]

Bulk Density

Settling Velocity

Total Nitrogen

[1 mg/kg]

Total Phosphate

[1 mg/kg]

As, Cd, Cr, Cu, Pb, Zn, Ni, Hg

Job No.: R240 1790

PRESERVATION DONE:

☐ On Site

☐ By Lab

Cold Box temp. at receipt: ____ °C
(if applicable)

☐ Sampling done by MLS

REMARKS / OBSERVATION /
SAMPLE CONDITION

RELINQUISHED BY:

DATE / TIME

Name: JANN

Signature: [Signature]

Company: [Signature]

RECEIVED BY:

DATE / TIME

Name: [Signature]

Signature: [Signature]

Company: [Signature]

RELINQUISHED BY:

DATE / TIME

Name: [Signature]

Signature: [Signature]

Company: [Signature]

RECEIVED BY:

DATE / TIME

Name: [Signature]

Signature: [Signature]

Company: [Signature]

SHIPMENT BY COURIER:

Courier Co. / Carrier Name:

Consignment Note/Airway Bill:

* = For Water sample: Please Indicate FW (Fresh Water), SW (Seawater), BW (Ballast Water), DW (Drinking Water), GW (Ground water), WW (Wastewater), OW (Other type of water e.g. canal/storm water)
Type of Sampling Containers/Bottles: G = Glass; P = Plastic; T = Tube; V = VOC vial; S = Sterilized bottle/bag; B = Bag.
* Type of Sampling Media: ST = Sorbent Tube; IM = Impinger solution; F = Filter; RT = Resin Trap;

TEST REPORT

(This Report is issued subject to the terms & conditions set out below)

Your Ref: 61803576

Date : 19/03/2024

Our Ref : EN8500305346/LWW

Page 1 of 3

SetSCO Services Pte Ltd
531 Bukit Batok Street 23
Singapore 659547
Tel : (65) 6566 7777
Fax: (65) 6566 7718
www.setsco.com
Business Reg. No. 196900269D

Subject : Analysis of Water Sample submitted by **DHI Water & Environment (S) Pte Ltd** on **23/02/2024** and testing commenced on **23/02/2024**.

Tested for : **DHI Water & Environment (S) Pte Ltd**
2 Venture Drive
#18-18 Vision Exchange
Singapore 608526
Attn : Ms. Vera Lim Shi Han

Sample Reference : Six (06) water samples were received.

Results : Refer to following pages.



MARIVIE VIANA GAPUD
SENIOR CHEMIST



LEE WEI WAH
SENIOR MANAGER

BIOLOGICAL AND CHEMICAL TECHNOLOGY DIVISION

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RESULTS :

Test Parameters	Units	Test Methods	Environmental Impact Study at Keppel Bay				*Detection Limits
			WQ1-E (S)	WQ2-E (S)	WQ3-E (S)		
			23/02/2024	23/02/2024	23/02/2024		
Physical							
Total Suspended Solids	mg/L	APHA : Pt 2540D	5.80	7.70	5.80	1.0	
Chemical							
Nitrate as NO ₃ -N	mg/L	APHA : Pt 4500-NO ₃ ⁻ (I)	0.0074	0.010	0.0083	0.01	
Nitrite as NO ₂ -N	mg/L	APHA : Pt 4500-NO ₃ ⁻ (I)	<0.003	<0.003	<0.003	0.01	
Phosphate as PO ₄ -P	mg/L	APHA : Pt 4500-P (G)	0.0058	0.0037	0.022	0.01	
Total Ammonia Nitrogen (NH ₃ +NH ₄)-N	mg/L	APHA : Pt 4500-NH ₃ (H)	0.011	0.0075	0.0097	0.01	
Oil & Grease (Total)	mg/L	BCTD/Env/SOP/050 Rev (4) (Ref. APHA : Pt 5520C using PCE Solvent Extraction)	<0.1	<0.1	<0.1	0.1	
Oil & Grease (Hydrocarbon)	mg/L	APHA : Pt 5520F	<0.1	<0.1	<0.1	0.1	
Heavy Metals (Dissolved)							
Arsenic as As	µg/L	APHA : Pt 3125B	6.44	6.31	5.23	0.3	
Cadmium as Cd	µg/L	APHA : Pt 3125B	<0.15	<0.15	<0.15	0.15	
Chromium as Cr	µg/L	APHA : Pt 3125B	0.45	0.50	0.51	0.15	
Copper as Cu	µg/L	APHA : Pt 3125B	2.71	3.64	3.08	0.15	
Lead as Pb	µg/L	APHA : Pt 3125B	<0.15	<0.15	<0.15	0.15	
Mercury as Hg	µg/L	APHA : Pt 3125B	<0.1	<0.1	<0.1	0.10	
Nickel as Ni	µg/L	APHA : Pt 3125B	1.31	1.44	1.35	3.0	
Zinc as Zn	µg/L	APHA : Pt 3125B	<1.5	<1.5	<1.5	1.5	
Biological							
Chlorophyll-a	µg/L	APHA : Pt 10150A & B	1.65	1.60	1.55	0.5	
<i>E.coli</i>	MPN/100mL	APHA : Pt 9222H	2	<1.8	4.5	1.8	
Biochemical Oxygen Demand (BOD ₅)	mg/L	APHA : Pt 5210B	0.61	0.53	0.59	1	
Faecal Coliforms	MPN/100mL	APHA : Pt 9222D	2	12	4.5	2	
Enterococci	cfu/100mL	APHA : Pt 9230C	3	2	<1	2	




RESULTS :

Test Parameters	Units	Test Methods	Environmental Impact Study at Keppel Bay				*Detection Limits
			WQ1-F (S)	WQ2-F (S)	WQ3-F (S)		
			23/02/2024	23/02/2024	23/02/2024	23/02/2024	
Physical							
Total Suspended Solids	mg/L	APHA : Pt 2540D	5.50	8.90	7.80	1.0	
Chemical							
Nitrate as NO ₃ -N	mg/L	APHA : Pt 4500-NO ₃ ⁻ (I)	<0.003	0.0055	<0.003	0.01	
Nitrite as NO ₂ -N	mg/L	APHA : Pt 4500-NO ₃ ⁻ (I)	<0.003	<0.003	<0.003	0.01	
Phosphate as PO ₄ -P	mg/L	APHA : Pt 4500-P (G)	0.0075	<0.003	0.0037	0.01	
Total Ammonia Nitrogen (NH ₃ +NH ₄)-N	mg/L	APHA : Pt 4500-NH ₃ (H)	0.0071	0.0074	0.0074	0.01	
Oil & Grease (Total)	mg/L	BCTD/Env/SOP/050 Rev (4) (Ref. APHA : Pt 5520C using PCE Solvent Extraction)	<0.1	<0.1	<0.1	0.1	
Oil & Grease (Hydrocarbon)	mg/L	APHA : Pt 5520F	<0.1	<0.1	<0.1	0.1	
Heavy Metals (Dissolved)							
Arsenic as As	µg/L	APHA : Pt 3125B	5.73	5.36	5.29	0.3	
Cadmium as Cd	µg/L	APHA : Pt 3125B	<0.15	<0.15	<0.15	0.15	
Chromium as Cr	µg/L	APHA : Pt 3125B	0.46	0.46	0.46	0.15	
Copper as Cu	µg/L	APHA : Pt 3125B	3.56	4.31	5.26	0.15	
Lead as Pb	µg/L	APHA : Pt 3125B	<0.15	<0.15	<0.15	0.15	
Mercury as Hg	µg/L	APHA : Pt 3125B	<0.1	<0.1	<0.1	0.10	
Nickel as Ni	µg/L	APHA : Pt 3125B	1.42	1.51	1.48	3.0	
Zinc as Zn	µg/L	APHA : Pt 3125B	<1.5	<1.5	<1.5	1.5	
Biological							
Chlorophyll-a	µg/L	APHA : Pt 10150A & B	1.19	1.28	1.37	0.5	
E.coli	MPN/100mL	APHA : Pt 9222H	7.8	11	4.5	1.8	
Biochemical Oxygen Demand (BOD ₅)	mg/L	APHA : Pt 5210B	0.71	0.62	0.71	1	
Faecal Coliforms	MPN/100mL	APHA : Pt 9222D	7.8	11	7.8	2	
Enterococci	cfu/100mL	APHA : Pt 9230C	6	2	4	2	

Remarks:

1. APHA is a Standard Method for the Determination of Water and Waste Water (APHA 24th Edition : 2023).
2. The tested result applies only to the sample as received by the laboratory.
3. "<" = Not Detectable (The reported values are less than (<) the detection limits of the test methods).
4. * = Requested by client.






SETSCO SERVICES PTE LTD
Business Registration No.: 196900269D

BIOLOGICAL & CHEMICAL TECHNOLOGY DIVISION
CHAIN OF CUSTODY DOCUMENT

EN8500-230224 (PH1)

CLIENT : DHI Water & Environment (S) Pte Ltd
JOB # : EN85002305346

TYPE OF SAMPLE : Water / Soil / Sediment /
(Please circle / indicate)

SAMPLE ID / LOCATION	Sample Information:	
	Date	TIME

WQ1-E (S)	23-Feb-24	
WQ2-E (S)		
WQ3-E (S)		
WQ1-F (S)		
WQ2-F (S)		
WQ3-F (S)	23-Feb-24	

TOTAL SAMPLES:

Total Number of Bottles:

24 x 1L plastic bottle
6 x 500ml glass bottle
6 x 1L glass bottle (amber)
6 x 300ml sterile bag

Contact Person :	Vera Lim
Contact Number:	8299 3254

RECEIVED BY (NAME): Faruqin Juh

DATE : 23 / 2 / 24 TIME : hrs

Email list for report releasing: vera@dhigroup.com; ziyu@dhigroup.com; alyl@dhigroup.com

Attention to: ENV LAB (water)

PAGE OF

23 FEB 2024

DATE : 23-Feb-24

Type of Sampling Bottles:

- # Glass
- * Plastic
- + Sterile
- @ VOC Vial

Remarks

SETSCO SERVICES PTE LTD

Receiving No: B033E

Date: 23/2/24

Dept: B23

TEST REPORT

(This Report is issued subject to the terms & conditions set out below)

Your Ref: 61803576

Date : 19/03/2024

Our Ref : EN8500305347/LWW

Page 1 of 3

SetSCO Services Pte Ltd
531 Bukit Batok Street 23
Singapore 659547
Tel : (65) 6566 7777
Fax: (65) 6566 7718
www.setsco.com
Business Reg. No. 196900269D

Subject : Analysis of Water Samples submitted by **DHI Water & Environment (S) Pte Ltd** on **05/03/2024** and testing commenced on **05/03/2024**.

Tested for : **DHI Water & Environment (S) Pte Ltd**
2 Venture Drive
#18-18 Vision Exchange
Singapore 608526
Attn : Ms. Vera Lim Shi Han

Sample Reference : Six (06) water samples were received.

Results : Refer to following pages.



MARIVIE VIANA GAPUD
SENIOR CHEMIST



LEE WEI WAH
SENIOR MANAGER

BIOLOGICAL AND CHEMICAL TECHNOLOGY DIVISION

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RESULTS :

Test Parameters	Units	Test Methods	Environmental Impact Study at Keppel Bay				*Detection Limits
			WQ1-E (S)	WQ2-E (S)	WQ3-E (S)		
			05/03/2024	05/03/2024	05/03/2024		
Physical							
Total Suspended Solids	mg/L	APHA : Pt 2540D	4.00	4.30	5.30	1.0	
Chemical							
Nitrate as NO ₃ -N	mg/L	APHA : Pt 4500-NO ₃ ⁻ (I)	0.0049	0.0052	0.0044	0.01	
Nitrite as NO ₂ -N	mg/L	APHA : Pt 4500-NO ₃ ⁻ (I)	0.0037	0.0036	0.0033	0.01	
Phosphate as PO ₄ -P	mg/L	APHA : Pt 4500-P (G)	0.0043	0.0034	<0.003	0.01	
Total Ammonia Nitrogen (NH ₃ +NH ₄)-N	mg/L	APHA : Pt 4500-NH ₃ (H)	0.0074	0.0069	0.0059	0.01	
Oil & Grease (Total)	mg/L	BCTD/Env/SOP/050 Rev (4) (Ref. APHA : Pt 5520C using PCE Solvent Extraction)	<0.1	<0.1	<0.1	0.1	
Oil & Grease (Hydrocarbon)	mg/L	APHA : Pt 5520F	<0.1	<0.1	<0.1	0.1	
Heavy Metals (Dissolved)							
Arsenic as As	µg/L	APHA : Pt 3125B	4.76	5.18	7.14	0.3	
Cadmium as Cd	µg/L	APHA : Pt 3125B	<0.15	<0.15	<0.15	0.15	
Chromium as Cr	µg/L	APHA : Pt 3125B	1.29	1.11	1.24	0.15	
Copper as Cu	µg/L	APHA : Pt 3125B	1.41	1.22	1.45	0.15	
Lead as Pb	µg/L	APHA : Pt 3125B	<0.15	<0.15	<0.15	0.15	
Mercury as Hg	µg/L	APHA : Pt 3125B	<0.1	<0.1	<0.1	0.10	
Nickel as Ni	µg/L	APHA : Pt 3125B	1.29	1.09	1.41	3.0	
Zinc as Zn	µg/L	APHA : Pt 3125B	<1.5	<1.5	<1.5	1.5	
Biological							
Chlorophyll-a	µg/L	APHA : Pt 10150A & B	0.76	0.60	0.48	0.5	
E.coli	MPN/100mL	APHA : Pt 9222H	40	24	9.3	1.8	
Biochemical Oxygen Demand (BOD ₅)	mg/L	APHA : Pt 5210B	0.11	0.11	0.03	1	
Faecal Coliforms	MPN/100mL	APHA : Pt 9222D	220	39	920	2	
Enterococci	cfu/100mL	APHA : Pt 9230C	2	12	9	2	




RESULTS :

Test Parameters	Units	Test Methods	Environmental Impact Study at Keppel Bay				*Detection Limits
			WQ1-F (S)		WQ3-F (S)		
			05/03/2024	05/03/2024	05/03/2024	05/03/2024	
Physical							
Total Suspended Solids	mg/L	APHA : Pt 2540D	5.00	5.00	5.10	1.0	
Chemical							
Nitrate as NO ₃ -N	mg/L	APHA : Pt 4500-NO ₃ ⁻ (I)	0.0043	0.0040	<0.003	0.01	
Nitrite as NO ₂ -N	mg/L	APHA : Pt 4500-NO ₃ ⁻ (I)	0.0032	0.0034	<0.003	0.01	
Phosphate as PO ₄ -P	mg/L	APHA : Pt 4500-P (G)	0.0049	0.0049	<0.003	0.01	
Total Ammonia Nitrogen (NH ₃ +NH ₄)-N	mg/L	APHA : Pt 4500-NH ₃ (H)	0.0063	0.0077	0.0094	0.01	
Oil & Grease (Total)	mg/L	BCTD/Env/SOP/050 Rev (4) (Ref. APHA : Pt 5520C using PCE Solvent Extraction)	<0.1	<0.1	<0.1	0.1	
Oil & Grease (Hydrocarbon)	mg/L	APHA : Pt 5520F	<0.1	<0.1	<0.1	0.1	
Heavy Metals (Dissolved)							
Arsenic as As	µg/L	APHA : Pt 3125B	5.78	5.81	7.06	0.3	
Cadmium as Cd	µg/L	APHA : Pt 3125B	<0.15	<0.15	<0.15	0.15	
Chromium as Cr	µg/L	APHA : Pt 3125B	1.00	0.78	1.13	0.15	
Copper as Cu	µg/L	APHA : Pt 3125B	1.14	0.92	1.30	0.15	
Lead as Pb	µg/L	APHA : Pt 3125B	<0.15	<0.15	<0.15	0.15	
Mercury as Hg	µg/L	APHA : Pt 3125B	<0.1	<0.1	<0.1	0.10	
Nickel as Ni	µg/L	APHA : Pt 3125B	1.48	4.17	1.38	3.0	
Zinc as Zn	µg/L	APHA : Pt 3125B	<1.5	<1.5	<1.5	1.5	
Biological							
Chlorophyll-a	µg/L	APHA : Pt 10150A & B	0.67	0.62	0.78	0.5	
E.coli	MPN/100mL	APHA : Pt 9222H	12	12	27	1.8	
Biochemical Oxygen Demand (BOD ₅)	mg/L	APHA : Pt 5210B	0.05	0.08	0.32	1	
Faecal Coliforms	MPN/100mL	APHA : Pt 9222D	79	27	27	2	
Enterococci	cfu/100mL	APHA : Pt 9230C	1	2	6	2	

Remarks:

1. APHA is a Standard Method for the Determination of Water and Waste Water (APHA 24th Edition : 2023).
2. The tested result applies only to the sample as received by the laboratory.
3. "<" = Not Detectable (The reported values are less than (<) the detection limits of the test methods)
4. * = Requested by client.



BCT

TEST REPORT

Our Reference No. : **R240 6232** Date of Monitoring : 07/06/24 to 21/06/24
Project Code / Ref. : 61803576 Date Reported : 25/07/24

Customer Ref. No. : 6160205
Customer Name : DHI Water & Environment (S) Pte Ltd
Customer Address : 2 Venture Drive
 #18-18 Vision Exchange
 Singapore 608526

Attention To : Mr Andre Low

Subject : Air Quality Monitoring for Keppel EIA

Description : Air Quality Monitoring at 3 locations between 07/06/24 to 21/06/24

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SCOPE OF WORK

Baseline Ambient Air Monitoring was carried out at 3 locations from 07/06/24 to 21/06/24.

Table 1A: Test parameters and specifications

Locations	Parameters	Range of Detection	Limit of Detection	Data Interval
AQ1 AQ2 AQ3	PM ₁₀	0 - 10000 µg/m ³	N.A.	10-min Avg
	PM _{2.5}	0 - 2000 µg/m ³	N.A.	
	SO ₂	0 - 10000 ppb	3 ppb	5-min Avg
	CO	0 - 12000 ppb	10 ppb	
	NO ₂	0 - 5000 ppb	2 ppb	
	O ₃	0 to 1800 ppb	3 ppb	

Table 1B: Monitoring location details

Locations	Assigned Air Monitor	GPS Coordinates	Monitoring Period	Description
AQ1	Kunak 3	N 01°15'50.6" E 103°48'34.2"	07/06/24 to 13/06/24	Keppel Island Viewpoint
AQ2	Kunak 4	N 01°15'53.2" E 103°48'52.8"	07/06/24 to 13/06/24	In front of Block 28 Caribbean at Keppel Bay
AQ3	Kunak 4	N 01°15'54.4" E 103°48'34.5"	15/06/24 to 21/06/24	Near Bukit Chermin Boardwalk end point

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MONITORING LOCATION

The monitoring location is shown in the Google Map image below. Refer to Appendix A for site photos.



SAMPLING METHODOLOGY AND EQUIPMENT

Kunak AIR Pro

PM10 and PM2.5 were monitored using Kunak AIR Pro (Kunak 3 Serial No: 0323380393, Kunak 4 Serial No: 0323380394). The Particulate Matter sensor consists of an Optical Particle Counter (OPC) capable of measuring particles from 0.3 μm up to 40 μm . PM1, PM2.5, PM4, PM10, Total Suspended Particles (TSP) and Total Particle Counter (TPC) are calculated assuming a particle density profile. The instrument is powered by solar. This instrument model is UKAS M-CERTS certified (certificate number: CSA MC230418/00). The gas sensors are individual electrochemical sensors for each of all 4 pollutants, providing real time concentration reading and data logging accessible online.

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SINGAPORE AMBIENT AIR QUALITY TARGETS

Table 2: The following table summarises the Singapore Ambient Air Quality Guidelines

Pollutant	Singapore Long Term Targets
Particulate Matter (PM _{2.5})	24-hour mean: 25 µg/m ³
Particulate Matter (PM ₁₀)	24-hour mean: 50 µg/m ³
Sulphur Dioxide (SO ₂)	24-hour mean: 20 µg/m ³
Carbon Monoxide (CO)	8-hour mean: 10 mg/m ³
	1-hour mean: 30 mg/m ³
Nitrogen Dioxide (NO ₂)	1-hour mean: 200 µg/m ³
Ozone (O ₃)	8-hour mean: 100 µg/m ³

MONITORING RESULTS

The results were summarised in the following tables. Raw air quality data are submitted electronically.

Table 3: Summary of 24-hour mean for PM₁₀ and PM_{2.5} for AQ1

Pollutants		PM ₁₀	PM _{2.5}
Averaging Period		24 hours	
Unit		µg/m ³	
24-hr mean Pollutant concentrations for each day	07-Jun-24	33.9	26.6
	08-Jun-24	34.9	26.7
	09-Jun-24	23.8	18.2
	10-Jun-24	26.8	21.0
	11-Jun-24	32.0	24.6
	12-Jun-24	23.8	17.9
	13-Jun-24	27.2	21.3
Singapore's Ambient Air Quality Long Term Targets		50	25

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Table 4: Summary of 24-hour mean for PM₁₀ and PM_{2.5} for AQ2

Pollutants		PM ₁₀	PM _{2.5}
Averaging Period		24 hours	
Unit		µg/m ³	
24-hr mean Pollutant concentrations for each day	07-Jun-24	17.8	13.2
	08-Jun-24	17.9	12.3
	09-Jun-24	14.6	9.3
	10-Jun-24	14.3	10.1
	11-Jun-24	16.3	11.5
	12-Jun-24	12.8	8.8
	13-Jun-24	13.8	10.1
Singapore's Ambient Air Quality Long Term Targets		50	25

Table 5: Summary of 24-hour mean for PM₁₀ and PM_{2.5} for AQ3

Pollutants		PM ₁₀	PM _{2.5}
Averaging Period		24 hours	
Unit		µg/m ³	
24-hr mean Pollutant concentrations for each day	15-Jun-24	24.6	17.7
	16-Jun-24	17.9	12.0
	17-Jun-24	17.0	10.5
	18-Jun-24	14.4	10.2
	19-Jun-24	23.2	15.6
	20-Jun-24	16.8	10.4
	21-Jun-24	17.9	9.4
Singapore's Ambient Air Quality Long Term Targets		50	25

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Table 6: Summary of Maximum Gas Pollutant Concentrations for each day at AQ1

Pollutants		CO	CO	NO ₂	SO ₂	O ₃
Averaging Period		1 hour	8 hours	1 hour	24 hours	8 hours
Unit		mg/m ³		µg/m ³		
Maximum Pollutant concentrations for each day and Daily Average SO ₂ concentrations	07-Jun-24	0.61	0.49	30.68	< 8	48.32
	08-Jun-24	0.37	0.28	38.38	< 8	33.11
	09-Jun-24	0.30	0.23	31.20	< 8	25.92
	10-Jun-24	0.32	0.27	37.23	< 8	26.59
	11-Jun-24	0.57	0.33	50.23	< 8	57.89
	12-Jun-24	0.42	0.32	39.79	30.94	20.97
	13-Jun-24	0.47	0.35	39.03	46.30	44.92
Max over 7 days		0.61	0.49	50.23	46.3	57.89
Singapore's Ambient Air Quality Long Term Targets		30	10	200	20	100

Table 7: Summary of Maximum Gas Pollutant Concentrations for each day at AQ2

Pollutants		CO	CO	NO ₂	SO ₂	O ₃
Averaging Period		1 hour	8 hours	1 hour	24 hours	8 hours
Unit		mg/m ³		µg/m ³		
Maximum Pollutant concentrations for each day and Daily Average SO ₂ concentrations	07-Jun-24	0.58	0.46	27.63	19.25	31.36
	08-Jun-24	0.41	0.28	36.21	< 8	24.28
	09-Jun-24	0.31	0.23	27.10	< 8	18.45
	10-Jun-24	0.34	0.26	36.62	< 8	32.84
	11-Jun-24	0.59	0.33	45.03	16.48	63.29
	12-Jun-24	0.36	0.29	31.27	< 8	18.20
	13-Jun-24	0.46	0.34	25.58	< 8	45.43
Max over 7 days		0.59	0.46	45.03	19.25	63.29
Singapore's Ambient Air Quality Long Term Targets		30	10	200	20	100

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Table 8: Summary of Maximum Gas Pollutant Concentrations for each day at AQ3

Pollutants		CO	CO	NO ₂	SO ₂	O ₃
Averaging Period		1 hour	8 hours	1 hour	24 hours	8 hours
Unit		mg/m ³		µg/m ³		
Maximum Pollutant concentrations for each day and Daily Average SO ₂ concentrations	15-Jun-24	0.39	0.29	39.51	< 8	34.65
	16-Jun-24	0.41	0.22	32.68	< 8	38.52
	17-Jun-24	0.32	0.24	30.69	< 8	39.42
	18-Jun-24	0.36	0.26	28.79	< 8	29.31
	19-Jun-24	0.54	0.26	30.22	9.05	18.64
	20-Jun-24	0.41	0.26	24.88	12.75	34.62
	21-Jun-24	0.25	0.20	34.27	43.22	19.27
Max over 7 days		0.54	0.29	39.51	43.22	39.42
Singapore's Ambient Air Quality Long Term Targets		30	10	200	20	100

Note:

- 1) The dates represent data collected between 0000hrs to 2359hrs.
- 2) Data for AQ4 are reported using USEPA approved air monitors.
- 3) The SO₂ data presented for each of the day is the daily average based on the above-mentioned time period.
- 4) Only NO₂ data have been adjusted using the gain and offset derived for each respective Kunak air monitor as shown in collocation report R240 3237.
- 5) Refer to collocation report R240 3237 for respective equipment calibration certificates.

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Date	Day	Time	0	5	10	15	20	25	30	35	40	45	50	55	LAeq 1 hr	LAeq 12 hr
29/2/2024	4	11:00	NA	NA	NA	NA	NA	71.3	53.6	57.5	50.1	52.1	58	53.4	NA	NA
29/2/2024	4	12:00	55.7	50.6	53.8	56.7	57.7	57.3	54.5	56.4	57	57.6	56.8	56.7	56.3	
29/2/2024	4	13:00	58.2	57.6	56.3	55.7	52.2	54.2	57.7	55.1	59	52.8	49.7	51.4	55.8	
29/2/2024	4	14:00	51.1	52.2	50.6	56	48.2	54.5	46.8	48.5	49.6	53.4	50.6	49.6	51.7	
29/2/2024	4	15:00	66.2	55.8	53.5	49.7	55.3	58	50.5	49.4	59.1	52	50.8	47.7	57.8	
29/2/2024	4	16:00	46	46.2	50.9	54.6	64.5	48.7	51.4	50.7	47.1	56.6	52.9	47.6	55.6	
29/2/2024	4	17:00	49	49.1	49.3	47.4	47.7	47.1	48.7	48.5	47.3	46.2	46	46	47.8	
29/2/2024	4	18:00	47.1	48	51.1	51.5	46.7	45.8	47.9	50	49.3	51.2	49.8	52.2	49.7	
29/2/2024	4	19:00	59.9	53.9	57.4	59.4	46.9	49.1	47.1	49.7	47.4	65.3	46.9	45.8	57.3	
29/2/2024	4	20:00	48.1	47.8	48.7	48.3	48.7	47.9	48.3	47.3	49.7	49.8	51.3	48.9	48.9	
29/2/2024	4	21:00	62.7	47.3	48.1	47.7	48.8	47.8	47.8	47.6	48.8	49	47.3	48.3	53.3	51.9
29/2/2024	4	22:00	47.9	47.7	49.2	48.8	49.6	47.9	47.9	49.1	50.1	51.1	50.1	51.6	49.4	
29/2/2024	4	23:00	49	49.4	49.1	49.8	48.3	48.8	48.9	49.5	49	49	48.5	48.1	49.0	
1/3/2024	5	0:00	48.3	51.1	48.6	47.8	48.3	48.7	49.3	50.9	50.1	49.3	50.7	50.1	49.6	
1/3/2024	5	1:00	49.9	49.8	49.3	49.1	49.2	49	49.4	48.8	48.6	49.4	49.9	49.6	49.4	
1/3/2024	5	2:00	49.9	49.1	49.5	50	49.7	50.2	50.4	49.8	50.5	50	49.9	50.2	49.9	
1/3/2024	5	3:00	49.8	49.7	49.7	50.5	51.7	49.4	49.4	49.6	49.5	49.7	55.8	53.2	51.2	
1/3/2024	5	4:00	49.7	51.6	51.4	50.9	50.8	49.7	50.6	50.4	48.9	49.9	51.1	50.7	50.5	
1/3/2024	5	5:00	51.4	51.1	51.1	51.3	51.8	51	50.8	50.8	50.6	50.1	50.4	50	50.9	
1/3/2024	5	6:00	58.2	55.8	50.9	52	50.4	50.9	50.5	50.2	50.6	51	51.6	53.4	53.0	
1/3/2024	5	7:00	55	54.6	52.6	50.8	51.6	51.7	50.9	50.9	51.4	50.5	54.5	53.2	52.6	56.9
1/3/2024	5	8:00	51.2	51	52.2	51.8	60.9	58.5	52.4	65.1	51.9	54	48.1	60.2	57.9	
1/3/2024	5	9:00	58.3	51.4	51.4	49.5	57.8	67.4	49.6	57.7	54.8	50.2	48.7	53.5	58.5	
1/3/2024	5	10:00	47.4	49.2	48.3	59.6	58.5	56.8	54.7	62.7	50.6	57.2	49.5	47	56.4	
1/3/2024	5	11:00	49.8	46.4	48.1	55.3	53.5	55.6	56.6	54.1	50.6	46.1	52.8	52.5	53.0	
1/3/2024	5	12:00	51.9	46	52.3	59.1	55.5	51.3	54.5	60.6	55.2	52.1	58.1	56.7	55.9	
1/3/2024	5	13:00	54.3	55.6	59	49.8	56.4	54.8	55	55.7	56.4	59.9	63.6	62	58.4	
1/3/2024	5	14:00	52.3	58.9	58.7	57.4	54	51.4	51.1	54.6	56.2	58.1	52.6	50.6	55.6	
1/3/2024	5	15:00	49.8	50	52.6	59.8	58.1	63.3	64.4	58.6	58.8	59.2	59.3	53.8	59.3	
1/3/2024	5	16:00	50.5	57.5	53.1	57.4	53.5	51	50.7	51.6	54.3	55.8	58.7	57.7	55.2	
1/3/2024	5	17:00	57.5	57.2	59.2	57.7	54.1	54	55	52.8	61	57.7	67.9	49.8	59.9	51.8
1/3/2024	5	18:00	47.4	50.7	51.6	50.2	47.7	58.6	51.5	47.2	48.5	46.9	47.8	48.4	51.4	
1/3/2024	5	19:00	51.3	56.1	52.2	53.8	50.9	48.1	48.5	47.9	48.6	50	49.3	48.7	51.2	
1/3/2024	5	20:00	52.5	49.8	50	49.8	63	52.4	47.2	47.8	55.2	55.8	54.3	48.3	55.0	
1/3/2024	5	21:00	48.6	49.1	49.4	50.3	50.7	50.3	51.2	53.4	58.2	49.4	51.2	50	52.0	
1/3/2024	5	22:00	50.2	50.5	50.8	49.6	50.1	51.6	52.7	52.5	52	53.5	52	52	51.6	
1/3/2024	5	23:00	52.1	51.1	51.4	51.5	49.9	50.4	50.4	50.6	51.9	51.7	51	51.1	51.1	
2/3/2024	6	0:00	50	49.9	50	51.1	51.7	52.2	52	52.2	51.3	49.8	49.6	48.7	50.9	
2/3/2024	6	1:00	49.3	49.8	51.3	51.2	51.5	51.7	51.2	49.6	50	51.2	51.6	51.4	50.9	
2/3/2024	6	2:00	51.6	51.8	51.8	50.9	50.8	51.1	50.7	50.2	51.5	52.6	52.8	51.7	51.5	
2/3/2024	6	3:00	51.5	52.1	50.6	49.9	50.2	49.9	50	49.8	49.5	49.6	49.6	50	50.3	
2/3/2024	6	4:00	50.6	50.6	50.3	50.4	49.2	49.2	49.5	49.9	50.2	50.1	49.5	49.6	50.0	
2/3/2024	6	5:00	49.4	49.8	49.9	50.1	50.1	50.7	50.5	49.1	49.4	50.2	50.4	50.9	50.1	
2/3/2024	6	6:00	60.9	52.9	51.2	51.1	51.1	50.8	50.4	50.5	51	51.7	52.1	53.3	53.7	58.4
2/3/2024	6	7:00	54	54.5	53.3	52.6	51.4	54.8	56.7	61.3	53.8	52.9	77.9	66.5	67.6	
2/3/2024	6	8:00	53	55.1	63.8	68	50.4	58.2	50.6	52.7	51.8	54.9	56.4	53.9	59.8	
2/3/2024	6	9:00	52.4	52.9	54.8	50.6	51	49.6	50.9	55.5	52.1	53	52.4	54.3	52.8	
2/3/2024	6	10:00	53.3	51.8	51.5	56.4	51.5	55.1	52.3	55.7	51.6	52.3	51.4	50.8	53.2	
2/3/2024	6	11:00	51.1	50.6	50.5	49.9	52.6	53.3	52	52.1	49.3	47.6	46.8	50.4	50.9	
2/3/2024	6	12:00	48.4	46.3	47.3	46.2	46.7	46.2	46.7	47.4	46.8	47.8	50.2	46.6	47.4	
2/3/2024	6	13:00	54.1	60.3	46.8	54	46.3	47.1	49.4	49.5	52.2	52.7	51.6	49.3	53.2	
2/3/2024	6	14:00	52.3	50.3	49.4	48.4	49	49.9	50.2	47.2	53.4	53.2	51	55.4	51.4	
2/3/2024	6	15:00	53.7	47	55.6	50.8	46.8	50.9	49	61.1	58.1	51	50	50.2	54.4	
2/3/2024	6	16:00	49.9	50.5	49.7	51	51.3	49.2	52	52.3	47.1	47.7	49.3	48.7	50.2	52.1
2/3/2024	6	17:00	46.4	47.9	49.4	49.3	49.1	50.9	50.8	50.5	49.6	50.5	48.5	48.4	49.5	
2/3/2024	6	18:00	51.9	48.8	49.5	52.5	48.1	56.6	56.1	50.7	47.4	47.2	47.6	49.4	51.8	
2/3/2024	6	19:00	50.7	51.9	49.9	51.1	48.2	47	48.3	50.6	50.6	50	53	50.3	50.4	
2/3/2024	6	20:00	51	50.8	51.4	50.7	50.9	51.7	51.5	51.5	52.9	54.2	52.1	51.6	51.8	
2/3/2024	6	21:00	52.6	52.6	52.6	51.5	52.1	52	50.6	51.3	51.4	51.9	51.3	51.7	51.8	
2/3/2024	6	22:00	52.3	52.2	51.7	52.3	52	51.4	51.7	50.7	51.3	51.6	50.9	50.6	51.6	
2/3/2024	6	23:00	50.3	50.2	49.6	50.1	51	50.5	51.7	51.9	51.4	51.7	51.1	50.8	50.9	
3/3/2024	7	0:00	50.6	50.6	51	50.9	49.6	49.8	50.1	49.8	50	50.2	50.8	50.1	50.3	
3/3/2024	7	1:00	50	50.1	50.6	50.9	50.7	51.1	50.9	51.7	51.5	51.1	51.7	50.5	50.9	
3/3/2024	7	2:00	50.6	50	49.6	49.3	49.2	49.5	49.3	49.7	49	49.9	49.6	49.2	49.6	
3/3/2024	7	3:00	49.7	50.2	50	50.6	50.6	49.1	49.4	49.1	48.9	49.4	48.6	49.6	49.6	
3/3/2024	7	4:00	49.7	51.2	50.8	49.7	50.7	50.3	50.4	50.9	51.5	60.2	60	61	55.6	
3/3/2024	7	5:00	59.2	53.3	50.8	50.9	50.4	49.4	50.2	50.2	51.1	50.9	51.2	51.1	52.6	
3/3/2024	7	6:00	51.2	51.8	51.7	62.4	50.7	56.1	54.1	50.4	51.4	51.6	51.4	53.7	54.9	

Date	Day	Time	0	5	10	15	20	25	30	35	40	45	50	55	LAeq 1 hr	LAeq 12 hr
3/3/2024	7	7:00	53.3	54.1	55.1	55.1	54.2	55.4	56.7	53.1	54.4	54.1	53.3	53.7	54.5	52.4
3/3/2024	7	8:00	53.6	52.1	51.7	51.9	52.3	51.4	51.4	52.5	56.1	50.1	52.3	53	52.6	
3/3/2024	7	9:00	52.4	52.9	51.7	51.4	51	52.6	53.2	50.4	49.3	49.2	49.6	49.1	51.3	
3/3/2024	7	10:00	49.6	49.4	50.7	51.5	52.1	52.3	51.4	48.7	49.9	52.7	52.7	66.8	57.2	
3/3/2024	7	11:00	52.4	51.7	50.4	53.3	54.9	49.2	48.7	55.9	53.6	50.9	51	48.2	52.3	
3/3/2024	7	12:00	48.4	48.1	48.4	47.8	47.8	48.6	47	46.2	47.8	48.6	49.7	45.9	48.0	
3/3/2024	7	13:00	45.3	47	47.2	49.7	49	47.4	47.5	47.8	46.4	46.2	46.2	47.4	47.4	
3/3/2024	7	14:00	46.7	45.6	47.2	53	47.3	47.6	48.4	46	46.2	46.9	48.9	48.4	48.2	
3/3/2024	7	15:00	48.7	50.5	49.7	46.4	47	48.1	47.8	50.4	49.6	46.5	47.2	48.6	48.6	
3/3/2024	7	16:00	49.3	49.9	55.5	50.6	52.1	50.3	52	49.2	48.8	50.6	49.8	47.7	51.0	
3/3/2024	7	17:00	47.2	49.4	47.8	54.9	49.7	47.7	54.9	46.2	46.5	47.2	50	51.5	50.5	
3/3/2024	7	18:00	53.1	61.3	55.1	51.6	51.2	49.9	54.1	56.7	50.6	50.2	49.8	51	54.5	
3/3/2024	7	19:00	58.5	54.7	50	50.7	50.9	49.4	50.3	50	51.5	51.5	52.2	52.3	52.7	
3/3/2024	7	20:00	52.1	52.2	53	51.1	50.5	50	50.6	51.6	51.6	51.2	50.6	51.6	51.4	
3/3/2024	7	21:00	52.8	52.4	52.3	50.8	51	50.7	50.2	51.3	51.9	52.1	51.3	50.9	51.5	
3/3/2024	7	22:00	52.1	51.5	50.3	49.9	51	51.6	52.7	51.6	50.9	52.2	52	50.6	51.4	
3/3/2024	7	23:00	50.6	50.9	50.7	50.6	50	45.7	47.2	49	49.7	49.5	49.9	49.6	49.7	51.4
4/3/2024	1	0:00	49.2	48.6	49.7	50	50	50.7	51.2	51.3	50.7	50.8	49.4	49.6	50.2	
4/3/2024	1	1:00	49.7	49.2	49.5	50.4	49.6	50.2	50.9	50.4	50.3	50.7	50.3	50.4	50.2	
4/3/2024	1	2:00	50.1	50.5	49.7	49.6	49.5	50.2	48.8	49.6	50	49.9	49.7	49.2	49.8	
4/3/2024	1	3:00	49	49	49.4	50.5	50.4	50.7	52.2	51.9	52	51.7	51.2	50.9	50.9	
4/3/2024	1	4:00	51.2	49.4	49.3	48.8	49	49.7	50	49.8	49	49.7	51.4	50.9	49.9	
4/3/2024	1	5:00	51.4	51.3	50.8	49.4	49.4	49.2	48.8	49.1	53.9	52.2	52.1	52.2	51.1	
4/3/2024	1	6:00	52	51.9	61	56.1	58	49.8	50.3	50.7	51.5	51.7	52.1	52.9	54.7	
4/3/2024	1	7:00	53	53.4	53.6	52.9	54	57.4	53.4	54	55	57.1	55.5	54	54.7	
4/3/2024	1	8:00	58	57.1	57.3	52	56.9	49.6	49.4	54.1	52.7	52.3	49.6	50.2	54.4	
4/3/2024	1	9:00	50.5	55.6	52.9	51.6	49.8	53.2	59.4	52.6	55.2	52.6	47.2	52.1	53.8	
4/3/2024	1	10:00	49.1	49.3	55	57.1	55.7	59.3	51.9	49.5	51.9	49.1	51.1	55.2	54.2	
4/3/2024	1	11:00	51.8	49.9	49	47.2	51.2	49.1	47.3	49.3	49.5	53.1	46.7	50.6	50.0	
4/3/2024	1	12:00	49.8	48.6	52	53.7	54.1	55	54.5	54	57.3	52.5	52.7	54.7	53.8	
4/3/2024	1	13:00	49.5	50.3	53.5	48.1	49.2	47.2	47.8	50.3	54.6	57.9	51.3	49.1	52.0	
4/3/2024	1	14:00	51.4	51.3	50.8	51.2	61.7	54.5	63.7	47	47.4	51.4	51.7	49.9	56.3	
4/3/2024	1	15:00	55.3	58.6	61.7	55.8	53.5	54.3	56.7	54.1	56.7	47.9	54.1	54.1	56.4	
4/3/2024	1	16:00	54.9	55.7	62.5	63.4	57.7	55.7	55	54.4	61.4	56.1	54	57.7	58.7	
4/3/2024	1	17:00	61.2	59.7	55.1	54.9	56.8	50	49.3	51.3	49.2	50.7	50.6	48.8	55.3	
4/3/2024	1	18:00	48.2	53	49.6	50	50.4	57.2	53.3	50	49.8	49.4	52.6	52.1	52.1	54.9
4/3/2024	1	19:00	52.5	51.1	51.7	61.1	61.7	52.6	59.9	58.7	55.7	54.7	52.8	50.2	57.1	
4/3/2024	1	20:00	49.8	49.7	51.1	51.8	50.4	51.1	53	53.1	53.1	58.3	52.7	54.7	53.1	
4/3/2024	1	21:00	56.2	55.9	63.2	65.8	63.6	65.9	59.7	56.5	55	52.5	51.9	50.6	61.0	
4/3/2024	1	22:00	50.6	50.5	50.6	53.1	54.3	51.6	52.6	53.4	54.8	65.8	66.5	67.2	61.0	
4/3/2024	1	23:00	66	68.4	69.2	69	66	67.3	67.7	64.3	60.3	56.4	55.5	54.9	66.0	
5/3/2024	2	0:00	55.6	55	61	59.7	56.5	54.2	53.8	54.6	53.5	53.1	54.1	52.3	56.2	
5/3/2024	2	1:00	52.3	52.2	51.5	51.8	52.3	54.8	55.4	54.9	53.9	54.8	54	52.9	53.6	
5/3/2024	2	2:00	53	52.8	52.7	52.5	53.2	52.7	53	53.1	52.7	53.4	52.7	52.3	52.9	
5/3/2024	2	3:00	50.9	52	50.7	51	51.6	52	52.2	52.8	52.3	52.7	52.7	53.5	52.1	
5/3/2024	2	4:00	52.6	51.6	51.6	51	51.1	51.3	52.1	51.5	51.9	51.2	51.6	51.7	51.6	
5/3/2024	2	5:00	51.6	51.7	51.9	52	52.4	52.3	52.1	52.7	52.5	52.1	51.8	52.1	52.1	
5/3/2024	2	6:00	53.6	61.4	51.7	53.2	51.9	53.4	54	53.9	53	53.4	53.9	55.5	55.1	
5/3/2024	2	7:00	55.4	54.2	54.1	53.9	55.2	58.6	56	56.9	54.3	55.4	57.2	54.8	55.7	
5/3/2024	2	8:00	54.2	57.4	58	56.5	54.9	54.3	53.8	57.5	59.2	64	64.3	66	60.4	
5/3/2024	2	9:00	67.2	78.2	77.3	60.5	54.4	55.6	54	49.5	48.4	54.9	51.1	48.4	70.3	
5/3/2024	2	10:00	47.4	48.2	50.2	56.3	52	53.2	53.6	49.9	55.5	51.1	53.2	53.5	52.8	
5/3/2024	2	11:00	48.9	51	48.6	49.3	56.9	56.3	50.5	50.4	53.7	51	50.9	47.9	52.3	
5/3/2024	2	12:00	48.4	50.3	49.1	45.1	51	50.7	51.8	53.1	51.1	50.3	55.3	55.5	51.8	
5/3/2024	2	13:00	50.9	49.9	50.1	50.2	48.3	65.8	61.9	55.5	49.4	50.4	48.9	52.8	57.4	
5/3/2024	2	14:00	47.5	49.2	69.1	57.1	54.4	49.7	48.2	46.5	50.4	49	50.6	45.9	59.0	
5/3/2024	2	15:00	53.6	50.4	45	46.9	48.5	47.5	47.7	54.9	54.5	52.7	51.8	50.1	51.3	
5/3/2024	2	16:00	51.8	52.7	51.2	50.8	50.7	51.2	52.6	51.3	56.4	58.3	53.2	59	54.4	
5/3/2024	2	17:00	57	58.6	50.6	51.1	54	49.6	51.9	49.3	46.9	46.6	49.5	47.2	52.8	
5/3/2024	2	18:00	47.2	47.7	48.8	50.5	52.8	50.9	51.6	50	49.3	51	49.7	48.8	50.1	60.9
5/3/2024	2	19:00	49.2	50.4	51.5	49.1	48.8	51.2	50.2	52.8	51.6	49.1	50.8	50.1	50.6	
5/3/2024	2	20:00	50.3	50.4	50.9	50.8	50.5	51.3	51.5	50.8	51.7	51.7	55.1	57.5	52.5	
5/3/2024	2	21:00	51.9	57.4	49.1	52.3	51	51.9	53	54.6	51.1	50.1	50.2	50.2	52.6	
5/3/2024	2	22:00	51	51.4	50.4	49.2	48.5	48.5	50.4	49.8	51	50.5	50.8	50.6	50.3	
5/3/2024	2	23:00	50.6	51.1	52.9	52.8	52.7	51.7	52.3	52.4	52	51	52.8	50.7	52.0	
6/3/2024	3	0:00	50.8	50	50.1	50.9	52.5	50.7	51.1	51.1	51.2	50.9	51.1	50.8	51.0	
6/3/2024	3	1:00	49.9	50.6	51.4	51.4	52.2	50.9	49.8	49.5	49.4	49.6	49.9	50	50.5	
6/3/2024	3	2:00	51.1	50	49.6	50.8	51	51.1	50	49	49.5	49.8	49.7	49.8	50.2	
6/3/2024	3	3:00	50.2	50.5	50.6	50.6	50.6	50.4	50.1	49.4	49.1	49.2	50.1	50.4	50.1	
6/3/2024	3	4:00	49.8	49.6	49.9	50.3	50.6	50.6	50.7	49.8	50.1	49.3	49.2	50	50.0	
6/3/2024	3	5:00	50.4	51	50.8	50.9	51.4	51.5	51.5	52.5	52.3	51.7	51.8	52.5	51.6	
6/3/2024	3	6:00	62.3	55.1	53.1	53.2	53.9	53.7	54.4	54.5	54.8	55	55.9	58	56.3	

Date	Day	Time	0	5	10	15	20	25	30	35	40	45	50	55	LAeq 1 hr	LAeq 12 hr
6/3/2024	3	7:00	57.1	55.8	56.5	56.1	54.7	54.4	53.7	55.6	60.6	52.9	52.4	54.1	55.9	55.7
6/3/2024	3	8:00	57.7	64.3	59.9	58.7	53.7	60.2	52.8	50.8	51.3	54.8	51.3	50.2	57.8	
6/3/2024	3	9:00	56.1	51	51.3	51.9	52.3	53.3	56.9	53.2	52.3	51.6	50.8	56.3	53.6	
6/3/2024	3	10:00	55.2	55.5	51	48.1	51.9	52.7	56.6	51.7	50.3	50.7	48.4	50.3	52.7	
6/3/2024	3	11:00	48	49	51.4	64.4	61	60.2	49.2	51.9	55.8	46.3	51.7	52.2	57.2	
6/3/2024	3	12:00	64.1	53.3	48	49	50.3	51.9	59.2	62.8	61.2	61.6	54.2	56.9	59.0	
6/3/2024	3	13:00	61.7	48	51.4	51.6	49.6	48.9	47.7	47	48.1	46.7	48.6	52.7	53.1	
6/3/2024	3	14:00	55.3	56.3	52.5	55.7	55.9	56.5	55.2	56.8	57.8	55.6	58.3	59.1	56.5	
6/3/2024	3	15:00	53.2	54.3	51.7	48.3	49.5	49.4	50.7	48.6	47.7	55.7	55.1	57.2	52.9	
6/3/2024	3	16:00	56.4	56	55.5	55.9	57.3	51.7	56.8	47.9	46.2	53.2	49.1	51.9	54.4	
6/3/2024	3	17:00	48.3	48.8	50.5	57	55	55.1	58.2	55.9	55.8	52.3	56.7	56.7	55.2	
6/3/2024	3	18:00	55.6	55.6	54.7	49.3	49.5	49.7	57.8	57.9	55.7	54.2	54.3	52.8	54.8	
6/3/2024	3	19:00	50	50.6	49.2	51.9	51.9	49.5	56.1	53.2	52.2	51.4	51.3	50.1	51.9	51.8
6/3/2024	3	20:00	51.2	49.8	50.5	50.6	50.2	56.9	49.2	48.8	49.1	50.4	50.3	49.7	51.2	
6/3/2024	3	21:00	50.5	50.8	51.5	50.2	50.2	49.8	50.5	51.4	51.3	51.4	52.6	50.3	50.9	
6/3/2024	3	22:00	51.6	49.9	50.6	50.8	52.3	51.3	51.5	51.2	50.8	49.9	50.7	50.7	51.0	
6/3/2024	3	23:00	50.9	50.2	50.2	50.4	51.2	50.7	51	50.6	50	50.4	49.9	50.3	50.5	
7/3/2024	4	0:00	50	49.9	50	50.5	50.9	50.9	49.8	50.8	51	51.2	51.5	51	50.7	
7/3/2024	4	1:00	51.2	51.8	53.3	50.9	51.7	51.1	50.6	50.5	51.2	61.4	51.4	49.7	53.8	
7/3/2024	4	2:00	50.2	51	51.2	51	50.7	51.6	51.2	51.6	50.9	50.7	52.3	53.4	51.4	
7/3/2024	4	3:00	50.5	50	50.6	51.4	52.6	53.1	52.9	52.7	52.1	51.6	50.8	49.8	51.7	
7/3/2024	4	4:00	50.3	49.9	50.3	49.9	50.4	49.9	49.6	49.9	49.9	50.3	50.8	52.5	50.4	
7/3/2024	4	5:00	52.6	53.8	52.8	53.1	53.2	52.5	52.5	52.3	52.7	52.3	49.8	49.5	52.4	
7/3/2024	4	6:00	59.6	51	53	51.6	52.4	51.7	51.6	51	51.6	52.2	52.6	54.6	53.6	
7/3/2024	4	7:00	55.1	54.3	53.5	53.5	54.2	54.7	54.9	53.1	56.8	68.4	56.3	52.5	59.3	67.9
7/3/2024	4	8:00	53.7	51.2	54.1	52.7	50.7	51.6	51.5	52.2	66.9	52.1	51.5	50.5	57.5	
7/3/2024	4	9:00	58.4	49	51.8	51.6	49.6	53	50.3	54.3	63.9	53	50.6	48.2	55.8	
7/3/2024	4	10:00	48.4	52.1	51.3	55.7	51.2	54.2	52.2	55.9	53.4	52.6	53.4	58.1	53.9	
7/3/2024	4	11:00	54.8	54.2	55.2	59.4	55.8	53.1	49.7	56	55.4	62.9	49.4	48.5	56.4	
7/3/2024	4	12:00	53.5	47.3	50.9	48.2	47.8	56.9	52	58.3	51.6	51.9	52.2	57.1	53.7	
7/3/2024	4	13:00	58.7	65.6	74.7	76.1	86.6	73.4	83.9	71.8	59.5	60.7	62.1	60.8	78.3	
7/3/2024	4	14:00	62.5	63.6	65.7	62.7	58.3	50	51.5	55.4	54.4	52.8	52.2	57.5	60.0	
7/3/2024	4	15:00	57.9	52.8	58.5	55.5	54.5	54.8	51.7	47.5	47.8	53.8	53.1	52.3	54.4	
7/3/2024	4	16:00	54.7	57	54.3	55.1	52.1	47.2	46.1	46.9	52.8	56.5	55.1	55.2	54.0	
7/3/2024	4	17:00	51	57.8	47.5	48.9	53.5	52.7	59.7	73.1	60.1	58.4	55.1	56.9	63.2	
7/3/2024	4	18:00	53.4	56.4	51.6	52.8	49.6	49.6	49.9	48.9	49.3	49.6	48.7	48.7	51.4	
7/3/2024	4	19:00	50.2	50.1	51.3	52.3	50.7	50.7	51.8	51.1	52.1	52.6	51.4	50.1	51.3	51.7
7/3/2024	4	20:00	50.3	50.1	50.7	50.3	49.7	49.5	50.6	51.3	55	53.1	51.1	50.5	51.3	
7/3/2024	4	21:00	49.7	50.6	50.4	53.3	53.6	51.7	50.9	52.8	52.1	53.3	51.3	52.1	52.0	
7/3/2024	4	22:00	50.2	52.3	51.5	52.1	52.3	52.5	54.5	52.7	52.6	52.5	52.1	52.7	52.4	
7/3/2024	4	23:00	52.3	53.5	51.9	51.8	53.3	57.7	56.1	50.6	51	51.6	53.2	51.9	53.5	
8/3/2024	5	0:00	52.3	51.4	52.3	52.6	52.6	52.1	51.6	51.2	51.6	51.5	51.1	51.1	51.8	
8/3/2024	5	1:00	51.2	51.5	51.6	51.4	52.1	51.6	51.7	51.4	51.5	51.3	50.8	51.1	51.4	
8/3/2024	5	2:00	51.1	51.6	51.9	50.7	51.4	50.7	50.1	49.9	50.7	50.2	49.9	50.4	50.8	
8/3/2024	5	3:00	50.1	50.3	50.4	52.2	50.1	49.6	50	49.9	50	50.5	49.8	49.8	50.3	
8/3/2024	5	4:00	49.8	49.7	49.2	49.6	49.6	50.2	51.2	50.5	50	49.7	49.4	49.7	49.9	
8/3/2024	5	5:00	49.4	49.5	49.9	50.2	50.4	49.8	49.9	50.1	50.8	51.8	50.8	51.1	50.4	
8/3/2024	5	6:00	59.1	52.3	52.8	50.7	51.1	50.8	51.5	51	50.9	51.2	51.5	56.7	53.5	
8/3/2024	5	7:00	55	56.1	54.1	54.5	52.8	52.3	54	54.3	54.2	55.7	52.9	52.1	54.2	NA
8/3/2024	5	8:00	53.2	53.6	54.1	53.5	53.1	52.4	54.1	52.3	54.4	56.8	53	61.4	55.3	
8/3/2024	5	9:00	58.1	56.8	58.8	54	49.4	62.5	54.1	56.3	52.2	53.9	52.3	51.5	56.5	
8/3/2024	5	10:00	48.7	52.9	61.5	61.9	59.7	56.7	55.8	52.2	48.8	49.9	54.7	52.4	56.9	
8/3/2024	5	11:00	56	47.9	48.1	54.1	51.7	54.2	57.2	55.3	52.6	53.9	55.7	53.4	54.1	
8/3/2024	5	12:00	54.2	60.3	55.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

AN02 - Airborne Noise Baseline at Caribbean at Keppel Bay

Date	Day	Time	0	5	10	15	20	25	30	35	40	45	50	55	LAeq 1 hr	LAeq 12 hr
29/2/2024	4	12:00	NA	68.7	47.3	53.8	54.4	55	53.9	53.5	56.2	57.6	54.7	54.5	NA	NA
29/2/2024	4	13:00	54.8	55.1	57.3	54.6	53.3	52.5	53.5	52.7	51.4	51.7	48.8	47.8	53.5	
29/2/2024	4	14:00	46.9	49.7	50.6	49.6	47.6	44.2	44.5	46.5	48.6	43.7	46	49.9	47.9	
29/2/2024	4	15:00	48.7	46.9	48.1	47.7	49.1	45.4	45	47.4	45.7	47.2	52.8	45.5	48.0	
29/2/2024	4	16:00	47	47.4	46.4	53.4	56.7	47	45.4	47.7	47.1	47.1	50.5	49.2	50.3	
29/2/2024	4	17:00	46	49.8	49.1	50.5	55.8	52.6	50	47.3	48.2	49.2	47.8	50.4	50.6	
29/2/2024	4	18:00	46.9	45.3	46.6	48.7	47.8	49.5	46.6	49.2	51.9	48.4	48.4	55.2	49.6	
29/2/2024	4	19:00	47.5	52.8	48.8	53.5	51.1	50.3	51.3	52.8	51.5	50.2	51.6	52.3	51.4	
29/2/2024	4	20:00	46.3	48.4	48	49.3	49.9	53	48	45.2	44.8	46.6	44.1	46	48.2	
29/2/2024	4	21:00	46.5	46.9	44.7	45.1	44.5	44.7	43.5	45.4	46.5	45.5	46.4	46	45.6	
29/2/2024	4	22:00	43.1	43.1	44.4	41.8	45	43.7	42	57.1	51.9	42.3	42.3	46.9	48.8	45.1
29/2/2024	4	23:00	41.1	41.2	41.3	40.6	41.4	40.1	41	42.8	38.4	39.6	41.8	40.2	40.9	
1/3/2024	5	0:00	39	44.6	40.1	39.6	39.6	38.7	37.6	42.1	39.2	36.9	37	36.7	39.9	
1/3/2024	5	1:00	35.7	36	36.4	35.7	36.9	36.2	35.3	35.7	35.4	37.5	35.3	35.3	36.0	
1/3/2024	5	2:00	35.1	35.4	37.4	35.2	37.7	42.7	37.9	35.9	34.9	36.3	35.9	34.8	37.3	
1/3/2024	5	3:00	35	35.1	35.5	35.8	38.4	42.9	36.3	35.4	35.9	35.5	46.5	48.1	41.4	
1/3/2024	5	4:00	37.2	38.7	36.4	36.4	36.5	35.9	36.7	36.6	36.6	35.7	35.7	35.2	36.5	
1/3/2024	5	5:00	36	35.4	35.8	35.8	35.7	36.2	36.8	37.4	37.1	36.1	36.3	35.6	36.2	
1/3/2024	5	6:00	38.2	37.7	40.2	42.8	39.2	39.6	42.2	44	45.2	43.4	41.2	43.1	42.0	
1/3/2024	5	7:00	47	44.9	46.2	45.7	43.4	44.2	44.2	56.8	47.1	47.3	46.5	53	49.5	
1/3/2024	5	8:00	48.5	49.1	49.7	46	60	54.1	48.7	60.9	62.5	54.9	49.9	49.1	56.3	54.7
1/3/2024	5	9:00	50.6	55	50.4	47.8	46.8	66.9	60.6	56.4	54.5	56.7	53	47.8	58.3	
1/3/2024	5	10:00	47.7	47.1	49	53.9	63	49.6	47.8	62.1	57.6	59	49.2	49.2	56.8	
1/3/2024	5	11:00	46.9	47.3	46.9	47.3	45.7	48.6	52.4	50	47.5	48.6	47	48.8	48.5	
1/3/2024	5	12:00	49.7	50.5	45.9	51.5	54.2	47	48.4	54.4	56	49.9	50.7	46	51.5	
1/3/2024	5	13:00	47.2	47.1	46.4	50.1	46.9	47.2	49.3	52.3	54.6	48.8	64.1	63.1	56.7	
1/3/2024	5	14:00	48.3	52.2	54.9	49.6	48.6	47.5	47	46.6	47.2	47.6	48.1	53.9	50.3	
1/3/2024	5	15:00	49.6	53.7	48.8	51	59.6	52.9	66.3	52.3	49.6	48.6	48.2	49.7	57.3	
1/3/2024	5	16:00	49.7	50.3	51.9	50.5	49	47.6	47.1	48.5	48.7	49.2	51.4	49.3	49.6	
1/3/2024	5	17:00	53.5	50.8	48.5	51.8	49.8	48.4	63.9	49.1	57.1	50.8	50.4	49.2	55.3	45.3
1/3/2024	5	18:00	49.2	52.4	50.9	49.8	48.4	55.1	50.3	49.1	46.7	52	51	50.9	51.0	
1/3/2024	5	19:00	52.6	53	54.7	52.1	50.7	48.4	51.4	48.9	48	46.3	50.5	48.1	51.0	
1/3/2024	5	20:00	53.3	46.4	50.6	47.6	48.1	46.8	45	59.3	47.7	48.6	47.6	45.6	51.4	
1/3/2024	5	21:00	46.5	46.3	46.2	47.8	45.6	44.1	49.8	45.6	45.8	49.2	47.4	49.2	47.3	
1/3/2024	5	22:00	45	42.9	44.3	43.5	46	45.2	44	45.9	43.5	46.1	47	42.3	44.9	
1/3/2024	5	23:00	42.5	40.8	40.6	42	48.9	38.3	38.2	37.9	41.4	38.3	39.8	37.5	42.0	
2/3/2024	6	0:00	39.1	39.2	38.3	40.8	38.1	43.8	38.1	37.6	37.5	37.9	37.6	38.7	39.3	
2/3/2024	6	1:00	37.4	36.7	37.5	38.2	36.9	36.1	37.4	36.8	36.4	37.4	39.2	36.3	37.3	
2/3/2024	6	2:00	40.6	36.3	35.4	35.1	35.4	36.3	36.5	38.1	38.7	36.4	36.6	36.6	37.1	
2/3/2024	6	3:00	35.6	36.3	36.1	36.7	35.7	36.3	37.3	37	36.4	35.9	35.6	35.3	36.2	
2/3/2024	6	4:00	37.2	37.1	35.7	35.5	36.7	35.6	35.3	35.4	34.7	35.7	37.9	36.6	36.2	
2/3/2024	6	5:00	36.5	38.1	36.8	36.1	36.7	40.6	38.8	40.8	37.8	36.9	36.2	37.1	38.0	
2/3/2024	6	6:00	39.9	42	39.5	38.4	38	37.7	39.4	39.6	40.2	42.6	42.3	42.5	40.5	52.4
2/3/2024	6	7:00	44.7	44.3	46.3	52.2	46.5	47.4	47.9	46.2	48.4	49.9	57.9	49.7	50.5	
2/3/2024	6	8:00	49.7	48.6	48.9	47.2	47.5	50.7	47	49	53.4	46.5	52.7	46.8	49.6	
2/3/2024	6	9:00	51.2	47.9	47.1	50.8	46	51.2	65.5	50.2	49.5	48.5	58.4	50.9	56.3	
2/3/2024	6	10:00	51.4	49.8	50.2	57.2	49.7	52.1	49.7	48.8	49.2	49.9	51.3	52.5	51.7	
2/3/2024	6	11:00	52.8	51.3	55	54.6	54.3	53.5	54.7	55.9	54.2	55.5	48.6	48.2	53.8	
2/3/2024	6	12:00	46.2	49.7	46.8	45.8	47.3	46.7	55.9	48.9	46.1	47.9	48.7	47.5	49.3	
2/3/2024	6	13:00	47.1	45.8	49.2	49.2	47.4	46.3	48.8	48.6	46.6	54.6	48.8	47.3	49.1	
2/3/2024	6	14:00	46	47.5	46.9	48.5	49.4	49.2	47.2	46.7	48.1	48.6	50.2	49	48.3	
2/3/2024	6	15:00	47.6	48.5	53.4	46.5	45.8	45.9	48	51.5	61.1	50.7	49.1	55.3	53.2	
2/3/2024	6	16:00	50.2	49	52.7	52.3	48.3	49	47.5	51.8	52.5	50.8	45.5	47.2	50.3	49.4
2/3/2024	6	17:00	46.6	45.8	54.2	49.9	49.8	51.5	50.5	52.5	49.2	50	64.3	60.2	56.1	
2/3/2024	6	18:00	45.9	51.5	54.3	53.6	52.9	49.1	48.9	49.9	53.4	48.6	47.8	46.4	51.0	
2/3/2024	6	19:00	48.5	50.4	51.9	50.5	48	52.7	55.9	49.7	47.4	50.8	66.1	51.9	56.7	
2/3/2024	6	20:00	50.6	49	50	48.6	47	53.5	46.8	47.4	48.3	50.3	47.9	54.6	50.2	
2/3/2024	6	21:00	47.1	52.9	46.3	52.2	47.7	47.4	49.2	47.7	47.6	48	45.6	45.4	48.8	
2/3/2024	6	22:00	44.1	43	42.7	44.7	44.5	43.5	43.2	46.4	43.3	43.6	45	42	44.0	
2/3/2024	6	23:00	41.5	42.1	42.8	42.5	43	45.5	46	46.6	39.9	40	40.4	41.8	43.3	
3/3/2024	7	0:00	40.4	41.5	41.4	41.3	39.8	39.9	39.7	38.6	39.2	39.3	39.5	38.4	40.0	
3/3/2024	7	1:00	38.5	38.9	38.6	38.6	38.1	37.4	38.6	39.4	39.6	37.9	38.5	38.2	38.6	
3/3/2024	7	2:00	38.6	43.5	38.3	40	38.6	38	41.4	38.8	38.5	39.4	38.5	38	39.6	
3/3/2024	7	3:00	38.2	38.6	38.5	39.3	38.6	38.2	38.4	39.6	51.3	39	38.9	38.5	42.6	
3/3/2024	7	4:00	40.1	37.8	38.3	38.1	40.5	39.1	38	39.1	40.2	56.8	59.8	57.1	52.3	
3/3/2024	7	5:00	58.8	53.7	47.5	46.5	45.7	45.3	43.3	41.9	41.3	41.5	40.3	39.9	50.2	
3/3/2024	7	6:00	39.8	40.8	40.6	41.8	42.3	43.1	43.9	44.6	43.2	48.4	46.6	49	44.7	

Date	Day	Time	0	5	10	15	20	25	30	35	40	45	50	55	LAeq 1 hr	LAeq 12 hr
3/3/2024	7	7:00	48.8	49.7	49.8	47.1	51.4	46.9	48.5	46	47.7	50	55.1	53.7	50.4	50.0
3/3/2024	7	8:00	49.5	49.5	50.8	50.3	54.7	51	50.8	49.4	50	51.4	49.3	49.8	50.8	
3/3/2024	7	9:00	49.7	46.5	46.8	47.8	47.4	44.4	48.1	52.4	48.9	47.1	51.4	45.1	48.6	
3/3/2024	7	10:00	46.5	47.4	46.2	51.4	46.5	48.3	47.7	50	47.8	46.9	50.1	51.8	48.8	
3/3/2024	7	11:00	47.2	45.9	49.5	48	48.9	47.1	47.1	46.2	45.8	46.6	45.3	52.1	47.9	
3/3/2024	7	12:00	46.2	46.1	49.7	47.3	48.1	45.6	47	47.6	50	47.1	46.9	50	47.9	
3/3/2024	7	13:00	44.7	45.5	45.7	47.7	52.4	46.4	47.1	48.9	45.9	46	49.3	45.9	47.7	
3/3/2024	7	14:00	45	46.6	47.3	49.5	48	46.1	45.8	47.7	45.9	48.6	49.9	50.6	47.9	
3/3/2024	7	15:00	50.7	49.8	51.3	48.5	49.6	49.8	52.5	45.8	52.4	46.5	53.7	45.7	50.4	
3/3/2024	7	16:00	48	47.7	48.9	49.3	49.3	46.9	45.2	46.6	45.7	45.5	49.3	46.4	47.7	
3/3/2024	7	17:00	47.1	46	48.3	53	55.4	46.9	52.7	57.2	49.6	47.4	49.8	46.3	51.6	
3/3/2024	7	18:00	47.9	55.2	62.1	49.3	48.2	47.2	50.5	53.1	55.2	52.9	50.2	49.6	54.3	
3/3/2024	7	19:00	51.1	51.6	50.6	49.3	49.7	49.2	53.9	49.7	48.7	47.3	47.8	46	50.1	43.9
3/3/2024	7	20:00	46.8	46.8	46.3	46.9	46.6	45	45.1	48.2	45.4	48.9	44.6	45.2	46.5	
3/3/2024	7	21:00	43.9	45.8	45.3	44.5	44.4	45.5	44.2	43.6	49.6	45.6	44.5	47	45.7	
3/3/2024	7	22:00	44.3	42.5	43.6	51	41.5	45.4	42.6	45	42.5	46.6	42.7	40.7	45.1	
3/3/2024	7	23:00	40.7	40.6	40.4	45.8	39.3	38.6	38.6	41.9	40.1	39	38.7	38.1	40.8	
4/3/2024	1	0:00	39.1	38.7	39.5	38.4	37.7	37.6	37.1	38.2	40.4	37.3	38.6	37.8	38.5	
4/3/2024	1	1:00	36.8	36.1	37	40.8	36.3	36.1	36.2	35.7	35.7	35.7	35.9	36.1	36.8	
4/3/2024	1	2:00	36.1	36.4	37.6	36.5	41.2	37.5	37.2	36.9	35.5	39.6	37.3	36.1	37.6	
4/3/2024	1	3:00	35.4	35.3	35.3	35.6	35.8	36.3	36.5	36.8	36.7	36.9	37	37.1	36.3	
4/3/2024	1	4:00	36.4	36.3	36.6	37.6	39	37.5	36.4	36.9	38.7	36.8	36.8	38.4	37.4	
4/3/2024	1	5:00	37.3	37.9	38.8	39.1	38.3	38.1	38.6	39	39	46.2	39.3	39.3	40.1	
4/3/2024	1	6:00	39.7	41	40.5	42.6	52.4	42.1	39.9	40.3	40	40.3	40.9	46.9	44.6	
4/3/2024	1	7:00	47.8	48.2	47.6	42.8	49.4	50.3	48	46.7	46.9	44.2	66.1	60	56.7	55.2
4/3/2024	1	8:00	52.7	49.2	46.8	47.7	49.6	49.8	48.6	46.9	45.4	48.2	46.7	47	48.7	
4/3/2024	1	9:00	45	47.1	46.8	46.5	45.8	45.6	49.5	59.7	47.6	45.5	48	49.3	51.0	
4/3/2024	1	10:00	60.6	49.6	48.3	49.3	49.8	47.6	46.9	46.5	48.8	50.1	50.1	52	52.4	
4/3/2024	1	11:00	49.2	47.3	48.6	49.6	53.1	51.8	49.8	50.6	45.9	49	52.8	46.7	50.1	
4/3/2024	1	12:00	46.8	44.9	47.4	47.2	44.8	46.1	47	46.5	50.2	48.3	46.4	46.5	47.1	
4/3/2024	1	13:00	48	46.4	49.4	49.5	50.8	52.6	55.7	58.4	57	57.1	50.6	48.7	53.8	
4/3/2024	1	14:00	50.4	55.5	56.7	72.4	57.7	62.1	54.5	49.7	53.1	52.3	53.5	49.2	62.5	
4/3/2024	1	15:00	48.6	57.9	56	60.4	46	48.4	51.8	50.2	50.3	55.9	45.4	46	54.1	
4/3/2024	1	16:00	48	50.2	49.3	63.4	53.1	49	51	50.2	53.7	60.3	50.1	52.3	55.8	
4/3/2024	1	17:00	59.8	56.6	52.5	50.5	52.6	53.4	49.1	48.7	48.1	49	50.2	51.1	53.4	
4/3/2024	1	18:00	46.2	47	48.8	48.8	49	49.7	53.4	49.4	48.8	49.7	48.3	48.6	49.3	
4/3/2024	1	19:00	49.8	48.4	48.8	59.8	56	59	57.1	59.1	53.2	54.3	49	47.8	55.6	56.5
4/3/2024	1	20:00	47.1	48.8	48.5	48.9	47.7	48.6	50.3	49	50.6	52.4	51.9	51.9	50.0	
4/3/2024	1	21:00	52.6	55.2	56	65.1	60.7	64.4	58.1	53.8	52.5	50.8	49.7	48.3	58.9	
4/3/2024	1	22:00	46	45.3	46.4	47.2	45.8	47.5	46.7	47.2	51.3	56.4	66.8	65.6	58.9	
4/3/2024	1	23:00	64.2	63.7	68.4	68	68	63	66.9	65	59.6	55.8	53.3	51.8	64.8	
5/3/2024	2	0:00	52	49.5	59.2	56.6	55.8	53.3	49.9	49.8	48.2	48	49.1	51.6	53.5	
5/3/2024	2	1:00	44.8	44.7	44.3	45.7	45	43.8	43.1	42.1	41.5	41.3	42.2	44	43.8	
5/3/2024	2	2:00	43.8	41.3	42.3	41.7	41.8	41.5	41.6	41.7	41.4	41.1	41	40.5	41.7	
5/3/2024	2	3:00	40.1	39.4	39.3	38.7	38.6	39.2	38.7	37.9	38.5	38.3	37.9	38.2	38.8	
5/3/2024	2	4:00	40.8	39.5	39.2	39.9	39.8	39.3	39.7	39	38	38	37.4	37.6	39.1	
5/3/2024	2	5:00	38.2	38.6	39	39.6	38.7	38.5	39	42	41.4	41.5	39.7	39.9	39.9	
5/3/2024	2	6:00	39.9	41.2	41.9	41	41.5	43.4	42.5	42.9	42	42.4	43.7	46.7	42.8	
5/3/2024	2	7:00	48.4	48.2	48	48.6	47.2	45.9	47.5	54.8	47.2	50.4	51.8	48.7	49.7	
5/3/2024	2	8:00	47.3	49.8	48.5	49.1	48.6	49.4	50.5	49.3	49.6	49.6	46.1	51.3	49.3	
5/3/2024	2	9:00	58.5	47.3	47.9	48.4	47.9	52.1	55.1	47	46.1	47.3	46.9	50.9	51.7	53.5
5/3/2024	2	10:00	60.1	58.4	47	51.6	56.6	50.3	49.4	47.7	52.9	50.8	52.2	52.2	54.3	
5/3/2024	2	11:00	53.8	49.8	47.9	49.8	50.7	45.8	47.1	46.4	49	48	49.1	45.8	49.2	
5/3/2024	2	12:00	45.8	47.7	46.9	47	46.7	46.6	44.3	46.1	46	49.2	43.8	44.1	46.4	
5/3/2024	2	13:00	44	44.3	48.5	48.6	48	45	65.8	45.2	46.7	46.8	44.6	45.7	55.5	
5/3/2024	2	14:00	46.3	46.4	49.6	71.8	55.3	46.7	44.3	44.9	45.5	48.7	51.1	47.2	61.3	
5/3/2024	2	15:00	45.2	44.4	43.5	43.4	45	44.6	45	48.6	45.4	48.1	46.4	46.5	45.8	
5/3/2024	2	16:00	48.3	46.1	50.2	48.4	45.5	46.5	47.5	46	44.5	51.5	44.2	48	47.8	
5/3/2024	2	17:00	46	48.7	49.5	47.3	48.1	47.2	53.4	45.3	47.2	48.6	48.6	49	48.8	
5/3/2024	2	18:00	47	49.3	45.7	48.6	44.8	46.9	47.1	49.5	48	47.5	49.3	51.3	48.3	
5/3/2024	2	19:00	47.6	49.2	50.2	51.4	46	47.6	49.9	46.4	47.5	45.1	44	48.4	48.3	44.8
5/3/2024	2	20:00	45.2	43.5	43.9	43.1	44.2	44	44.4	46.2	45.9	45.9	48.8	58.2	49.4	
5/3/2024	2	21:00	49.3	50.8	56.9	44.6	44	43.2	43.9	44.6	43.8	43.9	42.1	43.3	48.8	
5/3/2024	2	22:00	42.5	48.4	42.4	44.5	44.3	42.2	41.1	40.8	40.3	40.1	40.6	39.7	43.1	
5/3/2024	2	23:00	39.3	39.2	40.3	39.8	40.1	40.1	40.3	42.8	38.5	39.7	39.4	40.7	40.1	
6/3/2024	3	0:00	37.9	38.8	39.8	38.5	37.6	38.9	37.5	37.2	37.2	37.8	37.6	37.4	38.1	
6/3/2024	3	1:00	37.5	37.2	36.3	39.5	37	36.7	39.4	40.7	37.3	36.8	36.8	37.5	37.9	
6/3/2024	3	2:00	37.5	38	38.8	37.9	37.8	37.3	38.2	38.4	39	39.4	39.4	38.5	38.4	
6/3/2024	3	3:00	38.5	38.1	37.5	37.2	37.2	37.9	37.7	37.9	37.8	37.1	37.1	36.2	37.6	
6/3/2024	3	4:00	37.5	38.5	38.2	38.1	38.4	38.9	40.1	40	40.7	39.1	38	38.6	38.9	
6/3/2024	3	5:00	39	39.1	40.4	40.8	40.8	40.9	42	43.3	43.4	44.8	43.5	43.6	42.2	
6/3/2024	3	6:00	44.1	44.6	45	45	46.2	46.2	47	48.9	47.2	47.6	47.7	50.7	47.1	

Date	Day	Time	0	5	10	15	20	25	30	35	40	45	50	55	LAeq 1 hr	LAeq 12 hr
6/3/2024	3	7:00	51.8	51	47.4	48.7	50.1	50.4	51.6	47.1	54.4	49.9	49.4	51.7	50.7	51.7
6/3/2024	3	8:00	52	50.7	48.6	49.1	46	45	48.3	45.6	46.6	45.2	47.8	47.2	48.2	
6/3/2024	3	9:00	50	49.9	48.4	48	49.1	51.5	46	58	46.9	45.9	56.1	45.5	51.6	
6/3/2024	3	10:00	49	50.8	51.1	51.6	50.6	51	53.5	49.2	50.8	48.6	49.1	50.3	50.7	
6/3/2024	3	11:00	48.8	46.4	48.5	45.8	63.6	62.8	46.3	46.3	47.6	46.7	46.2	45.4	55.9	
6/3/2024	3	12:00	48.4	52.8	47.5	48	47.9	48	47.7	48.8	52.4	52.6	49.6	47.9	49.8	
6/3/2024	3	13:00	47.5	51	46.7	51	47.4	48.6	48.3	50	48.5	47.7	48.1	49.4	48.9	
6/3/2024	3	14:00	54	54.3	53.6	48.7	51	48.2	49.3	50	50.5	51	51.4	50.8	51.5	
6/3/2024	3	15:00	50.1	48.9	47.4	47.3	50.6	51.2	49.5	47.5	46.8	45.6	52.5	49.2	49.3	
6/3/2024	3	16:00	49.4	50.8	47.7	51.9	54.1	50.4	49.5	50.9	47.3	46.7	48	47.3	50.1	
6/3/2024	3	17:00	46.5	46	47.7	48.3	47.8	48.2	55	55.8	59.8	53.7	52.4	51.2	53.2	
6/3/2024	3	18:00	51.6	47.3	47.7	47.3	46.7	48.3	49.4	47.7	50.3	60.4	58.8	55.3	53.8	
6/3/2024	3	19:00	55.6	49.3	49.9	56.4	56.6	46.7	49.8	61.8	61.9	51.8	48.3	49.7	56.2	47.4
6/3/2024	3	20:00	46.6	50.8	45.4	45.3	46.4	47.9	46.5	45.6	44.5	47.5	46	46.2	46.9	
6/3/2024	3	21:00	45	45	45.9	48.5	44.8	44.6	43.5	45.7	46	45.4	52.2	50.9	47.4	
6/3/2024	3	22:00	44.5	45	44.2	42.9	43.9	45.5	44.3	42.9	46.1	42.8	43.3	45.7	44.4	
6/3/2024	3	23:00	42.8	42.8	40.4	40.2	40.4	40.7	39.3	39.1	44.9	40.1	38.2	37.6	41.0	
7/3/2024	4	0:00	37.3	37.4	37.7	37.7	36.8	37.3	37.7	37.4	39.3	37.8	37.7	37.5	37.7	
7/3/2024	4	1:00	37.3	39.5	41.6	46.4	38	37.1	37.5	36.7	36.7	52.4	52.7	37.9	45.9	
7/3/2024	4	2:00	37.3	37.1	37.6	45.9	37.8	37.2	37.9	38.7	40.3	38.8	38.9	41.3	40.0	
7/3/2024	4	3:00	37.1	36.9	36.6	37.4	35.6	35.4	35.2	35.8	38.2	36.8	37.2	37.3	36.7	
7/3/2024	4	4:00	35.9	36.4	35.7	35.3	36	37.4	35.9	35.2	35.5	36.9	37.9	36.6	36.3	
7/3/2024	4	5:00	35.9	36.2	37.1	36.6	36.7	36.7	36.9	40.1	38.5	37.3	38.1	37.5	37.5	
7/3/2024	4	6:00	38.9	39.6	39.5	42.8	41.1	40.8	44.7	42.9	43.5	42.2	43.9	50.7	44.0	
7/3/2024	4	7:00	50.8	49.7	45.4	45.9	47.6	47.8	46.8	46.7	49.7	47.7	45.2	47.4	47.9	55.7
7/3/2024	4	8:00	45.8	50.1	48.6	49.1	47.9	50.7	48.6	47.6	67.2	51.2	46.9	46.5	57.0	
7/3/2024	4	9:00	47.4	48.9	47.5	48.8	44.8	45.5	45.3	45	54.7	64	63.6	50.7	56.7	
7/3/2024	4	10:00	46.9	49.6	48.5	46.1	47.9	48.6	47.9	46.5	52.4	57.2	47.8	47.8	50.4	
7/3/2024	4	11:00	47.5	47	49.8	47.7	49	46.8	46.8	48.6	47.4	47.9	62.8	47.8	53.3	
7/3/2024	4	12:00	48.6	50.1	50.4	48	47	50.2	46.7	46.9	47.3	47.7	50.5	47.7	48.7	
7/3/2024	4	13:00	49	47.9	47.2	49.3	50.5	46.4	47.8	47	47.9	47.8	48.6	49	48.3	
7/3/2024	4	14:00	50.3	53.9	50.2	49.1	50.2	49.6	53.1	47.5	49	48.6	49	52	50.6	
7/3/2024	4	15:00	54.6	58.1	54.3	51.5	45.8	45.9	47.7	46.4	46	46.7	46.4	48.2	51.6	
7/3/2024	4	16:00	46.8	45.7	48	47.7	47.2	45.4	44.6	47.3	44.9	45.3	48.1	56.2	48.9	
7/3/2024	4	17:00	50.1	56.3	48.8	52.6	48.6	51.6	51.6	63.2	74.2	55.7	54.2	54.9	64.0	
7/3/2024	4	18:00	51.1	55.5	47.8	49.5	51.2	51.2	52.6	47.2	49.5	51.2	51.2	48.3	51.1	
7/3/2024	4	19:00	47.7	51.6	49.6	47.3	47.6	47	46.1	48.5	48.4	49.2	49.7	47.4	48.6	45.2
7/3/2024	4	20:00	48.6	49	52	48.9	49	52.4	49.1	48.6	49.8	50.6	48.9	49.1	49.9	
7/3/2024	4	21:00	46.9	46.8	48.8	49.4	50.1	53.1	51.4	45.7	44.8	46.1	46.4	44.7	48.7	
7/3/2024	4	22:00	44.6	43.2	44.3	48.9	46.2	44.9	46.5	43.8	47.9	44	42.7	42.2	45.4	
7/3/2024	4	23:00	46.5	46.5	45.3	43.3	42.7	43.2	41.7	41.2	43.1	42.2	40.8	39.9	43.5	
8/3/2024	5	0:00	40.6	41.5	39.5	40.1	41.3	41	42.5	39.6	40.6	40.8	39.7	37.6	40.6	
8/3/2024	5	1:00	37.2	38	37.2	37.3	38	43.4	37.4	41.2	38	37.5	37.8	40.4	39.1	
8/3/2024	5	2:00	39	37.5	40.4	37.8	40.3	37.3	37.5	37.1	38.2	38.3	38.7	37	38.4	
8/3/2024	5	3:00	37	37.5	38.1	37.4	37.8	38	37.5	39.4	38.6	39	38.1	38.5	38.1	
8/3/2024	5	4:00	37.7	37.3	37.8	37.9	38.2	38.9	37.8	37.7	37.7	37.7	38.5	38.1	38.0	
8/3/2024	5	5:00	38.1	37.6	38.2	38.1	38.5	38.9	39.9	40.6	40.7	42	43.4	40.5	40.1	
8/3/2024	5	6:00	41.2	42.5	46.2	43.7	43.9	44.4	44.4	44.8	44.4	46.5	51.4	52.2	46.9	
8/3/2024	5	7:00	51.4	49	48	46.8	47.6	47.8	51.1	47.1	49.1	50.4	47.4	48.2	48.9	NA
8/3/2024	5	8:00	49.2	51.2	48	49.6	50.5	50.2	52.9	53.7	51.4	48.8	47	49.4	50.6	
8/3/2024	5	9:00	56.9	51	51	48.2	48.9	53.9	62.5	57.5	54.3	50.1	51	48.5	55.3	
8/3/2024	5	10:00	48.2	49	53	51	49.8	52.7	53.2	55.5	52.3	48.6	51.2	54.5	52.2	
8/3/2024	5	11:00	55.8	48	53.3	50.8	51.2	50.4	49.1	52.9	52.8	48.4	47.6	48	51.4	
8/3/2024	5	12:00	48.7	57.8	54.9	52.5	45.9	46.1	NA	NA	NA	NA	NA	NA	NA	

APPENDIX D – Marine Ecology

Baseline Survey Results and Literature Review

D Marine Biodiversity Species Lists

D.1 Full list of species found around Berlayer Creek

D.1.1 During VQP surveys

Table D.1 List of species found during VQP surveys at the intertidal areas around Berlayer Creek

No.	Family	Scientific Name	Common Name	SRDB3 Status
1	Actinodendridae	<i>Actinostephanus haeckeli</i>	Haeckel's anemone	LC
2	Batillariidae	<i>Batillaria zonalis</i>	Bazillion snail	NA
3	Cardiidae	Family Cardiidae spp.	Large cockle	NA
4	Cerithiidae	<i>Cerithium coralium</i>	Coral cerith/creeper snail	LC
5	Columbellidae	<i>Pardalinops testudinaria</i>	Turtle dove snail	LC
6	Columbellidae	<i>Pictocolumbella ocellata</i>	Lightning dove snail	LC
7	Diogenidae	<i>Clibanarius infraspinus</i>	Orange-striped hermit crab	NA
8	Dotillidae	<i>Scopimera</i> sp.	Sand bubbler crab	NA
9	Littorinidae	Family Littorinidae spp.	Rock periwinkle snail	NA
10	Matutidae	<i>Ashtoret lunaris</i>	Spotted moon crab	NA
11	Menippidae	<i>Myomenippe hardwickii</i>	Stone crab	LC
12	Nassariidae	<i>Nassarius livescens</i>	Common whelk	LC
13	Nassariidae	<i>Nassarius olivaceus</i>	Olive whelk	LC
14	Neritidae	<i>Nerita chamaeleon</i>	Chameleon nerite	LC
15	Neritidae	<i>Nerita undata</i>	Waved nerite	NA
16	Onchidiidae	Family Onchidiidae	Onch slug	NA
17	Oulastreidae	<i>Oulastrea crispata</i>	Zebra coral	LC
18	Phymantidae	<i>Phymanthus pinnulatus</i>	Banded frilly sea anemone	LC
19	Pinnidae	Family Pinnidae spp.	Fan shell	NA
20	Portunidae	<i>Thalamita danae</i>	Blue swimming crab	NA
21	Stichodactylidae	<i>Stichodactyla haddoni</i>	Haddon's carpet anemone	LC
22	Strombidae	Family Strombidae spp.	Conch snails	NA
23	Tegulidae	<i>Rochia</i> sp.	Giant top shell snail	NA

No.	Family	Scientific Name	Common Name	SRDB3 Status
24	Tetillidae	<i>Cinachyrella australiensis</i>	Golf ball sponge	LC
25	Turbinidae	<i>Turbo intercostalis</i>	Ribbed turban snail	NA

D.1.2 From Literature Review

Full list of additional species found via literature review in the waters and intertidal areas around Berlayer Creek.

Table D.2 List of species found via literature review in the waters and intertidal areas around Berlayer Creek

No.	Family	Scientific Name	Common Name	SRDB3 Status
1	Ambassidae	<i>Ambassis kopsii</i>	Kops' glass perchlet	LC
2	Atherinidae	<i>Atherinomorus duodecimalis</i>	Tropical silverside	LC
3	Gerreidae	<i>Gerres erythrouus</i>	Deepbody mojarra	NT
4	Gerreidae	<i>Gerres filamentosus</i>	Scaly-breasted munia	LC
5	Hemiramphidae	<i>Hyporhamphus quoyi</i>	Quoy's halfbeak	LC
6	Carangidae	<i>Megalaspis cordyla</i>	Torpedo scad	VU
7	Poeciliidae	<i>Poecilia reticulata</i>	Guppy	DD
8	Hemiramphidae	<i>Zenarchopterus buffonis</i>	Stripe-nose halfbeak	LC
9	Ophichthidae	<i>Ophichthus lithinus</i>	Evermann's snake-eel	DD
10	Adrianichthyidae	<i>Oryzias javanicus</i>	Javanese ricefish	LC
11	Chaetodontidae	<i>Parachaetodon ocellatus</i>	Sixspine butterflyfish	VU
12	Gobiidae	<i>Parioglossus palustris</i>	Estaurine dart-goby	EN
13	Terapontidae	<i>Pelates quadrilineatus</i>	Trumpeter perch	LC
14	Gobiidae	<i>Periophthalmus gracilis</i>	Slender mudskipper	VU
15	Gobiidae	<i>Periophthalmus walailakae</i>	Yellow-spotted mudskipper	VU
16	Haemulidae	<i>Plectorhinchus gibbosus</i>	Brown sweetlips	DD
17	Plotosidae	<i>Plotosus canius</i>	Black eeltail catfish	DD
18	Gobiidae	<i>Pseudogobius javanicus</i>	Java fat-nose goby	DD
19	Toxotidae	<i>Toxotes jaculatrix</i>	Banded archerfish	LC

No.	Family	Scientific Name	Common Name	SRDB3 Status
20	Archasteridae	<i>Archaster typicus</i>	Common sand star	VU
21	Asterinidae	<i>Cryptasterina pentagona</i>	Cryptic sea star	VU
22	Oreasteridae	<i>Protoreaster nodosus</i>	Knobbly sea star	EN
23	Goniasteridae	<i>Stellaster childreni</i>	Galloping sea star	VU
24	Cyrenoididae	<i>Geloina expansa</i>	Giant mud clam, lokan	DD
25	Clypeasteridae	<i>Arachnoides placenta</i>	(Cake) Sand dollar	NT
26	Laganidae	<i>Jacksonaster depressum</i>	Thick-edged sand dollar	VU
27	Halymeniaceae	<i>Halymenia</i> sp.	Halymenia red seaweed	DD
28	Onchidiidae	<i>Onchidium</i> sp.	Onch slug	DD
29	Turbinidae	<i>Turbo Intercostalis</i>	Turban snail	DD
30	Assimineidae	<i>Assimineia</i> sp.	Red berry snail	DD
31	Ellobiidae	<i>Cassidula</i> sp.	Mangrove ear snail	DD
32	Potamididae	<i>Cerithidea obtusa</i>	Chut-chut	LC
33	Muricidae	<i>Chicoreus capucinus</i>	Mangrove murex	LC
34	Ellobiidae	<i>Ellobium</i> sp.	Belongkeng snail	DD
35	Cypraeidae	<i>Erronea erronea</i>	Wandering cowrie	LC
36	Columbellidae	<i>Euplica scripta</i>	Lettered dove shell	LC
37	Strombidae	<i>Lambis lambis</i>	Spider conch	NT
38	Trochidae	<i>Monodonta labio</i>	Maculated top shell	LC
39	Nassariidae	<i>Nassarius echinatus</i>	Prickly whelk	DD
40	Nassariidae	<i>Nassarius livescens</i>	Common whelk	LC
41	Neritidae	<i>Nerita balteata</i>	Lined nerite	LC
42	Neritidae	<i>Nerita chamaeleon</i>	Chameleon nerite	LC
43	Neritidae	<i>Nerita histrio</i>	Scaled nerite	LC
44	Neritidae	<i>Nerita planospira</i>	Flat-spire nerite	NT
45	Neritidae	<i>Nerita polita</i>	Polished nerite	DD
46	Neritidae	<i>Nerita undata</i>	Waved nerite	DD
47	Olividae	<i>Oliva mustelina</i>	Weasel olive snail	DD
48	Columbellidae	<i>Pictocolumbella ocellata</i>	Lightning dove shell	LC

No.	Family	Scientific Name	Common Name	SRDB3 Status
49	Naticidae	<i>Polinices mammatus</i>	Bosom moon snail	DD
50	Muricoidea	<i>Reishia bitubercularis</i>	Bituberculate rock shell	LC
51	Tegulidae	<i>Tectus niloticus</i>	Giant top shell snail	DD
52	Potamididae	<i>Terebralia sulcata</i>	Mud creeper	LC
53	Potamididae	<i>Terebralia sulcata</i>	Belitong snail	LC
54	Trochidae	<i>Umbonium vestiarium</i>	Button snail shells	NT
55	Melongenidae	<i>Volegalea cochlidium</i>	Spiral melogena	LC
56	Capneidae	<i>Actinoporus elongatus</i>	Very long anemone	DD
57	Actiniidae	<i>Anthopleura</i> sp.	Banded bead anemone	LC
58	Actiniidae	<i>Paracondylactis sinensis</i>	Pearly anemone	DD
59	Phymantidae	<i>Phymanthus</i> sp.	Frippy anemones	LC
60	Poritidae	<i>Porites</i> sp.	Pore hard coral	DD
61	Stichodactylidae	<i>Stichodactyla haddoni</i>	Haddon's carpet anemone	LC
62	Stichodactylidae	<i>Stichodactyla gigantea</i>	Giant carpet anemones	LC
63	Phyllophoridae	<i>Phyllophorus spriculata</i>	Tennis-ball sea cucumber	DD
64	Hydrocharitaceae	<i>Halophila ovalis</i>	Spoon seagrass	LC
65	Hydrocharitaceae	<i>Enhalus acoroides</i>	Tape seagrass	DD
66	Hydrocharitaceae	<i>Thalassia hemprichii</i>	Sickle seagrass	DD
67	Diogenidae	<i>Clibanarius Infraspinatus</i>	Orange striped hermit crab	DD
68	Coenobitidae	<i>Coenobita violascens</i>	Land Hermit Crab	DD
69	Portunidae	<i>Thalamita crenata</i>	Powder blue-clawed swimming crab	DD
70	Portunidae	<i>Thalamita danae</i>	Blue swimming crab	DD
71	Dotillidae	<i>Scopimera</i> and <i>Dotilla</i> spp.	Sand bubbler crabs	DD
72	Diogenidae	<i>Clibanarius infraspinatus</i>	Orange-striped hermit crab	DD
73	Portunidae	<i>Portunus pelacigus</i>	Tiny flower crab	DD
74	Limulidae	<i>Tachypleus gigas</i>	Coastal horseshoe crab	VU

No.	Family	Scientific Name	Common Name	SRDB3 Status
75	Sargassaceae	<i>Sargassum</i> sp.	Sargassum seaweed	DD
76	Chaetopteridae	-	Straw tubeworm	DD
77	Chaetopteridae	<i>Chaetopteridae</i> sp.	Gregarious tubeworm	DD
78	Onuphidae	<i>Diopatra</i> sp.	Solitary tubeworm	DD
79	Chitonidae	<i>Acanthopleura gemmata</i>	Jewelled chiton	NT
80	Goniasteridae	<i>Stellaster childreni</i>	Galloping sea star	VU
81	Halimedaceae	<i>Halimeda</i> sp.	Small coin green seaweed	DD
82	Mustelidae	<i>Lutrogale perspicillata</i>	Smooth-coated otter	EN
83	Delphinidae	NA	Dolphin	CR

D.2 Full list of species found around Keppel Island

D.2.1 During VQP survey

Table D.3 List of species found during VQP surveys at the intertidal areas around Keppel Island

No.	Family	Scientific Name	Common Name	SRDB3 Status
1	Phymanthidae	<i>Phymanthus pinnulatus</i>	Banded frilly sea anemone	LC
2	Stichodactylidae	<i>Stichodactyla gigantea</i>	Giant carpet anemone	LC
3	Cladiellidae	<i>Cladiella</i> sp.	Finger leather soft coral	DD
4	Sarcophytidae	<i>Lobophytum</i> sp.	Devil's hand soft coral	DD
5	Sarcophytidae	<i>Sarcophyton</i> sp.	Sarcophyton soft coral	DD
6	Sinulariidae	<i>Sinularia</i> sp.	Smooth leathery soft coral	LC
7	Discosomidae	<i>Discosoma nummiforme</i>	Beaded corallimorph	LC
8	Dendrophylliidae	<i>Turbinaria</i> sp.	Disk coral	LC
9	Merulinidae	<i>Platygyra</i> sp.	Lesser valley coral	LC
10	Merulinidae	<i>Pectinia</i> sp.	Carnation coral	LC
11	Sphenopidae	<i>Palythoa tuberculosa</i>	Sea mat zoanthid	LC
12	Littorinidae	<i>Echinolittorina</i> sp.	Round periwinkle snail	LC

13	Neritidae	<i>Nerita albicilla</i>	Ox-tongue nerite snail	LC
14	Chitonidae	<i>Acanthopleura gemmata</i>	Jewelled chiton	NT
15	Diadematidae	<i>Diadema setosum</i>	Diadema sea urchin	DD

D.2.2 From Literature Review

Table D.4 List of additional species found via literature review in the waters and intertidal areas around Keppel Island.

No.	Family	Scientific Name	Common Name	SRDB3 Status
1	Syngnathidae	<i>Dunckerocampus dactyliophorus</i>	Ringed pipefish	VU
2	Chaetodontidae	<i>Parachaetodon ocellatus</i>	Sixspine butterflyfish	VU
3	Delphinidae	NA	Dolphin	CR
4	Cheloniidae	NA	Sea Turtle	CR
5	Sabellidae	<i>Sabellastarte indica</i>	Feather duster worm	DD
6	Centriscidae	<i>Aeoliscus strigatus</i>	Razorfish	DD
7	Pomacentridae	<i>Amphiprion ocellaris</i>	False clown anemonefish	NT
8	Chaetodontidae	<i>Chelmon rostratu</i>	Copperband butterflyfish	LC
9	Labridae	<i>Choerodon oligacanthus</i>	White-patch tuskfish	NT
10	Monacanthidae	<i>Monacanthus chinensis</i>	Fan-bellied leatherjacket	DD
11	-	<i>Pleuronectiformes</i>	Flatfish	DD
12	Siganidae	<i>Siganus javus</i>	Streaked spinefoot	NT
13	Clavelinidae	<i>Clavelina moluccensis</i>	Bluebell tunicate	DD
14	Pyuridae	<i>Herdmania pallida</i>	-	DD
15	Pyuridae	<i>Microcosmus exasperatus</i>	Exasperating tunicate	DD
16	Asciidiidae	<i>Phallusia philippinensis</i>	-	DD
17	Alcyoniidae	-	Leathery soft coral	DD
18	Dendrophylliidae	<i>Tubastrea</i> and <i>Dendrophyllia</i> sp.	Cave coral	DD
19	Nephtheidea	<i>Tubastrea</i> sp.	Flowery pink soft coral	DD
20	Pocilloporidae	<i>Pocillopora damicornis</i>	Cauliflower coral	DD
21	Gorgoniidae	<i>Eunicella verrucosa</i>	Pink sea fan	DD

No.	Family	Scientific Name	Common Name	SRDB3 Status
22	Diadematidae	<i>Diadema</i> sp.	Long-spined black sea urchin	DD
23	Cucumariidae	<i>Colochirus quadrangularis</i>	Thorny sea cucumber	NT
24	Pteriidae	<i>Isognomon legumen</i>	Pod-tree oyster	DD
25	Arcidae	<i>Lamarcka avellana</i>	Hazelnut Ark-clam	DD
26	Limidae	<i>Limaria fragilis</i>	Fragile file clam	LC
27	Mytilidae	<i>Septifer bilocularis</i>	Ledge mussel	LC
28	Vermetidae	-	Worm snails	DD
29	Fissurellidae	<i>Diodora singaporensis</i>	Keyhole limpets	LC
30	Columbellidae	<i>Euplica scripta</i>	Dotted dove shell	LC
31	Fissurellidae	<i>Montfortista oldhamiana</i>	Oldham's slit limpet	DD
32	Siphonariidae	<i>Siphonaria guamensis</i>	Guam false limpet	DD
33	Trochidae	<i>Stomatia impertusa</i>	Elongate false ear shell	DD

D.3 List of Species of Corals found during surveys

No.	Family	Genera	Species	DACOR
1	Acroporidae	<i>Acropora</i>		Occasional
2	Acroporidae	<i>Astreopora</i>		Common
3	Acroporidae	<i>Montipora</i>		Common
4	Agariciidae	<i>Pachyseris</i>		Dominant
5	Agariciidae	<i>Pavona</i>		Common
6	Dendrophylliidae	<i>Duncanopsammia</i>	<i>Duncanopsammia peltata</i>	Common
7	Dendrophylliidae	<i>Turbinaria</i>		Common
8	Euphylliidae	<i>Euphyllia</i>		Occasional
9	Euphylliidae	<i>Galaxea</i>		Common
10	Fungiidae	<i>Fungia</i>		Common
11	Fungiidae	<i>Herpolitha</i>	<i>Herpolitha limax</i>	Occasional
12	Fungiidae	<i>Lithophyllon</i>		Occasional
13	Fungiidae	<i>Podabacia</i>		Common

No.	Family	Genera	Species	DACOR
14	Fungiidae	<i>Polyphyllia</i>		Rare
15	Leptastreidae	<i>Leptastrea</i>		Occasional
16	Lobophylliidae	<i>Acanthastrea</i>		Occasional
17	Lobophylliidae	<i>Lobophyllia</i>		Occasional
18	Lobophylliidae	<i>Echinophyllia</i>		Common
19	Lobophylliidae	<i>Oxypora</i>		Common
20	Lobophylliidae	<i>Symphyllia</i>		Occasional
21	Merulinidae	<i>Cyphastrea</i>		Common
22	Merulinidae	<i>Dipsastraea</i>		Common
23	Merulinidae	<i>Echinopora</i>		Common
24	Merulinidae	<i>Favites</i>		Common
25	Merulinidae	<i>Hydnophora</i>		Common
26	Merulinidae	<i>Merulina</i>		Dominant
27	Merulinidae	<i>Mycedium</i>	<i>Mycedium elephantotus</i>	Common
28	Merulinidae	<i>Pectinia</i>		Dominant
29	Merulinidae	<i>Platygyra</i>		Common
30	Oulastreidae	<i>Oulastrea</i>	<i>Oulastrea crispata</i>	Occasional
31	Pocilloporidae	<i>Pocillopora</i>		Occasional
32	Poritidae	<i>Bernardpora</i>	<i>Bernardpora stutchburyi</i>	Common
33	Poritidae	<i>Goniopora</i>		Common
34	Poritidae	<i>Porites</i>		Abundant
35	Psammocoridae	<i>Psammocora</i>		Occasional
36	Rhizangiidae	<i>Pseudosiderastrea</i>	<i>Pseudosiderastrea tayami</i>	Occasional

APPENDIX E – Terrestrial Flora

Baseline Survey Results

E Terrestrial Flora Baseline Survey Results

E.1 Terrestrial Flora Species List

Table E.1 Summary of local conservation status for all flora species found within the study area.

S/N	Scientific Name	Common Name	Growth Form	Family	Origin	National Status
1	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	Fabaceae	Non-native	Naturalised
2	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	Fabaceae	Non-native	Naturalised
3	<i>Alstonia scholaris</i>	Indian pulai, White cheesewood	Tree	Apocynaceae	Non-native	Naturalised
4	<i>Alyxia reinwardtii</i>	-	Climber	Apocynaceae	Native	Least Concern
5	<i>Archidendron contortum</i>	Lesser grasshopper tree, Petai belalang	Tree, Shrub	Fabaceae	Native	Endangered
6	<i>Ardisia elliptica</i>	Seashore ardisia, Mata pelandok	Tree, Shrub	Primulaceae	Native	Least Concern
7	<i>Arthrophyllum jackianum</i>	-	Tree	Araliaceae	Native	Least Concern
8	<i>Baphia nitida</i>	Camwood, African sandlewood	Shrub	Fabaceae	Non-native	Casual
9	<i>Bhesa robusta</i>	Red-flowered malayan spindle tree, Bikubiku	Tree	Centroplacaceae	Native	Vulnerable
10	<i>Bridelia stipularis</i>	Kenidai, Kernam	Climber, Vine & Liana, Shrub	Phyllanthaceae	Native	Least Concern
11	<i>Buchanania arborescens</i>	Sparrows' mango, Otak udang	Tree	Anacardiaceae	Native	Least Concern
12	<i>Calophyllum inophyllum</i>	Penaga laut, Bintangor laut	Tree	Calophyllaceae	Native	Endangered
13	<i>Calophyllum pulcherrimum</i>	Bintangor gasing, Bintangor batu	Tree	Calophyllaceae	Native	Least Concern

S/N	Scientific Name	Common Name	Growth Form	Family	Origin	National Status
14	<i>Campylospermum serratum</i>	-	Tree	Ochnaceae	Native	Vulnerable
15	<i>Caryota mitis</i>	Fishtail palm, Common fishtail palm	Cluster Palm, Palm	Arecaceae	Native	Least Concern
16	<i>Champereia manillana</i>	False olive, Chemperai	Tree, Shrub	Opiliaceae	Native	Least Concern
17	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	Lauraceae	Native	Least Concern
18	<i>Claoxylon indicum</i>	Laping budak, Jarak kayu	Tree, Shrub	Euphorbiaceae	Native	Least Concern
19	<i>Clausena excavata</i>	Pink lime-berry, Cama	Tree, Shrub	Rutaceae	Native	Least Concern
20	<i>Clerodendrum disparifolium</i>	Swaddling flower, Celeguri	Shrub, Tree	Lamiaceae	Native	Least Concern
21	<i>Coccoloba uvifera</i>	Sea grape, Jamaican kino	Tree	Polygonaceae	Non-native	Casual
22	<i>Cocos nucifera</i>	Coconut, Coconut palm	Palm, Solitary Palm	Arecaceae	Non-native	Naturalised
23	<i>Commersonia bartramia</i>	Brown kurrajong, Scrub christmas tree	Tree	Malvaceae	Native	Least Concern
24	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	Fabaceae	Non-native	Cultivated Only
25	<i>Cyperus sp.</i>	-	Herb, Lithophyte, Epiphyte	Cyperaceae	-	-
26	<i>Dalbergia latifolia</i>	Indian rosewood, Tamalan tree	Tree	Fabaceae	Non-native	Excluded (Cultivated Only)
27	<i>Davallia denticulata</i> var. <i>denticulata</i>	Rabbit's foot fern	Climber	Davalliaceae	Native	Least Concern
28	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	Rubiaceae	Native	Endangered
29	<i>Diospyros lanceifolia</i>	Common malayan ebony	Tree	Ebenaceae	Native	Least Concern

S/N	Scientific Name	Common Name	Growth Form	Family	Origin	National Status
30	<i>Drypetes cf. longifolia</i>	-	Tree	Putranjivaceae	Native	
31	<i>Elaeis guineensis</i>	Oil palm, Macaw fat	Palm, Solitary Palm	Arecaceae	Non-native	Casual
32	<i>Elaeocarpus pedunculatus</i>	Blunt-leafed oil-fruit, Pinang punai	Tree	Elaeocarpaceae	Native	Least Concern
33	<i>Erycibe leucoxylodes</i>	-	Climber, Vine & Liana	Convolvulaceae	Native	Vulnerable
34	<i>Ficus caulocarpa</i>	Stem-fruited fig	Tree	Moraceae	Native	Endangered
35	<i>Ficus fistulosa</i>	Common yellow stem-fig, Ara serapat	Tree	Moraceae	Native	Least Concern
36	<i>Ficus grossularioides</i> var. <i>grossularioides</i>	Ara putih, White-leafed fig	Tree, Shrub	Moraceae	Native	Least Concern
37	<i>Ficus microcarpa</i>	Malayan banyan, Jejawi	Tree	Moraceae	Native	Least Concern
38	<i>Ficus punctata</i>	Climbing fig, Tangisong burong	Climber, Vine & Liana	Moraceae	Native	Least Concern
39	<i>Ficus variegata</i>	Common red-stem fig, Variegated fig	Tree	Moraceae	Native	Least Concern
40	<i>Ficus vasculosa</i>	White fig, Ara nasi	Tree	Moraceae	Native	Vulnerable
41	<i>Garcinia nigrolineata</i>	Beaked kandis, Kandis hutan	Tree	Clusiaceae	Native	
42	<i>Goniophlebium percussum</i>	-	Epiphyte	Polypodiaceae	Native	Vulnerable
43	<i>Guioa pubescens</i>	-	Tree	Sapindaceae	Native	Least Concern
44	<i>Gynochthodes umbellata</i>	Akar ketang, Akar perut ayam	Climber, Vine & Liana	Rubiaceae	Native	Least Concern

S/N	Scientific Name	Common Name	Growth Form	Family	Origin	National Status
45	<i>Hamelia patens</i>	Fire bush, Scarlet bush	Shrub	Rubiaceae	Non-native	Cultivated Only
46	<i>Haplopteris elongata</i>	-	Herb, Lithophyte, Epiphyte	Pteridaceae	Native	Least Concern
47	<i>Hibiscus tiliaceus</i>	Sea hibiscus, Beach hibiscus	Tree	Malvaceae	Native	Least Concern
48	<i>Hopea odorata</i>	Chengal pasir, Merawan siput jantan	Tree	Dipterocarpaceae	Non-native	Cultivated Only
49	<i>Hypserpa nitida</i>	-	Climber, Vine & Liana	Menispermaceae	Native	Endangered
50	<i>Indorouchera griffithiana</i>	Akar biji, Akar kait putih	Climber, Vine & Liana	Linaceae	Native	Least Concern
51	<i>Ixora sp.</i>	-	Shrub	Rubiaceae	-	-
52	<i>Ixora congesta</i>	Malayan ixora, Jarum-jarum	Shrub, Tree	Rubiaceae	Native	Least Concern
53	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	Lythraceae	Non-native	Cultivated Only
54	<i>Lasianthus hirsutus</i>	-	Shrub	Rubiaceae	Native	Endangered
55	<i>Lepisanthes rubiginosa</i>	Mertajam, Kelat layu	Tree	Sapindaceae	Native	Least Concern
56	<i>Linostoma pauciflorum</i>	-	Climber, Vines	Thymelaeaceae	Native	Endangered
57	<i>Litsea elliptica</i>	Medang, Perawas	Tree	Lauraceae	Native	Least Concern
58	<i>Lygodium longifolium</i>	-	Fern	Lygodiaceae	Native	Least Concern
59	<i>Macrosolen cochinchinensis</i>	Common chinese mistletoe	Shrub	Loranthaceae	Native	Least Concern
60	<i>Mallotus paniculatus</i>	Turn-in-the-wind, Balik angin	Tree, Shrub	Euphorbiaceae	Native	Least Concern

S/N	Scientific Name	Common Name	Growth Form	Family	Origin	National Status
61	<i>Melastoma malabathricum</i>	Common sendudok, Singapore rhododendron	Shrub, Tree	Melastomataceae	Native	Least Concern
62	<i>Memecylon edule</i>	-	Shrub	Melastomataceae	Native	Endangered
63	<i>Murraya paniculata</i>	Mock lime, China box	Shrub	Rutaceae	Non-native	Cultivated Only
64	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	Primulaceae	Native	Endangered
65	<i>Nothaphoebe umbelliflora</i>	Medang losa, Medang	Tree	Lauraceae	Native	Least Concern
66	<i>Ochna kirkii</i>	Mickey mouse plant, Bird's eye bush	Shrub	Ochnaceae	Non-native	Naturalised
67	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	Oleaceae	Native	Vulnerable
68	<i>Oncosperma tigillarium</i>	Nibung, Nibong	Cluster Palm, Palm	Arecaceae	Native	Least Concern
69	<i>Oxyceros longiflorus</i>	-	Climber	Rubiaceae	Native	Least Concern
70	<i>Palaquium obovatum</i>	-	Tree	Sapotaceae	Native	Vulnerable
71	<i>Pandanus cf. tectorius</i>	Pandanus palm, Screw pine	Shrub, Tree	Pandanaceae	Non-native	Cultivated Only
72	<i>Pandanus tectorius</i>	Pandanus palm, Screw pine	Shrub, Tree	Pandanaceae	Non-native	Cultivated Only
73	<i>Piper sarmentosum</i>	Wild pepper, Wild betel	Creeper	Piperaceae	Native	Least Concern
74	<i>Planchonella obovata</i>	Sea gutta, Menasi	Tree	Sapotaceae	Native	Least Concern
75	<i>Plumeria rubra</i>	Frangipani, Common frangipani	Tree	Apocynaceae	Non-native	Cultivated Only
76	<i>Pteris ensiformis</i>	Sword brake, slender brake	Herb	Pteridaceae	Uncertain	Cryptogenic
77	<i>Ptychosperma macarthurii</i>	MacArthur palm, Hurricane palm	Cluster Palm, Palm	Arecaceae	Non-native	Naturalised

S/N	Scientific Name	Common Name	Growth Form	Family	Origin	National Status
78	<i>Rhodamnia cinerea</i>	Silver back tree, Mempoyan	Tree	Myrtaceae	Native	Least Concern
79	<i>Rourea fulgens</i>	-	Climber	Connaraceae	Native	Endangered
80	<i>Roystonea oleracea</i>	Cabbage palm, Palmiste	Palm, Solitary Palm	Arecaceae	Non-native	Cultivated Only
81	<i>Saribus rotundifolius</i>	Footstool palm, Java palm	Palm, Solitary Palm	Arecaceae	Non-native	Casual
82	<i>Scleria ciliaris</i>	-	Sedge	Cyperaceae	Native	Least Concern
83	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	Moraceae	Native	Least Concern
84	<i>Stelechocarpus burahol</i>	Kepel, Kepel apple	Tree	Annonaceae	Non-native	Excluded
85	<i>Symplocos adenophylla</i>	-	Shrub	Symplocaceae	Native	Endangered
86	<i>Syzygium grande</i>	Sea apple, Jambu laut	Tree	Myrtaceae	Native	Least Concern
87	<i>Syzygium myrtifolium</i>	Kelat oil, Kelat paya	Shrub, Tree	Myrtaceae	Native	
88	<i>Syzygium palembanicum</i>	-	Tree	Myrtaceae	Native	Vulnerable
89	<i>Syzygium polyanthum</i>	Indonesian bayleaf, Salam	Tree	Myrtaceae	Native	Least Concern
90	<i>Syzygium syzygioides</i>	Kelat hitam	Tree	Myrtaceae	Native	Least Concern
91	<i>Taenitis blechnoides</i>	Ribbon fern, Paku balu	Herb	Pteridaceae	Native	Least Concern
92	<i>Terminalia catappa</i>	Sea almond, Ketapang	Tree	Combretaceae	Native	Least Concern
93	<i>Trema tomentosum</i>	Poison peach	Shrub, Tree	Cannabaceae	Native	Vulnerable

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S/N	Scientific Name	Common Name	Growth Form	Family	Origin	National Status
94	<i>Triadica cochinchinensis</i>	Mouse deer's delight	Tree	Euphorbiaceae	Native	Least Concern
95	<i>Trigonachras acuta</i>	Seremkan	Tree	Sapindaceae	Native	
96	<i>Triphasia trifolia</i>	Limeberry, Limau keah	Tree, Shrub	Rutaceae	Non-native	Cultivated Only
97	<i>Vitex pinnata</i>	Leban, Malayan teak	Tree	Lamiaceae	Native	Least Concern

E.2 Full Flora Inventory

Table E.2 Full list of flora detected by the baseline terrestrial flora survey.

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263485	103.813028	T0002	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.7	10	4	Native	Least Concern	RDB3	1	
1.263497	103.812974	T0003	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.8	10	5	Native	Least Concern	RDB3	1	
1.263494	103.81294	T0004	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.6	12	5	Native	Least Concern	RDB3	1	
1.263511	103.812976	T0005	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.3	6	3	Non-native	Cultivated Only	Lindsay (2022)	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263496	103.812969	T0006	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.6	12	5	Native	Least Concern	RDB3	1	
1.263482	103.812899	T0007	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.6	10	5	Native	Least Concern	RDB3	1	
1.263469	103.812889	T0008	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.4	10	4	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263513	103.812772	T0009	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.5	12	4	Native	Least Concern	RDB3	1	
1.263525	103.812758	T0010	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.4	13	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263483	103.812746	T0011	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.7	13	6	Native	Least Concern	RDB3	1	
1.263446	103.812698	T0012	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.7	13	5	Native	Least Concern	RDB3	1	
1.263491	103.812649	T0013	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.7	13	5	Native	Least Concern	RDB3	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263507	103.812662	T0014	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	1.2	14	7	Native	Least Concern	RDB3	1	
1.263488	103.812584	T0015	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.4	8	4	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263503	103.812616	T0016	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.6	12	3	Native	Least Concern	RDB3	1	
1.26351	103.81256	T0017	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.3	6	3	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263514	103.812533	T0018	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	1.3	14	6	Native	Least Concern	RDB3	1	
1.263489	103.812531	T0019	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.3	6	2	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263498	103.812479	T0020	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.6	14	7	Native	Least Concern	RDB3	1	
1.263499	103.812457	T0021	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.3	13	2	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263485	103.81243	T0022	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.6	14	5	Native	Least Concern	RDB3	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263511	103.812412	T0023	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.3	6	1	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263482	103.81234	T0024	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.3	6	3	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263508	103.812328	T0025	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.5	14	6	Native	Least Concern	RDB3	1	
1.263494	103.812338	T0026	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.4	14	3	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263511	103.812291	T0027	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	1.3	14	6	Native	Least Concern	RDB3	1	
1.263507	103.812271	T0028	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	1.2	15	6	Native	Least Concern	RDB3	1	
1.263476	103.812254	T0029	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.4	7	2	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263518	103.812248	T0030	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.4	6	3	Native	Least Concern	RDB3	1	
1.263525	103.812211	T0031	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.5	13	5	Non-native	Cultivated Only	Lindsay (2022)	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.26351	103.812192	T0032	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.5	13	4	Native	Least Concern	RDB3	1	
1.263501	103.812186	T0033	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.5	12	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263496	103.812141	T0034	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.6	14	5	Native	Least Concern	RDB3	1	
1.263507	103.812091	T0035	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.5	13	6	Native	Least Concern	RDB3	1	
1.263509	103.812019	T0036	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.5	14	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263504	103.812007	T0037	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.6	14	6	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263436	103.811221	T0038	<i>Baphia nitida</i>	Camwood, African sandalwood	Shrub	NA	5	2	Non-native	Casual	Lindsay (2022)	1	Hedge
1.263341	103.811116	T0039	<i>Coccoloba uvifera</i>	Sea grape, Jamaican kino	Tree	0.4	5	3	Non-native	Casual	Lindsay (2022)	1	Cluster of 13
1.263345	103.811428	T0040	<i>Coccoloba uvifera</i>	Sea grape, Jamaican kino	Tree	0.4	5	4	Non-native	Casual	Lindsay (2022)	1	Cluster of 13

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263344	103.811561	T0041	<i>Coccoloba uvifera</i>	Sea grape, Jamaican kino	Tree	0.4	5	2	Non-native	Casual	Lindsay (2022)	1	Cluster of 2
1.263334	103.811608	T0042	<i>Coccoloba uvifera</i>	Sea grape, Jamaican kino	Tree	0.4	5	3	Non-native	Casual	Lindsay (2022)	1	Cluster of 2
1.262959	103.811151	T0043	<i>Terminalia catappa</i>	Sea almond, Ketapang	Tree	0.5	12	6	Native	Least Concern	RDB3	1	
1.262986	103.811296	T0044	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	0.6	7	6	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263005	103.811332	T0045	<i>Hibiscus tiliaceus</i>	Sea hibiscus, Beach hibiscus	Tree	1	8	5	Native	Least Concern	RDB3	1	Cluster of 4
1.263025	103.811608	T0046	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	1	10	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263049	103.811757	T0047	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	0.7	10	6	Non-native	Cultivated Only	Lindsay (2022)	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263064	103.811808	T0048	<i>Plumeria rubra</i>	Frangipani, Common frangipani	Tree	0.5	4	6	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263059	103.811921	T0049	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	0.5	10	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.26307	103.811969	T0050	<i>Plumeria rubra</i>	Frangipani, Common frangipani	Tree	0.5	4	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263101	103.812095	T0051	<i>Plumeria rubra</i>	Frangipani, Common frangipani	Tree	0.4	2	2	Non-native	Cultivated Only	Lindsay (2022)	1	
1.26309	103.812141	T0052	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	0.8	10	6	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263098	103.81221	T0053	<i>Plumeria rubra</i>	Frangipani, Common frangipani	Tree	0.6	3	4	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263099	103.812243	T0054	<i>Hibiscus tiliaceus</i>	Sea hibiscus, Beach hibiscus	Tree	1.2	9	6	Native	Least Concern	RDB3	1	
1.263115	103.812293	T0055	<i>Plumeria rubra</i>	Frangipani, Common frangipani	Tree	0.4	3	4	Non-native	Cultivated Only	Lindsay (2022)	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263118	103.812327	T0056	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	1.2	10	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263163	103.81255	T0057	<i>Syzygium grande</i>	Sea apple, Jambu laut	Tree	1.5	15	7	Native	Least Concern	RDB3	1	
1.263185	103.812568	T0058	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	0.4	6	4	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 3
1.263205	103.812612	T0059	<i>Hibiscus tiliaceus</i>	Sea hibiscus, Beach hibiscus	Tree	1	11	6	Native	Least Concern	RDB3	1	Cluster of 2
1.263206	103.812684	T0060	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	0.4	6	3	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 2
1.263213	103.812659	T0061	<i>Syzygium grande</i>	Sea apple, Jambu laut	Tree	1	14	5	Native	Least Concern	RDB3	1	
1.263239	103.812679	T0062	<i>Syzygium grande</i>	Sea apple, Jambu laut	Tree	1.2	14	6	Native	Least Concern	RDB3	1	Cluster of 2
1.263219	103.812737	T0063	<i>Lagerstroemia floribunda</i>	Malayan crape myrtle, Thai crape myrtle	Tree	0.4	8	3	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 2

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263224	103.812774	T0064	<i>Hibiscus tiliaceus</i>	Sea hibiscus, Beach hibiscus	Tree	1.3	6	4	Native	Least Concern	RDB3	1	
1.263243	103.812799	T0065	<i>Syzygium grande</i>	Sea apple, Jambu laut	Tree	1.5	14	6	Native	Least Concern	RDB3	1	Cluster of 5
1.263363	103.812858	T0066	<i>Plumeria rubra</i>	Frangipani, Common frangipani	Tree	1	3	4	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 3
1.263586	103.812915	T0067	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.5	8	4	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263582	103.812901	T0068	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.5	10	6	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263586	103.812793	T0069	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.5	6	4	Native	Least Concern	RDB3	1	
1.263553	103.812745	T0070	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.4	9	6	Native	Least Concern	RDB3	1	
1.263559	103.812706	T0071	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.5	9	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.26363	103.812759	T0072	<i>Roystonea oleracea</i>	Cabbage palm, Palmiste	Palm, Solitary Palm	1.7	15	5	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 10

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263622	103.812551	T0073	<i>Roystonea oleracea</i>	Cabbage palm, Palmiste	Palm, Solitary Palm	1.6	15	3	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 5
1.263608	103.812341	T0074	<i>Hopea odorata</i>	Chengal pasir, Merawan siput jantan	Tree	1.8	18	7	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 4
1.263574	103.812357	T0075	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.4	8	4	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263595	103.812328	T0076	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.6	8	5	Native	Least Concern	RDB3	1	Cluster of 3
1.263593	103.812254	T0077	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.8	8	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.26356	103.812216	T0078	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	0.6	9	5	Native	Least Concern	RDB3	1	Cluster of 3
1.263568	103.812037	T0079	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.4	8	4	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263576	103.812008	T0080	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	1.2	10	5	Native	Least Concern	RDB3	1	
1.263578	103.811992	T0081	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.3	7	3	Non-native	Cultivated Only	Lindsay (2022)	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263589	103.81197	T0082	<i>Cinnamomum iners</i>	Wild cinnamon, Clove cinnamon	Tree	1.2	10	3	Native	Least Concern	RDB3	1	Cluster of 5
1.263621	103.811756	T0083	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.6	12	5	Non-native	Cultivated Only	Lindsay (2022)	1	
1.26357	103.811698	T0084	<i>Cynometra malaccensis</i>	Belangkan, Katong	Tree	0.4	7	3	Non-native	Cultivated Only	Lindsay (2022)	1	
1.2635	103.811509	T0085	<i>Pandanus tectorius</i>	Pandanus palm, Screw pine	Shrub, Tree	>10	12	10	Non-native	Cultivated Only	Lindsay (2022)	1	Clusters
1.263449	103.811462	T0086	<i>Saribus rotundifolius</i>	Footstool palm, Java palm	Palm, Solitary Palm	0.5	15	4	Non-native	Casual	Lindsay (2022)		
1.26363	103.812363	T0087	<i>Roystonea oleracea</i>	Cabbage palm, Palmiste	Palm, Solitary Palm	1.2	15	3	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263832	103.812417	T0088	<i>Stelechocarpus burahol</i>	Kepel, Kepel apple	Tree	0.4	5	4	Non-native	Excluded	Lindsay (2022)		
1.263898	103.812389	T0089	<i>Roystonea oleracea</i>	Cabbage palm, Palmiste	Palm, Solitary Palm	1.8	14	4	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 4
1.264185	103.811252	T0113	<i>Cocos nucifera</i>	Coconut, Coconut palm	Palm, Solitary Palm	0.6	14	4	Non-native	Naturalised	Lindsay (2022)	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.264094	103.811165	T0114	<i>Cocos nucifera</i>	Coconut, Coconut palm	Palm, Solitary Palm	0.6	16	5	Non-native	Naturalised	Lindsay (2022)	1	
1.264003	103.811426	T0115	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	2.3	18	10	Native	Least Concern	RDB3	1	
1.263913	103.81143	T0116	<i>Memecylon edule</i>		Shrub	0.25	9	3	Native	Endangered	Lindsay (2022)	1	Cluster of 14
1.263899	103.811385	T0117	<i>Hypserpa nitida</i>		Climber, Vine & Liana	0.05	2		Native	Endangered	RDB3	0	Climber, cluster of 3
1.263999	103.811416	T0118	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.05	1	0.3	Native	Endangered	RDB3	1	Cluster of 3
1.263968	103.811438	T0119	<i>Memecylon edule</i>		Shrub	0.05	1.5	1	Native	Endangered	Lindsay (2022)	1	Cluster of 3
1.264017	103.811384	T0120	<i>Lasianthus hirsutus</i>		Shrub	0.05	2	2	Native	Endangered	RDB3	0	
1.264006	103.81142	T0121	<i>Lygodium longifolium</i>		Fern	0.05	4		Native	Least Concern	RDB3	0	Cluster of 5
1.263999	103.811403	T0122	<i>Palaquium obovatum</i>		Tree	0.25	6	4	Native	Vulnerable	Lindsay (2022)	1	Cluster of 5
1.264085	103.811401	T0123	<i>Calophyllum pulcherrimum</i>	Bintangor gasing, Bintangor batu	Tree	0.05	1	0.5	Native	Least Concern	RDB3	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.264018	103.811425	T0124	<i>Lasianthus hirsutus</i>		Shrub	0.05	3	1	Native	Endangered	RDB3	0	Cluster of 5, flowering
1.264056	103.811448	T0125	<i>Syzygium palembanicum</i>		Tree	0.05	0.5	0.3	Native	Vulnerable	RDB3	0	Cluster of 2
1.264064	103.811425	T0126	<i>Oncosperma tigillarum</i>	Nibung, Nibong	Cluster Palm, Palm	0.5	8	6	Native	Least Concern	RDB3	1	
1.264043	103.811447	T0127	<i>Palaquium obovatum</i>		Tree	0.1	2	3	Native	Vulnerable	Lindsay (2022)	1	Cluster of 2
1.264011	103.811454	T0128	<i>Hypserpa nitida</i>		Climber, Vine & Liana	0.05	0.1		Native	Endangered	RDB3	0	
1.264034	103.811419	T0129	<i>Syzygium grande</i>	Sea apple, Jambu laut	Tree	0.3	10	7	Native	Least Concern	RDB3	1	
1.263985	103.81141	T0130	<i>Guioa pubescens</i>		Tree	0.05	0.3	0.3	Native	Least Concern	RDB3	0	
1.263991	103.811453	T0131	<i>Hypserpa nitida</i>		Climber, Vine & Liana	0.05	7		Native	Endangered	RDB3	0	
1.264028	103.811446	T0132	<i>Palaquium obovatum</i>		Tree	0.2	6	2	Native	Vulnerable	Lindsay (2022)	1	Cluster of 3
1.263885	103.811394	T0133	<i>Memecylon edule</i>		Shrub	0.2	8	6	Native	Endangered	Lindsay (2022)	1	Cluster of 9

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263887	103.811433	T0134	<i>Hypserpa nitida</i>		Climber , Vine & Liana	0.2	10		Native	Endangered	RDB3	0	
1.263906	103.811489	T0135	<i>Memecylon edule</i>		Shrub	0.4	10	6	Native	Endangered	Lindsay (2022)	1	Cluster of 10
1.263895	103.811434	T0136	<i>Palaquium obovatum</i>		Tree	0.5	1	0.5	Native	Vulnerable	Lindsay (2022)	1	
1.263882	103.811474	T0137	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.8	18	10	Native	Least Concern	RDB3	1	
1.263864	103.811482	T0138	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.9	16	10	Native	Least Concern	RDB3	1	
1.263858	103.811457	T0139	<i>Memecylon edule</i>		Shrub	0.2	4	3	Native	Endangered	Lindsay (2022)	1	Cluster of 8
1.26391	103.81145	T0140	<i>Ficus vasculosa</i>	White fig, Ara nasi	Tree	0.1	3	2	Native	Vulnerable	RDB3	1	
1.263853	103.811458	T0141	<i>Ptychosperma macarthurii</i>	MacArthur palm, Hurricane palm	Cluster Palm, Palm	1	8	4	Non-native	Naturalised	Lindsay (2022)	1	
1.263831	103.811456	T0142	<i>Planchonella obovata</i>	Sea gutta, Menasi	Tree	0.1	5	2	Native	Least Concern	RDB3	1	
1.26386	103.811401	T0143	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1.3	14	12	Non-native	Naturalised	Lindsay (2022)	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263888	103.811387	T0144	<i>Gynochthodes umbellata</i>	Akar ketang, Akar perut ayam	Climber, Vine & Liana	0.1	6		Native	Least Concern	RDB3	1	
1.263871	103.811463	T0145	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.05	1.5	1	Native	Vulnerable	RDB3	0	Cluster of 3
1.263868	103.811473	T0146	<i>Rhodamnia cinerea</i>	Silver back tree, Mempoyan	Tree	0.05	0.5	0.3	Native	Least Concern	RDB3	1	Cluster of 2
1.263937	103.811516	T0147	<i>Rourea fulgens</i>		Climber	0.05	4		Native	Endangered	RDB3	0	
1.263936	103.811478	T0148	<i>Syzygium palembanicum</i>		Tree	0.05	0.5	1	Native	Vulnerable	RDB3	0	
1.263939	103.811517	T0149	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	0.05	0.5	0.3	Non-native	Naturalised	Lindsay (2022)	1	
1.263967	103.81153	T0150	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.05	1	0.3	Native	Endangered	RDB3	1	
1.263968	103.811509	T0151	<i>Rourea fulgens</i>		Climber	0.05	4		Native	Endangered	RDB3	0	
1.264016	103.811524	T0152	<i>Archidendron contortum</i>	Lesser grasshopper tree, Petai belalang	Tree, Shrub	0.05	2	0.5	Native	Endangered	RDB3	0	Cluster of 5
1.264021	103.811537	T0153	<i>Lasianthus hirsutus</i>		Shrub	0.1	4	2	Native	Endangered	RDB3	0	Cluster of 5

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Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.264073	103.811484	T0154	<i>Linostoma pauciflorum</i>		Climber , Vines	0.05	0.5	0.3	Native	Endangered	RDB3	0	Cluster of 2
1.264063	103.811486	T0156	<i>Calophyllum pulcherrimum</i>	Bintangor gasing, Bintangor batu	Tree	0.05	1	0.5	Native	Least Concern	RDB3	1	Cluster of 2
1.264068	103.811463	T0157	<i>Erycibe leucoxyloides</i>		Climber , Vine & Liana	0.05	0.5	1	Native	Vulnerable	RDB3	0	
1.264009	103.811521	T0158	<i>Linostoma pauciflorum</i>		Climber , Vines	0.05	0.3	0.3	Native	Endangered	RDB3	0	
1.263976	103.811557	T0159	<i>Linostoma pauciflorum</i>		Climber , Vines	0.05	8		Native	Endangered	RDB3	0	Cluster of 4
1.263997	103.811558	T0160	<i>Bhesa robusta</i>	Red-flowered malayan spindle tree, Biku-biku	Tree	0.2	4	2	Native	Vulnerable	RDB3	1	
1.263974	103.811581	T0161	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.05	2	2	Native	Vulnerable	RDB3	0	
1.263967	103.811579	T0162	<i>Linostoma pauciflorum</i>		Climber , Vines	0.05	0.3	0.3	Native	Endangered	RDB3	0	Cluster of 3
1.263988	103.811595	T0163	<i>Memecylon edule</i>		Shrub	0.05	2	2	Native	Endangered	Lindsay (2022)	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263977	103.811586	T0164	<i>Caryota mitis</i>	Fishtail palm, Common fishtail palm	Cluster Palm, Palm	0.3	3	6	Native	Least Concern	RDB3	1	
1.263991	103.81157	T0165	<i>Lasianthus hirsutus</i>		Shrub	0.05	1	0.5	Native	Endangered	RDB3	0	
1.263998	103.811611	T0166	<i>Linostoma pauciflorum</i>		Climber , Vines	0.05	0.5		Native	Endangered	RDB3	0	Cluster of 7
1.26401	103.811631	T0167	<i>Arthropphyllum jackianum</i>		Tree	0.2	12	4	Native	Least Concern	RDB3	1	
1.26401	103.811629	T0168	<i>Alstonia scholaris</i>	Indian pulai, White cheesewood	Tree	0.1	3	1	Non-native	Naturalised	Lindsay (2022)	1	
1.263969	103.811644	T0169	<i>Memecylon edule</i>		Shrub	0.4	10	7	Native	Endangered	Lindsay (2022)	1	Cluster of 4
1.263975	103.811661	T0170	<i>Litsea elliptica</i>	Medang, Perawas	Tree	0.05	1	0.3	Native	Least Concern	RDB3	1	
1.263998	103.811672	T0171	<i>Memecylon edule</i>		Shrub	0.05	1	0.5	Native	Endangered	Lindsay (2022)	1	
1.26401	103.811681	T0172	<i>Linostoma pauciflorum</i>		Climber , Vines	0.05	4		Native	Endangered	RDB3	0	Cluster of 4
1.263978	103.811667	T0173	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.05	0.5	0.3	Native	Vulnerable	RDB3	0	

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Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263983	103.8117	T0174	<i>Ficus punctata</i>	Climbing fig, Tangisong burong	Climber, Vine & Liana	0.05	1		Native	Least Concern	RDB3	1	
1.263982	103.811651	T0175	<i>Vitex pinnata</i>	Leban, Malayan teak	Tree	0.05	1	0.3	Native	Least Concern	RDB3	1	
1.263984	103.811676	T0176	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.05	4	2	Native	Endangered	RDB3	1	Cluster of 10
1.263984	103.811666	T0177	<i>Linostoma pauciflorum</i>		Climber, Vines	0.05	0.5		Native	Endangered	RDB3	0	Cluster of 2
1.264003	103.811703	T0178	<i>Elaeocarpus pedunculatus</i>	Blunt-leafed oil-fruit, Pinang punai	Tree	0.05	1	0.5	Native	Least Concern	RDB3	1	Cluster of 2
1.26396	103.811615	T0179	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.5	14	7	Native	Least Concern	RDB3	1	
1.263944	103.811609	T0180	<i>Clausena excavata</i>	Pink lime-berry, Cama	Tree, Shrub	0.05	0.3	0.3	Native	Least Concern	RDB3	0	
1.263972	103.811541	T0181	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.8	17	6	Native	Least Concern	RDB3	1	
1.264066	103.811351	T0182	<i>Diospyros lanceifolia</i>	Common malayan ebony	Tree	1.3	22	8	Native	Least Concern	RDB3	0	

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Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.264194	103.811274	T0184	<i>Elaeis guineensis</i>	Oil palm, Macaw fat	Palm, Solitary Palm	2	9	4	Non-native	Casual	Lindsay (2022)	1	Cluster of 2
1.264159	103.811345	T0185	<i>Syzygium palembanicum</i>		Tree	0.05	3	1.5	Native	Vulnerable	RDB3	0	
1.26418	103.811336	T0186	<i>Palaquium obovatum</i>		Tree	0.1	3	2.5	Native	Vulnerable	Lindsay (2022)	1	
1.264146	103.811321	T0187	<i>Arthrophyllum jackianum</i>		Tree	0.3	2.5	2	Native	Least Concern	RDB3	1	
1.264143	103.811388	T0188	<i>Ficus fistulosa</i>	Common yellow stem-fig, Ara serapat	Tree	0.2	4.5	3	Native	Least Concern	RDB3	1	
1.264112	103.811376	T0189	<i>Melastoma malabathricum</i>	Common sendudok, Singapore rhododendron	Shrub, Tree	0.1	2.2	1	Native	Least Concern	RDB3	1	
1.26408	103.811368	T0190	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.05	0.3	0.15	Native	Endangered	RDB3	1	
1.264046	103.811411	T0191	<i>Lasianthus hirsutus</i>		Shrub	0.05	0.1	0.2	Native	Endangered	RDB3	0	
1.264063	103.811365	T0192	<i>Triphasia trifolia</i>	Limeberry, Limau keah	Tree, Shrub	0.1	2.1	1.5	Non-native	Cultivated Only	Lindsay (2022)	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.264039	103.811338	T0193	<i>Calophyllum inophyllum</i>	Penaga laut, Bintangor laut	Tree	0.2	4	2	Native	Endangered	RDB3	1	
1.263999	103.811311	T0194	<i>Syzygium polyanthum</i>		Tree	0.1	1.8	1	Native	Least Concern	RDB3	0	
1.26402	103.811333	T0195	<i>Ficus grossularioides</i>	Ara putih, White-leafed fig	Tree, Shrub	0.2	4	2	Native	Least Concern	RDB3	1	
1.263924	103.811265	T0196	<i>Syzygium grande</i>	Sea apple, Jambu laut	Tree	0.5	12	6	Native	Least Concern	RDB3	1	
1.263871	103.811189	T0197	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	1.6	14	10	Non-native	Naturalised	Lindsay (2022)	1	
1.263879	103.811193	T0198	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.4	6	6	Native	Least Concern	RDB3	1	
1.263887	103.811337	T0199	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.05	0.3	0.3	Native	Vulnerable	RDB3	0	
1.263877	103.811328	T0200	<i>Memecylon edule</i>		Shrub	0.05	0.6	0.3	Native	Endangered	Lindsay (2022)	1	
1.263898	103.811291	T0201	<i>Ficus vasculosa</i>	White fig, Ara nasi	Tree	0.05	1.4	0.5	Native	Vulnerable	RDB3	1	
1.263896	103.811305	T0202	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.05	1.5	0.6	Native	Endangered	RDB3	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263891	103.811334	T0203	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.4	8	6	Native	Least Concern	RDB3	1	
1.26388	103.811327	T0204	<i>Memecylon edule</i>		Shrub	0.05	1.5	0.4	Native	Endangered	Lindsay (2022)	1	Cluster of 2
1.263895	103.811292	T0205	<i>Syzygium syzygioides</i>	Kelat hitam	Tree	0.45	6	6	Native	Least Concern	RDB3	0	
1.263975	103.811337	T0206	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	0.05	0.4	0.5	Native	Endangered	RDB3	0	Cluster of 2
1.263882	103.811381	T0207	<i>Syzygium syzygioides</i>	Kelat hitam	Tree	0.5	6	4	Native	Least Concern	RDB3	0	
1.263892	103.811332	T0208	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.4	3.5	3	Native	Least Concern	RDB3	1	
1.263808	103.811351	T0209	<i>Ficus vasculosa</i>	White fig, Ara nasi	Tree	0.6	8	4	Native	Vulnerable	RDB3	1	Crown obstructed
1.263754	103.811343	T0210	<i>Elaeis guineensis</i>	Oil palm, Macaw fat	Palm, Solitary Palm	1	4	4	Non-native	Casual	Lindsay (2022)	1	
1.263763	103.811332	T0211	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1.2	16	12	Non-native	Naturalised	Lindsay (2022)	1	
1.263774	103.811299	T0212	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.1	2.3	1.5	Native	Endangered	RDB3	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263754	103.81125	T0213	<i>Memecylon edule</i>		Shrub	0.3	2.5	2.5	Native	Endangered	Lindsay (2022)	1	
1.263747	103.811266	T0214	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.1	3	2	Native	Vulnerable	RDB3	0	
1.263756	103.811233	T0215	<i>Ochna kirkii</i>	Mickey mouse plant, Bird's eye bush	Shrub	0.05	1.8	1	Non-native	Naturalised	Lindsay (2022)	1	
1.263759	103.811282	T0216	<i>Claoxylon indicum</i>	Laping budak, Jarak kayu	Tree, Shrub	0.2	3	2.5	Native	Least Concern	RDB3	1	
1.263853	103.811268	T0217	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.25	6	5	Native	Least Concern	RDB3	1	
1.263835	103.811204	T0218	<i>Palaquium obovatum</i>		Tree	0.25	6	3	Native	Vulnerable	Lindsay (2022)	1	
1.263862	103.811224	T0219	<i>Memecylon edule</i>		Shrub	0.25	5	3	Native	Endangered	Lindsay (2022)	1	
1.263828	103.811182	T0220	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.2	2	3	Native	Vulnerable	RDB3	0	
1.263848	103.811202	T0221	<i>Planchonella obovata</i>	Sea gutta, Menasi	Tree	0.1	4.5	2	Native	Least Concern	RDB3	1	
1.263861	103.811152	T0222	<i>Champereia manillana</i>	False olive, Chemperai	Tree, Shrub	0.2	4	3	Native	Least Concern	RDB3	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263855	103.811161	T0223	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	1.9	18	12	Non-native	Naturalised	Lindsay (2022)	1	
1.263893	103.811107	T0224	<i>Ixora congesta</i>	Malayan ixora, Jarum-jarum	Shrub, Tree	0.1	3	3	Native	Least Concern	RDB3	1	
1.26387	103.811089	T0225	<i>Palaquium obovatum</i>		Tree	0.1	2.5	1.5	Native	Vulnerable	Lindsay (2022)	1	
1.263836	103.811148	T0226	<i>Memecylon edule</i>		Shrub	0.1	1	1	Native	Endangered	Lindsay (2022)	1	
1.263844	103.811101	T0227	<i>Planchonella obovata</i>	Sea gutta, Menasi	Tree	0.5	5	4	Native	Least Concern	RDB3	1	
1.263861	103.811107	T0228	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.05	1	1	Native	Vulnerable	RDB3	0	
1.263829	103.811135	T0229	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.1	1.7	1	Native	Endangered	RDB3	1	
1.263819	103.811118	T0230	<i>Memecylon edule</i>		Shrub	0.1	3	2	Native	Endangered	Lindsay (2022)	1	
1.263793	103.811061	T0231	<i>Vitex pinnata</i>	Leban, Malayan teak	Tree	0.5	12	4	Native	Least Concern	RDB3	1	
1.263777	103.811116	T0232	<i>Ptychosperma macarthurii</i>	MacArthur palm, Hurricane palm	Cluster Palm, Palm	1	4.5	3	Non-native	Naturalised	Lindsay (2022)	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263774	103.811124	T0233	<i>Memecylon edule</i>		Shrub	0.3	4	2.5	Native	Endangered	Lindsay (2022)	1	Cluster of 2
1.263755	103.811137	T0234	<i>Caryota mitis</i>	Fishtail palm, Common fishtail palm	Cluster Palm, Palm	1.5	4.5	3	Native	Least Concern	RDB3	1	
1.263715	103.811115	T0235	<i>Piper sarmentosum</i>	Wild pepper, Wild betel	Creeper	0.05	0.3	0.1	Native	Least Concern	RDB3	1	Cluster
1.263698	103.811127	T0236	<i>Mallotus paniculatus</i>	Turn-in-the-wind, Balik angin	Tree, Shrub	0.3	6	3	Native	Least Concern	RDB3	1	
1.263673	103.811126	T0237	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1.5	13	10	Non-native	Naturalised	Lindsay (2022)	1	
1.263684	103.811154	T0238	<i>Hamelia patens</i>	Fire bush, Scarlet bush	Shrub	0.1	1.8	2	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263662	103.811207	T0239	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1.8	12	8	Non-native	Naturalised	Lindsay (2022)	1	
1.263684	103.811211	T0240	<i>Saribus rotundifolius</i>	Footstool palm, Java palm	Palm, Solitary Palm	0.3	1.2	2.5	Non-native	Casual	Lindsay (2022)		

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.2636874	103.8112196	T0241	<i>Vitex pinnata</i>	Leban, Malayan teak	Tree	0.5	12	4	Native	Least Concern	RDB3	1	
1.263685	103.811151	T0242	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	1	16	7	Non-native	Naturalised	Lindsay (2022)	1	
1.263674	103.811753	T0243	<i>Syzygium syzygioides</i>	Kelat hitam	Tree	0.3	5	3	Native	Least Concern	RDB3	0	
1.263626	103.811652	T0244	<i>Vitex pinnata</i>	Leban, Malayan teak	Tree	0.4	6	5	Native	Least Concern	RDB3	1	
1.26363	103.811596	T0245	<i>Vitex pinnata</i>	Leban, Malayan teak	Tree	0.5	8	6	Native	Least Concern	RDB3	1	cluster of two
1.263607	103.811517	T0246	<i>Ficus microcarpa</i>	Malayan banyan, Jejawi	Tree	1.6	9	8	Native	Least Concern	RDB3	1	
1.263595	103.811466	T0247	<i>Piper sarmentosum</i>	Wild pepper, Wild betel	Creeper	0.05	0.3		Native	Least Concern	RDB3	1	large patch
1.263598	103.811445	T0248	<i>Dalbergia latifolia</i>	Indian rosewood, Tamalan tree	Tree	0.05	1	1	Non-native	Excluded (Cultivated Only)	Lindsay (2022)	1	
1.26363	103.811446	T0249	<i>Vitex pinnata</i>	Leban, Malayan teak	Tree	0.7	14	8	Native	Least Concern	RDB3	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263573	103.811362	T0250	<i>Murraya paniculata</i>	Mock lime, China box	Shrub	0.05	2	2	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263994	103.811395	T0251	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	0.05	1	1	Native	Endangered	RDB3	0	Cluster of 5
1.263963	103.811417	T0252	<i>Calophyllum pulcherrimum</i>	Bintangor gasing, Bintangor batu	Tree	0.05	1.5	1	Native	Least Concern	RDB3	1	Midrib at upper lamina prominent, flat below
1.263953	103.811414	T0253	<i>Hypserpa nitida</i>		Climber, Vine & Liana	0.05	3		Native	Endangered	RDB3	0	Cluster
1.264011	103.811401	T0254	<i>Syzygium myrtifolium</i>	Kelat oil, Kelat paya	Shrub, Tree	0.05	2	1	Native	Critically Endangered	RDB3	1	Cluster of 3
1.264032	103.81141	T0255	<i>Oncosperma tigillarum</i>	Nibung, Nibong	Cluster Palm, Palm	0.3	5	4	Native	Least Concern	RDB3	1	Clump
1.264097	103.811409	T0256	<i>Lasianthus hirsutus</i>		Shrub	0.5	1	0.5	Native	Endangered	RDB3	0	Sapling
1.264092	103.811393	T0257	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	2	20	14	Native	Least Concern	RDB3	1	
1.264076	103.811384	T0258	<i>Nothaphoebe umbelliflora</i>	Medang losa, Medang	Tree	0.1	3	2	Native	Least Concern	RDB3	1	Alt spital simple leaf sometimes subopposite,

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
													Nothaphoebe?
1.263906	103.811405	T0259	<i>Ficus vasculosa</i>	White fig, Ara nasi	Tree	0.05	0.5	0.5	Native	Vulnerable	RDB3	1	Cluster of 2
1.26394	103.811442	T0260	<i>Indorouchera griffithiana</i>	Akar biji, Akar kait putih	Climber, Vine & Liana	0.1	3		Native	Least Concern	RDB3	1	Large cluster
1.263901	103.811371	T0261	<i>Buchanania arborescens</i>	Sparrows' mango, Otak udang	Tree	2.4	22	16	Native	Least Concern	RDB3	1	
1.263883	103.811371	T0262	<i>Syzygium myrtifolium</i>	Kelat oil, Kelat paya	Shrub, Tree	0.7	10	6	Native	Critically Endangered	RDB3	1	
1.263918	103.811357	T0263	<i>Drypetes cf. longifolia</i>		Tree	0.3	11	4	Native	Critically Endangered	RDB3	0	
1.263891	103.811443	T0264	<i>Hypserpa nitida</i>		Climber, Vine & Liana	0.05	1		Native	Endangered	RDB3	0	
1.263902	103.811464	T0265	<i>Lasianthus hirsutus</i>		Shrub	0.05	0.5	0.5	Native	Endangered	RDB3	0	
1.263921	103.811511	T0266	<i>Caryota mitis</i>	Fishtail palm, Common fishtail palm	Cluster Palm, Palm	0.3	5	3	Native	Least Concern	RDB3	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263893	103.811474	T0267	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.7	20	12	Native	Least Concern	RDB3	1	
1.263869	103.811446	T0268	<i>Rourea fulgens</i>		Climber	0.2	10		Native	Endangered	RDB3	0	Liana dark brown and strongly fluted and ribbon like, not cylindrical, surface smooth with some minute flakings
1.263904	103.811494	T0269	<i>Lasianthus hirsutus</i>		Shrub	0.2	4	2	Native	Endangered	RDB3	0	
1.26387	103.811429	T0270	<i>Trigonachras acuta</i>	Seremkan	Tree	0.6	8	10	Native	Critically Endangered	RDB3	0	Leaf sample collected
1.263832	103.811432	T0271	<i>Hypserpa nitida</i>		Climber, Vine & Liana	0.1	2		Native	Endangered	RDB3	0	Cluster of 3
1.264035	103.811531	T0272	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	1	20	12	Native	Least Concern	RDB3	1	Check if got duplicate
1.264056	103.811447	T0273	<i>Syzygium grande</i>	Sea apple, Jambu laut	Tree	1.2	24	16	Native	Least Concern	RDB3	1	Check if got duplicate

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.264022	103.811497	T0274	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	0.4	14	6	Native	Endangered	RDB3	0	Cluster of 10 seedlings in vicinity
1.264037	103.811504	T0275	<i>Rourea fulgens</i>		Climber	0.05	1		Native	Endangered	RDB3	0	
1.264021	103.811524	T0276	<i>Taenitis blechnoides</i>	Ribbon fern, Paku balu	Herb	0.05	1		Native	Least Concern	RDB3	1	
1.264024	103.81151	T0277	<i>Haplopteris elongata</i>		Herb, Lithophyte, Epiphyte	0.05	0.1		Native	Least Concern	RDB3	0	
1.264072	103.811556	T0278	<i>Bhesa robusta</i>	Red-flowered malayan spindle tree, Biku-biku	Tree	0.5	10	8	Native	Vulnerable	RDB3	1	
1.264066	103.811474	T0279	<i>Guioa pubescens</i>		Tree	0.6	12		Native	Least Concern	RDB3	0	Dark brown smooth bark
1.264046	103.811732	T0280	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	0.05	1.5	1	Native	Endangered	RDB3	0	Cluster of 3
1.264047	103.811726	T0283	<i>Memecylon edule</i>		Shrub	0.05	1	0.5	Native	Endangered	Lindsay (2022)	1	Cluster of 3

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.264041	103.811767	T0284	<i>Alyxia reinwardtii</i>		Climber	0.05	3		Native	Least Concern	RDB3	0	
1.26402	103.811703	T0285	<i>Syzygium palembanicum</i>		Tree	0.1	2	1	Native	Vulnerable	RDB3	0	
1.264045	103.811694	T0286	<i>Lasianthus hirsutus</i>		Shrub	0.1	1.5	1	Native	Endangered	RDB3	0	Cluster of 2
1.264034	103.811674	T0287	<i>Memecylon edule</i>		Shrub	0.4	6	4	Native	Endangered	Lindsay (2022)	1	
1.264037	103.81169	T0288	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.3	3	3	Native	Endangered	RDB3	1	Cluster of 7
1.263997	103.811669	T0289	<i>Syzygium myrtifolium</i>	Kelat oil, Kelat paya	Shrub, Tree	0.4	6	4	Native	Critically Endangered	RDB3	1	Cluster of 4
1.264009	103.811664	T0290	<i>Linostoma pauciflorum</i>		Climber, Vines	0.05	1	1	Native	Endangered	RDB3	0	Cluster of 5
1.264047	103.811678	T0291	<i>Scleria ciliaris</i>		Sedge	0.05	2		Native	Least Concern	RDB3	0	Large clump, triquetrous, contraligule pronounced, rough surface, nutlet surface rough
1.264002	103.811591	T0292	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.5	10	6	Native	Least Concern	RDB3	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263951	103.811534	T0293	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.8	12	10	Native	Least Concern	RDB3	1	
1.264063	103.811378	T0294	<i>Commersonia bartramia</i>	Brown kurrajong, Scrub christmas tree	Tree	0.4	6	4	Native	Least Concern	RDB3	0	Cluster of 2
1.264173	103.811334	T0295	<i>Davallia denticulata</i>	Rabbit's foot fern	Climber	0.05	0.2		Native	Least Concern	RDB3	1	
1.264173	103.811334	T0295	<i>Goniophlebium percussum</i>		Epiphyte	0.05	0.2		Native	Vulnerable	RDB3	0	
1.264149	103.81129	T0296	<i>Palaquium obovatum</i>		Tree	0.1	3	2	Native	Vulnerable	Lindsay (2022)	1	
1.264159	103.811342	T0297	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.05	1	0.5	Native	Vulnerable	RDB3	0	Cluster of 3 seedlings
1.263983	103.811374	T0298	<i>Calophyllum pulcherrimum</i>	Bintangor gasing, Bintangor batu	Tree	0.2	3	2	Native	Least Concern	RDB3	1	Midrib flat below, protruded above
1.263994	103.811345	T0299	<i>Commersonia bartramia</i>	Brown kurrajong, Scrub christmas tree	Tree	0.5	13	8	Native	Least Concern	RDB3	0	
1.263909	103.811308	T0300	<i>Bhesa robusta</i>	Red-flowered malayan	Tree	1	15	10	Native	Vulnerable	RDB3	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
				spindle tree, Biku-biku									
1.263892	103.811223	T0301	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.8	12	9	Native	Least Concern	RDB3	1	
1.263882	103.811232	T0302	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.5	11	8	Native	Least Concern	RDB3	1	
1.263898	103.811252	T0303	<i>Lasianthus hirsutus</i>		Shrub	0.05	1	1	Native	Endangered	RDB3	0	
1.263894	103.811219	T0304	<i>Hypserpa nitida</i>		Climber , Vine & Liana	0.05	3		Native	Endangered	RDB3	0	
1.263862	103.811338	T0305	<i>Ixora congesta</i>	Malayan ixora, Jarum-jarum	Shrub, Tree	0.2	5	3	Native	Least Concern	RDB3	1	
1.26386	103.811346	T0306	<i>Hypserpa nitida</i>		Climber , Vine & Liana	0.05	2		Native	Endangered	RDB3	0	
1.263922	103.811314	T0307	<i>Unidentified</i>		Tree	0.7	12						Crown obstructed. Bark dark brown, generally smooth, no white sap

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263871	103.811278	T0308	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.7	13	9	Native	Least Concern	RDB3	1	
1.263909	103.811339	T0309	<i>Garcinia nigrolineata</i>	Beaked kandis, Kandis hutan	Tree	0.2	6	3	Native	Critically Endangered	RDB3	1	
1.263827	103.811385	T0310	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.5	10	8	Native	Least Concern	RDB3	1	
1.263777	103.811313	T0311	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	1.2	6	6	Non-native	Naturalised	Lindsay (2022)	1	
1.263818	103.811302	T0312	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	1.5	12	8	Non-native	Naturalised	Lindsay (2022)	1	
1.263838	103.811339	T0313	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	0.1	2	1.5	Native	Endangered	RDB3	0	
1.263758	103.811278	T0314	<i>Clausena excavata</i>	Pink lime-berry, Cama	Tree, Shrub	0.5	10	6	Native	Least Concern	RDB3	0	
1.263764	103.811254	T0315	<i>Hypserpa nitida</i>		Climber, Vine & Liana	0.05	3		Native	Endangered	RDB3	0	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263849	103.811198	T0316	<i>Hypserpa nitida</i>		Climber , Vine & Liana	0.05	10		Native	Endangered	RDB3	0	Cluster growing to canopy of saga tree
1.263834	103.811203	T0317	<i>Memecylon edule</i>		Shrub	0.05	1.5	1	Native	Endangered	Lindsay (2022)	1	
1.2638	103.811201	T0318	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.4	8	6	Native	Least Concern	RDB3	1	
1.263795	103.811189	T0319	<i>Memecylon edule</i>		Shrub	0.2	4	3	Native	Endangered	Lindsay (2022)	1	
1.263779	103.811195	T0320	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.4	6	4	Native	Least Concern	RDB3	1	Cluster of 2
1.263775	103.811197	T0321	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1	12	10	Non-native	Naturalised	Lindsay (2022)	1	
1.263779	103.811209	T0322	<i>Trema tomentosum</i>	Poison peach	Shrub, Tree	0.1	5	3	Native	Vulnerable	RDB3	0	
1.263807	103.811141	T0323	<i>Campylospermum serratum</i>		Tree	0.2	3	2	Native	Vulnerable	RDB3	0	
1.263854	103.81108	T0324	<i>Memecylon edule</i>		Shrub	0.3	6	5	Native	Endangered	Lindsay (2022)	1	Cluster of 4
1.26386	103.811113	T0325	<i>Dibridsonia conferta</i>	Green coffee,	Tree	0.2	4	2	Native	Endangered	RDB3	0	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
				Kahwa utan									
1.263869	103.811102	T0326	<i>Triphasia trifolia</i>	Limeberry, Limau keah	Tree, Shrub	0.05	0.2	0.2	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 2
1.26385	103.811145	T0327	<i>Symplocos adenophylla</i>		Shrub	0.4	5	3	Native	Endangered	RDB3	0	
1.263813	103.811138	T0328	<i>Ixora cf. javanica</i> var. <i>retinervia</i>		Shrub	0.05	1.5	1	Native	Endangered	RDB3	1	
1.263779	103.811116	T0329	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1	12	12	Non-native	Naturalised	Lindsay (2022)	1	
1.263719	103.811029	T0330	<i>Ficus variegata</i>	Common red-stem fig, Variegated fig	Tree	0.4	8	5	Native	Least Concern	RDB3	1	
1.263734	103.811034	T0331	<i>Triadica cochinchinensis</i>	Mouse deer's delight	Tree	0.05	2	1	Native	Least Concern	RDB3	1	
1.263655	103.811155	T0332	<i>Pandanus cf. tectorius</i>	Pandanus palm, Screw pine	Shrub, Tree	0.8	10	3	Non-native	Cultivated Only	Lindsay (2022)	1	Cluster of 8
1.263716	103.811122	T0333	<i>Memecylon edule</i>		Shrub	0.4	6	5	Native	Endangered	Lindsay (2022)	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263914	103.812105	T0334	<i>Hopea odorata</i>	Chengal pasir, Merawan siput jantan	Tree	1.3	24	12	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263912	103.812035	T0335	<i>Elaeis guineensis</i>	Oil palm, Macaw fat	Palm, Solitary Palm	2.2	7	8	Non-native	Casual	Lindsay (2022)	1	
1.263918	103.812029	T0336	<i>Memecylon edule</i>		Shrub	0.1	3	2	Native	Endangered	Lindsay (2022)	1	
1.263869	103.812113	T0337	<i>Hopea odorata</i>	Chengal pasir, Merawan siput jantan	Tree	1	24	12	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263808	103.812108	T0338	<i>Hopea odorata</i>	Chengal pasir, Merawan siput jantan	Tree	1.6	24	12	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263781	103.812026	T0339	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.2	4	4	Native	Vulnerable	RDB3	0	Cluster of 3
1.263811	103.81204	T0340	<i>Davallia denticulata</i>	Rabbit's foot fern	Climber	0.05	0.3		Native	Least Concern	RDB3	1	
1.263772	103.81198	T0341	<i>Pteris ensiformis</i>	Sword brake, Slender brake	Herb	0.05	0.2		Uncertain	Cryptogenic	Lindsay (2022)	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263741	103.812044	T0342	<i>Memecylon edule</i>		Shrub	0.3	6	3	Native	Endangered	Lindsay (2022)	1	
1.263825	103.811959	T0343	<i>Syzygium polyanthum</i>	Indonesian bayleaf, Salam	Tree	0.05	0.3	0.2	Native	Least Concern	RDB3	1	
1.263819	103.811962	T0344	<i>Bridelia stipularis</i>	Kenidai, Kernam	Climber, Vine & Liana, Shrub	0.05	2		Native	Least Concern	RDB3	0	
1.263803	103.811968	T0345	<i>Murraya paniculata</i>	Mock lime, China box	Shrub	0.3	4	4	Non-native	Cultivated Only	Lindsay (2022)	1	
1.263835	103.81197	T0346	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.1	2	3	Native	Vulnerable	RDB3	0	Cluster of 2
1.263874	103.811972	T0347	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.2	3	3	Native	Vulnerable	RDB3	0	Cluster of 7, Flowering and fruiting
1.263822	103.811962	T0348	<i>Ficus caulocarpa</i>	Stem-fruited fig	Tree	0.1	1.5	1	Native	Endangered	RDB3	1	
1.26389	103.811972	T0349	<i>Elaeis guineensis</i>	Oil palm, Macaw fat	Palm, Solitary Palm	2.2	8	8	Non-native	Casual	Lindsay (2022)	1	Cluster of 2
1.263873	103.812007	T0350	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.2	3	2	Native	Vulnerable	RDB3	0	Cluster of 3 *to shift coordinate to mid slope

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.26392	103.812005	T0351	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.2	4	3	Native	Vulnerable	RDB3	0	
1.263971	103.811997	T0352	<i>Memecylon edule</i>		Shrub	0.2	4	3	Native	Endangered	Lindsay (2022)	1	Cluster of 3
1.263889	103.811925	T0353	<i>Memecylon edule</i>		Shrub	0.05	1.5	1	Native	Endangered	Lindsay (2022)	1	Cluster of 8
1.263875	103.811924	T0354	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.05	1	1	Native	Vulnerable	RDB3	0	Cluster of 5
1.263948	103.811889	T0355	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.1	2	1	Native	Vulnerable	RDB3	0	Cluster of 3
1.263984	103.811968	T0356	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.2	2	2	Native	Vulnerable	RDB3	0	Cluster of 4
1.26397	103.811898	T0357	<i>Memecylon edule</i>		Shrub	0.1	3	1	Native	Endangered	Lindsay (2022)	1	Cluster of 2
1.263997	103.811857	T0358	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	0.1	3	2	Native	Endangered	RDB3	0	Flowering
1.263941	103.811864	T0359	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1	12	10	Non-native	Naturalised	Lindsay (2022)	1	
1.263967	103.811795	T0360	<i>Memecylon edule</i>		Shrub	0.4	6	5	Native	Endangered	Lindsay (2022)	1	Cluster of 10, Fruiting

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.264023	103.811837	T0361	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.1	1.5	2	Native	Vulnerable	RDB3	0	
1.264043	103.81185	T0362	<i>Memecylon edule</i>		Shrub	0.3	7	7	Native	Endangered	Lindsay (2022)	1	
1.264035	103.811876	T0363	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1	12	6	Non-native	Naturalised	Lindsay (2022)	1	
1.264013	103.811897	T0364	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.1	3	1	Native	Vulnerable	RDB3	0	Cluster of 3
1.264068	103.811798	T0365	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.3	8	3	Native	Endangered	RDB3	1	Cluster of 4
1.26398	103.811791	T0366	<i>Linostoma pauciflorum</i>		Climber, Vines	0.05	3		Native	Endangered	RDB3	0	
1.263959	103.811763	T0367	<i>Palaquium obovatum</i>		Tree	0.05	0.3	0.3	Native	Vulnerable	Lindsay (2022)	1	Seedling
1.263962	103.811752	T0368	<i>Guioa pubescens</i>		Tree	0.5	7	6	Native	Least Concern	RDB3	0	
1.26394	103.811753	T0369	<i>Cyperus sp.</i>		Herb, Lithophyte, Epiphyte								Small dense cluster of suspect sage with no flower, to monitor for fertile specimen to check for

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
													exact species (e.g. potentially <i>Cyperus dubius</i>)
1.263926	103.811763	T0370	<i>Memecylon edule</i>		Shrub	0.3	7	5	Native	Endangered	Lindsay (2022)	1	
1.263933	103.811742	T0371	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.3	5	3	Native	Endangered	RDB3	1	Cluster of 4
1.264009	103.811762	T0372	<i>Linostoma pauciflorum</i>		Climber, Vines	0.05	1		Native	Endangered	RDB3	0	
1.264012	103.811804	T0373	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	0.05	1	1	Native	Endangered	RDB3	0	
1.264018	103.811786	T0374	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.3	7	5	Native	Endangered	RDB3	1	
1.264041	103.811791	T0375	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.1	2	1	Native	Vulnerable	RDB3	0	Cluster of 3
1.264069	103.811749	T0376	<i>Syzygium syzygioides</i>	Kelat hitam	Tree	0.4	8	4	Native	Least Concern	RDB3	0	
1.264029	103.811736	T0377	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	0.05	2	2	Native	Endangered	RDB3	0	Cluster of 3
1.263912	103.811819	T0378	<i>Rourea fulgens</i>		Climber	0.05	0.2		Native	Endangered	RDB3	0	Seedling

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263929	103.811823	T0379	<i>Memecylon edule</i>		Shrub	0.5	8	6	Native	Endangered	Lindsay (2022)	1	Cluster of 2
1.263916	103.811785	T0380	<i>Dibridsonia conferta</i>	Green coffee, Kahwa utan	Tree	0.05	1.5	2	Native	Endangered	RDB3	0	
1.26393	103.811745	T0381	<i>Macrosolen cochinchinensis</i>	Common chinese mistletoe	Shrub	0.1	6		Native	Least Concern	RDB3	0	Fruiting
1.263881	103.811841	T0382	<i>Memecylon edule</i>		Shrub	0.4	7	5	Native	Endangered	Lindsay (2022)	1	Cluster of 4
1.263858	103.811829	T0383	<i>Elaeis guineensis</i>	Oil palm, Macaw fat	Palm, Solitary Palm	2.2	8	8	Non-native	Casual	Lindsay (2022)	1	
1.26388	103.811855	T0384	<i>Lepisanthes rubiginosa</i>	Mertajam, Kelat layu	Tree	0.05	1	0.5	Native	Least Concern	RDB3	1	
1.263825	103.811804	T0385	<i>Memecylon edule</i>		Shrub	0.3	6	4	Native	Endangered	Lindsay (2022)	1	Cluster of 4
1.26383	103.811781	T0386	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1.1	14	10	Non-native	Naturalised	Lindsay (2022)	1	
1.263733	103.811784	T0387	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.1	3	2	Native	Vulnerable	RDB3	0	Cluster of 3
1.263741	103.811754	T0388	<i>Caryota mitis</i>	Fishtail palm, Common	Cluster Palm, Palm	0.3	4	4	Native	Least Concern	RDB3	1	Cluster of 2

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
				fishtail palm									
1.263624	103.811381	T0389	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.3	3	3	Native	Vulnerable	RDB3	0	fruiting
1.263611	103.811522	T0390	<i>Oxyceros longiflorus</i>		Climber	0.05	2.5	3	Native	Least Concern	RDB3	0	
1.263642	103.811415	T0391	<i>Sloetia elongata</i>	Tempinis, Tampines tree	Tree	0.4	8	4	Native	Least Concern	RDB3	1	
1.263649	103.81143	T0392	<i>Vitex pinnata</i>	Leban, Malayan teak	Tree	1.2	14	8	Native	Least Concern	RDB3	1	
1.263659	103.811422	T0393	<i>Memecylon edule</i>		Shrub	0.05	2	2	Native	Endangered	Lindsay (2022)	1	
1.263685	103.811425	T0394	<i>Vitex pinnata</i>	Leban, Malayan teak	Tree	0.6	15	8	Native	Least Concern	RDB3	1	
1.263671	103.811429	T0395	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1.5	20	10	Non-native	Naturalised	Lindsay (2022)	1	
1.263647	103.811412	T0396	<i>Pandanus tectorius</i>	Pandanus palm, Screw pine	Shrub, Tree	3	8	10	Non-native	Cultivated Only	Lindsay (2022)	1	cluster of two
1.263682	103.811365	T0397	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.2	3	1	Native	Endangered	RDB3	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263618	103.811323	T0398	<i>Buchanania arborescens</i>	Sparrows' mango, Otak udang	Tree	1.8	18	10	Native	Least Concern	RDB3	1	cluster of two
1.263718	103.811344	T0399	<i>Memecylon edule</i>		Shrub	0.3	8	8	Native	Endangered	Lindsay (2022)	1	cluster of four
1.263733	103.811384	T0400	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	1.6	18	10	Non-native	Naturalised	Lindsay (2022)	1	
1.263683	103.811404	T0401	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.05	2	3	Native	Vulnerable	RDB3	0	
1.263756	103.811376	T0402	<i>Hypserpa nitida</i>		Climber, Vine & Liana	0.05	1		Native	Endangered	RDB3	0	
1.263729	103.811322	T0403	<i>Hypserpa nitida</i>		Climber, Vine & Liana	0.05	5		Native	Endangered	RDB3	0	large cluster
1.263753	103.811463	T0404	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	2.5	24	16	Non-native	Naturalised	Lindsay (2022)	1	
1.263822	103.811457	T0405	<i>Memecylon edule</i>		Shrub	0.3	8	4	Native	Endangered	Lindsay (2022)	1	cluster of four
1.263662	103.811482	T0406	<i>Planchonella obovata</i>	Sea gutta, Menasi	Tree	0.6	14	6	Native	Least Concern	RDB3	1	cluster of two

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263703	103.811431	T0407	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.2	3	2	Native	Vulnerable	RDB3	0	
1.263652	103.811512	T0408	<i>Syzygium palembanicum</i>		Tree	0.2	8	5	Native	Vulnerable	RDB3	0	
1.263719	103.811505	T0409	<i>Elaeis guineensis</i>	Oil palm, Macaw fat	Palm, Solitary Palm	2.5	12	12	Non-native	Casual	Lindsay (2022)	1	
1.263753	103.811496	T0410	<i>Ixora congesta</i>	Malayan ixora, Jarum-jarum	Shrub, Tree	0.05	1.5	1.5	Native	Least Concern	RDB3	1	cluster of seven
1.263776	103.811543	T0411	<i>Memecylon edule</i>		Shrub	0.3	4	2	Native	Endangered	Lindsay (2022)	1	
1.26375	103.811633	T0412	<i>Acacia auriculiformis</i>	Acacia-tree, Earleaf acacia	Tree	3	18	8	Non-native	Naturalised	Lindsay (2022)	1	cluster of two
1.263735	103.811642	T0413	<i>Caryota mitis</i>	Fishtail palm, Common fishtail palm	Cluster Palm, Palm	1.5	5	8	Native	Least Concern	RDB3	1	
1.263757	103.811686	T0414	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	1.2	16	10	Non-native	Naturalised	Lindsay (2022)	1	
1.263744	103.811725	T0415	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	2	16	10	Non-native	Naturalised	Lindsay (2022)	1	

Terrestrial Flora Baseline Survey Results

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263834	103.811623	T0416	<i>Memecylon edule</i>		Shrub	0.2	4	3	Native	Endangered	Lindsay (2022)	1	
1.263855	103.811606	T0417	<i>Baphia nitida</i>	Camwood, African sandlewood	Shrub	0.05	0.3	0.3	Non-native	Casual	Lindsay (2022)	1	
1.263876	103.811632	T0418	<i>Myrsine capitellata</i>	Kicar, Kicar-kicar	Tree, Shrub	0.05	3	2	Native	Endangered	RDB3	1	
1.263937	103.81161	T0419	<i>Linostoma pauciflorum</i>		Climber, Vines	0.05	1	1	Native	Endangered	RDB3	0	cluster of seven
1.263927	103.811612	T0420	<i>Memecylon edule</i>		Shrub	0.4	6	4	Native	Endangered	Lindsay (2022)	1	
1.264018	103.81173	T0421	<i>Ardisia elliptica</i>	Seashore ardisia, Mata pelandok	Tree, Shrub	0.05	0.5	0.5	Native	Least Concern	RDB3	1	
1.263833	103.811854	T0422	<i>Memecylon edule</i>		Shrub	0.3	6	4	Native	Endangered	Lindsay (2022)	1	cluster of seven
1.263836	103.811848	T0423	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	1.4	16	10	Non-native	Naturalised	Lindsay (2022)	1	
1.263807	103.811911	T0424	<i>Memecylon edule</i>		Shrub	0.5	7	5	Native	Endangered	Lindsay (2022)	1	cluster of three
1.263799	103.811882	T0425	<i>Adenanthera pavonina</i>	Saga, Coral bean tree	Tree	1.7	16	10	Non-native	Naturalised	Lindsay (2022)	1	

Latitude	Longitude	Flora ID	Scientific Name	Common Name	Growth Form	Girth (m)	Height (m)	Canopy (m)	Origin	National Status	Source	Cultivated	Comments
1.263824	103.811845	T0426	<i>Baphia nitida</i>	Camwood, African sandlewood	Shrub	0.05	2		Non-native	Casual	Lindsay (2022)	1	
1.263814	103.811827	T0427	<i>Memecylon edule</i>		Shrub	0.5	7	5	Native	Endangered	Lindsay (2022)	1	cluster of two
1.263746	103.811824	T0428	<i>Olea brachiata</i>	Sea olive	Tree, Shrub	0.05	2	2	Native	Vulnerable	RDB3	0	cluster of five

APPENDIX F – Terrestrial Fauna

Baseline Survey Results

F Terrestrial Fauna Baseline Survey Results

F.1 Overall Terrestrial Fauna List

Table F.1 List of species found during terrestrial faunal surveys on Keppel Island

Group	Species		Survey Location			Conservation Status	
	Scientific Name	Common Name	RP01	RP02	Transect	IUCN	RDB3
Bird	<i>Acridotheres javanicus</i>	Javan Myna	✓	✓		VU	NA
Bird	<i>Aegithina tiphia</i>	Common Iora	✓			LC	LC
Bird	<i>Aerodramus sp</i>	Swiftlet sp	✓	✓		NA	NA
Bird	<i>Aplonis panayensis</i>	Asian Glossy Starling	✓		✓	LC	LC
Bird	<i>Cacomantis merulinus</i>	Plaintive Cuckoo		✓		LC	LC
Bird	<i>Caprimulgus macrurus</i>	Large-tailed Nightjar		✓	✓	LC	LC
Bird	<i>Cinnyris jugularis</i>	Olive-backed Sunbird	✓	✓		LC	LC
Bird	<i>Copsychus saularis</i>	Oriental Magpie-Robin	✓	✓	✓	LC	VU
Bird	<i>Corvus splendens</i>	House Crow	✓	✓	✓	LC	NA
Bird	<i>Dicaeum cruentatum</i>	Scarlet-backed Flowerpecker	✓	✓		LC	LC
Bird	<i>Dinopium javanense</i>	Common Flameback	✓			LC	LC
Bird	<i>Eudynamys scolopaceus</i>	Asian Koel		✓		LC	LC
Bird	<i>Gallus gallus</i>	Red Junglefowl	✓	✓	✓	LC	NT
Bird	<i>Geopelia striata</i>	Zebra Dove			✓	LC	LC
Bird	<i>Halcyon smyrnensis</i>	White-throated Kingfisher	✓			LC	LC
Bird	<i>Haliaeetus leucogaster</i>	White-bellied Sea Eagle		✓		LC	LC
Bird	<i>Haliastur indus</i>	Brahminy Kite		✓		LC	LC

Group	Species		Survey Location			Conservation Status	
	Scientific Name	Common Name	RP01	RP02	Transect	IUCN	RDB3
Bird	<i>Hirundo tahitica</i>	Pacific Swallow	✓			LC	LC
Bird	<i>Loriculus galgulus</i>	Blue-crowned Hanging Parrot	✓	✓		LC	LC
Bird	<i>Merops viridis</i>	Blue-throated Bee-eater	✓	✓	✓	LC	LC
Bird	<i>Mixornis gularis</i>	Pin-striped Tit-Babbler			✓	LC	LC
Bird	<i>Muscicapa dauurica</i>	Asian Brown Flycatcher	✓			LC	LC
Bird	N.A.	Tern sp		✓		NA	NA
Bird	<i>Oriolus chinensis</i>	Black-naped Oriole	✓	✓	✓	LC	LC
Bird	<i>Orthotomus ruficeps</i>	Ashy Tailorbird		✓	✓	LC	LC
Bird	<i>Orthotomus sutorius</i>	Common Tailorbird	✓	✓	✓	LC	LC
Bird	<i>Psilopogon lineatus</i>	Lineated Barbet	✓	✓	✓	LC	NA
Bird	<i>Psittacula longicauda</i>	Long-tailed Parakeet	✓			VU	NT
Bird	<i>Psittacula sp</i>	Parakeet sp			✓	NA	NA
Bird	<i>Pycnonotus goiavier</i>	Yellow-vented Bulbul	✓	✓	✓	LC	LC
Bird	<i>Pycnonotus zeylanicus</i>	Straw-headed Bulbul	✓			CR	EN
Bird	<i>Spilopelia chinensis</i>	Spotted Dove	✓	✓	✓	LC	LC
Bird	<i>Todiramphus chloris</i>	Collared Kingfisher	✓	✓		LC	LC
Bird	<i>Treron vernans</i>	Pink-necked Green Pigeon	✓	✓	✓	LC	LC
Mammal (non-volant)	<i>Felis catus</i>	Domestic Cat	✓	✓	✓^	NA	NA
Mammal (non-volant)	<i>Paradoxurus musangus</i>	Sumatran Palm Civet				LC	LC
Mammal (non-volant)	<i>Rattus sp</i>	Rat sp			✓^	NA	NA
Mammal (non-volant)	<i>Suncus murinus</i>	House Shrew		✓		LC	LC

Group	Species		Survey Location			Conservation Status	
	Scientific Name	Common Name	RP01	RP02	Transect	IUCN	RDB3
Mammal (Bat)	<i>Pipistrellus stenopterus</i>	Narrow-winged Pipistrelle		✓		LC	LC
Mammal (Bat)	<i>Saccolaimus saccolaimus</i>	Pouched Tomb Bat	✓	✓	✓	LC	LC
Mammal (Bat)	<i>Scotophilus kuhlii</i>	Lesser Asian House Bat	✓	✓	✓	LC	LC
Amphibian	<i>Duttaphrynus bengalensis</i>	Asian Toad	✓		✓	LC	NA
Amphibian	<i>Eleutherodactylus planirostris</i>	Greenhouse Frog		✓	✓	LC	NA
Amphibian	<i>Polypedates leucomystax</i>	Common tree frog				LC	LC
Reptile	<i>Calotes versicolor</i>	Changeable lizard				LC	NA
Reptile	<i>Dendrelaphis pictus</i>	Painted Bronzeback		✓		LC	LC
Reptile	<i>Gekko monarchus</i>	Spotted house gecko			✓	LC	LC
Reptile	<i>Hemidactylus frenatus</i>	Common House Gecko	✓	✓		LC	LC
Reptile	<i>Lycodon capucinus</i>	Common House Snake			✓	LC	LC
Butterfly	<i>Acraea terpsicore</i>	Tawny Coster		✓		NA	LC
Butterfly	<i>Catopsilia scylla cornelia</i>	Orange Emigrant		✓		NA	LC
Butterfly	<i>Delias hyparete metarete</i>	Painted Jezebel		✓	✓	NA	LC
Butterfly	<i>Eurema sp</i>	Grass Yellow sp			✓	NA	NA
Butterfly	<i>Junonia hedonia ida</i>	Chocolate Pansy			✓	NA	LC
Odonate	<i>Thylomis tillarga</i>	White-barred Duskhawk			✓	LC	LC

APPENDIX G – Soil Investigation Report

Final Report

G Soil Investigation Report



Soil Investigation Report

SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND

Contract No. : 3040-0100002-0001-EGT-LOA

Prepared for

KEPPEL BAY PTE LTD

Marina at Keppel Bay
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24 January 2024

Prepared by:

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**SOIL INVESTIGATION WORK FOR PROPOSED
DEVELOPMENT AT PLOT 6
AT KEPPEL ISLAND**

Contract No: 3040-0100002-0001-EGT-LOA

Location: Keppel Island

SOIL INVESTIGATION REPORT

Client : Keppel Bay Pte Ltd

Contractor : Element Geotechnical Testing (S) Pte Ltd

	Revision No. : 0	Date : 24 January 2024
Prepared by : Khin Ei Ei Soe	Reviewed by : Nel Cortes	



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Certification by Professional Engineer for Soil Investigation Report

1. I, Er. Tan Chin Gee the Professional Engineer, PE Registration No. 3448 certify the Soil Investigation Report for Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island comprising all field and laboratory data, tests and results therein has been carried out by me or under my supervision or direction, and I have verified the accuracy of the information given in the soil investigation report, and to the best of my knowledge and belief, all have been prepared in compliance in all respects with the provisions of the Building Control Act and Regulations, relevant Codes and Practice and Standards.

2. I further certify that I have the appropriate qualifications and experience, and I am familiar with the purpose of the investigation for which this Soil Investigation Report is prepared in reference to Project Ref. No. 3040-0100002-0001-EGT-LOA.

3. Total number of pages in the Soil Investigation Report is 321.



Professional Engineer
Signature and Stamp

Date 24/1/2024

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1.0 INTRODUCTION

ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd has been appointed by the client, Keppel Bay Pte Ltd to provide Soil Investigation Work for Proposed Development at Plot 6 at Keppel Island. The works described in this report have been carried out as per specification and under the technical direction of the Client.

The particulars of this project are as follows:

Project Title	:	Soil Investigation Work for Proposed Development at Plot 6 at Keppel Island
Location	:	Keppel Island
Client	:	Keppel Bay Pte Ltd
Contractor	:	ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd
Period of Work	:	Field Works ➤ 7 September 2023 to 22 December 2023
Scope of Work	:	Soil Drilling (16 Boreholes) In-situ Testing ➤ Standard Penetration Test Sampling ➤ Disturbed Sampling ➤ Undisturbed Sampling Laboratory Testing Reporting

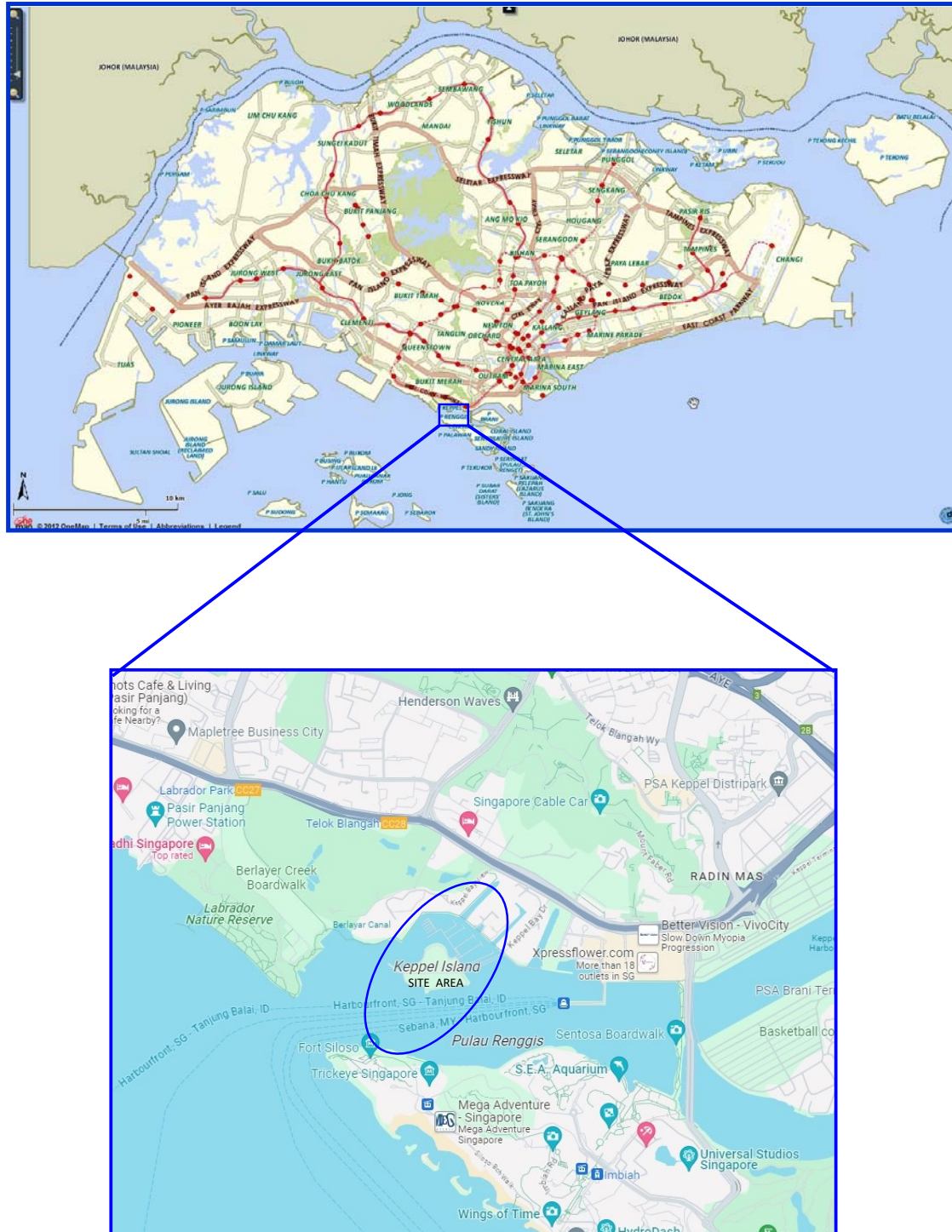
SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND/ KEPPEL ISLAND

2.0 LOCATION OF SITE

The Project site is located at Keppel Island.

The location of site is shown below in **Figure 1.1**.

Figure 1.1 SITE LOCATION MAP



SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND/ KEPPEL ISLAND

2.1 LOCATION OF BOREHOLES

The Sixteen (16) number of Soil Investigation boreholes location is shown in **APPENDIX A**, Boreholes location details are summarized below in **Table 2.1**.

Table 2.1 Boreholes Location of Land and Marine SI Borehole Details

Borehole No.	Coordinates (SVY 21)		Ground Level (m SHD)
	Northing	Easting	
BH-01/WSP	27335.077	25474.006	3.904
BH-02	27322.315	25518.287	3.849
BH-03/PZ	27323.394	25579.066	3.910
BH-04	27291.861	25595.295	3.651
BH-05/WSP	27316.497	25618.692	3.864
BH-06	27307.896	25656.639	3.757
BH-07/WSP	27324.334	25695.587	3.972
BH-09/PZ	27309.181	25474.624	3.812
BH-10	27280.221	25508.005	3.669
BH-11/WSP	27298.036	25548.936	3.755

Borehole No.	Coordinates (SVY 21)		Sea bed Level (m SHD)
	Northing	Easting	
BH-08	27317.038	25746.149	-2.952
BH-12	27272.932	25547.737	-2.752
BH-13	27276.992	25629.346	-5.352
BH-14	27267.502	25650.919	-9.652
BH-15	27287.931	25720.901	-5.152
BH-16	27298.845	25758.099	-6.152

3.0 SCOPE OF WORK

3.1 GENERAL

The scope of the fieldworks was specified by the Engineer and was undertaken in general accordance with Eurocodes - BS 5930: 2015 "Code of Practice for Site Investigation". The soil investigation service of this project is summarized as follows:

Drilling a total Sixteen (16) exploratory boreholes and including with standard penetration test at every 3.00m interval.

- ❖ All boreholes were terminated as per instruction given by the engineer.
- ❖ Submission of three (3) copies of final report (including one (1) CD containing the report) duly endorsed by Professional Engineer.

Soil and rock logging has been undertaken in accordance with the relevant Eurocodes – BS 5930: 2015, Listed in the references for this report.

3.2 DESCRIPTION OF FIELD INVESTIGATION

3.2.1 DRILLING

The boreholes were drilled by rotary wash boring method. Drilling fluid was pumped down via the hollow drilling rods and cutting bit to wash out the soil remnants. The diameter of the borehole is 100mm.

All boreholes were backfilled with cement / bentonite grout upon completion of drilling.

A summary of the field investigation works and laboratory tests is listed in **Table 1**. Detailed boring logs are presented in **APPENDIX B**.

3.2.2 ROCK CORING (DIAMOND DRILLING)

An NMLC (triple tube) diamond annular bit, fixed to the bottom of the outer rotating tube of a rotary core barrel cuts **52mm** diameter cores, which is retained within the inner stationary tube of the core barrel and brought to the surface for examination and testing.

All description and logging is in general accordance with Eurocodes - BS EN ISO 14689-1:2003. Besides linear core recovery, a determination of Rock Quality Designation (RQD, which is defined as percentage of rock recovered as sound lengths which are 100mm or more in length) as a quantitative measure of the fracture state of the rock is given. It is to be noted that the RQD is not the only criteria to assess the strength of the rock mass.

Rock cores recovered were logged and subsequently delivered to geotechnical contractor's office to be photographed. Upon completion of the photography and chosen samples for testing, the remaining core samples were properly placed in a store. Core Photographs are presented in **APPENDIX E**.

3.2.3 IN-SITU TESTING

3.2.3.1 STANDARD PENETRATION TESTING

Standard penetration tests were carried out at intervals of **3.00m** interval of below ground level and test were carry out in accordance to BS EN ISO 22476-3:2005+A1:2011. The SPT test serves the following purposes:

- a) to determine the relative density or consistency of soils, and
- b) to recover disturbed samples for visual inspection.

This empirical dynamic penetration test determines the resistance of soils to the penetration of a split barrel sampler of 50mm external diameter, driven by a 65 kg automatic drop hammer, allowing a free fall of 760mm. The penetration resistance, N is the number of blows required to effect a 300mm penetration below the seating drive which is, for this project, taken as completed at 25 blows or 150mm penetration.

The values of N obtained in this investigation are recorded in borehole logs attached in the **APPENDIX B**.

3.2.3.2 PRESSUREMETER TEST (OYO)

The pressuremeter test was performed to determine the deformability and strength properties of soil at depth specified by the Client. The apparatus used was OYO Elastmeter-2 with a maximum capacity of 200kg/cm² and comprised of the probe, the Elastmeter-2 indicator and pressure unit. Two types of probe (rubber membrane) are applicable for tests upon the strength of the soil. Medium rubber membrane is used in the soil of SPT N-value <50 blows/30cm and hard rubber is used for the soil of SPT N-value >50 blows per 30 cm.

The probe and pressure were calibrated before the first testing of any one borehole and was then lowered into the predetermined testing depth. The test was commenced by inflating the probe with water. The pressure was increased at an interval of 2 minutes with radius readings monitored at 30, 60 and 120 seconds. When a constant creep was noted, the pressure was unloaded and again reloaded to failure or when the maximum capacity of the Pressuremeter or radius of Rubber Membrane was reached. The test is terminated by releasing the pressure at a minimum of 6 pressure decrement to zero pressure.

After calculating $P' = P - P_g$, where P' = corrected pressure; P = reading from pressure gauge; P_g = correction value (thickness correction volume of rubber tube), draw the graph of pressure (P') against radius (R_o) containing all calibrations, the following can be derived: P_o - At-Rest Earth Pressure ; P_y - Yield Pressure.

The coefficient of soil reaction can be calculated as follows:

$$K_m = \Delta p / \Delta r$$

The pressuremeter modulus, E_m can be calculated as follows:

$$E_m = (1 + \mu) \cdot K_m \cdot R_m$$

where μ = Poisson's Ratio (Assumed to be 0.33)

SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND/ KEPPEL ISLAND

Km	=	Coefficient of Soil Reaction
	=	Gradient of straight portion of loading curve
Rm	=	Mean radius used in Km value calculation

The pressuremeter cyclic modulus, K_r & E_r are also interpreted for the unload-reload loop.

The results are tabulated in the following table and data sheets are attached in **APPENDIX E**.

3.2.4 Soil Sampling

3.2.4.1 UNDISTURBED SAMPLER (THIN WALL)

Undisturbed Samples were carry out in accordance with BS EN ISO 22475-1:2006, open tube of 75mm diameter, having a sharp cutting edge at its lower end was pushed into the soil at the bottom of the boring by hydraulic means. Thin-Wall sampler is generally used for sampling soft to stiff soils. After a sample was retrieved from borehole, it was immediately labeled and sealed with wax at both ends before sending to laboratory.

3.2.4.2 DISTURBED SAMPLES (SPT)

Disturbed samples were taken from the drill tools or from a split tube sampler for identification purpose, and were stored in sealed plastic containers.

3.2.5 INSTALLATION OF WATER STANDPIPE AND CASAGRANDE PIEZOMETER

Grout the existing terminated borehole till the specified installation depth and wait for grout set. Lower down the water standpipe to the required depth. Water standpipe consists of 50 mm diameter PVC Pipe. 3-mm holes will be allocated at the spacing of 25 mm along the pipe. This perforated section at the lower end of the pipe up to 2/3 of total length and covered by geo-fabric cloth (green net). Place sand covering the perforated section. Withdraw all borehole casings once the water standpipe has been firmly put into place meter by meter. Place the rest of the remaining borehole with bentonite and cement grout until the top of the borehole reaching the ground level. Install protective box to cover the top of the water standpipe.

A drilling rig will be used to drill 100mm diameter borehole at the proposed location to 0.50m below the required installation depth. After drilling of borehole (100mm diameter) to required depth, measure length of HW casing protruding from ground Level and PVC pipe length required. The piezometer tip consists of a porous ceramic element of 290mm length with a diameter of 33mm and protected at each end by PVC fittings. The ceramic filter was soaked in clean water for 24 hours to assemble of the piezometer element. The PVC pipes 20mm in diameter and 3m and/or 6m in length with supplementary shorter length as required to suit the standpipe dimension were joined together and to the porous element with approved couplings, glue and installation tapes in such a manner that the joints remained leak proof under the anticipated head of water. Piezometer tip joined with PVC tube was placed inside 1.0m thick of washed clean sand at specified depth. One meter thick of bentonite pellet layer was filled on top of the washed sand layer and was followed by cement/bentonite grout up to ground level. The borehole is grouted until the depth that required installation. 1-m thickness of bentonite seal is placed top of the grout but before intake filter. 1-m of sand intake is added on top of bentonite seal. The piezometer tip which is attached with PVC riser is placed into borehole. Another 1-m of sand filter is added up and followed up 1-m of bentonite seal. The rest of the borehole section is filled with the grout. The depth of the piezometer tip is to be determined in advance by the client.

SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND/ KEPPEL ISLAND

Detailed water standpipe and casagrande piezometer data are presented in **APPENDIX C**.

3.2.6 TERMINATION OF BORING

All the boreholes were terminated as per instruction given by the engineer. Termination depths of boreholes are summarized below in **Table 3.2**.

Table 3.2 Boreholes Termination Depth & SPT

Borehole No.	Termination Depth (m)	Final SPT 'N' Value (blow count/mm)	Remarks
BH-01/WSP	30.00	100/0 @ 19.50m	Encountered rock at 19.50 and coring 10.50m, Installed WSP at 12.00m depth
BH-02	25.00	100/0 @ 9.80m	Encountered rock at 9.80 and coring 12.00m
BH-03/PZ	15.00	100/0 @ 2.00m	Encountered rock at 2.00 and coring 13.00m, Installed PZ at 12.00m depth
BH-04	27.00	100/0 @ 10.00m	Encountered rock at 10.00 and coring 17.00m
BH-05/WSP	22.00	100/0 @ 2.00m	Encountered rock at 2.00 and coring 20.00m, Installed WSP at 12.00m depth
BH-06	15.50	100/0 @ 2.00m	Encountered rock at 2.00 and coring 13.50m
BH-07/WSP	23.00	100/0 @ 2.80m	Encountered rock at 2.80 and coring 20.20m, Installed WSP at 12.00m depth
BH-08	24.50	100/0 @ 14.30m	Encountered rock at 14.30 and coring 10.20m, Marine borehole
BH-09/PZ	20.00	100/0 @ 7.00m	Encountered rock at 7.00 and coring 13.00m, Installed PZ at 12.00m depth
BH-10	36.00	100/0 @ 12.00m	Encountered rock at 12.00 and coring 24.00m
BH-11/WSP	20.00	100/0 @ 10.00m	Encountered rock at 10.00 and coring 10.00m, Installed WSP at 12.00m depth
BH-12	17.30	100/0 @ 2.30m	Encountered rock at 2.30 and coring 15.00m, Marine borehole
BH-13	20.50	100/0 @ 6.50m	Encountered rock at 6.50 and coring 14.00m, Marine borehole
BH-14	38.00	100/0 @ 13.00m	Encountered rock at 13.00 and coring 25.00m, Marine borehole
BH-15	20.50	100/0 @ 9.50m	Encountered rock at 9.50 and coring 11.00m, Marine borehole
BH-16	24.00	100/0 @ 11.00m	Encountered rock at 11.00 and coring 13.00m, Marine borehole

3.3 DESCRIPTION OF LABORATORY TESTING

3.3.1 GENERAL

The laboratory test program is to evaluate the soil properties as scheduled by the Client' Engineer. All soil tests were carried out at SAC-SINGLAS accredited laboratory Geo Lab (S) Pte Ltd (Cert No. LA-2011-0501-B).

The following laboratory tests were conducted on the undisturbed samples recovered from the boreholes:

- * Consolidated Undrained (CU) Triaxial test
- * Unconfined Compression (UC) Test on Rock Core Samples
- * Point Load Test on Rock Core Samples

The testing program aimed towards the evaluation of shear strength, compressibility characteristics and for classification purposes.

The summary and results of tests are provided in **APPENDIX D**.

3.3.2 CODE OF PRACTICE

Unless mentioned otherwise, the following tests were carried out in accordance BS1377:1990 – Part 1 to 9 “Methods of Test for Civil Engineering Purposes”.

3.3.3 STRENGTH AND COMPRESSIBILITY PROPERTIES

3.3.3.1 CONSOLIDATED UNDRAINED (CU) TRIAXIAL TEST

Consolidated Undrained Triaxial Compression test was conducted to determine the effective parameters of the soil. Drainage of the soil specimen is permitted under a specified all-round pressure until consolidation is complete; the principal stress difference is then applied with no drainage being permitted. Pore water pressure measurements are made during the undrained part of the test.

3.3.4 STRENGTH AND COMPRESSIBILITY PROPERTIES ON ROCK SAMPLES

3.3.4.1 UNCONFINED COMPRESSION (UC) TEST ON ROCK CORE SAMPLE

Unconfined compression test was conducted on selected rock core sample to assess the strength characteristic. This is determined by statically loading the cylinder of rock to failure, the load being applied across the upper and lower faces of the sample. The test was conducted in accordance with ASTM D7012-10.

3.3.4.2 POINT LOAD TEST ON ROCK CORE SAMPLE

Point load test on rock core can be conducted diametrically and axially. In diametrical test, rock core specimen of diameter D is loaded between the point load apparatus across its diameter. The length / diameter ratio for the diametrical test should be greater than 1.0. For axial test, rock core is cut to a height between 0.5 D to D and is loaded between the point load apparatus axially.

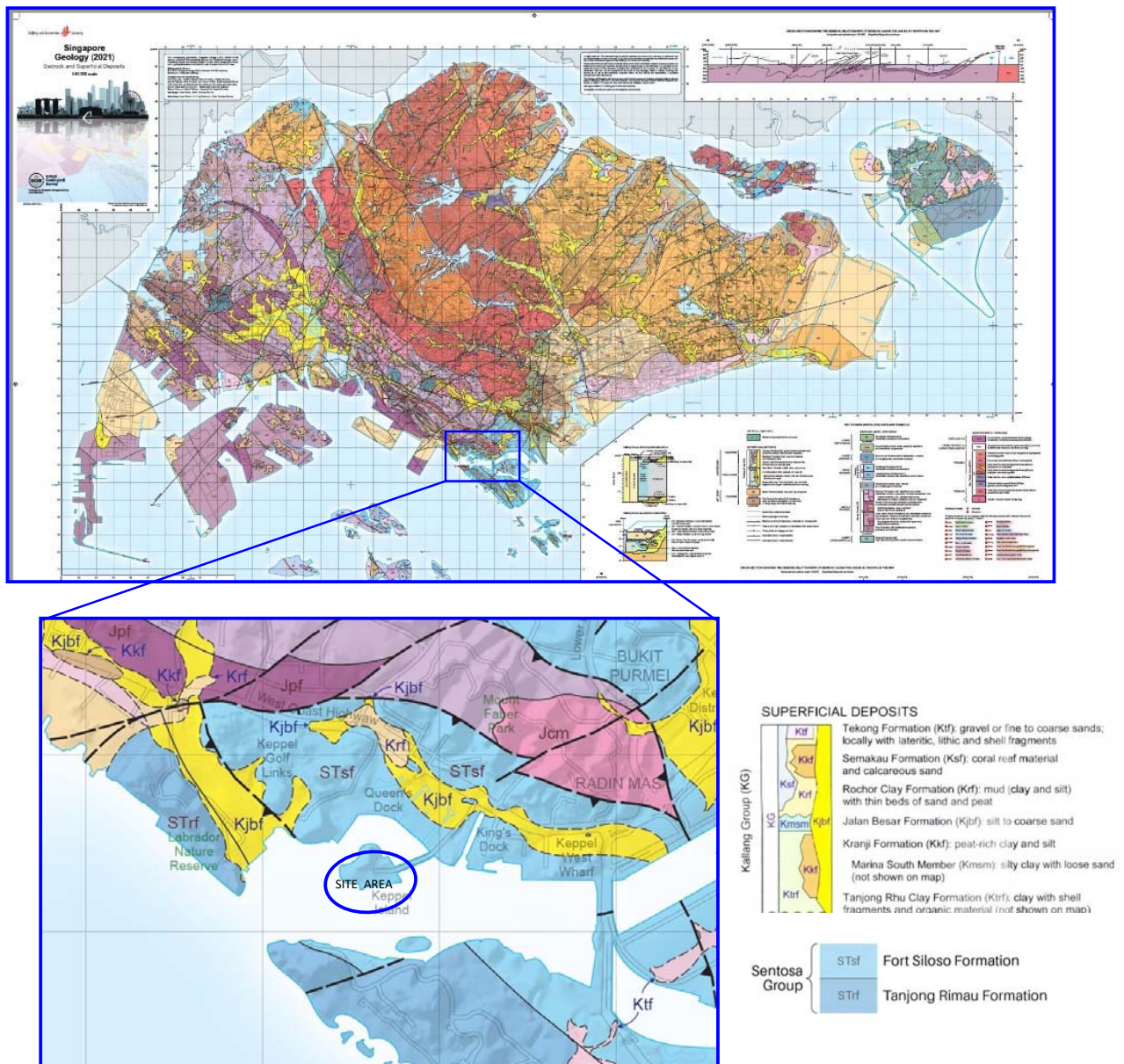
4.0 SITE GEOLOGY & SOIL PROFILE

4.1 GENERAL GEOLOGY OF SITE

The investigation site area lies within the geological formation of **KALLANG GROUP, SENTOSA GROUP; FORT SILOSO FORMATION**.

The following (**Figure 4.1**) shows the approximate site location on the Geological Map extracted from the “Geology Map of Singapore” published by Building and Construction Authority (BCA), Singapore (2021).

Figure 4.1 The Approximate site location on the Geological Map extracted from the “Geological Map of Singapore” published by BCA, 2021



SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND/ KEPPEL ISLAND

4.2 SOIL & ROCK CLASSIFICATION

Soil descriptions contained in this report have been produced in accordance with the procedures and principles given in BS EN ISO 14688-1:2002, BS EN ISO 14688-2:2004 and also where there is no conflict with the European standards, in accordance with BS 5930: 2015. The consistencies of clay / silt and relative densities of sand have been classified according to the following criteria:

Table 4.1 Classification of Clays/Silts from Undrained Shear Strength (C_u) kPa (BS EN ISO 14688-2)

Undrained Shear Strength (kPa)	Consistency (BS5930:1999)	Undrained Shear Strength of Clays (BS EN ISO 14688-2:2004)
< 10	Very Soft	Extremely Low
10 – 20		Very Low
20 – 40	Soft	Low
40 – 75	Firm	Medium
75 – 150	Stiff	High
150 – 300	Very Stiff	Very High
> 300	Hard	Extremely High

Table 4.2 Classification of Clays/Silts from (BS EN ISO 14688 - 1: 2002/Eurocode: 7)

Term	Field Identification
Very Soft	Exudes between finger when squeezed in the hand
Soft	Can be moulded by light finger pressure
Firm	Cannot be moulded, but can be rolled into 3mm thick thread
Stiff	Crumbles when rolled into 3mm thick thread
Very Stiff	Cannot be moulded and crumbles under pressure. Indented by thumbnail

Table 4.3 Classification of Clays/Silts from SPT results (Local Practice extracted from Terzaghi and Peck)

Approximate Relation of Consistency to SPT	
N-Value (blows / 300mm of penetration)	Consistency
< 2	Very Soft
2 – 4	Soft
4 – 8	Firm
8 – 15	Stiff
15 – 30	Very Stiff
> 30	Hard

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Table 4.4 Classification of Sands from SPT results (BS5930: 2015 / Eurocode: 7)

For granular deposits relative density may only be determined by the Standard Penetration Test (SPT).

Approximate Relation of Relative Density to SPT	
N-Value (blows/300mm of penetration)	Consistency
< 4	Very Loose
4 – 10	Loose
10 – 30	Medium Dense
30 – 50	Dense
> 50	Very Dense

*(The field identification terms for very loose/loose material and dense /very dense material are very subjective and should be treated with caution).

Table 4.5 Terms for description of rock strength (BS5930-2015/ Table25)

Term for use in field or based on measurement	Definition for field use	Definition on basis of Unconfined Compressive Strength Measurements (MPa)
Extremely weak	Can be indented by thumbnail. Gravel sized lumps crush between finger and thumb.	0.6-1.0
Very weak	Crumbles under firm blows with point of geological hammer. Can be peeled by a pocket knife.	1-5
Weak	Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow with the point of geological hammer.	5-25
Medium strong	Cannot be scraped with pocket knife. Can be fractured with a single firm blow of geological hammer.	25-50
Strong	Requires more than one blow of geological hammer to fracture.	50-100
Very strong	Requires many blows of geological hammer to fracture.	100-250
Extremely strong	Can only be chipped with geological hammer.	>250

*(Based on BS EN ISO 14689-1:2003 4.2.7, Table5.)

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Table 4.6 Weathering classification for Old Alluvium
(Rail & Engineering Groups, Civil Design Criteria, Revision A1, 2010)

Class	Classifier	Characteristic	Indicative SPT Blows / 300mm*
A	Unweathered	Original strength	>50 (cannot usually be penetrated by CPTs with 20t load capacity)
B	Partially Weathered	Slightly reduced strength	
C	Distinctly weathered	Further weakened	30 to 50
D	Destructured	Greatly weakened, often mottled, bedding disturbed	10 to 30
E	Residual	No bedding remains	<10

*(Bedok Formation, BCA, 2021 former name as Old Alluvium)

Table 4.7 Classification of Weathered Rock for Engineering Purposes (BS EN ISO 14689-1:2003 / Eurocode: 7)

Approach 2: Classification For Uniform Materials		
Grade	Classifier	Typical Characteristics
I	Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces
II	Slightly Weathered	Discoloration indicates weathering of rock material and discontinuity surfaces
III	Moderately Weathered	Less than half of the rock material is decomposed or disintegrated. Fresh or discolored rock is present either as a continuous framework or as core stones
IV	Highly Weathered	More than half of the rock material is decomposed or disintegrated. Fresh or discolored rock is present either as a discontinuous framework or as core stones
V	Completely Weathered	All rock material is decomposed &/or disintegrated to soil. The original mass structure is still largely intact
VI	Residual Soil	All rock material is converted to soil. The mass structure & material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported

* The SPT result should not be used in isolation to assess weathering, see text above

4.3 BOREHOLE LOGS

Borehole logs, presented in **APPENDIX B**, give a general indication of the soil conditions at each borehole location. The borehole logs show:

- ❖ Soil description
- ❖ Stratum changes
- ❖ SPT results
- ❖ General information such as borehole coordination, level, sample reference, etc.

In the borehole logs, the consistency/ density of the subsoil are based on SPT N-values of soils.

SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND/ KEPPEL ISLAND

4.4 SUBSOIL DESCRIPTION

The present site investigation report is mainly based on the “*Code of practice for Ground investigations*”, British Standard BS5930: 2015, “*Eurocode 7: Geotechnical design*” – Part 2 : Ground investigation and testing SS EN 1997-2: 2010, “*Geotechnical Investigation and Testing – Identification and classification of Soil*” Part 1: Identification and description BS EN ISO 14688 – 1:2003, “*Geotechnical Investigation and Testing – Identification and classification of Soil*” Part 2: Principles for a classification BS EN ISO 14688 – 2:2004, “*Geotechnical Investigation and testing- Field testing*” BS EN ISO 22476-3:2005 + A1:2011, “*Geotechnical Investigation and testing – Identification and classification of rock*” Part 1: Identification and description BS EN ISO 14689-1:2003, “*Methods of Test for Soils For Civil Engineering Purposes*” British Standards Institution BS 1377: 1990: Part 1 to 9, “*Civil Design Criteria for Road and Rail Transit Systems*”, Revision A6, Rail & Engineering groups, LTA, Singapore and “*Geology of Singapore*”, 2021, BCA, Singapore.

In the borehole logs, the consistency/density of the subsoil was based on **SPT N-values** and **Core Samples**.

Based on the borehole data, visual classification, the underlying sub-soils can be sub-divided into the following layers:

- RECONSTITUTED GROUND
- KALLANG GROUP
- SENTOSA GROUP; FORT SILOSO FORMATION

4.4.1 Reconstituted Ground

This layer is consists of Sandy SILT, Silty SAND, Asphalt, Tar and Concrete.

This layer was observed in (15) boreholes with thickness range from **1.00 to 3.30m**.

Details are summarizes below in table.

BOREHOLE	DEPTH (m)		THICKNESS (m)	SPT 'N' Value		SOIL TYPE
	Top (m)	Bottom (m)		minimum	maximum	
BH-01/WSP	0.00	3.30	3.30			Sandy SILT, Silty SAND
BH-02	0.00	1.00	1.00			Sandy SILT, Silty SAND, Asphalt, Tar
BH-03/PZ	0.00	1.50	1.50			Concrete
BH-04	0.00	1.80	1.80			Gravelly sandy SILT, asphalt concrete
BH-05/WSP	0.00	1.20	1.20			Silty SAND

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BOREHOLE	DEPTH (m)		THICKNESS (m)	SPT 'N' Value		SOIL TYPE
	Top (m)	Bottom (m)		minimum	maximum	
BH-06/PZ	0.00	1.50	3.30			Silty SAND, Asphalt, Tar
BH-07/WSP	0.00	2.50	1.00			Sandy SILT
BH-08	1.30	2.80	1.50			Sandy SILT mixed with shell fragments
BH-09/PZ	0.00	2.50	1.80			Sandy SILT
BH-10	0.00	1.00	1.20			Sandy SILT, Asphalt ,Tar
BH-11/WSP	0.00	1.00	1.50			Silty SAND, Asphalt, Tar
BH-12	1.10	2.30	2.50			Silty SAND
BH-13	3.70	4.00	1.50			Sandy SILT
BH-15	3.50	4.00	2.50			Sandy SILT
BH-16	4.50	7.50	1.00			Sandy SILT

4.4.2 KALLANG GROUP

4.4.2.1 ROCHOR CLAY FORMATION (Krf) (UPPER Mc)

The formation comprises soft, blue-grey mud (clay and silt) with thin beds of sand and peat. In addition, fragments of bivalve and gastropod shells are relatively common. This formation was previously referred to as the (Kallang Formation - Upper Marine Clay Member).

This layer was observed in only one borehole (Thin Wall Sample) with thickness **0.90m**.

Details are summarized below in table.

BOREHOLE	DEPTH (m)		THICKNESS (m)	SPT 'N' Value		SOIL TYPE
	Top (m)	Bottom (m)		minimum	maximum	
BH-14	8.00	8.90	0.90			Marine CLAY

SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND/ KEPPEL ISLAND

4.4.3 SENTOSA GROUP;

FORT SILOSO FORMATION

The soil and rock samples, retrieved from the boreholes indicated the occurrence of “Sentosa Group; Fort Siloso Formation”. In this formation mainly composed of dark purplish red to dark red and light grey, SILTSTONE interbedded with fine to medium grained SANDSTONE.

4.4.3.1 RESIDUAL SOIL (S VI)

The Residual Soils are composed of dark reddish purple to Reddish brown and light grey, hard, sandy SILT and dense to very dense, light grey to yellowish brown, Silty SAND.

This layer was observed in (12) boreholes with thickness range from **0.30 to 4.50m**. SPT N value range in this layer was from **4 to 100**.

Details are summarizes below in table.

BOREHOLE	DEPTH (m)		THICKNESS (m)	SPT 'N' Value		SOIL TYPE
	Top (m)	Bottom (m)		minimum	maximum	
BH-01/WSP	3.30	6.00	2.70	25	37	Sandy SILT, Silty SAND
BH-02	1.00	4.50	3.50	73	73	Sandy SILT, Silty SAND
BH-04	1.80	3.00	1.20			Sandy SILT, Silty SAND
BH-05/WSP	1.20	2.00	0.80			Silty SAND
BH-06/PZ	1.50	2.00	0.50			Sandy SILT
BH-07/WSP	2.50	2.80	0.30			Silty SAND
BH-08	2.80	5.80	3.00	30	33	Sandy SILT
BH-09/PZ	2.50	7.00	4.50	5	40	Sandy SILT, Silty SAND
BH-10	1.00	5.50	4.50	4	4	Sandy SILT
BH-11/WSP	1.00	2.50	1.50			Sandy SILT
BH-13	4.00	5.50	1.50	100	100	Sandy SILT
BH-14	8.90	12.00	3.10	7	39	Sandy CLAY

SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND/ KEPPEL ISLAND

4.4.3.2 COMPLETELY WEATHERED (S V)

The Completely Weathered Sedimentary Rocks (S V) were composed of Reddish brown and light grey, very dense, Silty fine SAND and hard, sandy SILT.

This layer was observed in (11) boreholes with thickness range from **0.50 to 13.50m**. SPT N value range in this layer was from **9 to 100**.

Details are summarized below in the table.

BOREHOLE	DEPTH (m)		THICKNESS (m)	SPT 'N' Value		SOIL TYPE
	Top (m)	Bottom (m)		minimum	maximum	
BH-01/WSP	6.00	19.50	13.50	65	100	Slightly silty fine SAND
BH-02	4.50	9.80	5.30	100	100	Slightly fine sandy SILT
	13.80	17.00	3.20	100	100	Sandy SILT
BH-03/PZ	1.50	2.00	0.50	100	100	Sandy SILT
BH-04	3.00	10.00	7.00	100	100	Sandy SILT
BH-08	5.80	14.30	8.50	100	100	Slightly fine sandy SILT
BH-10	5.50	12.00	6.50	9	100	Fine to medium sandy SILT
BH-11/WSP	2.50	10.00	7.50	74	100	Sandy SILT
BH-13	5.50	6.50	1.00	100	100	Slightly sandy SILT
BH-14	12.00	13.00	1.00	66	100	Sandy CLAY
BH-15	4.00	9.50	5.50	90	100	Slightly fine sandy SILT
BH-16	7.50	11.00	3.50	94	100	Fine to medium sandy SILT

SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND/ KEPPEL ISLAND

4.4.3.3 HIGHLY WEATHERED SEDIMENTARY ROCK (S IV)

The **Highly Weathered Sedimentary Rocks(S IV)** encountered as SANDSTONE and SILTSTONE layer in (15) boreholes. This layer was encountered depth between **2.00m to 27.00m**.

Details are summarizes below in table.

BOREHOLE	DEPTH (m)		THICKNESS (m)	RQD (%)	ROCK TYPE
	Top (m)	Bottom (m)			
BH-02	17.00	19.00	2.00	0	SANDSTONE
BH-03/PZ	2.00	9.00	7.00	0-20	SANDSTONE
BH-04	10.00	22.00	12.00	0-39	SANDSTONE
BH-05/WSP	2.00	17.30	15.30	0-45	SANDSTONE
BH-06/PZ	7.00	8.00	1.00	0	SANDSTONE
	9.00	15.50	6.50	0-30	SANDSTONE, SILTSTONE
BH-07/WSP	2.80	14.80	12.00	0-55	SANDSTONE
BH-08	14.30	24.50	10.20	0-60	SANDSTONE, SILTSTONE
BH-09/PZ	7.00	10.00	3.00	10-30	SANDSTONE
	12.00	15.00	3.00	0-18	SANDSTONE
BH-10	12.00	16.00	4.00	0-65	SANDSTONE
	17.00	18.00	1.00	13	SANDSTONE
	25.00	26.00	1.00	0	SANDSTONE, SILTSTONE
BH-11/WSP	10.00	19.00	9.00	0-25	SANDSTONE
BH-12	3.00	4.30	1.30	0	SILTSTONE
	10.70	12.30	1.60	0	SILTSTONE
	16.60	17.30	0.70	0	SANDSTONE
BH-13	6.50	8.50	2.00	0	SILTSTONE
	13.50	15.50	2.00	18-20	SILTSTONE
BH-14	13.00	15.00	2.00	0-10	SILTSTONE
	16.00	18.40	2.40	0-30	SANDSTONE
	22.00	25.00	3.00	20-50	SILTSTONE
	27.00	27.40	0.40		SILTSTONE
BH-15	9.50	14.50	5.00	0-25	SANDSTONE

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BOREHOLE	DEPTH (m)		THICKNESS (m)	RQD (%)	ROCK TYPE
	Top (m)	Bottom (m)			
BH-16	11.00	14.50	3.50	0-15	SILTSTONE
	17.00	19.00	2.00	53- 8256	SILTSTONE
	21.00	24.00	3.00	0-20	SILTSTONE

4.4.3.4 MODERATELY WEATHERED SEDIMENTARY ROCK (S III)

The **Moderately Weathered Sedimentary Rocks(S III)** encountered as SANDSTONE and SILTSTONE layer in (15) boreholes. This layer was encountered depth between **2.00m to 27.40m**.

Details are summarizes below in table.

BOREHOLE	DEPTH (m)		THICKNESS (m)	RQD (%)	ROCK TYPE
	Top (m)	Bottom (m)			
BH-01/WSP	19.50	30.00	10.50	0-60	SANDSTONE
BH-02	9.80	13.80	4.00	0-45	SANDSTONE
	19.00	25.00	6.00	0-46	SILTSTONE
BH-03/PZ	9.00	15.00	6.00	0-55	SANDSTONE
BH-04	22.00	27.00	5.00	0-30	SANDSTONE
BH-05/WSP	17.30	22.00	4.70	0-28	SANDSTONE
BH-06/PZ	2.00	7.00	5.00	0-40	SANDSTONE
	8.00	9.00	1.00	35	SANDSTONE
BH-07/WSP	14.80	23.00	8.20	0-35	SANDSTONE
BH-09/PZ	10.00	12.00	2.00	45-70	SANDSTONE
	15.00	20.00	5.00	15-45	SANDSTONE
BH-10	16.00	17.00	1.00	65	SANDSTONE
	18.00	25.00	7.00	0-45	SILTSTONE
	26.00	36.00	10.00	0-45	SILTSTONE
BH-11/WSP	19.00	20.00	1.00	10	SANDSTONE
BH-12	2.30	3.00	0.70	0	SANDSTONE
	4.30	10.70	6.40	0-38	SILTSTONE
	12.30	16.60	4.30	0	SANDSTONE

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BOREHOLE	DEPTH (m)		THICKNESS (m)	RQD (%)	ROCK TYPE
	Top (m)	Bottom (m)			
BH-13	8.50	13.50	5.00	0-23	SANDSTONE
	15.50	20.50	5.00	0-30	SILTSTONE
BH-14	15.00	16.00	1.00	20	SANDSTONE
	18.40	22.00	3.60	0	SILTSTONE
	25.00	27.00	2.00	10	SILTSTONE
	27.40	38.00	10.60	0-40	SILTSTONE
BH-15	14.50	20.50	6.00	0-15	SANDSTONE
BH-16	14.50	17.00	2.50	0-35	SANDSTONE
	19.00	21.00	2.00	15	SANDSTONE

For further details of soil and rock strata, please refer to the borehole log, in- situ test results, laboratory test results and logs of the profile. Detailed boring logs are presented in **APPENDIX B**.

References:

1. BS 5930: 2015, "*Code of Practice for Ground Investigations*", British Standard Institution.
2. SS EN 1997-2: 2010, "*Geotechnical design – Part2*" Ground investigation and testing.
3. BS EN ISO 14688–1:2003, "*Geotechnical Investigation and Testing – Identification and classification of Soil*", Part 1: Identification and description.
4. BS EN ISO 14688–2:2004, "*Geotechnical Investigation and Testing – Identification and classification of Soil*", Part 2: Principles for a classification.
5. BS EN ISO 22476 - 3:2005 + A1:2011, "*Geotechnical Investigation and testing-Field testing*" Part 3: Standard penetration test.
6. BS EN ISO 14689 – 1:2003, "*Geotechnical Investigation and Testing – Identification and classification of Rock*", Part 1: Identification and description.
7. BS 1377:1990: Parts 1 to 9 "*Methods of Test for Soils For Civil Engineering Purposes*". British Standards Institution.
8. DSTA, 2009, Geology of Singapore, 2nd Edition, Defence Science & Technology Agency, Singapore.
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TABLE 1

Summary of Total Quantity of
Field Investigation Works And
Laboratory Tests

TABLE 1 SUMMARY OF TOTAL QUANTITY OF FIELD INVESTIGATION WORKS AND LABORATORY TESTS

CLIENT : Keppel Bay Pte Ltd			PROJECT : Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island														LOCATION : Keppel Island		PROJECT REF. NO. : 3040-0100002-0001-EGT-LOA															
Site	Borehole No. (LAND)	Period of Fieldwork		Noting	Easting	Reduce Level (m SHD)	Total Borehole Depth (m)	Drilling in Soil (m)	Sampling & In-situ Tests						Instrument Installation				LABORATORY TESTS						Rock Test									
		Commenced Date	Completed Date						TW (no.)	TW (Piston) (no.)	MZ (no.)	SPT (no.)	Disturbed sample (no.)	Pressure meter test (no.)	Wave meter test (no.)	Water Sample (no.)	Water Standpipe (no.)	Piezometer (no.)	PVC Shear Box (no.)	Moisture Content (no.)	Bulk/Dry Density (no.)	Particle Density (no.)	Atterberg Limit (no.)	Grain Size Analysis Mech. (no.)		Hydro. (no.)	Conso (no.)	UU (no.)	CU (no.)	CD (no.)	Direct Shear Box Test (no.)	pH Value of soil	Organic Content of soil	Acid Soluble Sulphate
Keppel Island	BH-01WSP	15-Sep-23	21-Sep-23	27335.077	25474.005	3.90	30.00	19.50	2			12	12					1	1															1
	BH-02	25-Oct-23	28-Oct-23	27323.315	25518.287	3.85	25.00	13.00	1			10	10																				1	
	BH-03PZ	14-Oct-23	18-Oct-23	27323.394	25570.066	3.91	15.00	2.00	13.00			1																					1	
	BH-04	30-Sep-23	9-Oct-23	27291.881	25595.295	3.65	27.00	10.00	2			6	6																				1	
	BH-05WSP	19-Sep-23	27-Sep-23	27316.697	25618.692	3.86	22.00	2.00	20.00			1	1					1															1	
	BH-06PZ	20-Oct-23	25-Oct-23	27307.896	25656.639	3.76	15.50	2.00	13.50			1	1																				1	
	BH-07WSP	7-Sep-23	16-Sep-23	27324.334	25606.597	3.97	23.00	2.80	20.20			1	1					1															1	
	BH-09PZ	23-Sep-23	27-Sep-23	27309.181	25474.624	3.81	20.00	7.00	13.00	2		4	4																				1	
	BH-10	10-Oct-23	20-Oct-23	27280.221	25508.005	3.67	36.00	12.00	24.00	2		7	7																				2	
	BH-11WSP	16-Oct-23	19-Oct-23	27298.036	25548.936	3.76	20.00	10.00	10.00	1		6	6					1															1	
TOTAL	10						233.50	80.30	153.20	10	0	49	49	1	0	4	4	3	0	0	0	0	0	0	0	0	1	0	0	1	1	1	6	7

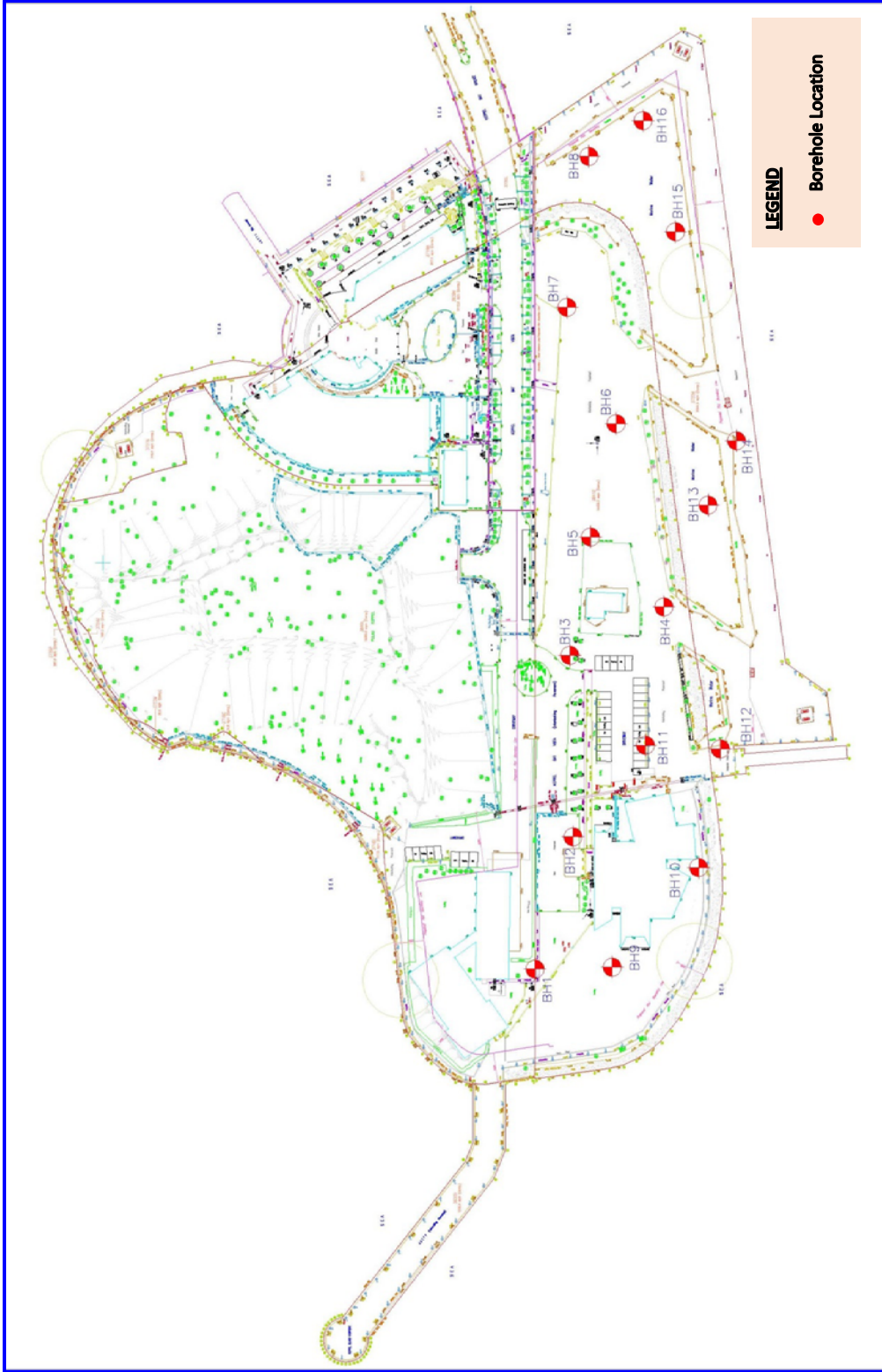
Site	Borehole No. (MARINE)	Period of Fieldwork		Northing	Easting	Sea bed Depth (m SHD)	Total Borehole Depth (m)	Drilling in Soil (m)	Sampling & In-situ Tests							Instrument Installation				LABORATORY TESTS						Rock Test							
		Commenced Date	Completed Date						TW (no.)	TW (Piston) (no.)	MZ (no.)	SPT (no.)	Disturbed sample (no.)	Pressure meter test (no.)	Vane Shear test (no.)	Water Sample (no.)	Water Standpipe (no.)	Piezometer (no.)	PVC Shear Box (no.)	Physical Test			Strength Test				Chemical Test (Soil)						
																				Moisture Content (no.)	Bulk/Dry Density (no.)	Particle Density (no.)	Atterberg Limit (no.)	Grain Size Analysis (no.)	Comp. (no.)		UU (no.)	CU (no.)	CD (no.)	Direct Shear Box Test (no.)	pH Value of soil	Organic Content of soil	Acid Soluble Sulphate
Keppel Island	BH-08	17-Oct-23	23-Oct-23	27317.038	25746.149	-2.95	24.50	14.30	1			9	9																				1
	BH-12	17-Nov-23	22-Nov-23	27272.932	25547.737	-2.75	17.30	2.30				1	1																			1	
	BH-13	8-Nov-23	14-Nov-23	27276.992	25620.346	-5.35	20.50	14.00				2	2																			1	
	BH-14	20-Nov-23	22-Dec-23	27267.502	25650.919	-9.65	39.00	13.00	25.00	1		4	4																			1	
	BH-15	2-Nov-23	6-Nov-23	27287.931	25720.901	-5.15	20.50	9.50	11.00	1		4	4																			1	
	BH-16	25-Oct-23	31-Oct-23	27298.845	25758.089	-6.15	24.00	11.00	13.00	1		4	4																			1	
TOTAL	6						144.80	56.60	88.20	4	0	24	24	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	6	4

APPENDICES

- APPENDIX A** - Borehole Location Plan
- APPENDIX B** - Geological Cross Section & Borehole Logs
- APPENDIX C** - Water Standpipe & Piezometer Monitoring Data
- APPENDIX D** - Field Pressuremeter Test Results
- APPENDIX E** - Laboratory Tests Results
 - * Summary of Laboratory Test Results
 - * Consolidated Undrained (CU) Triaxial Test
 - * Unconfined Compression (UC) Test on Rock Core Samples
 - * Point Load Test on Rock Core Samples
 - * Chemical Test
- APPENDIX F** - Core Samples Photograph
- APPENDIX G** - Hammer Calibration Reports
- APPENDIX H** - Suspension PS Report

APPENDIX A

Borehole Location Plan



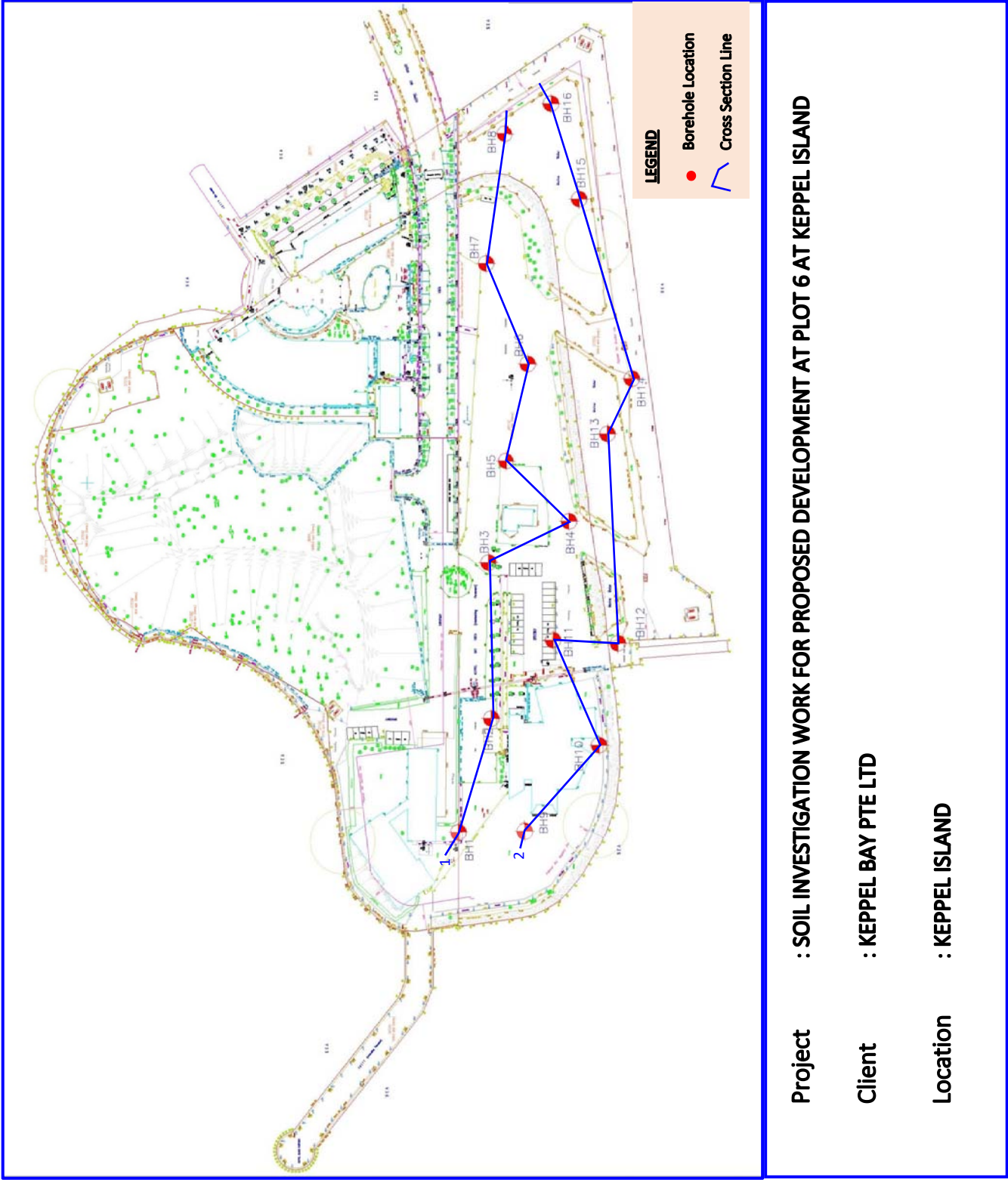
Project : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND

Client : KEPPEL BAY PTE LTD

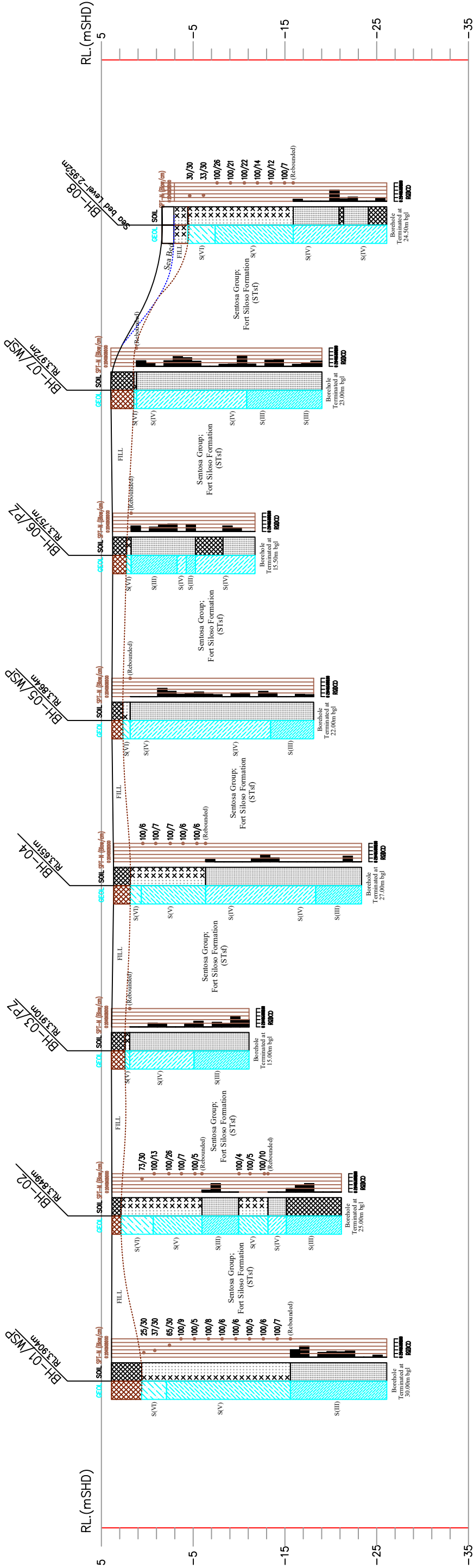
Location : KEPPEL ISLAND

APPENDIX B

Geological Cross Section and Borehole Logs

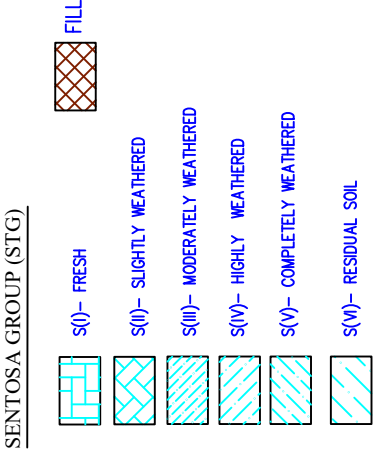


PROBABLE SOIL PROFILE



CROSS-SECTION 1

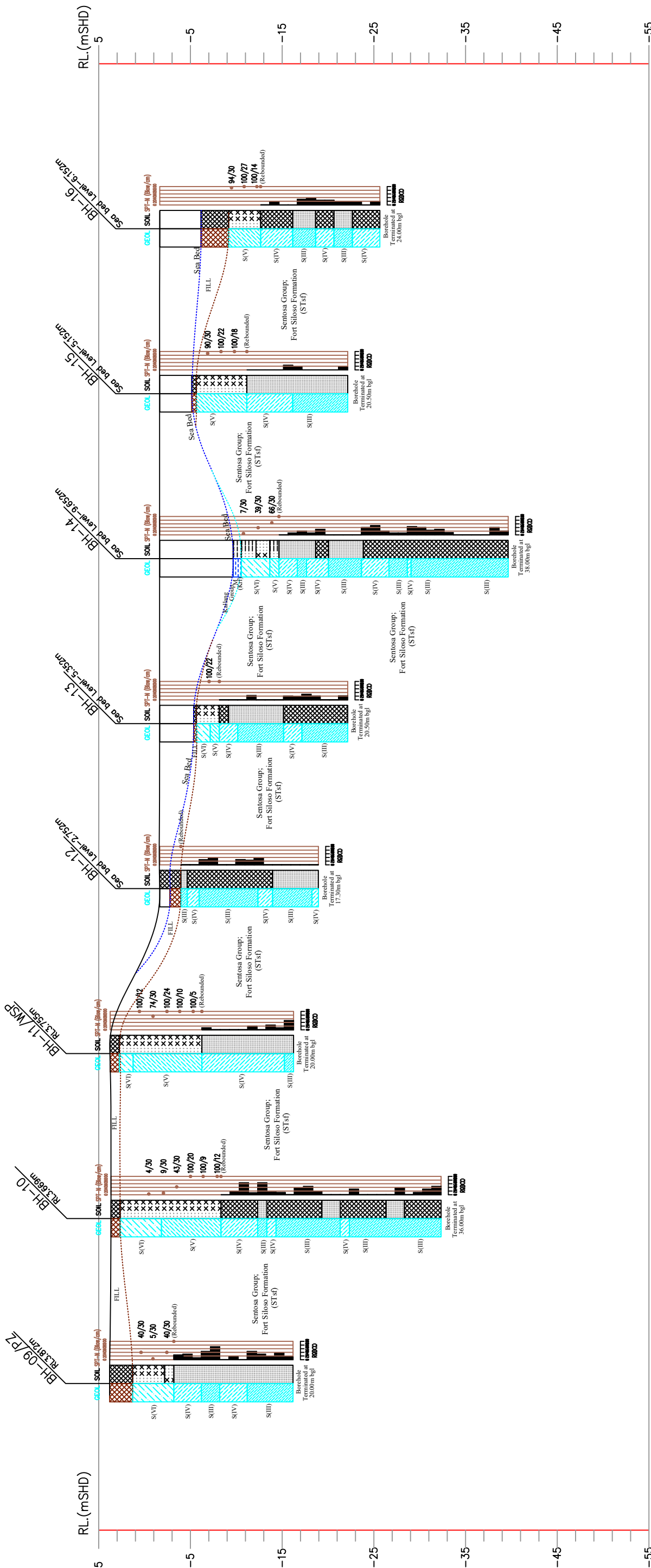
GEOLOGICAL CLASSIFICATION



CROSS-SECTION 1 - (BH-01/WSP , BH-02, BH-03/PZ , BH-04, BH-05/WSP, BH-06/PZ , BH-07/WSP & BH-08)

VERTICAL SCALE - 1:400 HORIZONTAL SCALE - 1:2000	Drawn By: Khin Ei Soe	Date: 22/01/2024
	Checked By: Nel Cortes	Date: 22/01/2024
CLIENT: Keppel Bay Pte Ltd		
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		

PROBABLE SOIL PROFILE



CROSS-SECTION 2

GEOLOGICAL CLASSIFICATION

Kallang Group		SENTOSA GROUP (STG)	
	Kpf: Jalan Besar Formation		S(I) – FRESH
	Knsn: Marina South Member		S(II) – SLIGHTLY WEATHERED
	Kkf: Kranj Formation		S(III) – MODERATELY WEATHERED
	Krf: Rochor Clay Formation (Upper MC)		S(IV) – HIGHLY WEATHERED
	Ktrf: Tanjong Rhu Clay Formation (Lower MC)		S(V) – COMPLETELY WEATHERED
			S(VI) – RESIDUAL SOIL
			FILL

CROSS-SECTION 2 - (BH-09/PZ, BH-10, BH-11/WSP, BH-12, BH-13, BH-14, BH-15 & BH-16)

	CLIENT: Keppel Bay Pte Ltd		Drawn By: Khin Ei Ei Soe Date: 23/01/2024
	PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		Checked By: Nel Cortes Date: 23/01/2024

GEOLOGICAL CLASSIFICATION

 MG: FILL

FORT CANNING FORMATION

 Fcf: Fort Canning Formation

KALLANG GROUP

 Kjbf: Jalan Besar Formation

 Kmsm: Marina South Member

 Kkf: Kranji Formation

 Krf: Rochor Clay Formation (Upper MC)

 Ktrf: Tanjong Rhu Clay Formation (Lower MC)

BEDOK FORMATION

 O(A)

 O(D)

 O(B)

 O(E)

 O(C)

JURONG FORMATION/SENTOSA GROUP (STG) /BUKIT BATOK FORMATION /KUSU FORMATION/BUONA VISTA FORMATION

     S(I)

     S(II)

     S(III)

     S(IV)

     S(V)

     S(VI)

BUKIT TIMAH GRANITE

 G(I)

 G(IV)

 G(II)

 G(V)

 G(III)

 G(VI)

ENGINEERING CLASSIFICATION

 AS : ASPHALT, TAR

 BF : BACKFILL

 BE : BEDROCK

 BR : BRICK

 BO : BOULDER

 C : CLAY / MARINE CLAY

 CM : SILTY CLAY

 CO : ORGANIC CLAY

 CS : SANDY CLAY

 CG : GRAVELY CLAY

 CPt : PEATY CLAY

 CNG : CONGLOMERATE

 CON : CONCRETE

 GM : SILTY GRAVEL

 G : GRAVEL

 GS : SANDY GRAVEL

 GPt : PEATY GRAVEL

 GC : CLAYEY GRAVEL

 GR : GRANITE

 GO : ORGANIC GRAVEL

 LI : LIMESTONE

 M : SILT

 MPt : PEATY SILT

 MG : GRAVELLY SILT

 MU : MUDSTONE

 MS : SANDY SILT

 MC : CLAYEY SILT

 MO : ORGANIC SILT

 Pt : PEAT

 PtS : SANDY PEAT

 PtG : GRAVELLY PEAT

 PtM : SILTY PEAT

 PtC : CLAYEY PEAT

 S : SAND

 SG : GRAVELLY SAND

 SO : ORGANIC SAND

 SM : SILTY SAND

 SC : CLAYEY SAND

 SPt : PEATY SAND

 SA : SANDSTONE

 SI : SILTSTONE

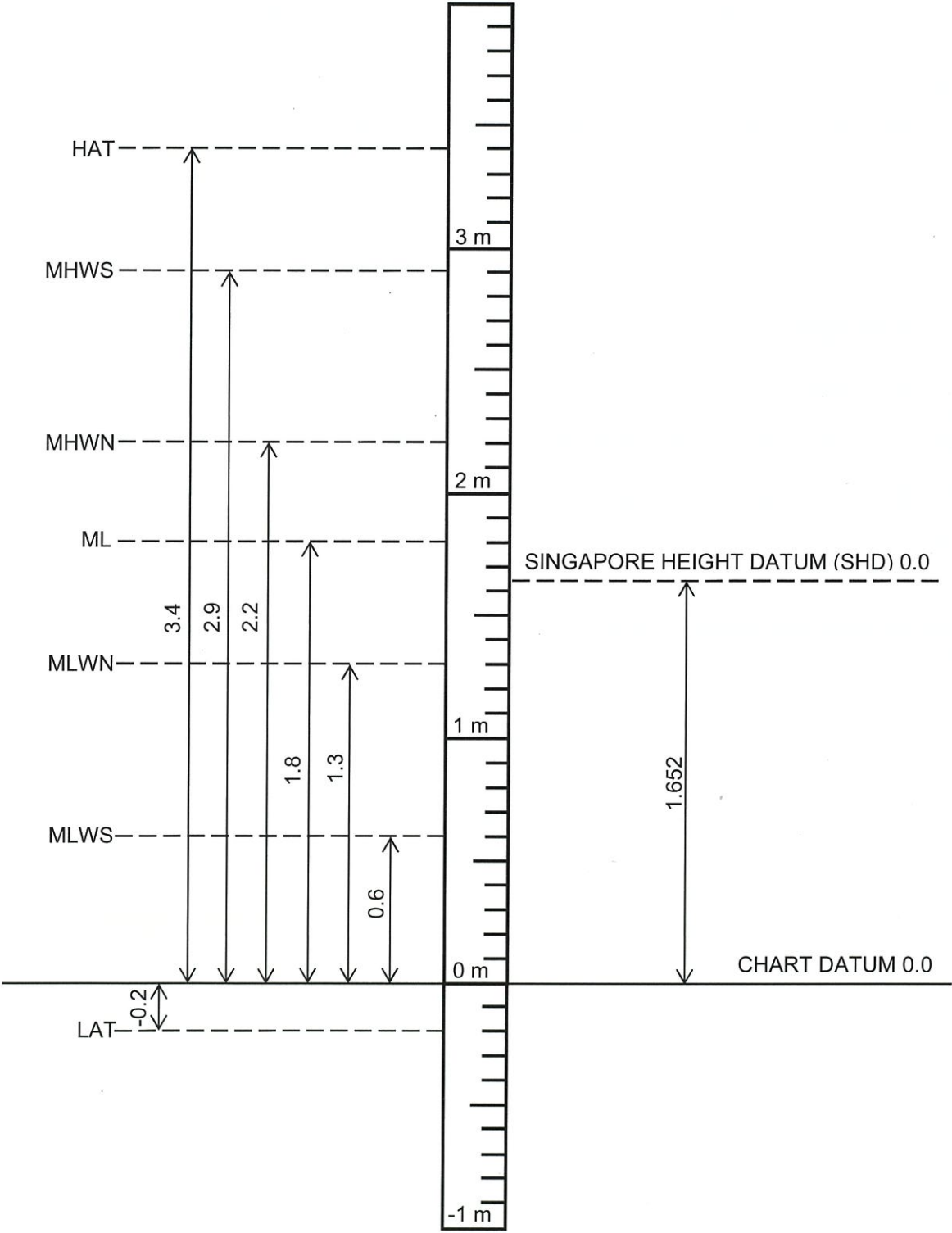
 SH : SHALE

 SCH : SCHIST

 TB : TIMBER

GEOLOGICAL CLASIFICATION

RELATIONSHIP BETWEEN VARIOUS LEVELS IN
TANJONG PAGAR



HEIGHTS IN METERS

TIDAL LEVELS FOR TIDAL STATIONS

Stations/Positions In WGS 84	Heights In Metres Above Chart Datum							Reference To SHD
	MHWS	MHWN	MLWN	MLWS	ML	HAT	LAT	
West Tuas 1° 20.7'N 103° 38.0'E	3.1	2.2	1.2	0.4	1.7	3.9	-0.1	1.636m below SHD
Sultan Shoal Lighthouse 1° 14.4'N 103° 38.9'E	3.1	2.3	1.3	0.6	1.8	3.8	0.2	1.741m below SHD
Raffles Lighthouse 1° 09.6'N 103° 44.5'E	2.9	2.2	1.3	0.5	1.7	3.6	0.0	-
West Coast 1° 17.5'N 103° 45.7'E	3.0	2.3	1.4	0.6	1.8	3.6	0.1	1.722m below SHD
Bukom 1° 13.5'N 103° 46.7'E	2.9	2.2	1.2	0.5	1.7	3.5	-0.1	-
Tanjong Pagar 1° 15.7'N 103° 51.1'E	2.9	2.2	1.3	0.6	1.8	3.4	-0.2	1.652m below SHD
Tanah Merah 1° 18.7'N 103° 59.3'E	2.7	2.1	1.2	0.6	1.7	3.2	-0.3	1.566m below SHD
Tanjong Changi 1° 23.4'N 103° 59.9'E	3.0	2.4	1.4	0.8	1.9	3.4	-0.3	1.713m below SHD
Sembawang 1° 27.9'N 103° 50.1'E	3.1	2.5	1.4	0.7	1.9	3.7	-0.3	1.83m below SHD
Singapore Strait – Horsburgh Lighthouse 1° 19.8'N 104° 24.2'E	2.4	2.0	1.2	0.8	1.6	3.1	0.0	1.53m below SHD

Legend:

- SHD - Singapore Height Datum
- ML - Mean Level
- MLWS - Mean Low Water Springs
- MLWN - Mean Low Water Neaps
- MHWN - Mean High Water Neaps
- MHWS - Mean High Water Springs
- LAT - Lowest Astronomical Tide
- HAT - Highest Astronomical Tide

LOCATION: Keppel Island		BOREHOLE NO. BH-01/WSP	
		NORTHING: 27335.077	
		EASTING: 25474.006	
		REDUCED LEVEL : 3.90 mSHD	
		DESCRIPTION	
FIELD TESTS		SPT N VALUE	
0 10 20 30 40 50 60 70 80 90 100		SPT (N)/mm SCR%	
Fracture per meter		Weathering grade	
Reduced level (mSHD)		Depth (m)	
Sample type		Graphic log	
Geological classification		British soil classification	
Trial Pit : (1.0 x 0.5 x 1.5)m depth Light grey and yellowish brown Silty SAND mixed with hardcores and gravels (FILL)		Hand Auger (1.5 – 3.0)m depth Reddish brown dappled yellowish brown Sandy SILT mixed with gravels (FILL)	
Medium dense Reddish brown spotted light grey Slightly silty fine to medium SAND Residual Soil (S-VI) (Sentosa Group; Fort Siloso Formation)		Dense Yellowish brown Very silty fine SAND Residual Soil (S-VI) (Sentosa Group; Fort Siloso Formation)	
Very dense Light grey streaked and dappled yellowish brown Slightly silty fine SAND Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)		Very dense Light grey to grey dappled yellowish brown Slightly silty fine SAND mixed with rock fragments Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
Very dense Light grey to grey Slightly silty fine SAND Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)		Very dense Light grey Slightly silty fine SAND Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
Very dense Light grey Slightly silty fine SAND Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)		Very dense Light grey Slightly silty fine to medium SAND Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
Moderately strong Light grey and light reddish brown mottled yellowish brown Fine grained SANDSTONE Very close to close spacing, highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)		MC=MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)	
BORING TYPE RO		TCR,RQD (%)	
DIAMETER(mm) 100		TCR	
		RQD	
SAMPLE		PERMEABILITY TEST /PACKER TEST	
PRESSURE METER TEST		SPT N VALUE	
CORE RUN		TW THIN WALL PUSH IN	
VANE SHEAR TEST		MZ MAZIER	
		SPT STANDARD PENETRATION TEST	
CLIENT: Keppel Bay Pte Ltd		LOG OF BORING GEOTECHNICAL STUDY – FIELD INVESTIGATIONS	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		DRILLED BY: Khun Aung/Uddin	
		DATE OF FIELD WORK: 15/09/23–21/09/23	
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd		CHECKED BY: Nel Cortes	
		SHEET NO. 33	
		<1> / <2>	

LOCATION: Keppel Island		SPT (N)/mm SCR%		FRACTURE PER METER	WEATHERING GRADE	REDUCED LEVEL (mSHD)	DEPTH (m)	SAMPLE TYPE	GRAPHIC LOG	GEOLOGICAL CLASSIFICATION	BRITISH SOIL CLASSIFICATION	BOREHOLE NO. BH-01/WSP
FIELD TESTS		SPT N VALUE										NORTHING: 27335.077
												EASTING: 25474.006
												REDUCED LEVEL : 3.90 mSHD
DESCRIPTION												
		48		>15			CR1					Moderately strong Light grey and light reddish brown mottled yellowish brown Fine grained SANDSTONE Very close to close spacing, highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation) CR2 (Is(50)=1.54, UCS=16.15)
		60		>15			CR2					
		25		>15			CR3			STsf	SA	
		75		>15			CR4			STsf	SA	
		90		9			CR5					
		86		7			CR6					
		90		8			CR7			STsf	SA	
		28		>15			CR8					
		40		>15			CR9					
		52		>15			CR10					
		10		>15			CR11			STsf	SA	
Borehole terminated at 30.00m bgl Installed WSP at 12.00m depth.												
Boring Type RO Diameter (mm) 100 TCR, RQD (%) TCR RQD												
☒ SAMPLE ☐ PRESSURE METER TEST ☐ CORE RUN ☒ VANE SHEAR TEST ☐ PERMEABILITY TEST / PACKER TEST ☒ SPT N VALUE TW THIN WALL PUSH IN MZ MAZIER SPT STANDARD PENETRATION TEST CR-CORE DS-Direct Shear Box Test CRS-Constant Rate of Strain RCT-Rowe Cell Test MC-MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)												
CLIENT: Keppel Bay Pte Ltd						LOG OF BORING GEOTECHNICAL STUDY – FIELD INVESTIGATIONS						
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island						DRILLED BY: Khun Aung/Uddin			DATE OF FIELD WORK: 15/09/23–21/09/23			
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd						CHECKED BY: Nel Cortes			SHEET NO. 34 <2> / <2>			

LOCATION: Keppel Island		BOREHOLE NO. BH-02	
NORTHING: 27322.315		EASTING: 25518.287	
REDUCED LEVEL : 3.85 mSHD		DESCRIPTION	
FIELD TESTS		SPT N VALUE	
DAILY WATER LEVEL		SPT (N)/mm SCR%	
DATE (dd/mm/yy)		READING (m.BGL)	
25/10/23		1.80	
26/10/23		3.50	
26/10/23		1.60	
27/10/23		4.50	
27/10/23		1.30	
28/10/23		5.40	
28/10/23		2.40	
FRACTURE PER METER		WEATHERING GRADE	
REDUCED LEVEL (mSHD)		DEPTH (m)	
SAMPLE TYPE		GRAPHIC LOG	
GEOLOGICAL CLASSIFICATION		BRITISH SOIL CLASSIFICATION	
Trial Pit : (1.0 x 0.5 x 1.5)m depth		Light grey dappled dark brown	
Gravelly sandy SILT mixed with hardcores (FILL)		Black mottled light grey	
Asphalt Tar mixed with hardcores (FILL)		Yellowish brown mottled light grey	
Sandy SILT mixed with hardcores (FILL)		Hand Auger (1.5 - 3.0)m depth	
Light grey		Slightly fine sandy SILT, Residual Soil (S-VI)	
(Sentosa Group; Fort Siloso Formation)		Hard	
Pinkish grey mottled light grey and yellow		Slightly fine sandy SILT, Residual Soil (S-VI)	
(Sentosa Group; Fort Siloso Formation)		Hard	
Light grey		Fine sandy SILT	
Completely weathered (S-V)		(Sentosa Group; Fort Siloso Formation)	
Hard		Light brown striped light grey and yellow	
Slightly fine sandy SILT		Completely weathered (S-V)	
(Sentosa Group; Fort Siloso Formation)		Hard	
Grey		Sandy SILT mixed with rock fragments	
Completely weathered (S-V)		(Sentosa Group; Fort Siloso Formation)	
Hard		Light grey	
Slightly fine sandy SILT mixed with rock fragments		Completely weathered (S-V)	
(Sentosa Group; Fort Siloso Formation)		Hard	
Light grey		Fine sandy SILT mixed with rock fragments	
Completely weathered (S-V)		(Sentosa Group; Fort Siloso Formation)	
Moderately strong		Light grey	
Fine to medium grained SANDSTONE		Very close to close spacing, highly fractured	
Moderately weathered (S-III)		(Core loss at 12.80-13.80m-CR-4)	
(Sentosa Group; Fort Siloso Formation)		Hard	
Light grey		Slightly fine sandy SILT mixed with rock fragments	
Completely weathered (S-V)		(Sentosa Group; Fort Siloso Formation)	
Hard		Light grey mottled pinkish grey and reddish brown	
Fine to coarse sandy SILT		Completely weathered (S-V)	
(Sentosa Group; Fort Siloso Formation)		Moderately weak	
Light grey		Fine grained SANDSTONE Very close to close spacing, highly fractured	
Highly weathered (S-IV)		(Sentosa Group; Fort Siloso Formation)	
Moderately strong		Light grey striped purplish red	
SILTSTONE		Close to medium spacing, Moderately fractured	
Moderately weathered (S-III)		(Sentosa Group; Fort Siloso Formation)	
BORING TYPE		TCR,RQD (%)	
RO		SAMPLE	
DIAMETER(mm)		PRESSURE METER TEST	
100		CORE RUN	
VANE SHEAR TEST		PERMEABILITY TEST /PACKER TEST	
SPT N VALUE		CR-CORE	
THIN WALL PUSH IN		DS-Direct Shear Box Test	
MAZIER		CRS-Constant Rate of Strain	
STANDARD PENETRATION TEST		RCT-Rowe Cell Test	
MC-MOISTURE CONTENT		BD-BULK DENSITY	
PD-PARTICLE DENSITY		LL=LIQUID LIMIT(%)	
PL=PLASTIC LIMIT (%)		UU/CU=UNCONSOLIDATED /CONSOLIDATED	
UNDRAINED TEST (kPa)		CLIENT:	
Keppel Bay Pte Ltd		LOG OF BORING	
PROJECT:		GEOTECHNICAL STUDY - FIELD INVESTIGATIONS	
Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		DRILLED BY:	
Saw Lynn Myint Aung/Bali Ji		DATE OF FIELD WORK:	
25/10/24-28/10/23		SHEET NO.	
35		<1> / <2>	
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd		CHECKED BY:	
Nel Cortes			

LOCATION: Keppel Island										BOREHOLE NO. BH-03/PZ	
										NORTHING: 27323.394	
										EASTING: 25579.066	
										REDUCED LEVEL : 3.91 mSHD	
										DESCRIPTION	
FIELD TESTS		SPT N VALUE		SPT (N)/mm SCR%		FRACTURE PER METER		WEATHERING GRADE		REDUCED LEVEL (mSHD)	
		0 10 20 30 40 50 60 70 80 90 100								DEPTH (m)	
DAILY WATER LEVEL										SAMPLE TYPE	
DATE (dd/mm/yy)		READING (m.BGL)								GRAPHIC LOG	
17/10/23		1.60								GEOLOGICAL CLASSIFICATION	
18/10/23		2.80								BRITISH SOIL CLASSIFICATION	
18/10/23		1.40									
19/10/23		3.10									

LOCATION: Keppel Island		BOREHOLE NO. BH-04	
NORTHING: 27291 .861		EASTING: 25595.295	
REDUCED LEVEL : 3.65 mSHD		DESCRIPTION	
FIELD TESTS		SPT N VALUE	
DAILY WATER LEVEL		SPT (N)/mm SCR%	
DATE (dd/mm/yy)		READING (m.BGL)	
03/10/23		1.50	
04/10/23		2.60	
04/10/23		1.70	
05/10/23		3.60	
05/10/23		1.40	
06/10/23		3.80	
06/10/23		1.80	
07/10/23		3.70	
07/10/23		1.30	
09/10/23		3.60	
09/10/23		2.10	
FRACTURE PER METER		WEATHERING GRADE	
REDUCED LEVEL (mSHD)		DEPTH (m)	
SAMPLE TYPE		GRAPHIC LOG	
GEOLOGICAL CLASSIFICATION		BRITISH SOIL CLASSIFICATION	
Trial Pit : (1.0 x 0.5 x 1.5)m depth		Light grey and brown	
Gravelly sandy SILT mixed with hardcores (FILL)		Black mottled light grey	
Gravel premixed asphalt concrete smooth with fine aggregates (sand & gravels) (FILL)		Light grey and brown	
Gravelly sandy SILT mixed with hardcores concrete block (FILL)		Yellowish brown mottled light grey	
Sandy SILT mixed with hardcores (FILL)		Hand Auger (1.5 - 3.0)m depth	
Yellowish brown mottled grey and light yellow		Sandy SILT mixed with rock fragments	
Residual Soil (S-VI)		(Sentosa Group; Fort Siloso Formation)	
Hard		Reddish brown mottled light grey	
Sandy SILT, Completely weathered (S-V)		(Sentosa Group; Fort Siloso Formation)	
Hard		Reddish brown mottled light grey and yellow	
Sandy SILT mixed with rock fragments		Completely weathered (S-V)	
(Sentosa Group; Fort Siloso Formation)		Hard	
Light grey mottled yellowish brown and pink		Sandy SILT mixed with rock fragments	
Completely weathered (S-V)		(Sentosa Group; Fort Siloso Formation)	
Hard		Light grey streaked purplish grey	
Slightly fine sandy SILT,		Completely weathered (S-V)	
(Sentosa Group; Fort Siloso Formation)		Moderately weak	
Light grey mottled yellowish brown striped purple		Fine to medium grained SANDSTONE	
Close spacing, highly fractured Highly to moderately weathered (S-IV)		(Sentosa Group; Fort Siloso Formation)	
Moderately weak to weak		Light grey mottled yellowish brown	
Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Close spacing, highly fractured Highly to moderately weathered (S-IV)(Sentosa Group; Fort Siloso Formation)		Moderately weak to weak	
Light grey mottled yellowish brown striped purple		Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Close spacing, highly fractured Highly to moderately weathered (S-IV)(Sentosa Group; Fort Siloso Formation)	
Moderately weak to weak		Light grey mottled yellowish brown striped purple	
Fine to medium grained SANDSTONE Close spacing, highly fractured		Highly to moderately weathered (S-IV)	
(Sentosa Group; Fort Siloso Formation)		Weak	
Purplish red		Fine grained SANDSTONE	
(Sandstone interbedded and intimately mixed with an underlying layer of soil) Close spacing, Moderately fractured		Highly weathered (S-IV)	
(Sentosa Group; Fort Siloso Formation)		Moderately weak to weak	
Purplish red striped light grey		Fine grained SANDSTONE	
Close spacing, highly fractured		Highly to moderately weathered (S-IV)	
(Sentosa Group; Fort Siloso Formation)		MC-MOISTURE CONTENT	
BD-BULK DENSITY		PD-PARTICLE DENSITY	
LL=LIQUID LIMIT(%)		PL=PLASTIC LIMIT (%)	
UU/CU=UNCONSOLIDATED /CONSOLIDATED		UNDRAINED TEST (kPa)	
BORING TYPE RO		TCR,RQD (%)	
DIAMETER(mm) 100		TCR	
RQD		RQD	
SAMPLE		PRESSURE METER TEST	
CORE RUN		VANE SHEAR TEST	
PERMEABILITY TEST /PACKER TEST		SPT N VALUE	
TW THIN WALL PUSH IN		MZ MAZIER	
SPT STANDARD PENETRATION TEST		CR-CORE	
DS-Direct Shear Box Test		CRS-Constant Rate of Strain	
RCT-Rowe Cell Test		MC-MOISTURE CONTENT	
BD-BULK DENSITY		PD-PARTICLE DENSITY	
LL=LIQUID LIMIT(%)		PL=PLASTIC LIMIT (%)	
UU/CU=UNCONSOLIDATED /CONSOLIDATED		UNDRAINED TEST (kPa)	
CLIENT: Keppel Bay Pte Ltd		LOG OF BORING	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		GEOTECHNICAL STUDY - FIELD INVESTIGATIONS	
DRILLED BY: Saw Lynn Myint Aung/Shiquil		DATE OF FIELD WORK: 30/09/23-09/10/23	
CHECKED BY: Nel Cortes		SHEET NO. 38	
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd		<1> / <2>	

[illegible]

LOCATION: Keppel Island		SPT (N)/mm SCR%		FRACTURE PER METER		WEATHERING GRADE		REDUCED LEVEL (mSHD)		DEPTH (m)		SAMPLE TYPE		GRAPHIC LOG		GEOLOGICAL CLASSIFICATION		BRITISH SOIL CLASSIFICATION		BOREHOLE NO. BH-05/WSP	
FIELD TESTS		SPT N VALUE																		NORTHING: 27316.497	
		0 10 20 30 40 50 60 70 80 90 100																		EASTING: 25618.692	
																				REDUCED LEVEL : 3.86 mSHD	
																				DESCRIPTION	
DAILY WATER LEVEL																				Trial Pit : (1.0 x 0.5 x 1.5)m depth	
DATE		READING																		Light grey	
(dd/mm/yy)		(m.BGL)																		Silty SAND mixed with hardcores and gravels (FILL)	
23/09/23		1.80																		Hand Auger (1.5 - 3.0)m depth	
25/09/23		2.40																		Yellowish brown	
25/09/23		2.50																		Slightly silty SAND, Residual Soil (S-VI)	
26/09/23		2.10																		(Sentosa Group; Fort Siloso Formation)	
26/09/23		1.60																		Weak	
27/09/23		2.45																		Light grey and purplish red	
27/09/23		1.40																		Fine grained SANDSTONE	
Water (pH=6.3, Tol So3=3, Cl=1)																				Highly fractured, Highly weathered (S-IV)	
																				(Sentosa Group; Fort Siloso Formation)	
																				Weak	
																				Purplish red and light grey dappled yellowish brown	
																				Fine grained SANDSTONE	
																				Close spacing Highly to moderately fractured	
																				Highly weathered (S-IV)	
																				(Sentosa Group; Fort Siloso Formation)	
																				Weak	
																				Purplish red	
																				Fine grained SANDSTONE	
																				Close spacing Highly to moderately fractured	
																				Highly weathered (S-IV)	
																				(Sentosa Group; Fort Siloso Formation)	
																				Very weak to weak	
																				Purplish red	
																				Fine grained SANDSTONE	
																				Close to medium spacing Highly to moderately fractured	
																				Highly weathered (S-IV)	
																				(Sentosa Group; Fort Siloso Formation)	
																				Very weak to weak	
																				Purplish red	
																				Fine grained SANDSTONE	
																				Close to medium spacing Highly to moderately fractured	
																				Highly weathered (S-IV)	
																				(Sentosa Group; Fort Siloso Formation)	
																				Weak	
																				Purplish red and light grey dappled yellowish brown	

LOCATION: Keppel Island		BOREHOLE NO. BH-07/WSP	
		NORTHING: 27324.334	
		EASTING: 25695.587	
		REDUCED LEVEL : 3.97 mSHD	
		DESCRIPTION	
FIELD TESTS Water (pH=7.3, Tol So ₃ =0, Cl=8)	SPT N VALUE 0 10 20 30 40 50 60 70 80 90 100		
		SPT (N)/mm SCR%	
		FRACTURE PER METER	
		WEATHERING GRADE	
		REDUCED LEVEL (mSHD)	
		DEPTH (m)	
		SAMPLE TYPE	
		GRAPHIC LOG	
		GEOLOGICAL CLASSIFICATION	
		BRITISH SOIL CLASSIFICATION	
			Trial Pit : (1.0 x 0.5 x 1.5)m depth, Dark grey Sandy SILT mixed with hardcores and concrete block (FILL)
			Hand Auger (1.5 – 3.0)m depth, Dark grey Sandy SILT with traces of hardcore and other (FILL)
			Very dense, Yellowish brown mottled grey Slightly silty fine to coarse SAND Residual Soil (S-VI)
			(Sentosa Group; Fort Siloso Formation)
			Moderately weak, Light grey Fine to medium grained SANDSTONE Close spacing Moderately fractured Highly weathered (S-IV)
			(Sentosa Group; Fort Siloso Formation)
			Weak, Reddish brown spotted light grey Fine grained SANDSTONE Close spacing Moderately fractured Highly weathered (S-IV)
			(Sentosa Group; Fort Siloso Formation)
			Weak, Light grey dappled reddish brown Fine grained SANDSTONE Close spacing Highly fractured Highly weathered (S-IV)
			(Sentosa Group; Fort Siloso Formation)
			Weak, Light grey dappled light reddish brown Fine to medium grained SANDSTONE Very close to close spacing Highly to moderately fractured Highly weathered (S-IV)
			(Sentosa Group; Fort Siloso Formation)
			Moderately weak Light grey dappled yellowish brown Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Highly weathered (S-IV)
			(Sentosa Group; Fort Siloso Formation)
			Weak, Grey Fine grained SANDSTONE Close to medium spacing Moderately fractured Highly weathered (S-IV)
			(Sentosa Group; Fort Siloso Formation)
			Moderately strong, Grey Fine grained SANDSTONE Close spacing, Moderately fractured Moderately weathered (S-III)
			(Sentosa Group; Fort Siloso Formation)
			Moderately strong, Dark grey Fine grained SANDSTONE Very close to close spacing, Highly fractured Moderately weathered (S-III)
			(Sentosa Group; Fort Siloso Formation)
			Moderately strong Dark grey to grey Fine grained SANDSTONE Close to medium spacing Moderately fractured Moderately weathered (S-III)
			(Sentosa Group; Fort Siloso Formation)
			Moderately strong, Light grey streaked dark grey Fine grained SANDSTONE Close spacing, Moderately fractured Moderately weathered (S-III)
			(Sentosa Group; Fort Siloso Formation)
			Fine grained SANDSTONE
BORING TYPE RO	TCR,RQD (%) TCR RQD	☒ SAMPLE ☒ PRESSURE METER TEST ☒ CORE RUN ☒ VANE SHEAR TEST	☒ PERMEABILITY TEST /PACKER TEST ☒ SPT N VALUE TW THIN WALL PUSH IN MZ MAZIER SPT STANDARD PENETRATION TEST
DIAMETER(mm) 100			CR-CORE DS-Direct Shear Box Test CRS-Constant Rate of Strain RCT-Rowe Cell Test
			MC-MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)
CLIENT: Keppel Bay Pte Ltd		LOG OF BORING GEOTECHNICAL STUDY – FIELD INVESTIGATIONS	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		DRILLED BY: Khun Aung/Ananth	DATE OF FIELD WORK: 07/09/23–16/09/23
  ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd		CHECKED BY: Nel Cortes	SHEET NO. 43 <1> / <2>

LOCATION: Keppel Island		BOREHOLE NO. BH-07/WSP	
		NORTHING: 27324.334	
		EASTING: 25695.587	
		REDUCED LEVEL : 3.97 mSHD	
FIELD TESTS		DESCRIPTION	
0 10 20 30 40 50 60 70 80 90 100 SPT N VALUE		53 77 95 SPT (N)/mm SCR%	
		FRACTURE PER METER WEATHERING GRADE REDUCED LEVEL (mSHD) DEPTH (m) SAMPLE TYPE GRAPHIC LOG GEOLOGICAL CLASSIFICATION BRITISH SOIL CLASSIFICATION CR18 CR19 CR20 STsf STsf STsf SA SA SA	
		Moderately strong Light grey streaked reddish brown Fine grained SANDSTONE Very close to close spacing, Highly to moderately fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation) Moderately strong, Light grey Fine grained SANDSTONE Close spacing, Moderately fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation) Moderately strong, Grey Fine to medium grained SANDSTONE Close spacing, Moderately fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
		Borehole terminated at 23.00m bgl Installed WSP at 12.00m depth.	
BOREHOLE TYPE RO DIAMETER(mm) 100		TCR,RQD (%) TCR RQD SAMPLE PRESSURE METER TEST CORE RUN VANE SHEAR TEST PERMEABILITY TEST /PACKER TEST SPT N VALUE TW THIN WALL PUSH IN MZ MAZIER SPT STANDARD PENETRATION TEST CR-CORE DS-Direct Shear Box Test CRS-Constant Rate of Strain RCT-Rowe Cell Test MC-MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)	
CLIENT: Keppel Bay Pte Ltd		LOG OF BORING GEOTECHNICAL STUDY – FIELD INVESTIGATIONS	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		DRILLED BY: Khun Aung/Ananth	
		DATE OF FIELD WORK: 07/09/23–16/09/23	
element Accredited Inspection body ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd		CHECKED BY: Nel Cortes SHEET NO. 44	

LOCATION: Keppel Island		BOREHOLE NO. BH-08	
		NORTHING: 27317.038	
		EASTING: 25746.149	
		SEA BED LEVEL : -2.95 mSHD	
		DESCRIPTION	
FIELD TESTS	SPT N VALUE	SPT (N)/mm SCR%	FRACTURE PER METER
	0 10 20 30 40 50 60 70 80 90 100		WEATHERING GRADE
			REDUCED LEVEL (mSHD)
			DEPTH (mCD)
			SAMPLE TYPE
			GRAPHIC LOG
			GEOLOGICAL CLASSIFICATION
			BRITISH SOIL CLASSIFICATION
			Deck to Seabed Seabed Level -1.3mCD
			Light brown to grey Sandy SILT mixed with shell fragments
			Very stiff Purplish red motled yellowish brown and light grey Slightly fine sandy SILT, Residual Soil (S-VI) (Sentosa Group; Fort Siloso Formation)
			Hard Reddish brown motled yellow and light grey Slightly fine sandy SILT, Residual Soil (S-VI) (Sentosa Group; Fort Siloso Formation)
			Hard Purplish red motled yellow and light grey Slightly fine sandy SILT Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)
			Hard Yellowish brown motled light grey and purplish grey Slightly fine sandy SILT Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)
			Hard, Light grey striped pinkish grey Slightly fine sandy SILT Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)
			Hard, Light grey striped light purple Fine to medium sandy SILT mixed with rock fragments Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)
			Moderately weak Yellowish brown mottled light grey striped reddish brown Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)
			Weak Light grey striped yellow mottled reddish brown Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)
			Weak to moderately weak Light grey striped yellow and purplish red Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)
			Moderately weak, Light reddish brown Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)
			Weak, Purplish red motled light grey SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)
			Fine to medium grained SANDSTONE
BORING TYPE RO	TCR,RQD (%)	SAMPLE	PERMEABILITY TEST /PACKER TEST
DIAMETER(mm) 100		PRESSURE METER TEST	CR-CORE
		CORE RUN	DS-Direct Shear Box Test
		VANE SHEAR TEST	CRS-Constant Rate of Strain
			RCT-Rowe Cell Test
			MC-MOISTURE CONTENT
			BD=BULK DENSITY
			PD=PARTICLE DENSITY
			LL=LIQUID LIMIT(%)
			PL=PLASTIC LIMIT (%)
			UU/CU=UNCONSOLIDATED /CONSOLIDATED
			UNDRAINED TEST (kPa)
CLIENT: Keppel Bay Pte Ltd		LOG OF BORING GEOTECHNICAL STUDY - FIELD INVESTIGATIONS	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		DRILLED BY: Saw Lynn Myint Aung/Chinnyah	DATE OF FIELD WORK: 17/10/23-23/10/23
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd		CHECKED BY: Nel Cortes	SHEET NO. 45

LOCATION: Keppel Island		BOREHOLE NO. BH-08	
		NORTHING: 27317.038	
		EASTING: 25746.149	
		SEA BED LEVEL : -2.95 mSHD	
FIELD TESTS		DESCRIPTION	
0 10 20 30 40 50 60 70 80 90 100 SPT N VALUE		55 50 30 20 40 70 SPT (N)/mm SCR%	
		>15 >15 >15 >15 >15 3 FRACTURE PER METER	
		WEATHERING GRADE	
		-24.15 -25.95 -26.15 REDUCED LEVEL (mSHD)	
		CR6 CR7 CR8 CR9 CR10 CR11 DEPTH (mCD)	
		GRAPHIC LOG	
		STsf STsf GEOLOGICAL CLASSIFICATION	
		SA SI BRITISH SOIL CLASSIFICATION	
		Moderately weak Light grey striped yellowish brown and purplish red Fine to medium grained SANDSTONE Close spacing Highly fractured Highly to moderately weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
		Very weak to weak Purplish red to light yellowish brown SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
		Moderately weak Purplish red mottled light grey SILTSTONE medium spacing Moderately fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
		Borehole terminated at -24.50mCD	
BORING TYPE RO DIAMETER(mm) 100		TCR,RQD (%) TCR RQD	
SAMPLE PRESSURE METER TEST CORE RUN VANE SHEAR TEST		PERMEABILITY TEST /PACKER TEST SPT N VALUE TW THIN WALL PUSH IN MZ MAZIER SPT STANDARD PENETRATION TEST	
CR-CORE DS-Direct Shear Box Test CRS-Constant Rate of Strain RCT-Rowe Cell Test		MC-MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)	
CLIENT: Keppel Bay Pte Ltd		LOG OF BORING GEOTECHNICAL STUDY – FIELD INVESTIGATIONS	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		DRILLED BY: Saw Lynn Myint Aung/Chinnnyah	DATE OF FIELD WORK: 17/10/23-23/10/23
element Accredited Inspection Body 90-2017-1881-F		CHECKED BY: Nel Cortes	SHEET NO. 46 <2> / <2>
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd			

LOCATION: Keppel Island										BOREHOLE NO. BH-09/PZ	
										NORTHING: 27309.181	
										EASTING: 25474.624	
										REDUCED LEVEL : 3.81 mSHD	
										DESCRIPTION	
FIELD TESTS		SPT N VALUE		SPT (N)/mm SCR%		FRACTURE PER METER		WEATHERING GRADE		REDUCED LEVEL (mSHD)	
		0 10 20 30 40 50 60 70 80 90 100								DEPTH (m)	
DAILY WATER LEVEL										SAMPLE TYPE	
DATE (dd/mm/yy)		READING (m.BGL)								GRAPHIC LOG	
25/09/23		1.80								GEOLOGICAL CLASSIFICATION	
26/09/23		3.50								BRITISH SOIL CLASSIFICATION	
26/09/23		1.20									
27/09/23		3.40									
27/09/23		1.60									
				40/300							
				5/300							
				40/300							
				(Rebounded)							
				40		>15					
				45		>15					
				40		>15					
				50		>15					
				80		5					
				60		>15					
				50		>15					
				30		>15					
				70		8					
				60		10					
				75		>15					
				60		>15					
				60		9					

LOCATION: Keppel Island		BOREHOLE NO. BH-10	
NORTHING: 27280.221		EASTING: 25508.005	
REDUCED LEVEL : 3.67 mSHD		DESCRIPTION	
FIELD TESTS		SPT N VALUE	
DAILY WATER LEVEL		SPT (N)/mm SCR%	
DATE (dd/mm/yy)		READING (m.BGL)	
13/10/23		1.20	
14/10/23		2.60	
14/10/23		1.40	
16/10/23		2.40	
16/10/23		2.80	
17/10/23		2.90	
17/10/23		1.40	
18/10/23		2.70	
18/10/23		1.20	
19/10/23		2.80	
19/10/23		1.30	
20/10/23		2.40	
20/10/23		1.40	
4/300		9/300	
43/300		100/200	
100/90		100/120	
(Rebounded)		25	
70		75	
80		75	
30		35	
60		60	
TCR,RQD (%)		SAMPLE	
TCR		PRESSURE METER TEST	
RQD		CORE RUN	
VANE SHEAR TEST		PERMEABILITY TEST /PACKER TEST	
SPT N VALUE		SPT N VALUE	
TW THIN WALL PUSH IN		MZ MAZIER	
SPT STANDARD PENETRATION TEST		SPT STANDARD PENETRATION TEST	
CR-CORE		DS-Direct Shear Box Test	
CRS-Constant Rate of Strain		RCT-Rowe Cell Test	
MC-MOISTURE CONTENT		BD-BULK DENSITY	
PD-PARTICLE DENSITY		LL=LIQUID LIMIT(%)	
PL=PLASTIC LIMIT (%)		UU/CU=UNCONSOLIDATED /CONSOLIDATED	
UNDRAINED TEST (kPa)		UNDRAINED TEST (kPa)	
CLIENT: Keppel Bay Pte Ltd		LOG OF BORING	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		GEOTECHNICAL STUDY – FIELD INVESTIGATIONS	
DRILLED BY: Kyaw Swar Lwin/Shiquil		DATE OF FIELD WORK: 10/10/23-20/10/23	
CHECKED BY: Nel Cortes		SHEET NO. 48	
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd		<1> / <2>	

LOCATION: Keppel Island						BOREHOLE NO. BH-10						
						NORTHING: 27280.221						
						EASTING: 25508.005						
						REDUCED LEVEL : 3.67 mSHD						
DESCRIPTION												
FIELD TESTS		SPT N VALUE 0 10 20 30 40 50 60 70 80 90 100	SPT (N)/mm SOR%	FRACTURE PER METER	WEATHERING GRADE	REDUCED LEVEL (mSHD)	DEPTH (m)	SAMPLE TYPE	GRAPHIC LOG	GEOLOGICAL CLASSIFICATION	BRITISH SOIL CLASSIFICATION	
		[Pattern]	70	>12	[Diagonal Lines]		CR9 21	[Cross-hatch]				Moderately strong Purplish red mottled light grey SILTSTONE Close to medium spacing, Moderately fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)
		[Pattern]	80	10	[Diagonal Lines]		CR10 22	[Cross-hatch]				
		[Pattern]	60	>15	[Diagonal Lines]	-19.33	CR11 23	[Cross-hatch]	STsf	SI		
		[Pattern]	0	>15	[Diagonal Lines]		CR12 24	[Cross-hatch]				Moderately strong Light grey to purplish red Fine to medium grained SANDSTONE interbedded with Siltstone Very close to close spacing, Highly fractured Highly to moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)
		[Pattern]	10	>15	[Diagonal Lines]	-21.33	CR13 25	[Cross-hatch]	STsf	SA		
		[Pattern]	30	>15	[Diagonal Lines]	-22.33	CR14 26	[Cross-hatch]	STsf	SI		Very weak to moderately weak Purplish red mottled light grey SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)
		[Pattern]	50	>15	[Diagonal Lines]	-23.33	CR15 27	[Cross-hatch]	STsf	SI		Moderately weak to moderately strong Purplish red mottled light grey SILTSTONE (Quartz mineral observed in minor amount) Very close to close spacing, Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)
		[Pattern]	40	>15	[Diagonal Lines]	-24.33	CR16 28	[Cross-hatch]	STsf	SI		Weak to moderately strong Purplish red mottled light grey SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly to moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)
		[Pattern]	10	>15	[Diagonal Lines]		CR17 29	[Cross-hatch]				
		[Pattern]	30	>15	[Diagonal Lines]	-26.33	CR18 30	[Cross-hatch]	STsf	SI		Moderately weak to moderately strong Purplish red mottled light grey SILTSTONE Very close to close spacing, Highly fractured Highly to moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)
		[Pattern]	70	>15	[Diagonal Lines]	-28.33	CR20 32	[Cross-hatch]	STsf	SA		Moderately weak to moderately strong Light grey spotted red to purplish red Fine to medium grained SANDSTONE interbedded with Siltstone Very close to close spacing, Highly fractured Highly to moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)
		[Pattern]	30	>15	[Diagonal Lines]		CR21 33	[Cross-hatch]				
		[Pattern]	80	>15	[Diagonal Lines]		CR22 34	[Cross-hatch]				Moderately weak to moderately strong Purplish red mottled grey SILTSTONE Very close to close spacing, Highly fractured Highly to moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)
		[Pattern]	90	8	[Diagonal Lines]		CR23 35	[Cross-hatch]				
		[Pattern]	80	12	[Diagonal Lines]	-32.33	CR24 36	[Cross-hatch]	STsf	SI		Borehole terminated at 36.00m bgl
		[Pattern]					37					
		[Pattern]					38					
		[Pattern]					39					
		[Pattern]					40					
BORING TYPE RO DIAMETER(mm) 100		TCR,RQD (%) [Patterns] TCR RQD	[Symbol] SAMPLE [Symbol] PRESSURE METER TEST CORE RUN ⊕ VANE SHEAR TEST	PERMEABILITY TEST /PACKER TEST ● SPT N VALUE TW THIN WALL PUSH IN MZ MAZIER SPT STANDARD PENETRATION TEST			CR-CORE DS-Direct Shear Box Test CRS=Constant Rate of Strain RCT-Rowe Cell Test			MC-MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)		
CLIENT: Keppel Bay Pte Ltd							LOG OF BORING GEOTECHNICAL STUDY – FIELD INVESTIGATIONS					
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island							DRILLED BY: Kyaw Swar Lwin/Shiquil			DATE OF FIELD WORK: 10/10/23–20/10/23		
element Accredited Inspection Body SAC IB-2017-101-P							ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd			CHECKED BY: Nel Cortes		
										SHEET NO. 49 <2> / <2>		

LOCATION: Keppel Island		BOREHOLE NO. BH-11/WSP	
NORTHING: 27298.036		EASTING: 25548.936	
REDUCED LEVEL : 3.76 mSHD		DESCRIPTION	
FIELD TESTS		SPT N VALUE	
DAILY WATER LEVEL		SPT (N)/mm SCR%	
DATE (dd/mm/yy)		READING (m.BGL)	
16/10/23 1.60		100/120	
17/10/23 3.10		74/300	
17/10/23 1.20		100/240	
18/10/23 3.50		100/100	
18/10/23 1.60		100/50	
19/10/23 3.80		(Rebounded)	
Water (pH=7.8, Tol So3=3, Cl=2)			
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
55		>15	
85		>15	
55		>15	
35		>15	
50		>15	
25		>15	
45		>15	
60		>15	
40		>15	
75		10	
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45		>15	
60		>15	
40		>15	
75		10	
55		>15	

LOCATION: Keppel Island		SPT (N)/mm SOR%		FRACTURE PER METER	WEATHERING GRADE	REDUCED LEVEL (mSHD)	DEPTH (mCD)	SAMPLE TYPE	GRAPHIC LOG	GEOLOGICAL CLASSIFICATION	BRITISH SOIL CLASSIFICATION	BOREHOLE NO. BH-12
												NORTHING: 27272.932
												EASTING: 25547.737
												SEA BED LEVEL : -2.75 mSHD
DESCRIPTION												
FIELD TESTS		SPT N VALUE										Deck to Seabed Seabed Level -1.1m CD
		0 10 20 30 40 50 60 70 80 90 100										
												</

LOCATION: Keppel Island		SPT (N)/mm SCR%		FRACTURE PER METER		WEATHERING GRADE		REDUCED LEVEL (mMSHD)		DEPTH (mCD)		SAMPLE TYPE		GRAPHIC LOG		GEOLOGICAL CLASSIFICATION		BRITISH SOIL CLASSIFICATION		BOREHOLE NO. BH-13	
FIELD TESTS		SPT N VALUE																		NORTHING: 27276.992	
		0 10 20 30 40 50 60 70 80 90 100																		EASTING: 25629.346	
																				SEA BED LEVEL : -5.35 mMSHD	
																				DESCRIPTION	
																				Deck to Seabed Seabed Level -3.70mCD	
																				Light brown to grey Sandy SILT mixed with hardcores and traces of shell fragments (FILL)	
																				Hard,Reddish brown mottled light grey and yellow Slightly fine sandy SILT Residual Soil (S-VI) (Sentosa Group; Fort Siloso Formation)	
																				Hard,Reddish brown mottled yellowish brown Slightly sandy SILT Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
																				Weak,Reddish brown mottled light grey SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
																				Weak to moderately weak Reddish brown mottled light grey and yellow Fine to medium grained SANDSTONE interbedded with Siltstone (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
																				Moderately weak to moderately strong Yellowish brown striped light grey and reddish brown Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Highly to moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
																				Moderately strong Light grey mottled yellowish brown striped pink Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
																				Weak to moderately weak Light grey and yellowish brown SILTSTONE interbedded with Sandstone Close to medium spacing Highly fractured Highly to moderately weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
																				CR8 (UCS=4.47)	
																				Weak to moderately weak Purplish red striped yellow SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly to moderately weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
																				Moderately strong Light grey and yellowish brown SILTSTONE Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
																				CR10 (Is(50)=1.11)	
																				SILTSTONE	
BORING TYPE RO		TCR,RQD (%)		SAMPLE		PRESSURE METER TEST		PERMEABILITY TEST /PACKER TEST		CR-CORE		DS-Direct Shear Box Test		MC-MOISTURE CONTENT							
DIAMETER(mm) 100				CORE RUN		VANE SHEAR TEST		SPT N VALUE		CRS-Constant Rate of Strain		RCT-Rowe Cell Test		BD=BULK DENSITY							
								THIN WALL PUSH IN		CRS-Constant Rate of Strain		RCT-Rowe Cell Test		PD=PARTICLE DENSITY							
								MAZIER		CRS-Constant Rate of Strain		RCT-Rowe Cell Test		LL=LIQUID LIMIT(%)							
								SPT STANDARD PENETRATION TEST		CRS-Constant Rate of Strain		RCT-Rowe Cell Test		PL=PLASTIC LIMIT (%)							
										CRS-Constant Rate of Strain		RCT-Rowe Cell Test		UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)							
CLIENT: Keppel Bay Pte Ltd		PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		LOG OF BORING GEOTECHNICAL STUDY - FIELD INVESTIGATIONS		DRILLED BY: Saw Lynn Myint Aung/Chinnyah		DATE OF FIELD WORK: 08/11/23-14/11/23													
CHECKED BY: Nel Cortes		SHEET NO. 52																			

LOCATION: Keppel Island		SPT (N)/mm SCR%		FRACTURE PER METER	WEATHERING GRADE	REDUCED LEVEL (mSHD)	DEPTH (mCD)	SAMPLE TYPE	GRAPHIC LOG	GEOLOGICAL CLASSIFICATION	BRITISH SOIL CLASSIFICATION	BOREHOLE NO. BH-13	
												NORTHING: 27276.992	
												EASTING: 25629.346	
												SEA BED LEVEL : -5.35 mSHD	
FIELD TESTS		SPT N VALUE										DESCRIPTION	
				40	>15	-22.15	CR14			STsf	SI	Moderately strong Light grey SILTSTONE Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
							21					Borehole terminated at -20.50mCD	
							22						
							23						
							24						
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							36						
							37						
							38						
							39						
							40						
BORING TYPE RO DIAMETER(mm) 100		TCR,RQD (%) 		☒ SAMPLE ☐ PRESSURE METER TEST ☐ CORE RUN ☒ VANE SHEAR TEST	☒ PERMEABILITY TEST /PACKER TEST ☒ SPT N VALUE TW THIN WALL PUSH IN MZ MAZIER SPT STANDARD PENETRATION TEST	CR-CORE DS-Direct Shear Box Test CRS-Constant Rate of Strain RCT-Rowe Cell Test	MC-MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)						
CLIENT: Keppel Bay Pte Ltd						LOG OF BORING GEOTECHNICAL STUDY - FIELD INVESTIGATIONS							
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island						DRILLED BY: Saw Lynn Myint Aung/Chinnyah			DATE OF FIELD WORK: 08/11/23-14/11/23				
						ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd			CHECKED BY: Nel Cortes			SHEET NO. 53 <2> / <2>	

LOCATION: Keppel Island		SPT (N)/mm SCR%		FRACTURE PER METER	WEATHERING GRADE	REDUCED LEVEL (mSHD)	DEPTH (mCD)	SAMPLE TYPE	GRAPHIC LOG	GEOLOGICAL CLASSIFICATION	BRITISH SOIL CLASSIFICATION	BOREHOLE NO. BH-14	
FIELD TESTS		SPT N VALUE										NORTHING: 27267.502	
												EASTING: 25650.919	
												SEA BED LEVEL : -9.65 mSHD	
												DESCRIPTION	
												Deck to Seabed Seabed Level -8.00mCD	
												Greenish grey Marine CLAY with shell fragments (Kallang Group: Rochor Clay Formation) TW1 (C'cu=3,φ'cu=23)	
												Firm, Purplish red mottled light grey Slightly fine sandy CLAY mixed with rock fragments and traces of coral Residual Soil (S-VI) (Sentosa Group; Fort Siloso Formation)	
												Dense, Yellowish brown Silty fine to medium SAND Residual Soil (S-VI) (Sentosa Group; Fort Siloso Formation)	
												Hard, Pinkish grey mottled light grey and yellowish brown Sandy CLAY mixed with rock fragments Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
												Weak to moderately weak Light grey mottled yellowish brown Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Core loss at 13.60-14.00mCD-CR1) (Sentosa Group; Fort Siloso Formation)	
												Moderately strong Light grey mottled purplish red and yellow Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Moderately weathered (S-III) (Core loss at 15.80-16.00mCD CR-3) (Sentosa Group; Fort Siloso Formation)	
												Weak to moderately weak Light grey mottled reddish brown and pink Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly to moderately weathered (S-IV) (Core loss at 16.50-17.00mCD CR-4) (Sentosa Group; Fort Siloso Formation)	
												Very weak Reddish brown SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Core loss at 18.20-18.40mCD-CR-6) (Sentosa Group; Fort Siloso Formation)	
												Moderately strong Yellowish brown mottled purplish red Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
												Moderately strong Light grey mottled reddish brown and yellow Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
												CR= CORE DS=Direct Shear Box Test CRS=Constant Rate of Strain RCT=Rowe Cell Test	
												MC=MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)	
BORING TYPE RO		TCR,RQD (%)		SAMPLE		PERMEABILITY TEST /PACKER TEST		CR-CORE					
DIAMETER(mm) 100				PRESSURE METER TEST		SPT N VALUE		DS=Direct Shear Box Test					
				CORE RUN		THIN WALL PUSH IN		CRS=Constant Rate of Strain					
				VANE SHEAR TEST		MAZIER		RCT=Rowe Cell Test					
						SPT STANDARD PENETRATION TEST							

LOCATION: Keppel Island		BOREHOLE NO. BH-14	
		NORTHING: 27267.502	
		EASTING: 25650.919	
		SEA BED LEVEL : -9.65 mSHD	
		DESCRIPTION	
FIELD TESTS		SPT N VALUE	
0 10 20 30 40 50 60 70 80 90 100		SPT (N)/mm SOR%	
FRACTURE PER METER		WEATHERING GRADE	
REDUCED LEVEL (mSHD)		DEPTH (mCD)	
SAMPLE TYPE		GRAPHIC LOG	
GEOLOGICAL CLASSIFICATION		BRITISH SOIL CLASSIFICATION	
Moderately strong Light grey to reddish brown mottled yellow Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)		STsf STsf	
Moderately weak Reddish brown mottled yellow Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)		STsf STsf	
Very weak to weak Reddish brown SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation) CR11 (UCS=2.09)		STsf STsf	
Moderately strong Purplish red to light grey SILTSTONE Very close to close spacing, Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)		STsf STsf	
Weak Light grey SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Close spacing Moderately fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)		STsf STsf	
Moderately strong Light grey SILTSTONE Close to medium spacing, Moderately fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)		STsf STsf	
Moderately weak to moderately strong Light grey to grey SILTSTONE Very close spacing, Highly fractured Highly to moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)		STsf STsf	
Moderately strong Grey SILTSTONE Close to medium spacing, Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation) CR24 (Is(50)=1.81)		STsf STsf	
Borehole terminated at -38.00mCD			
BORING TYPE RO DIAMETER(mm) 100		TCR,RQD (%)	
TCR RQD		SAMPLE PRESSURE METER TEST CORE RUN VANE SHEAR TEST	
PERMEABILITY TEST /PACKER TEST SPT N VALUE THIN WALL PUSH IN MAZIER STANDARD PENETRATION TEST		CR-CORE DS-Direct Shear Box Test CRS-Constant Rate of Strain RCT-Rowe Cell Test MC-MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)	
CLIENT: Keppel Bay Pte Ltd		LOG OF BORING GEOTECHNICAL STUDY - FIELD INVESTIGATIONS	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		DRILLED BY: Saw Lynn Myint Aung/Ravi	
CHECKED BY: Nel Cortes		DATE OF FIELD WORK: 20/11/23-22/12/23	
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd		SHEET NO. 55	

LOCATION: Keppel Island						BOREHOLE NO. BH-15	
						NORTHING: 27287.931	
						EASTING: 25720.901	
						SEA BED LEVEL : -5.15 mSHD	
						DESCRIPTION	
FIELD TESTS						Deck to Seabed Seabed Level -3.50mCD	
SPT N VALUE							
0 10 20 30 40 50 60 70 80 90 100							
SPT (N)/mm SCR%							
FRACTURE PER METER							
WEATHERING GRADE							
REDUCED LEVEL (mSHD)							
DEPTH (mCD)							
SAMPLE TYPE							
GRAPHIC LOG							
GEOLOGICAL CLASSIFICATION							
BRITISH SOIL CLASSIFICATION							
						Sea Bed	
						Light grey spotted black Hardcores (FILL)	
						Pinkish grey mottled dark grey Sandy SILT mixed with hardcores (FILL)	
						Hard Yellowish brown mottled light grey Slightly fine sandy SILT Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
						Hard Light yellowish brown striped light grey Slightly fine sandy SILT Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
						Hard Light grey striped light yellow Slightly fine sandy SILT Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
						Moderately weak Light grey mottled yellowish brown and pink Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
						Weak to moderately weak Light grey to yellowish brown Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
						Moderately weak to moderately strong Light grey mottled yellowish brown and red Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
						Moderately strong Light grey Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
						Moderately strong Reddish brown mottled light grey Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
BORING TYPE RO						MC-MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)	
DIAMETER(mm) 100							
TCR,RQD (%)							
TCR							
RQD							
SAMPLE						PERMEABILITY TEST /PACKER TEST	
PRESSURE METER TEST						CR-CORE DS-Direct Shear Box Test CRS-Constant Rate of Strain RCT-Rowe Cell Test	
CORE RUN						SPT N VALUE	
VANE SHEAR TEST						THIN WALL PUSH IN	
						MZ MAZIER	
						SPT STANDARD PENETRATION TEST	
CLIENT: Keppel Bay Pte Ltd						LOG OF BORING GEOTECHNICAL STUDY – FIELD INVESTIGATIONS	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island						DRILLED BY: Saw Lynn Myint Aung/Chinnyah	
						DATE OF FIELD WORK: 02/11/23-06/11/23	
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd						CHECKED BY: Nel Cortes	
						SHEET NO. 56	
						<1> / <2>	

LOCATION: Keppel Island		SPT (N)/mm SCR%		FRACTURE PER METER		WEATHERING GRADE		REDUCED LEVEL (mSHD)		DEPTH (mCD)		SAMPLE TYPE		GRAPHIC LOG		GEOLOGICAL CLASSIFICATION		BRITISH SOIL CLASSIFICATION		BOREHOLE NO. BH-16	
FIELD TESTS		SPT N VALUE																		NORTHING: 27298.845	
		0 10 20 30 40 50 60 70 80 90 100																		EASTING: 25758.099	
																				SEA BED LEVEL : -6.15 mSHD	
																				DESCRIPTION	
																				Deck to Seabed Seabed Level -4.50mCD	
																				Light grey spotted black Hardcores (FILL)	
																				Hard, Light grey Slightly fine sandy SILT Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
																				Hard, Light grey Fine to medium sandy SILT mixed with rock fragments Completely weathered (S-V) (Sentosa Group; Fort Siloso Formation)	
																				Weak to moderately weak Light grey SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
																				Moderately strong Yellowish brown striped reddish brown Fine to medium grained SANDSTONE Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
																				Moderately strong Light grey SILTSTONE (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
																				Moderately strong Light grey spotted red striped reddish brown Fine to medium grained SANDSTONE Close to medium spacing, Moderately fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
																				Moderately strong Light grey striped yellowish brown Fine to medium grained SANDSTONE (Sandstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
																				CR6 (Is(50)=1.63,UCS=16.15) Moderately weak,Purplish red striped light grey SILTSTONE interbedded with Sandstone (Siltstone interbedded and intimately mixed with an underlying layer of soil) Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
																				Moderately weak to moderately strong Light grey striped purplish red SILTSTONE interbedded with Sandstone Very close to close spacing Highly fractured Highly to moderately weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
																				Moderately strong,Light grey striped purplish red Fine to medium grained SANDSTONE interbedded with Siltstone Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
																				CR9 Moderately strong,Light grey striped purplish red Fine to medium grained SANDSTONE interbedded with Siltstone Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
																				CR-CORE DS-Direct Shear Box Test CRS-Constant Rate of Strain RCT-Rowe Cell Test	
																				MC-MOISTURE CONTENT BD=BULK DENSITY PD=PARTICLE DENSITY LL=LIQUID LIMIT(%) PL=PLASTIC LIMIT (%) UU/CU=UNCONSOLIDATED /CONSOLIDATED UNDRAINED TEST (kPa)	
																				CLIENT: Keppel Bay Pte Ltd	
																				LOG OF BORING GEOTECHNICAL STUDY - FIELD INVESTIGATIONS	
																				PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island	
																				DRILLED BY: Saw Lynn Myint Aung/Chinnyah	
																				DATE OF FIELD WORK: 25/10/23-31/10/23	
																				CHECKED BY: Nel Cortes	
																				SHEET NO. 58	
																				<1> / <2>	
																				ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd	
																				element	
																				Accredited Inspection SAC Body 08-2017-181-F	

LOCATION: Keppel Island		BOREHOLE NO. BH-16	
		NORTHING: 27298.845	
		EASTING: 25758.099	
		SEA BED LEVEL : -6.15 mSHD	
FIELD TESTS		DESCRIPTION	
SPT N VALUE			
0 10 20 30 40 50 60 70 80 90 100			
SPT (N)/mm SCR%			
FRACTURE PER METER			
WEATHERING GRADE			
REDUCED LEVEL (mSHD)			
DEPTH (mCD)			
SAMPLE TYPE			
GRAPHIC LOG			
GEOLOGICAL CLASSIFICATION			
BRITISH SOIL CLASSIFICATION			
		Moderately strong Light grey striped purplish red Fine to medium grained SANDSTONE interbedded with Siltstone	
		Very close to close spacing Highly fractured Moderately weathered (S-III) (Sentosa Group; Fort Siloso Formation)	
		Moderately weak Purplish red mottled light grey SILTSTONE interbedded with Sandstone (Siltstone interbedded and intimately mixed with an underlying layer of soil)	
		Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
		Moderately weak Purplish red mottled light grey SILTSTONE Very close to close spacing Highly fractured Highly weathered (S-IV) (Sentosa Group; Fort Siloso Formation)	
		Borehole terminated at -24.00mCD	
BORING TYPE RO		SAMPLE	
DIAMETER(mm) 100		PRESSURE METER TEST	
TCR,RQD (%)		CORE RUN	
TCR		VANE SHEAR TEST	
RQD		PERMEABILITY TEST /PACKER TEST	
		SPT N VALUE	
		TW THIN WALL PUSH IN	
		MZ MAZIER	
		SPT STANDARD PENETRATION TEST	
		CR-CORE	
		DS-Direct Shear Box Test	
		CRS-Constant Rate of Strain	
		RCT-Rowe Cell Test	
		MC-MOISTURE CONTENT	
		BD=BULK DENSITY	
		PD=PARTICLE DENSITY	
		LL=LIQUID LIMIT(%)	
		PL=PLASTIC LIMIT (%)	
		UU/CU=UNCONSOLIDATED /CONSOLIDATED	
		UNDRAINED TEST (kPa)	
CLIENT: Keppel Bay Pte Ltd		LOG OF BORING GEOTECHNICAL STUDY - FIELD INVESTIGATIONS	
PROJECT: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island		DRILLED BY: Saw Lynn Myint Aung/Chinnyah	
		DATE OF FIELD WORK: 25/10/23-31/10/23	
ELEMENT GEOTECHNICAL TESTING (S) Pte Ltd		CHECKED BY: Nel Cortes	
		SHEET NO. 59	
		<2> / <2>	

APPENDIX C

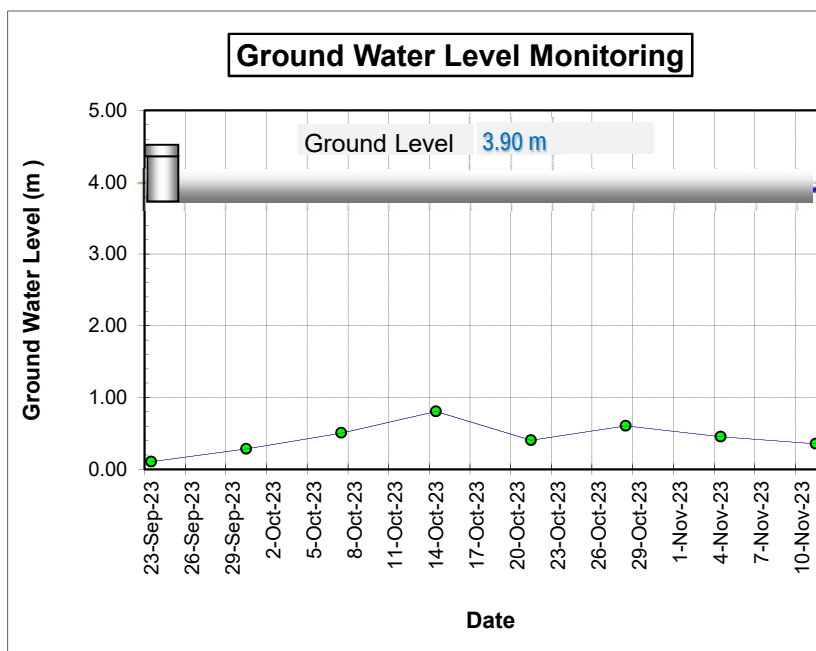
Water Standpipe & Piezometer Monitoring Data

WATER STANDPIPE

GROUND WATER LEVEL MONITORING DATA AND GRAPH

CLIENT	: Keppel Bay Pte Ltd	INSTRUMENT NO.	: WSP
PROJECT	: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island	BOREHOLE NO.	: BH -01
		REDUCE LEVEL	: 3.90 m
		TOP OF PIPE LEVEL	: 3.90 m
LOCATION	: Keppel Island	DATE INSTALLED	: 22-Sep-23

Date (dd-mmm-yy)	Ground Level (m)	Top of Pipe Level (m)	Depth of Water (m)	Ground Water Level (m)	Remarks	SKETCH OF WATER STANDPIPE (not to scale)
23-Sep-23	3.904	3.904	3.800	0.104	Initial	Top Cap Ground Level 100 diameter Borehole PVC Pipe 50mm diameter Compacted Seal of Local Soil 1.00 m bgl 1.50 m bgl Graded Filter Material of Clean Sand and Gravels Mix 5mm Hole Staggered At 100mm (Both Direction) 50mm dia. Perforated PVC pipe Wrapped all round with Green Nylon Net 12.00 m bgl Bottom Cap Graded Filter Material Of Clean Sand Gravels Mix
30-Sep-23	3.904	3.904	3.620	0.284		
7-Oct-23	3.904	3.904	3.400	0.504		
14-Oct-23	3.904	3.904	3.100	0.804		
21-Oct-23	3.904	3.904	3.500	0.404		
28-Oct-23	3.904	3.904	3.300	0.604		
4-Nov-23	3.904	3.904	3.450	0.454		
11-Nov-23	3.904	3.904	3.550	0.354		

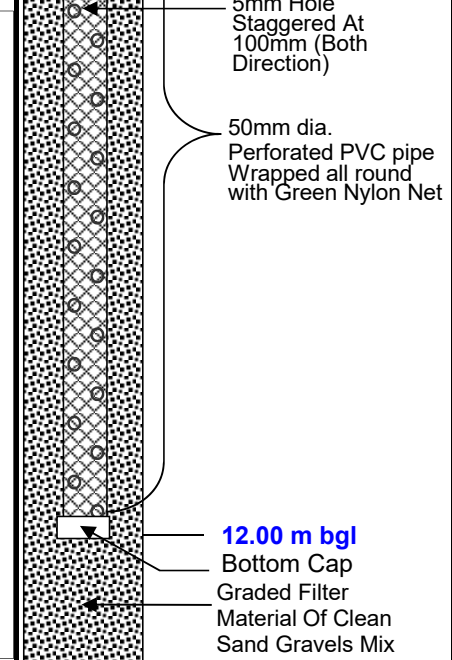
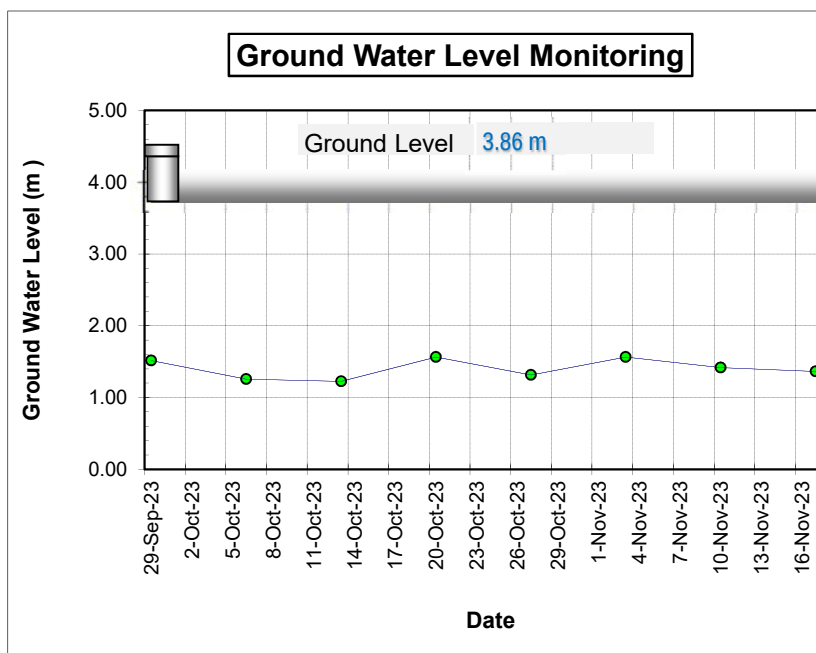


WATER STANDPIPE

GROUND WATER LEVEL MONITORING DATA AND GRAPH

CLIENT	: Keppel Bay Pte Ltd	INSTRUMENT NO.	: WSP
PROJECT	: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island	BOREHOLE NO.	: BH -05
		REDUCE LEVEL	: 3.86 m
		TOP OF PIPE LEVEL	: 3.86 m
LOCATION	: Keppel Island	DATE INSTALLED	: 28-Sep-23

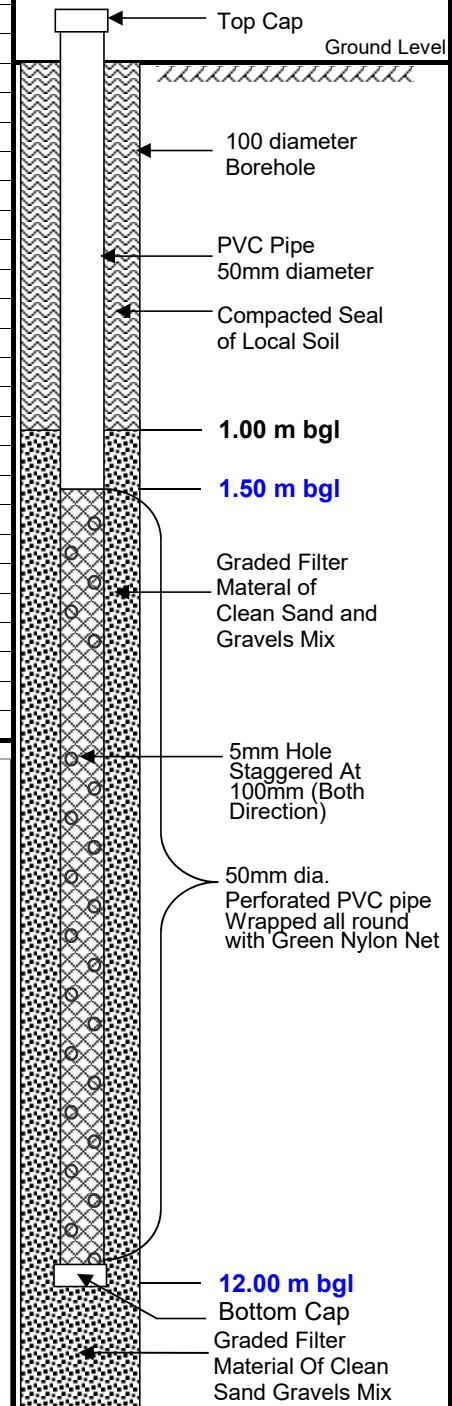
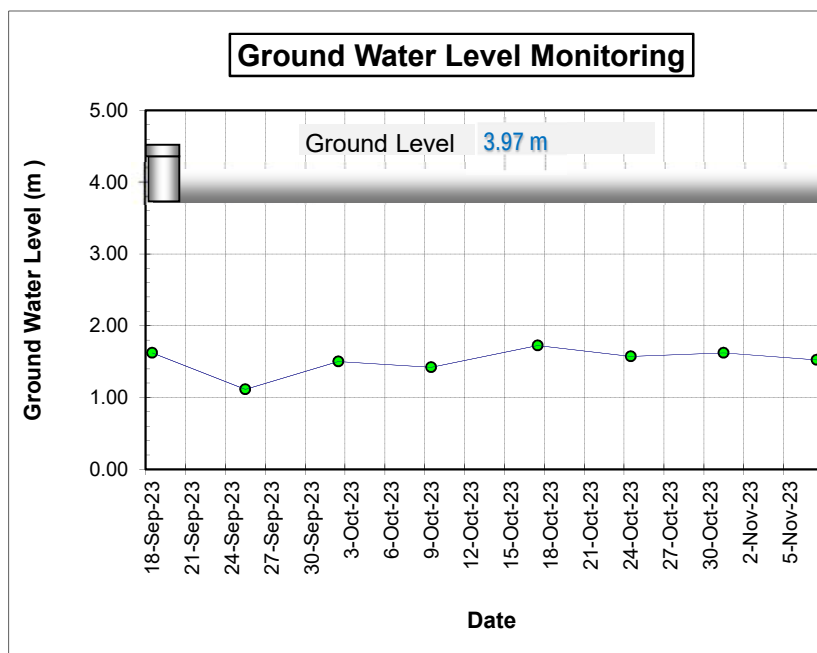
Date (dd-mmm-yy)	Ground Level (m)	Top of Pipe Level (m)	Depth of Water (m)	Ground Water Level (m)	Remarks	SKETCH OF WATER STANDPIPE (not to scale)
29-Sep-23	3.864	3.864	2.350	1.514	Initial	
6-Oct-23	3.864	3.864	2.610	1.254		
13-Oct-23	3.864	3.864	2.640	1.224		
20-Oct-23	3.864	3.864	2.300	1.564		
27-Oct-23	3.864	3.864	2.550	1.314		
3-Nov-23	3.864	3.864	2.300	1.564		
10-Nov-23	3.864	3.864	2.450	1.414		
17-Nov-23	3.864	3.864	2.500	1.364		



WATER STANDPIPE

GROUND WATER LEVEL MONITORING DATA AND GRAPH

CLIENT	: Keppel Bay Pte Ltd	INSTRUMENT NO.	: WSP
PROJECT	: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island	BOREHOLE NO.	: BH -07
		REDUCE LEVEL	: 3.97 m
		TOP OF PIPE LEVEL	: 3.97 m
LOCATION	: Keppel Island	DATE INSTALLED	: 16-Sep-23

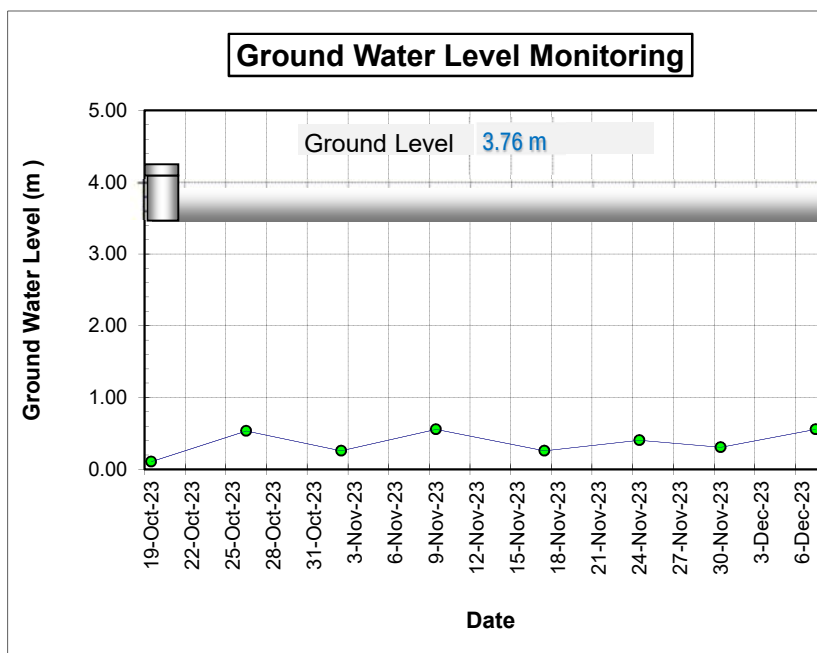
[illegible]

WATER STANDPIPE

GROUND WATER LEVEL MONITORING DATA AND GRAPH

CLIENT	: Keppel Bay Pte Ltd	INSTRUMENT NO.	: WSP
PROJECT	: Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island	BOREHOLE NO.	: BH -11
		REDUCE LEVEL	: 3.76 m
		TOP OF PIPE LEVEL	: 3.76 m
LOCATION	: Keppel Island	DATE INSTALLED	: 18-Oct-23

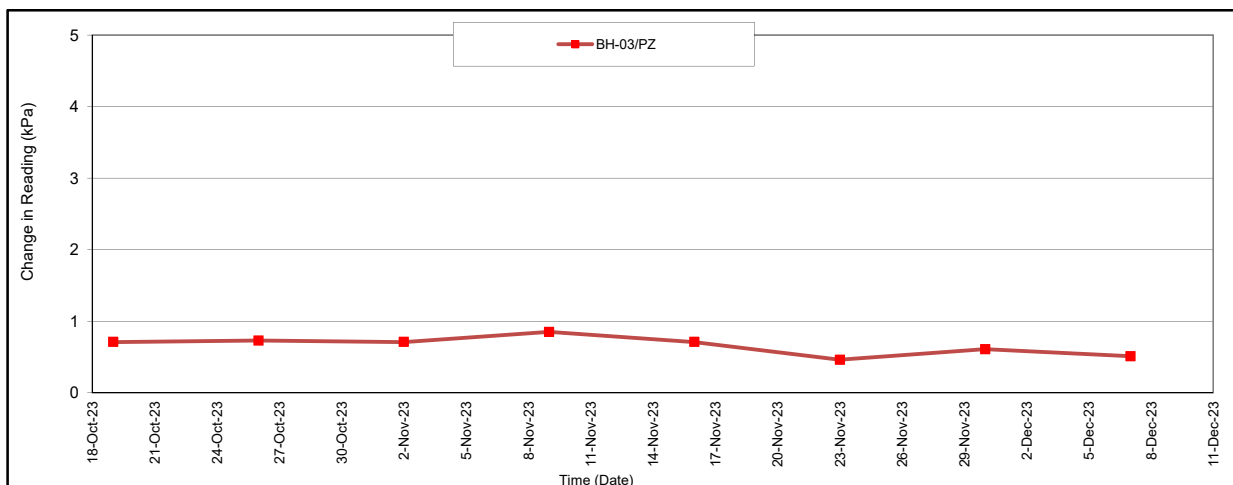
Date (dd-mmm-yy)	Ground Level (m)	Top of Pipe Level (m)	Depth of Water (m)	Ground Water Level (m)	Remarks	SKETCH OF WATER STANDPIPE (not to scale)
19-Oct-23	3.755	3.755	3.650	0.105	Initial	Top Cap Ground Level 100 diameter Borehole PVC Pipe 50mm diameter Compacted Seal of Local Soil 1.00 m bgl 1.50 m bgl Graded Filter Material of Clean Sand and Gravels Mix 5mm Hole Staggered At 100mm (Both Direction) 50mm dia. Perforated PVC pipe Wrapped all round with Green Nylon Net 12.00 m bgl Bottom Cap Graded Filter Material Of Clean Sand Gravels Mix
26-Oct-23	3.755	3.755	3.220	0.535		
2-Nov-23	3.755	3.755	3.500	0.255		
9-Nov-23	3.755	3.755	3.200	0.555		
17-Nov-23	3.755	3.755	3.500	0.255		
24-Nov-23	3.755	3.755	3.350	0.405		
30-Nov-23	3.755	3.755	3.450	0.305		
7-Dec-23	3.755	3.755	3.200	0.555		



Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island

Client: Keppel Bay Pte Ltd

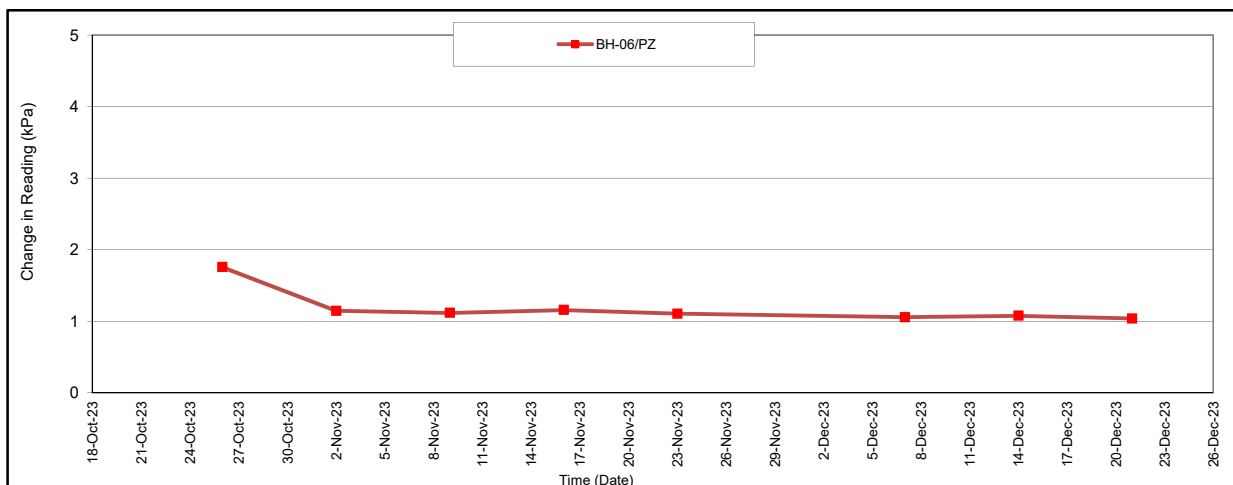
Instrument ID	BH-03/PZ
Date of Installation	18-10-23
Depth of Installation (m)	12.00
Tip Level (m)	-
Ground Level (m)	3.910
Pipe Top Level (m)	3.910
Initial Readings (m)	3.200

[illegible]

Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island

Client: Keppel Bay Pte Ltd

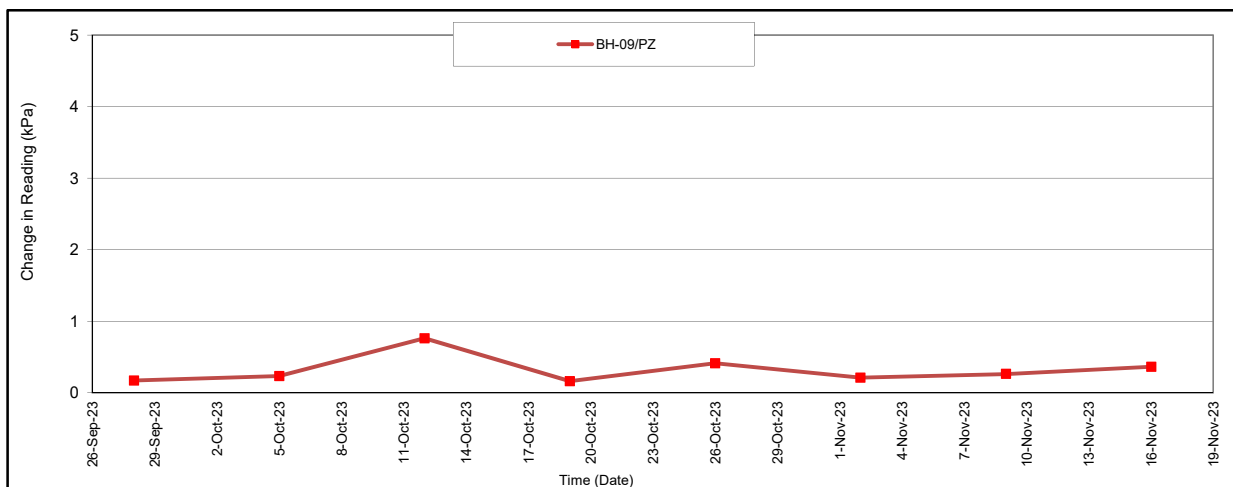
Instrument ID	BH-06/PZ
Date of Installation	25-10-23
Depth of Installation (m)	12.00
Tip Level (m)	-
Ground Level (m)	3.757
Pipe Top Level (m)	3.757
Initial Readings (m)	2.000

[illegible]

Soil Investigation Work For Proposed Development At Plot 6 At Keppel Island

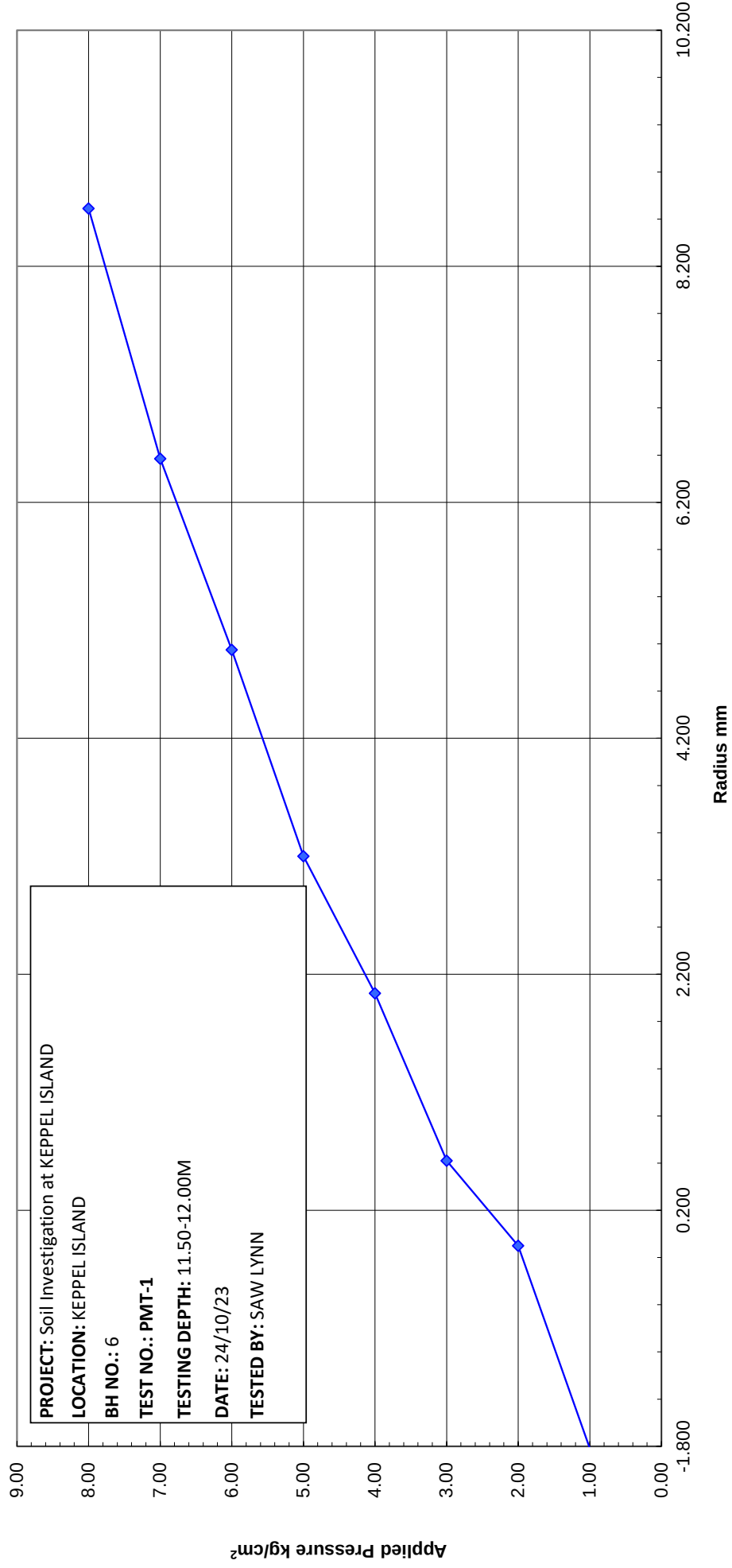
Client: Keppel Bay Pte Ltd

Instrument ID	BH-09/PZ
Date of Installation	27-09-23
Depth of Installation (m)	12.00
Tip Level (m)	-
Ground Level (m)	3.812
Pipe Top Level (m)	3.812
Initial Readings (m)	3.640

[illegible]

APPENDIX D

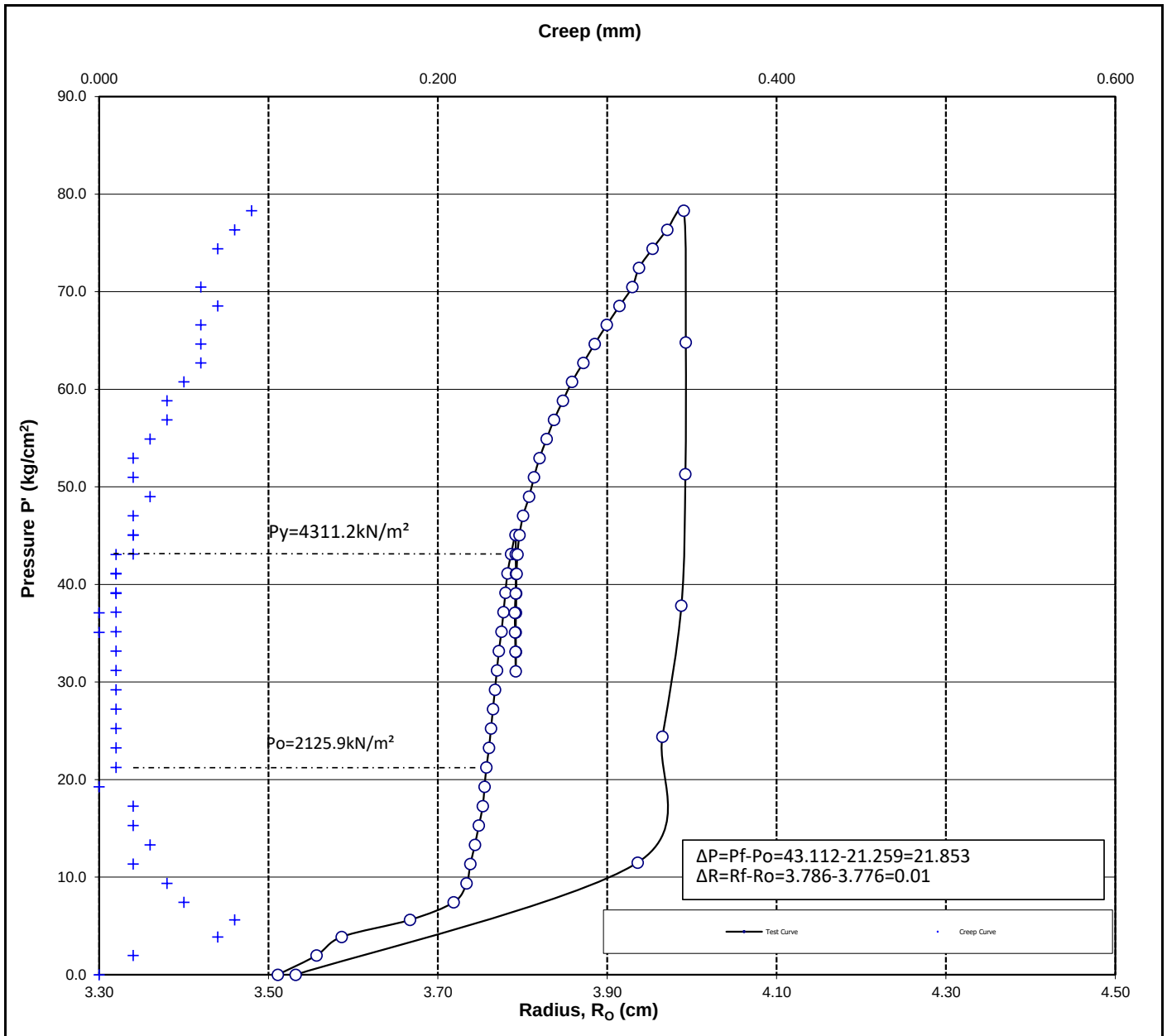
Field Pressuremeter Test Results



PROJECT	:	SI WORKS FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND
CLIENT	:	KEPPEL BAY PTE LTD

Boring No.	:	BH-6	Ground Level RL(m)	:	103.757	PMT Type	:	ELASTMETER 2
Test Depth (m)	:	11.50M	Water Level RL(m)	:	3.10	Rubber Type	:	HARD
Test No.	:	1	Soil Type	:	SILTSTONE	Comment:	:	INITIAL
Test Date	:	24/10/2023	N-Value	:				

EARTH PRESSURE AT REST	YIELD PRESSURE	FAILURE PRESSURE	COEFFICIENT OF SOIL REACTION	MODULUS OF ELASTICITY	MEAN RADIUS
Po (kN/m ²)	Py (kN/m ²)	Pf (kN/m ²)	Km (kN/m ³)	Em (kN/m ²)	Rm (m) x 10 ⁻²
2125.9	4311.2		21,216,505	1,042,813	3.781

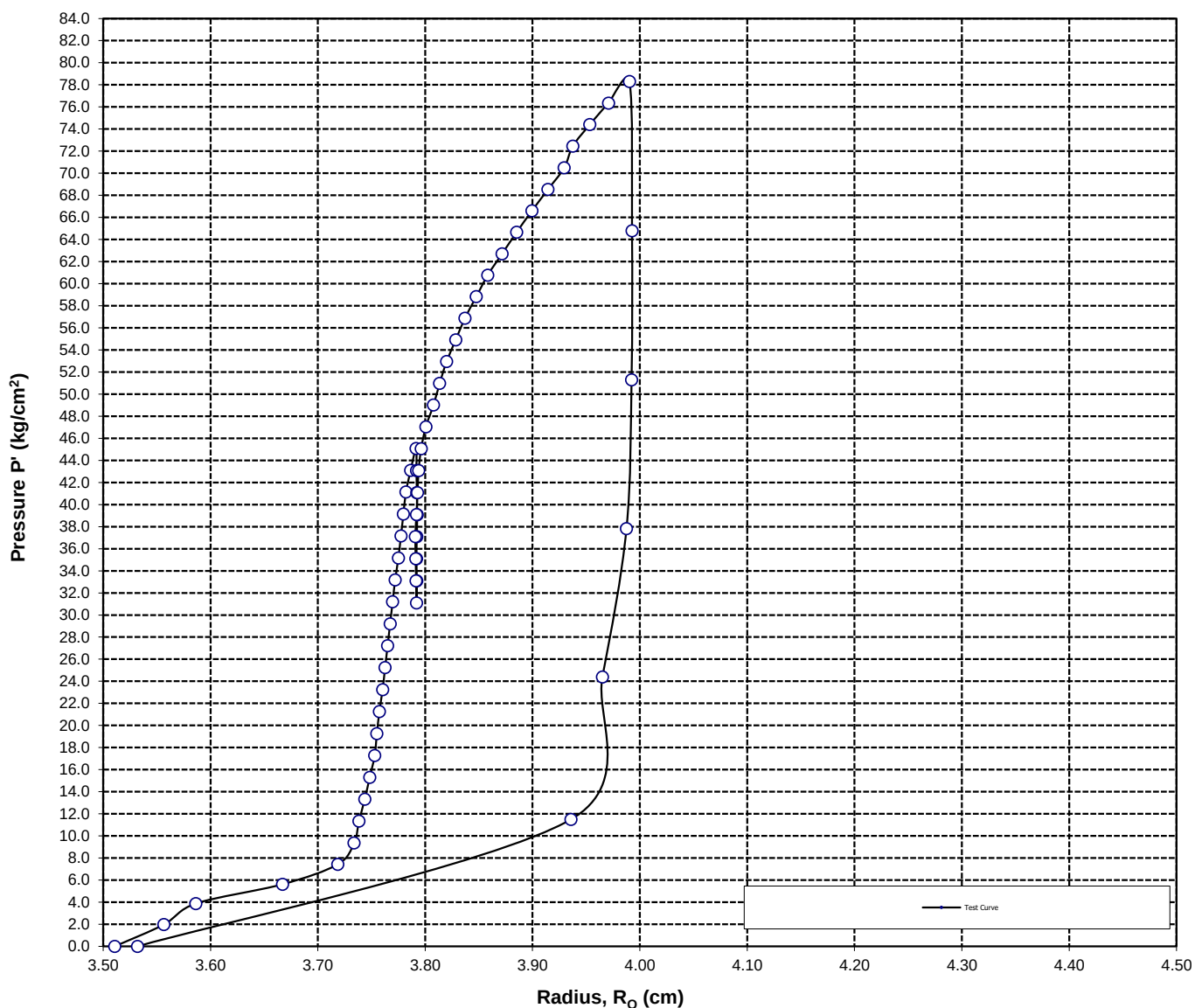


PROJECT	:	SI WORKS FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND
CLIENT	:	KEPPEL BAY PTE LTD

Boring No.	:	BH-6	Ground Level RL(m)	:	103.757	PMT Type	:	ELASTMETER 2
Test Depth (m)	:	11.50M	Water Level RL(m)	:	3.10	Rubber Type	:	HARD
Test No.	:	1	Soil Type	:	SILTSTONE	Comment:	CYCLIC	
Test Date	:	24/10/2023	N-Value	:				

EARTH PRESSURE AT REST	YIELD PRESSURE	FAILURE PRESSURE	COEFFICIENT OF SOIL REACTION	MODULUS OF ELASTICITY	MEAN RADIUS
Po (kN/m ²)	Py (kN/m ²)	Pf (kN/m ²)	Kr (kN/m ³)	Er (kN/m ²)	Rr (m) x 10 ⁻²
4506.5	5295.0		3,285,417	125,109	3.808

Test Curve



PROJECT	:	SI WORKS FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND
CLIENT	:	KEPPEL BAY PTE LTD

Boring No.	:	BH-6	Ground Level	:	103.757	PMT Type	:	ELASTMETER 2
Test Depth (m)	:	11.50M	Water Level	:	3.10	Rubber Type	:	HARD
Test No.	:	1	Soil Type	:	SILTSTONE	Conducted	:	SAW LYNN
Test Date	:	24/10/23	N-Value	:		Checked	:	NEL CORTES

No.	P (kg/cm ²)	P'=P-Pg (kg/cm ²)	Pg (kg/cm ²)	Rn(30) (mm)	Rn(60) (mm)	Rn(120) (mm)	Creep Ind. (mm)	R _s (cm)	R _o (cm)
1	0.00	0.000	0.000	-2.320	-2.320	-2.320	0.00	2.118	3.511
2	2.00	1.979	0.021	-1.590	-1.590	-1.570	0.02	2.193	3.557
3	4.00	3.880	0.120	-1.160	-1.120	-1.090	0.07	2.241	3.586
4	6.00	5.621	0.379	0.100	0.140	0.180	0.08	2.368	3.667
5	8.00	7.425	0.575	0.920	0.940	0.970	0.05	2.447	3.719
6	10.00	9.362	0.638	1.160	1.180	1.200	0.04	2.470	3.734
7	12.00	11.343	0.657	1.250	1.260	1.270	0.02	2.477	3.738
8	14.00	13.320	0.680	1.320	1.330	1.350	0.03	2.485	3.744
9	16.00	15.300	0.700	1.400	1.410	1.420	0.02	2.492	3.748
10	18.00	17.280	0.720	1.470	1.480	1.490	0.02	2.499	3.753
11	20.00	19.271	0.729	1.520	1.520	1.520	0.00	2.502	3.755
12	22.00	21.259	0.741	1.550	1.550	1.560	0.01	2.506	3.757
13	24.00	23.244	0.756	1.600	1.600	1.610	0.01	2.510	3.760
14	26.00	25.233	0.767	1.640	1.640	1.650	0.01	2.514	3.763
15	28.00	27.221	0.779	1.680	1.680	1.690	0.01	2.517	3.765
16	30.00	29.209	0.791	1.720	1.720	1.730	0.01	2.521	3.767
17	32.00	31.197	0.803	1.760	1.760	1.770	0.01	2.524	3.770
18	34.00	33.185	0.815	1.800	1.800	1.810	0.01	2.528	3.772
19	36.00	35.169	0.831	1.850	1.850	1.860	0.01	2.532	3.775
20	38.00	37.157	0.843	1.890	1.890	1.900	0.01	2.536	3.777
21	40.00	39.145	0.855	1.930	1.930	1.940	0.01	2.539	3.780
22	42.00	41.133	0.867	1.970	1.980	1.980	0.01	2.543	3.782
23	44.00	43.112	0.888	2.030	2.040	2.050	0.02	2.549	3.786
24	46.00	45.087	0.913	2.110	2.120	2.130	0.02	2.557	3.792
25	44.00	43.087	0.913	2.130	2.130	2.130		2.557	3.792
26	42.00	41.087	0.913	2.130	2.130	2.130		2.558	3.792
27	40.00	39.087	0.913	2.130	2.130	2.130		2.558	3.793
28	38.00	37.090	0.910	2.120	2.120	2.120		2.558	3.792
29	36.00	35.093	0.907	2.120	2.120	2.110		2.557	3.792
30	34.00	33.093	0.907	2.110	2.110	2.110		2.558	3.792
31	32.00	31.096	0.904	2.100	2.100	2.100		2.557	3.792
32	34.00	33.096	0.904	2.100	2.100	2.100		2.557	3.792
33	36.00	35.096	0.904	2.100	2.100	2.100	0.00	2.556	3.791
34	38.00	37.096	0.904	2.100	2.100	2.100	0.00	2.556	3.791
35	40.00	39.090	0.910	2.110	2.110	2.120	0.01	2.557	3.792
36	42.00	41.084	0.916	2.130	2.130	2.140	0.01	2.559	3.793
37	44.00	43.078	0.922	2.150	2.150	2.160	0.01	2.560	3.794
38	46.00	45.065	0.935	2.180	2.190	2.200	0.02	2.564	3.796
39	48.00	47.044	0.956	2.250	2.260	2.270	0.02	2.570	3.801
40	50.00	49.009	0.991	2.350	2.360	2.380	0.03	2.581	3.808
41	52.00	50.982	1.018	2.450	2.460	2.470	0.02	2.589	3.814
42	54.00	52.950	1.050	2.550	2.560	2.570	0.02	2.599	3.820
43	56.00	54.910	1.090	2.670	2.680	2.700	0.03	2.611	3.828
44	58.00	56.870	1.130	2.790	2.810	2.830	0.04	2.624	3.837
45	60.00	58.821	1.179	2.950	2.970	2.990	0.04	2.639	3.848
46	62.00	60.773	1.227	3.100	3.120	3.150	0.05	2.655	3.858
47	64.00	62.714	1.286	3.290	3.320	3.350	0.06	2.674	3.872
48	66.00	64.656	1.344	3.490	3.520	3.550	0.06	2.694	3.885
49	68.00	66.598	1.402	3.700	3.730	3.760	0.06	2.714	3.899
50	70.00	68.539	1.461	3.910	3.940	3.980	0.07	2.736	3.914
51	72.00	70.484	1.516	4.140	4.170	4.200	0.06	2.757	3.930
52	74.00	72.455	1.545	4.860	4.290	4.320	-0.54	2.769	3.938
53	76.00	74.402	1.598	4.480	4.510	4.550	0.07	2.791	3.953
54	78.00	76.350	1.650	4.720	4.760	4.800	0.08	2.816	3.971
55	80.00	78.297	1.703	4.990	5.030	5.080	0.09	2.843	3.990
56	66.50	64.797	1.703	5.080	5.080	5.080		2.846	3.993
57	53.00	51.304	1.696	5.040	5.040	5.040		2.846	3.992
58	39.50	37.823	1.677	4.950	4.950	4.940		2.839	3.988
59	26.00	24.394	1.606	4.600	4.600	4.590		2.808	3.965
60	13.00	11.493	1.507	4.180	4.170	4.160		2.766	3.936

APPENDIX D

Laboratory Tests Results

- * Summary of Laboratory Test Results
 - * Consolidated Undrained (CU) Triaxial Test
 - * Unconfined Compression (UC) Test on Rock Core Samples
 - * Point Load Test on Rock Core Samples
 - * Chemical Test

Summary of Laboratory Test Results



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F: +65 67478940
E: info.geolab@element.com

SUMMARY OF LABORATORY TEST RESULTS



Main Con.: **Element Geotechnical Testing (S) Pte Ltd**

Client : **Keppel Bay Pte Ltd (KBPL)**

Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**

Job No.: **322/23**

Borehole No.		BH-1	
Sample No.		CR-2	WATER
Sample Depth (m)		From	20.50
		To	21.50
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa	16.15	
Point Load (Rock)	Point Load Strength Index Is (50) Mpa	1.54	
Chemical Test	pH Value		8.9
	Sulphate Content mg/L		28
	Chloride Content mg/L		29

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS."

This laboratory is accredited under the Singapore Accreditation Council - Singapore Laboratory Accreditation Scheme (SAC-SINGLAS) and has met the requirement of ISO / ICE 17025 : 2017.

San San

Laboratory Manager
Element Geolab (S) Pte Ltd



Element Geolab (S) Pte Ltd
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F: +65 67478940
E: Info.geolab@element.com

SUMMARY OF LABORATORY TEST RESULTS



Main Con.: **Element Geotechnical Testing (S) Pte Ltd**
Client : **Keppel Bay Pte Ltd (KBPL)**
Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**
Job No.: **322/23**

Borehole No.		BH-2
Sample No.		CR-9
Sample Depth (m)	From	21.00
	To	22.00
Point Load (Rock)	Point Load Strength Index Is (50) Mpa	1.16

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS."

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San San

Laboratory Manager
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SUMMARY OF LABORATORY TEST RESULTS



Main Con.: **Element Geotechnical Testing (S) Pte Ltd**

Client : **Keppel Bay Pte Ltd (KBPL)**

Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**

Job No.: **322/23**

Borehole No.		BH-3
Sample No.		CR-12
Sample Depth (m)	From	13.00
	To	14.00
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa	20.29
Point Load (Rock)	Point Load Strength Index Is (50) Mpa	0.94

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SUMMARY OF LABORATORY TEST RESULTS



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Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**
Job No.: **322/23**

Borehole No.		BH-5
Sample No.		WATER
Sample Depth (m)	From	-
	To	-
Chemical Test	pH Value	6.3
	Total Sulphate Content mg/L	3
	Chloride Content mg/L	1

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SUMMARY OF LABORATORY TEST RESULTS



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Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**
Job No.: **322/23**

Borehole No.		BH-6
Sample No.		CR-5
Sample Depth (m)	From	6.00
	To	7.00
Point Load (Rock)	Point Load Strength Index Is (50) Mpa	2.91

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SUMMARY OF LABORATORY TEST RESULTS



Main Con.: **Element Geotechnical Testing (S) Pte Ltd**
Client : **Keppel Bay Pte Ltd (KBPL)**
Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**
Job No.: **322/23**

Borehole No.		BH-7
Sample No.		WATER
Sample Depth (m)	From	-
	To	-
Chemical Test	pH Value	7.3
	Total Sulphate Content mg/L	0
	Chloride Content mg/L	8

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SUMMARY OF LABORATORY TEST RESULTS



Main Con.: Element Geotechnical Testing (S) Pte Ltd
Client : Keppel Bay Pte Ltd (KBPL)
Project : Soil Investigation Work For Proposed Development At Plot 6 Keppel Island
Job No.: 322/23

Borehole No.		BH-8
Sample No.		CR-5
Sample Depth (m)	From	18.30
	To	19.30
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa	6.18

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SUMMARY OF LABORATORY TEST RESULTS



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Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**

Job No.: **322/23**

Borehole No.		BH-9
Sample No.		CR-5
Sample Depth (m)	From	11.00
	To	12.00
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa	23.29
Point Load (Rock)	Point Load Strength Index Is (50) Mpa	0.93

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SUMMARY OF LABORATORY TEST RESULTS



Main Con.: **Element Geotechnical Testing (S) Pte Ltd**
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Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**
Job No.: **322/23**

Borehole No.		BH-10		
Sample No.		TW-1	CR-3	CR-5
Sample Depth (m)	From	3.00	14.00	16.00
	To	3.90	15.00	17.00
Triaxial Compression Test	Internal friction (°)	31		
	Cohesion Intercept. kPa	7		
	Type of Test	CU		
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa		8.03	39.54
Point Load (Rock)	Point Load Strength Index Is (50) Mpa			3.05
Chemical Test	pH Value	6.9		
	Organic Matter Content %	0.1		
	Acid Soluble Sulphate %	0.03		
	Chloride Content %	< 0.01		

Legends

UU : Unconsolidated-Undrained Triaxial Compression
CU : Consolidated-Undrained Triaxial Compression

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SUMMARY OF LABORATORY TEST RESULTS



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Job No.: **322/23**

Borehole No.		BH-11	
Sample No.		CR-10	WATER
Sample Depth (m)		From	19.00
		To	20.00
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa	10.27	
Point Load (Rock)	Point Load Strength Index Is (50) Mpa	0.81	
Chemical Test	pH Value		7.8
	Total Sulphate Content mg/L		3
	Chloride Content mg/L		2

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SUMMARY OF LABORATORY TEST RESULTS



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Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**
Job No.: **322/23**

Borehole No.		BH-12
Sample No.		CR-4
Sample Depth (m)	From	5.30
	To	6.30
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa	3.25
Point Load (Rock)	Point Load Strength Index Is (50) Mpa	0.81

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SUMMARY OF LABORATORY TEST RESULTS



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Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**

Job No.: **322/23**

Borehole No.		BH-13	
Sample No.		CR-8	CR-10
Sample Depth (m)	From	13.50	15.50
	To	14.50	16.50
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa	4.47	
Point Load (Rock)	Point Load Strength Index Is (50) Mpa		1.11

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SUMMARY OF LABORATORY TEST RESULTS

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Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**

Job No.: **322/23**



Borehole No.		BH-14		
Sample No.		TW-1	CR-11	CR-24
Sample Depth (m)	From	8.00	23.00	36.00
	To	8.90	24.00	37.00
Triaxial Compression Test	Internal friction (°)	23		
	Cohesion Intercept. kPa	3		
	Type of Test	CU		
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa		2.09	
Point Load (Rock)	Point Load Strength Index Is (50) Mpa			1.81

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SUMMARY OF LABORATORY TEST RESULTS



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Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**

Job No.: **322/23**

Borehole No.		BH-15
Sample No.		CR-5
Sample Depth (m)	From	13.50
	To	14.50
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa	5.16

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SUMMARY OF LABORATORY TEST RESULTS



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Project : **Soil Investigation Work For Proposed Development At Plot 6 Keppel Island**

Job No.: **322/23**

Borehole No.		BH-16
Sample No.		CR-6
Sample Depth (m)	From	16.00
	To	17.00
Unconfined Compressive Strength Test (Rock)	Unconfined Compressive Strength MPa	16.15
Point Load (Rock)	Point Load Strength Index Is (50) Mpa	1.63

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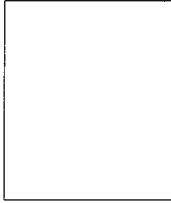
Consolidated Undrained (CU) Triaxial Test

Effective Stress Triaxial Compression

Consolidated Undrained

Sample details

Sketch showing specimen location in original Sample



Depth 3.00-3.90m
Description: Brown and light grey sandy SILT (Visual)

	Specimen 1	Specimen 2	Specimen 3
Type			
Height H_0 (mm)	76	76	76
Diameter D_0 (mm)	38	38	38
Weight W_0 (gr)	179.06	180.42	180.61
Bulk Density ρ (Mg/m ³)	2.08	2.09	2.10
Particle Density ρ_s	2.7	2.7	2.7
	(assumed)	(assumed)	(assumed)

Initial Conditions

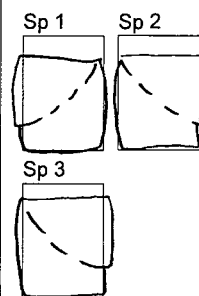
	Specimen 1	Specimen 2	Specimen 3
Cell Pressure σ_3 (kPa)	330.00	360.00	420.00
Pore Pressure u (kPa)	300.00	300.00	300.00
Machine Speed d_t (mm/min)	0.060	0.060	0.060
No. of Membranes	1	1	1
Total Thickness (mm)	0.2	0.2	0.2
Strain Channel	2	10	18
Load Channel	1	9	17
Pore P. Channel	3	7	13
Volume Channel	4	8	14
Moisture Content w_0 %	16	16	14
Dry Density ρ_{d0} (Mg/m ³)	1.80	1.80	1.83
Voids Ratio e_0	0.47	0.47	0.45
Deg of Saturation S_0 %	86.78	90.88	85.38
Final B Value	0.97	0.98	0.98

Final Conditions

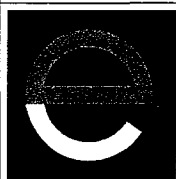
	Specimen 1	Specimen 2	Specimen 3
Moisture Content w_f %	18	18	16
Dry Density ρ_d (Mg/m ³)	1.81	1.84	1.89
Voids Ratio e_f	0.46	0.44	0.40
Deg of Saturation S_f %	100.00	100.00	100.00
Failure Criteria	Mx Dev Stress	Mx Dev Stress	Mx Dev Stress
Axial Strain ϵ_f %	15.3	12.5	14.6
Corr Dev Stress $(\sigma_1 - \sigma_3)_f$ (kPa)	212.5	238.7	306.5
Minor Stress σ_{3f} (kPa)	86.0	98.0	129.8
Major Stress σ_{1f} (kPa)	298.5	336.7	436.3
Stress Ratio $(\sigma_1/\sigma_3)_f$	3.5	3.4	3.4

Notes:

Failure Sketch



ELEMENT GEOLAB (S) PTE LTD



Test Method : BS1377 : Part 8 : 1990 : 7

Test name CU (SS)

Date of Test: 06-01-24

Site Reference: SI Wks at Keppel Island

Sample: TW-1

Jobfile: C:\ELEMENT\KEPPEL~1\KEPPEL.JC Borehole:

BH-10

Operator:

Pen

Checked:

M

Approved:

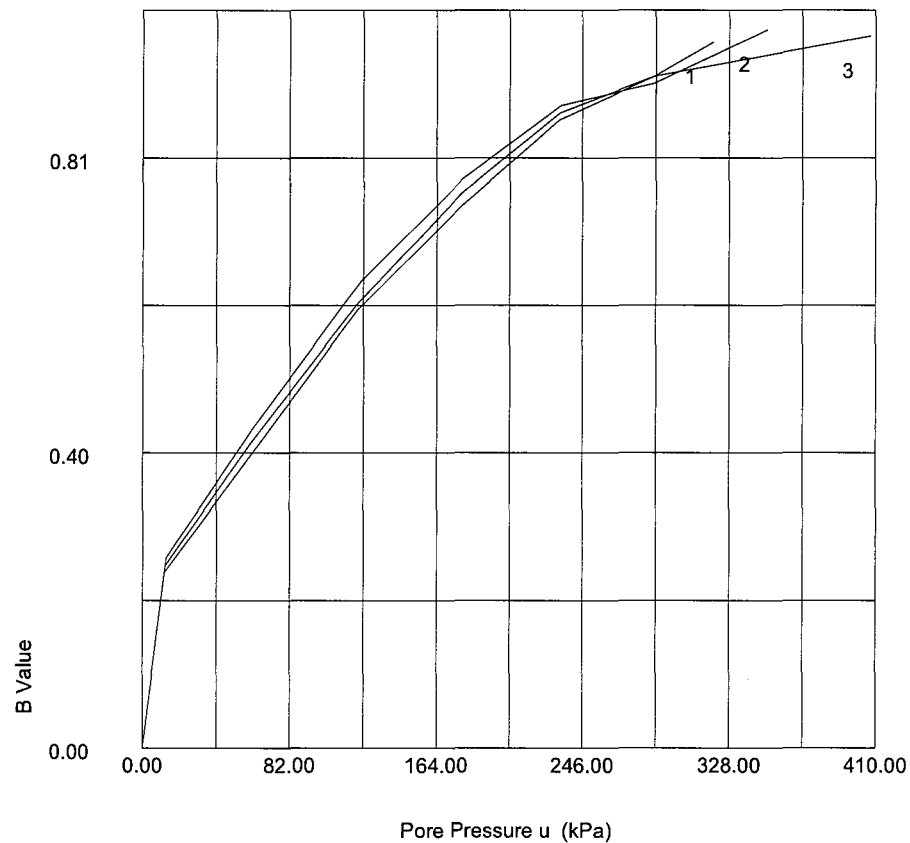
Don

Effective Stress Triaxial Compression

Consolidated Undrained

Saturation Stage Data

	Specimen 1	Specimen 2	Specimen 3
Test Method:	Cell P. And Back P.	Cell P. And Back P.	Cell P. And Back P.
Final Cell Pressure σ_{3f} (kPa)	330.00	360.00	420.00
Final Pore Pressure u_f (kPa)	319.00	349.00	407.00
Final B Value	0.97	0.98	0.98



ELEMENT GEOLAB (S) PTE LTD



Test Method : BS1377 : Part 8 : 1990 : 7

Test name : CU (SS)

Date of Test: 06-01-24

Site Reference: SI Wks at Keppel Island

Sample: TW-1

Jobfile: C:\ELEMENT\KEPPEL~1\KEPPEL.JC

Borehole: BH-10

Operator: *Pen*

Checked: *RV*

Approved: *Pen*

Effective Stress Triaxial Compression

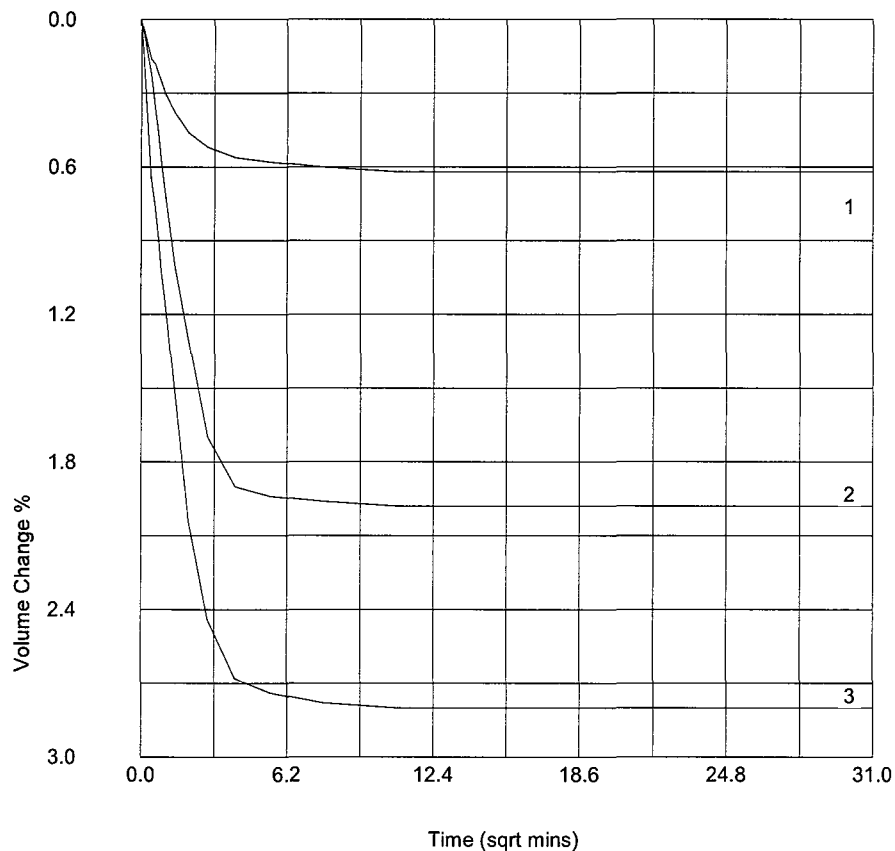
Consolidated Undrained

Consolidation Initial Conditions

	Specimen 1	Specimen 2	Specimen 3
Cell Pressure σ_3 (kPa)	330.00	360.00	420.00
Pore Pressure u_i (kPa)	319.00	349.00	407.00
Back Pressure u_b (kPa)	300.00	300.00	300.00
Drainage Method	Radial, One End	Radial, One End	Radial, One End

Consolidation Final Results

	Specimen 1	Specimen 2	Specimen 3
Deg of Consolidation $U\%$	100.0	100.0	100.0
Volumetric Strain $\varepsilon_v\%$	0.7	2.3	3.2
Corr Length L_c (mm)	75.8	75.4	75.2
Corr Area A_c (mm) ²	1128.7	1116.7	1109.6
Corr Volume V_c (cc)	85.6	84.2	83.4
t_{100} (min)	5.40	11.10	7.80
Coef. of Consolidation c_v (m ² /year)	5.515	2.683	3.818
Coef. of Compressibility m_v (m ² /MN)	0.379	0.469	0.304
Testing Time (min) t_f	9.72	19.98	14.04
Est Strain at Failure ε_f	0.8	1.6	1.2
Machine Speed d_r (mm/min)	0.0624	0.06039	0.06372



ELEMENT GEOLAB (S) PTE LTD



Test Method : BS1377 : Part 8 : 1990 : 7

Test name CU (SS)

Date of Test: 06-01-24

Site Reference: SI Wks at Keppel Island

Sample: TW-1

Jobfile: C:\ELEMENT\KEPPEL~1\KEPPEL.JC

Borehole: BH-10

Operator:

Ru

Checked:

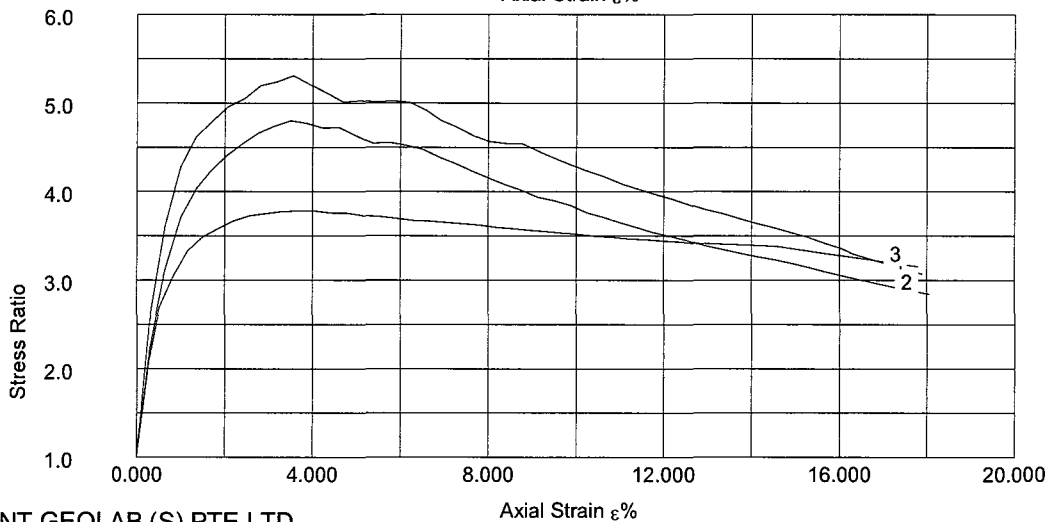
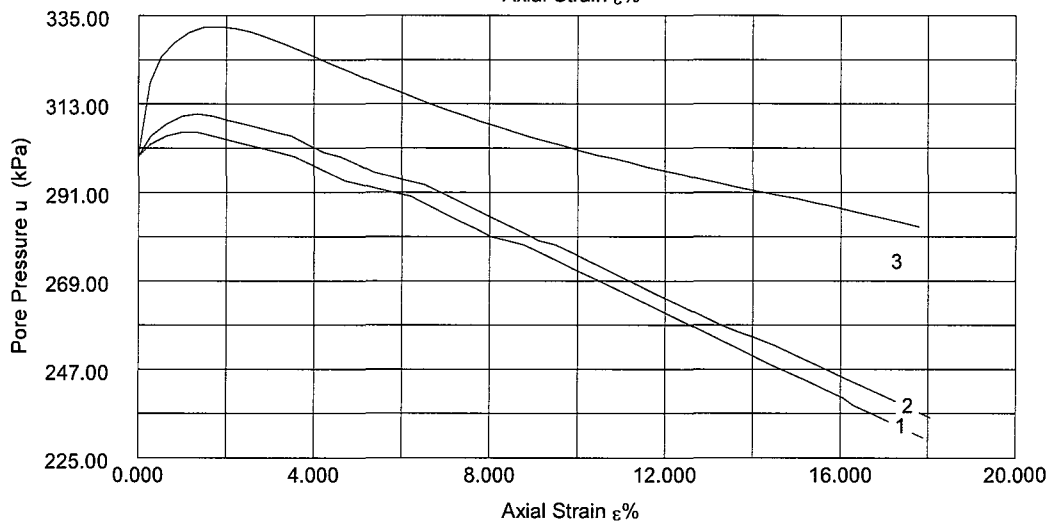
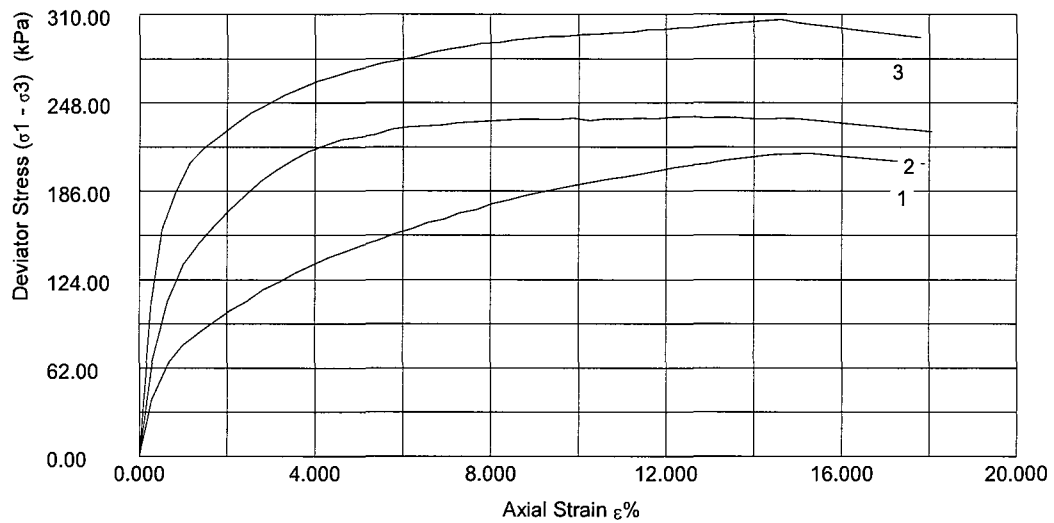
Ru

Approved:

Ru

Effective Stress Triaxial Compression

Consolidated Undrained



ELEMENT GEOLAB (S) PTE LTD



Test Method : BS1377 : Part 8 : 1990 : 7

Test name : CU (SS)

Date of Test: 06-01-24

Site Reference: SI Wks at Keppel Island

Sample: TW-1

Jobfile: C:\ELEMENT\KEPPEL~1\KEPPEL.JC

Borehole: BH-10

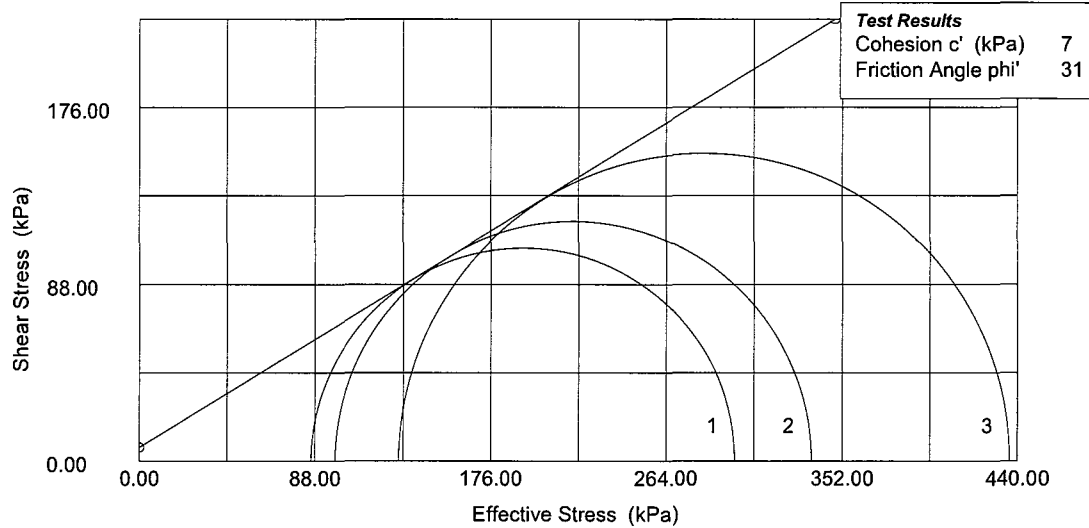
Operator: *Ren*

Checked: *R*

Approved: *DM*

Effective Stress Triaxial Compression

Consolidated Undrained

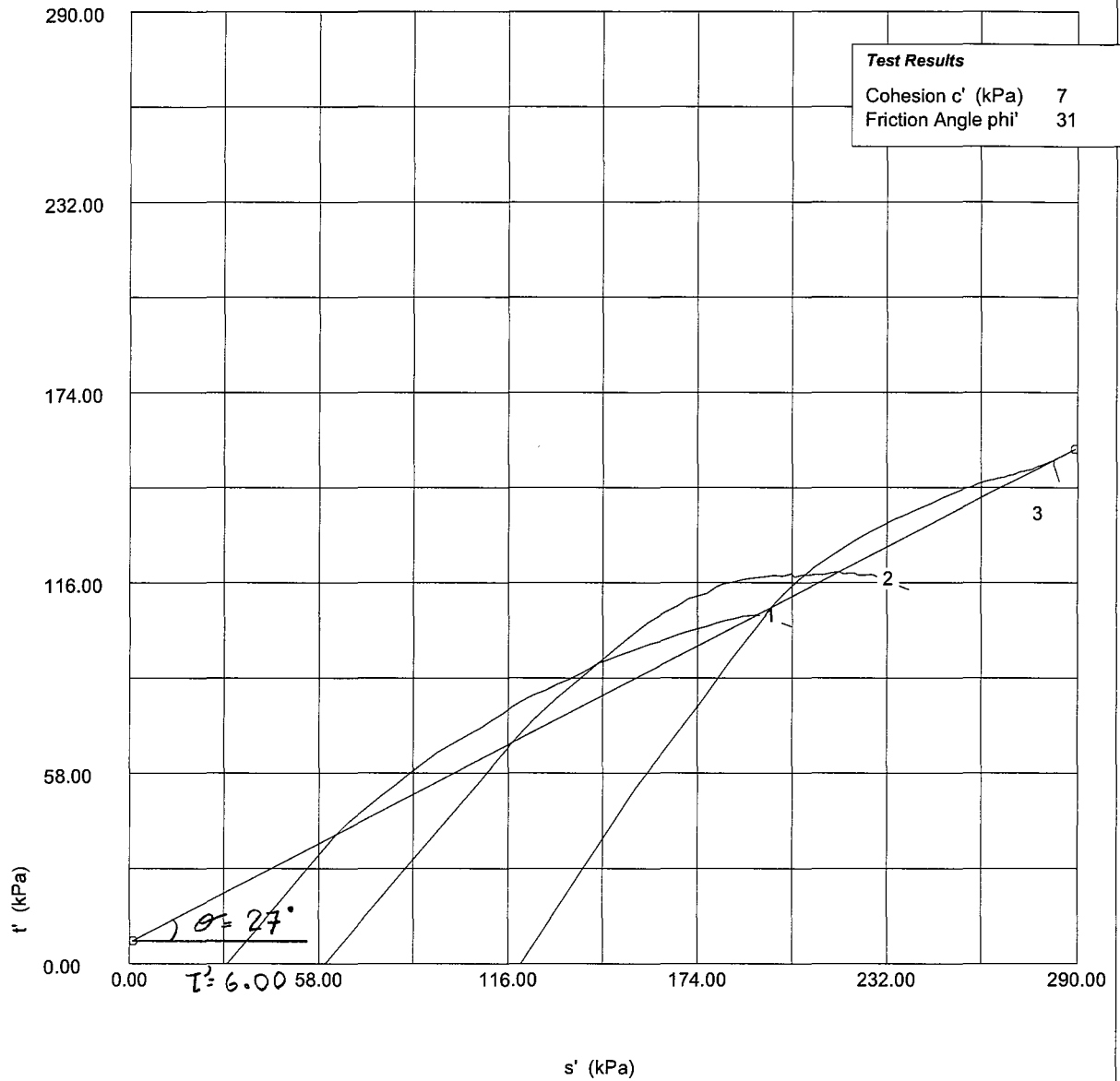


ELEMENT GEOLAB (S) PTE LTD

	Test Method : BS1377 : Part 8 : 1990 : 7		Test name	CU (SS)
			Date of Test:	06-01-24
	Site Reference:	SI Wks at Keppel Island	Sample:	TW-1
	Jobfile:	C:\ELEMENT\KEPPEL~1\KEPPEL.JC	Borehole:	BH-10
Operator:	<i>Ben</i>	Checked:	<i>h</i>	Approved: <i>Ben</i>

Effective Stress Triaxial Compression

Consolidated Undrained



ELEMENT GEOLAB (S) PTE LTD



Test Method : BS1377 : Part 8 : 1990 : 7

Test name : CU (SS)

Date of Test: 06-01-24

Site Reference: SI Wks at Keppel Island

Sample: TW-1

Jobfile: C:\ELEMENT\KEPPEL~1\KEPPEL.JC

Borehole: BH-10

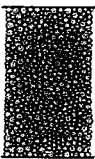
Operator: *For*

Checked: *M*

Approved: *Jan*

Effective Stress Triaxial Compression

Consolidated Undrained

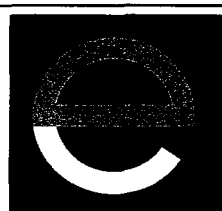
Sample details 	Depth	8.00-8.90m		
	Description	Greenish grey marine CLAY (Visual)		
	Type	Undisturbed Sample		
		Specimen 1	Specimen 2	Specimen 3
	Height H_0 (mm)	76.0	76.0	76.0
	Diameter D_0 (mm)	38.0	38.0	38.0
	Weight W_0 (gr)	137.7	138.0	139.9
Sketch showing specimen location in original sample	Bulk Density ρ_0 (Mg/m ³)	1.60	1.60	1.62
	Particle Density ρ_s	2.68 (Assumed)	2.68 (Assumed)	2.68 (Assumed)

Initial Conditions		Specimen 1	Specimen 2	Specimen 3
Cell Pressure σ_3i	(kPa)	330	360	420
Back Pressure U_{bi}	(kPa)	300	300	300
Strain Rate $\dot{\epsilon}_s$	(mm/min)	0.060	0.060	0.060
Membrane Thickness	(mm)	0.200	0.200	0.200
Displacement Input	(mm)	CH2	CH11	CH11
Load Input	(N)	CH1	CH10	CH10
Pore Water Pressure Input	(kPa)	CH3	CH12	CH12
Sample Volume	(cc)	CH4	CH14	CH14
Initial Moisture	(%)	56	58	57
Initial Dry Density ρ_{d0}	(Mg/m ³)	1.02	1.02	1.03
Initial Void Ratio e_0		1.619	1.640	1.598
Initial Deg. of Saturation S_0	(%)	93	94	96
B Value		0.97	0.97	0.98

Final Conditions		Specimen 1	Specimen 2	Specimen 3
Final Moisture	(%)	58	59	58
Final Dry Density ρ_{df}	(Mg/m ³)	1.08	1.12	1.24
Final Void Ratio e_f		1.480	1.400	1.162
Final Deg. of Saturation S_f	(%)	100.0	100.0	100.0
Failure Criteria		Max. Dev.	Max. Dev.	Max. Dev.
		Stress	Stress	Stress
Strain at Failure ϵ_f	(%)	1.58	12.58	7.72
Corr Dev Stress $(\sigma_1 - \sigma_3)_f$	(kPa)	42.7	54.8	68.3
Minor Stress at Failure σ_3'	(kPa)	22.0	30.0	39.5
Major Stress at Failure σ_1'	(kPa)	64.7	84.8	107.8
Principal Stress Ratio at Failure σ_1'/σ_3'		2.941	2.828	2.728



Failure Sketch



Test Method BS1377-8 : 1990 : Clause 7

Site Reference SI Wks for Keppel Island

Jobfile C:/KEPPEL

Test Name CU

Test Date 05.01.24

Borehole BH-14

Sample TW-1

Operator

Pen

Checked

R

Approved

Don

Effective Stress Triaxial Compression

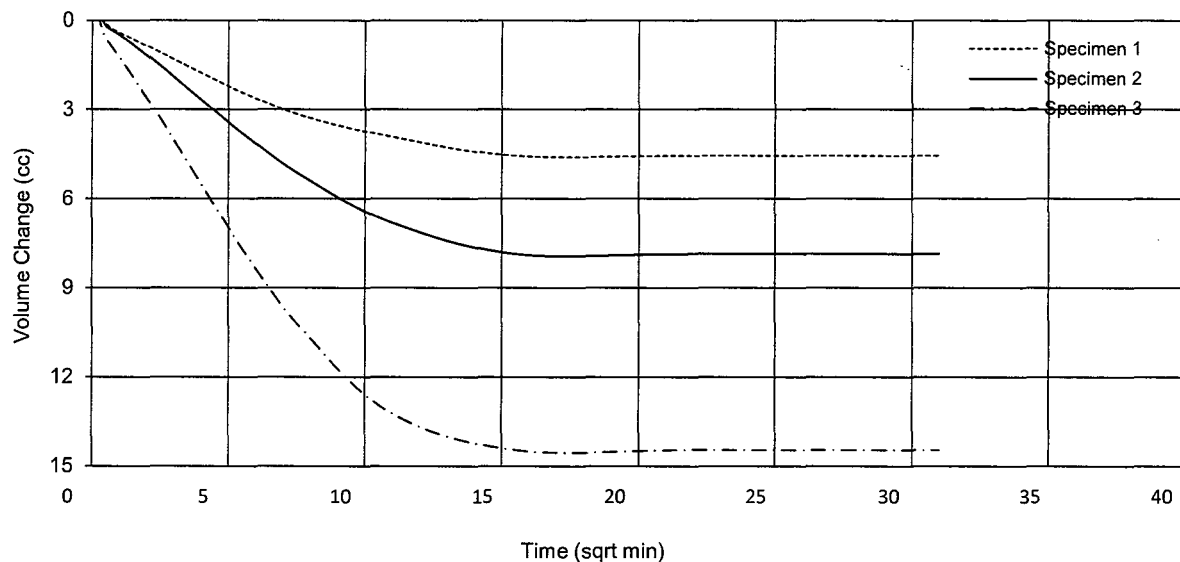
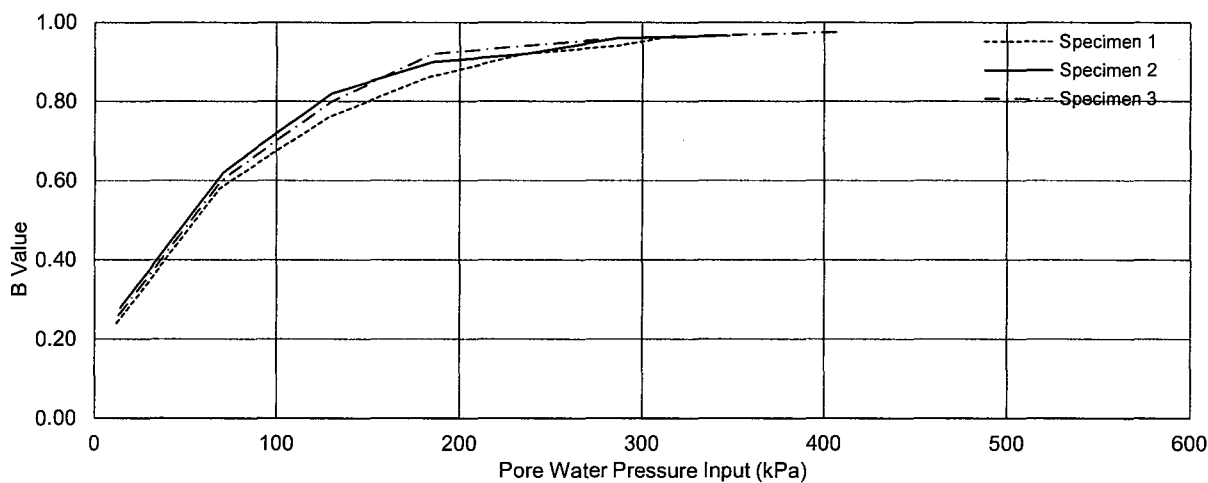
Consolidated Undrained

Saturation and Consolidation Data

	Specimen 1	Specimen 2	Specimen 3
Saturation Method	Stepped	Stepped	Stepped
B value	0.97	0.97	0.98
Cell Pressure σ_3 (kPa)	330	360	420
Back Pressure U_b (kPa)	300	300	300
Pore Water Pressure Input u_i (kPa)	319	348	407
Drainage method	From radial boundary and one end		

Consolidation Final Conditions

PWP Dissipation U%	100	100	100
Volumetric Strain ϵ_v (%)	5.29	9.11	16.78
Corrected Length L_c (mm)	74.7	73.7	71.7
Corrected Area A_c (cm ²)	10.9	10.7	10.07
Corrected Volume V_c (cc)	81.63	78.34	71.73
T_{100} Time to failure t_{100} (min)	106.69	124.02	103.65
Consolidation c_v (m ² /Year)	0.28	0.24	0.29
Compressibility m_v (m ² /MN)	4.81	2.40	1.479



Test Method BS1377-8 : 1990 : Clause 7
Site Reference SI Wks for Keppel Island
Jobfile C:/KEPPEL

Test Name CU
Test Date 05.01.24
Borehole BH-14
Sample TW-1

Operator

Pen

Checked

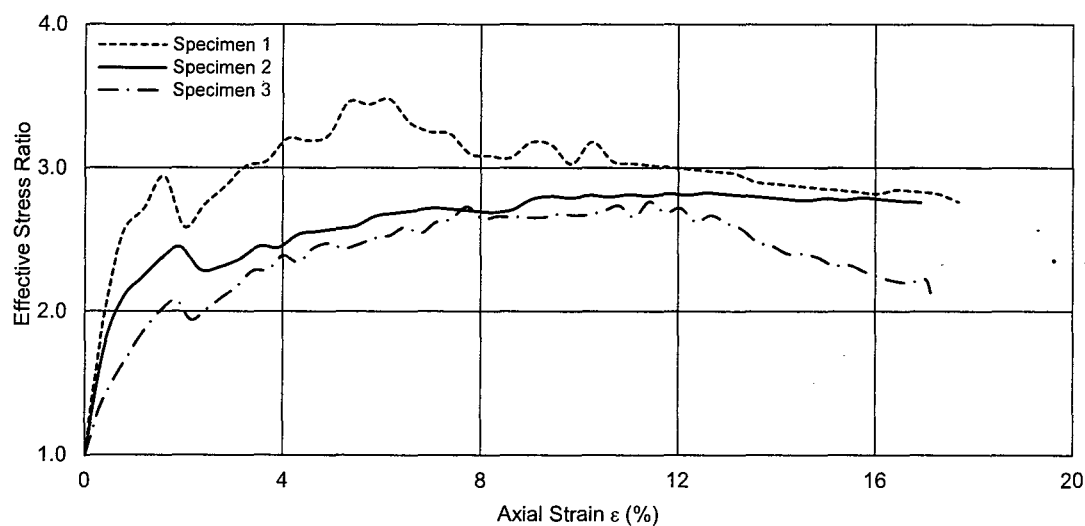
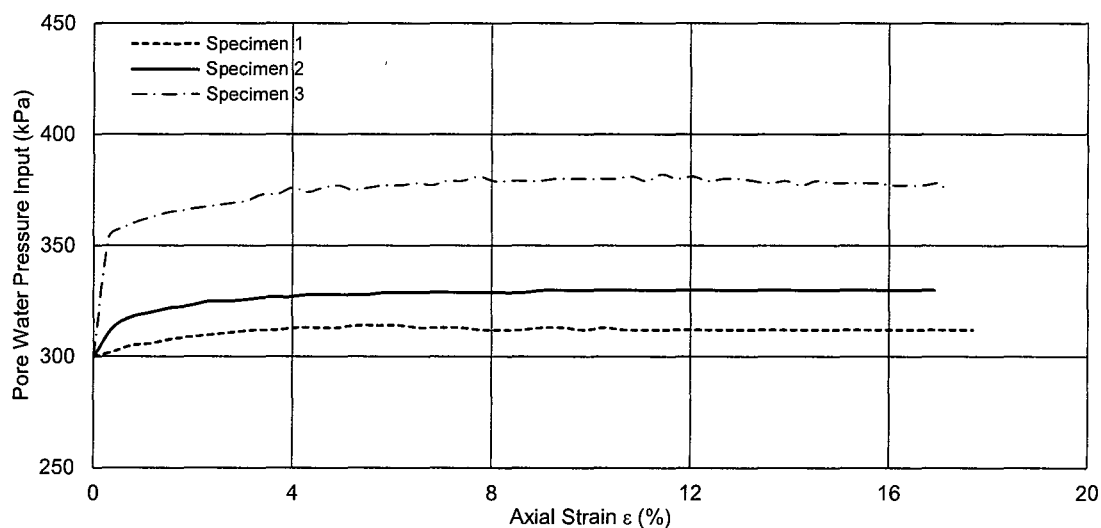
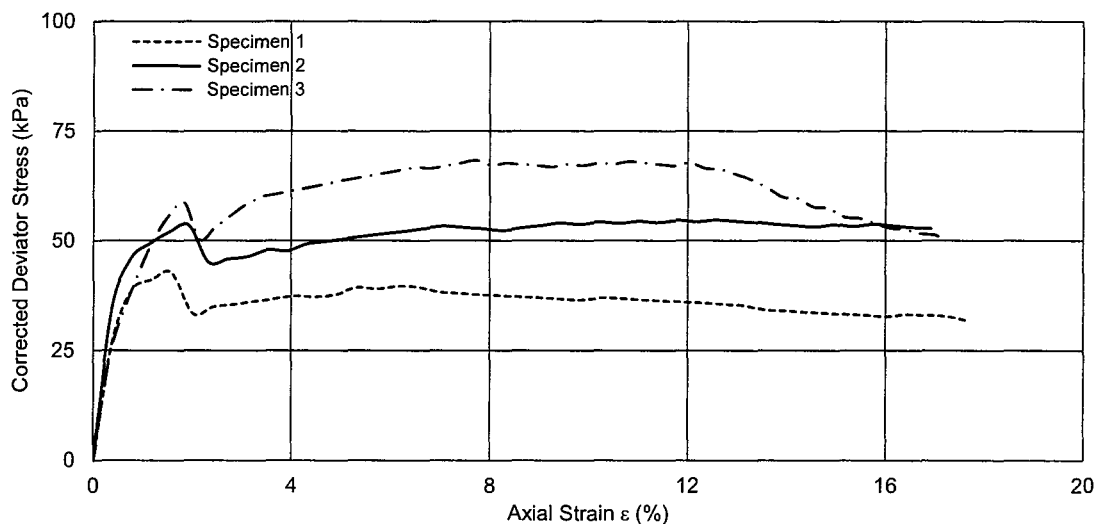
My

Approved

[Signature]

Effective Stress Triaxial Compression

Consolidated Undrained



Note : Side drain correction shall be applied for strain exceeding 2% according to BS 1377.



Test Method BS1377-8 : 1990 : Clause 7

Site Reference SI Wks for Keppel Island

Jobfile C:/KEPPEL

Test Name CU

Test Date 05.01.24

Borehole BH-14

Sample TW-1

Operator

Pen

Checked

Pen

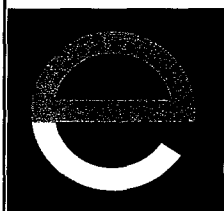
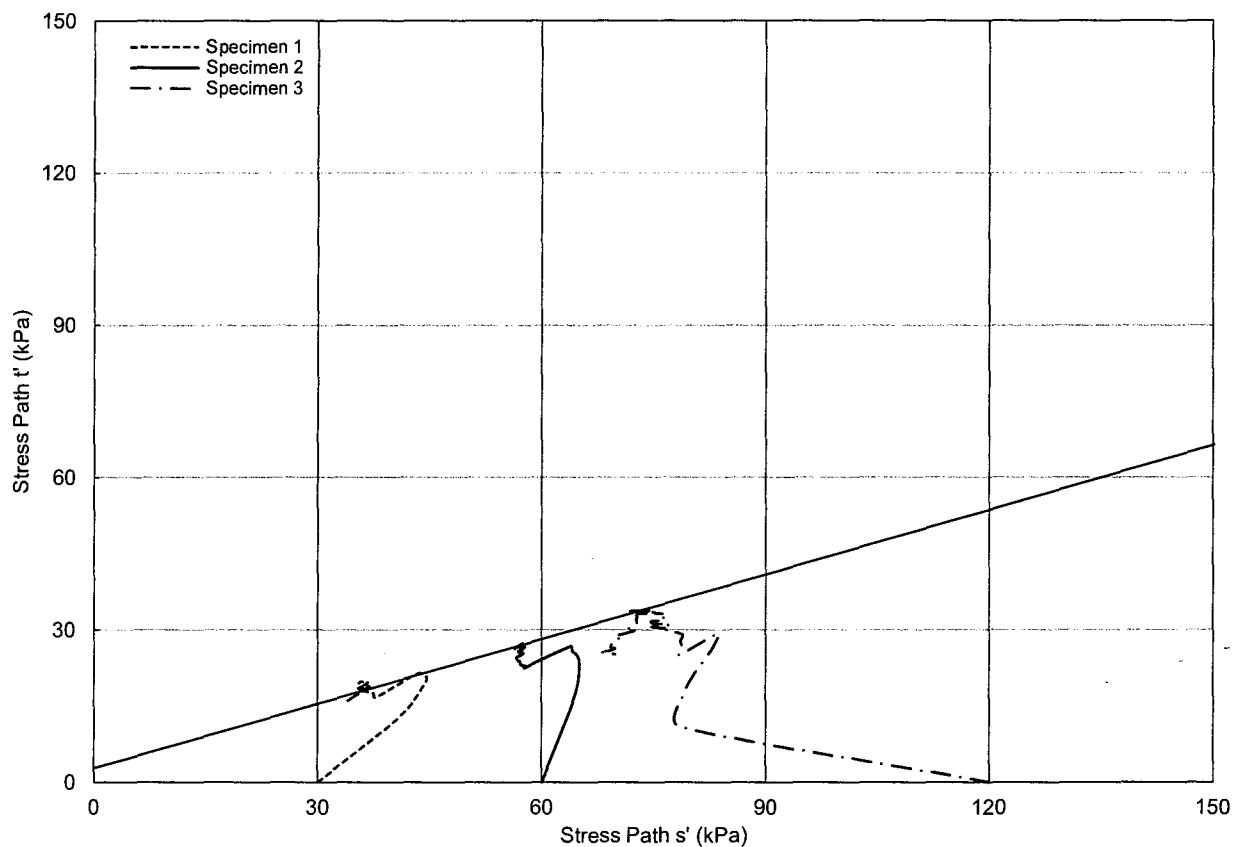
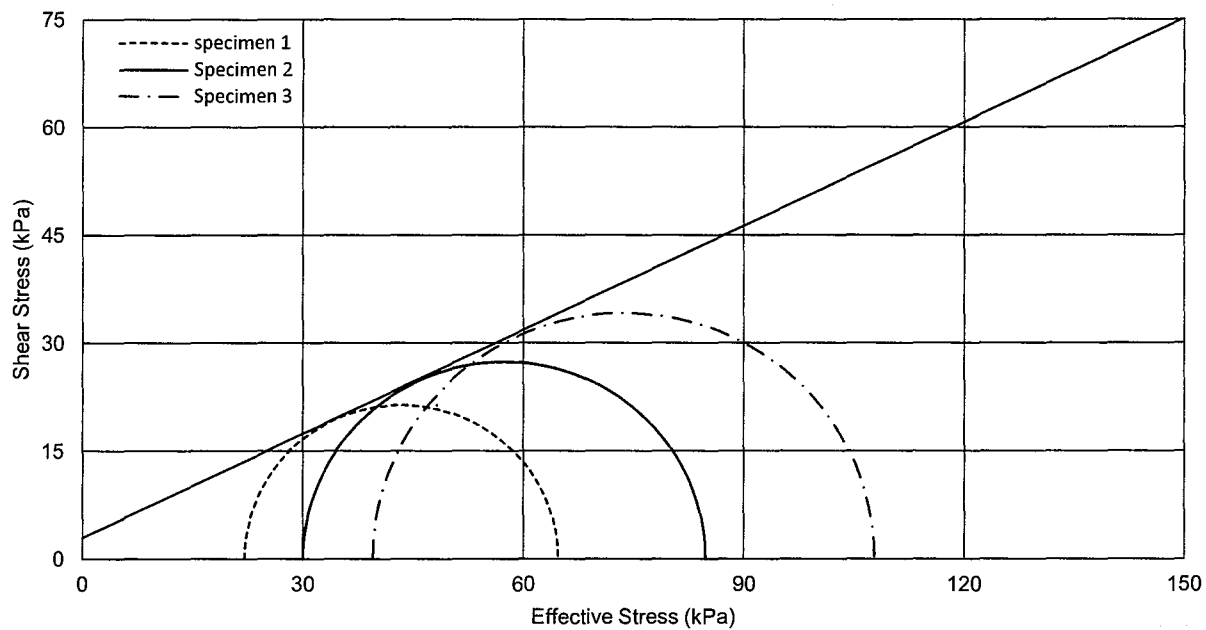
Approved

Pen

Effective Stress Triaxial Compression

Consolidated Undrained

Effective Cohesion	C'	(kPa)	3.0	Stress path Intercept	t_0'	(kPa)	2.8
Effective Friction angle	ϕ'	(deg)	22.5	Stress path Inclination	θ	(deg)	20.9



Test Method BS1377-8 : 1990 : Clause 7
 Site Reference SI Wks for Keppel Island
 Jobfile C:/KEPPEL

Test Name CU
 Test Date 05.01.24
 Borehole BH-14
 Sample TW-1

Operator

Pen

Checked

Pa

Approved

Pen

Unconfined Compressive Strength test (Rock)

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

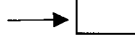
PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 23-Dec-23

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C

Load Direction: 

BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-1	CR2	20.50-21.50	Light reddish brown SANDSTONE	0.26	2.68	558.47	51.00	102.00	32.99	16.15		*

Legend : HRC - Hairline cracks visible FRL - Fracture line or veins present * - No visible sign of defects

Terms for description of rock strength (BS EN ISO14689:2018)

Term	Unconfined Compressive Strength (Mpa)	Term	Unconfined Compressive Strength(Mpa)
Extremely weak	0.6-1.0	Medium strong	25-50
Very weak	1-5	Strong	50-100
Weak	5-12.5	Very strong	100-250
Moderately weak	12.5-25	Extremely strong	>250

Tested By: 

Checked/Approved By:

Date: 23/12/2023

Date:

29.12.23

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

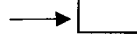
PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 18-Dec-23

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C

Load Direction: 

BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-3	CR12	13.00-14.00	Yellowish brown and purplish grey SANDSTONE	0.28	2.41	502.59	51.00	102.00	41.44	20.29		*

Legend : HRC - Hairline cracks visible FRL - Fracture line or veins present * - No visible sign of defects

Terms for description of rock strength (BS EN ISO14689:2018)

Term	Unconfined Compressive Strength (Mpa)	Term	Unconfined Compressive Strength(Mpa)
Extremely weak	0.6-1.0	Medium strong	25-50
Very weak	1-5	Strong	50-100
Weak	5-12.5	Very strong	100-250
Moderately weak	12.5-25	Extremely strong	>250

Tested By: 

Checked/Approved By:

Date: 18/12/2023

Date:

21.12.23

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 23-Dec-23

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C



BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-8	CR5	18.30-19.30	Light reddish brown SANDSTONE	0.24	2.56	532.92	51.00	102.00	12.63	6.18		*

Legend : HRC - Hairline cracks visible				FRL - Fracture line or veins present				* - No visible sign of defects			
Terms for description of rock strength (BS EN ISO 14689:2018)				Unconfined Compressive Strength (Mpa)				Unconfined Compressive Strength(Mpa)			
Term				Term				Term			
Extremely weak				0.6-1.0				25-50			
Very weak				1-5				50-100			
Weak				5-12.5				100-250			
Moderately weak				12.5-25				>250			
Tested By: 				Checked/Approved By: 							
Date: 23/12/2023				Date: 27.12.23							

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 18-Dec-23

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C

Load Direction: 

BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-9	CR5	11.00-12.00	Light grey and yellowish brown SANDSTONE	0.24	2.68	558.26	51.00	102.00	47.57	23.29		*

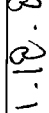
Legend : HRC - Hairline cracks visible FRL - Fracture line or veins present * - No visible sign of defects

Terms for description of rock strength (BS EN ISO14689:2018)

Term	Unconfined Compressive Strength (Mpa)	Term	Unconfined Compressive Strength(Mpa)
Extremely weak	0.6-1.0	Medium strong	25-50
Very weak	1-5	Strong	50-100
Weak	5-12.5	Very strong	100-250
Moderately weak	12.5-25	Extremely strong	>250

Tested By: 

Checked/Approved By:

Date: 

18/12/2023

Date:

21.12.23

"The results reported herein have been performed in accordance with the laboratory's term of accreditation under the SAC-SINGLAS"

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

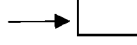
PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 18-Dec-23

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C

Load Direction: 

BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-10	CR3	14.00-15.00	Light grey and yellowish brown SILTSTONE	0.24	2.44	507.42	51.00	102.00	16.41	8.03		*
BH-10	CR5	16.00-17.00	Light grey and yellowish brown SANDSTONE	0.25	2.42	503.77	51.00	102.00	80.77	39.54		*

Legend : HRC - Hairline cracks visible FRL - Fracture line or veins present * - No visible sign of defects

Terms for description of rock strength (BS EN ISO14689:2018)

Term	Unconfined Compressive Strength (Mpa)	Term	Unconfined Compressive Strength(Mpa)
Extremely weak	0.6-1.0	Medium strong	25-50
Very weak	1-5	Strong	50-100
Weak	5-12.5	Very strong	100-250
Moderately weak	12.5-25	Extremely strong	>250



Tested By:

Checked/Approved By:

Date:

18/12/2023

Date:

22.12.23

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 23-Dec-23

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C



BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-11	CR10	19.00-20.00	Light reddish brown SANDSTONE	0.24	2.70	562.89	51.00	102.00	20.98	10.27		*

Legend : HRC - Hairline cracks visible FRL - Fracture line or veins present * - No visible sign of defects

Terms for description of rock strength (BS EN ISO14689:2018)

Term	Unconfined Compressive Strength (Mpa)	Term	Unconfined Compressive Strength(Mpa)
Extremely weak	0.6-1.0	Medium strong	25-50
Very weak	1-5	Strong	50-100
Weak	5-12.5	Very strong	100-250
Moderately weak	12.5-25	Extremely strong	>250

Tested By:

Checked/Approved By:

Date:

23/12/2023

Date:

23.12.23

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 18-Dec-23

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C

Load Direction: 

BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-12	CR4	5.30-6.30	Light grey and yellowish brown SILTSTONE	0.24	2.55	530.59	51.00	102.00	6.63	3.25		*

Legend : HRC - Hairline cracks visible FRL - Fracture line or veins present * - No visible sign of defects

Terms for description of rock strength (BS EN ISO14689:2018)

Term	Unconfined Compressive Strength (Mpa)	Term	Unconfined Compressive Strength(Mpa)
Extremely weak	0.6-1.0	Medium strong	25-50
Very weak	1-5	Strong	50-100
Weak	5-12.5	Very strong	100-250
Moderately weak	12.5-25	Extremely strong	>250

Tested By: 

Checked/Approved By:

Date: 18/12/2023

Date: 21.12.23

"The results reported herein have been performed in accordance with the laboratory's term of accreditation under the SAC-SINGLAS"

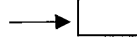
UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 18-Dec-23

Rate of Loading : 0.5MPa/s
Average Room Temperature : 25 °C

Load Direction: 

BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-13	CR8	13.50-14.50	Light grey and yellowish brown SILTSTONE	0.26	2.58	537.63	51.00	102.00	9.13	4.47		*

Legend : HRC - Hairline cracks visible FRL - Fracture line or veins present * - No visible sign of defects

Terms for description of rock strength (BS EN ISO14689:2018)

Term	Unconfined Compressive Strength (Mpa)	Term	Unconfined Compressive Strength(Mpa)
Extremely weak	0.6-1.0	Medium strong	25-50
Very weak	1-5	Strong	50-100
Weak	5-12.5	Very strong	100-250
Moderately weak	12.5-25	Extremely strong	>250

Tested By: 

Date: 18/12/2023

Checked/Approved By:

Date:

21.12.23

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

PROJECT / LOCATION :

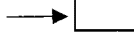
Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 8-Jan-24

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C

Load Direction:



BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-14	CR11	23.00-24.00	Reddish brown SILTSTONE	0.23	2.56	533.68	51.00	102.00	4.27	2.09		*

Legend : HRC - Hairline cracks visible FRL - Fracture line or veins present * - No visible sign of defects

Terms for description of rock strength (BS EN ISO14689:2018)

Term	Unconfined Compressive Strength (Mpa)	Term	Unconfined Compressive Strength(Mpa)
Extremely weak	0.6-1.0	Medium strong	25-50
Very weak	1-5	Strong	50-100
Weak	5-12.5	Very strong	100-250
Moderately weak	12.5-25	Extremely strong	>250

Tested By:

Date:

8/1/2024

Checked/Approved By:

Date:

10.01.2024

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

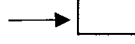
PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 18-Dec-23

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C

Load Direction: 

BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-15	CR5	13.50-14.50	Light grey SANDSTONE	0.24	2.72	567.24	51.00	102.00	10.55	5.16		*

Legend : HRC - Hairline cracks visible			FRL - Fracture line or veins present			* - No visible sign of defects		
Terms for description of rock strength (BS EN ISO14689:2018)			Term			Unconfined Compressive Strength(Mpa)		
Extremely weak			0.6-1.0			Medium strong		
Very weak			1-5			Strong		
Weak			5-12.5			Very strong		
Moderately weak			12.5-25			Extremely strong		
Tested By: 			Checked/Approved By: 					
Date: 18/12/2023			Date: 21.12.23					

UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS (ASTM D7012-14e1)

PROJECT / LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 18-Dec-23

Rate of Loading : 0.5MPa/s

Average Room Temperature : 25 °C



BH No.	Core No.	Depth (m)	Classification/Description	Water Content (%)	Bulk Density (Mg/m ³)	Sample Weight (g)	Sample Diameter D (mm)	Sample Height H (mm)	Max Load (kN)	Compressive Strength (MPa)	Failure Condition	Remarks
BH-16	CR6	16.00-17.00	Light grey and yellowish brown SANDSTONE	0.23	2.68	558.47	51.00	102.00	32.99	16.15		*

Legend : HRC - Hairline cracks visible FRL - Fracture line or veins present * - No visible sign of defects

Terms for description of rock strength (BS EN ISO14689:2018)

Term	Unconfined Compressive Strength (Mpa)	Term	Unconfined Compressive Strength(Mpa)
Extremely weak	0.6-1.0	Medium strong	25-50
Very weak	1-5	Strong	50-100
Weak	5-12.5	Very strong	100-250
Moderately weak	12.5-25	Extremely strong	>250

Tested By: 

Checked/Approved By:

Date: 

18/12/2023

Date:

22.12.23

POINT LOAD TEST ON ROCK CORE SAMPLE

Point Load Test Result
(ISRM 1984)

PROJECT/LOCATON :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date : 23.12.23

[illegible]

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Point Load Test Result
(ISRM 1984)

PROJECT/LOCATON :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 23.12.23

[illegible]

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Date: 18.12.23

Borehole No	Depth Range of Sample (m)	Sample No	Rock Name	Relation of weak plane to Loading Axis (°)	'D' of Sample (mm)	Type of Test (i / d / a)	Equivalent Core Diameter D _e (mm)	Failure Load (KN)	Uncorrected Point Load Strength I _s (MN/m ²)	Correction Factor	Point Load Strength Index I _{sg(90)} (MN/m ²)	Sample Condition Before Test
BH-3	13.00-14.00	CR12	Yellowish brown and purplish grey SANDSTONE	0	51	d	51	2.42	0.93	1.01	0.94	*
d = Diametral Test				a = Axial Test				W - width = (W ₁ + W ₂)/2				
i=Irregular Lump (Block Sample)				*No Noticeable Adverse Condition Present								
f=Fracture Line Present				Tested By :	Checked By :	Approved By :						
Remarks :				Date :	Date :	Date :						

117

Date: 18.12.23

[illegible]

The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Point Load Test Result
(ISRM 1984)

PROJECT/LOCATION : **Soil Investigation Works for proposed Development At Plot 6 At Keppel Island**

Date : 18.12.23

Borehole No	Depth Range of Sample (m)	Sample No	Rock Name	Relation of weak plane to Loading Axis (°)	'D' of Sample (mm)	Type of Test (i / d / a)	Equivalent Core Diameter D _e (mm)	Failure Load (KN)	Uncorrected Point Load Strength Index I _s (MN/m ²)	Correction Factor	Point Load Strength Index I _{s(90)} (MN/m ²)	Sample Condition Before Test
BH-9	11.00-12.00	CR5	Light grey and yellowish brown SANDSTONE	0	51	d	51	2.39	0.92	1.01	0.93	*
d = Diametral Test hrc=Hairline Crack Present				a = Axial Test *=No Noticeable Adverse Condition Present				W - width = (W ₁ + W ₂) / 2				
Remarks :				Tested By :	Checked By :		Approved By :					
				Date :	Date :		Date :					

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Date: 18.12.23

[illegible]

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Point Load Test Result
(ISRM 1984)

PROJECT/LOCATION : Soil Investigation Works for proposed Development At Plot 6 At Keppel Island Date : 23.12.23

Borehole No	Depth Range of Sample (m)	Sample No	Rock Name	Relation of weak plane to Loading Axis (°)	'D' of Sample (mm)	Type of Test (i/d/a)	Equivalent Core Diameter D _e (mm)	Failure Load (KN)	Uncorrected Point Load Strength Index I _s (MN/m ²)	Correction Factor	Point Load Strength Index I _{s(50)} (MN/m ²)	Sample Condition Before Test
BH-11	19.00-20.00	CR10	Light grey and yellowish brown SANDSTONE	0	51	d	51	2.08	0.80	1.01	0.81	*

d = Diametral Test
hrc=Hairline Crack Present

i=Irregular Lump (Block Sample)
fri=Fracture Line Present

a = Axial Test
*=No Noticeable Adverse Condition Present

W - width = (W₁+ W₂)/2

Tested By : 	Checked By : 	Approved By : 
Date : 23.12.23	Date : 28.12.23	Date : 29.12.23

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Point Load Test Result

(ISRM 1984)

PROJECT/LOCATON :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date : 18.12.23

Borehole No	Depth Range of Sample (m)	Sample No	Rock Name	Relation of weak plane to Loading Axis (°)	'D' of Sample (mm)	Type of Test (i / d / a)	Equivalent Core Diameter D _e (mm)	Failure Load (KN)	Uncorrected Point Load Strength Index I _s (MN/m ²)	Correction Factor	Point Load Strength Index I _{s(50)} (MN/m ²)	Sample Condition Before Test
BH-12	5.30-6.30	CR4	Light grey and yellowish brown SILTSTONE	0	51	d	51	2.08	0.80	1.01	0.81	*
d = Diametral Test hrc=Hairline Crack Present				a = Axial Test *=No Noticeable Adverse Condition Present				W - width = (W ₁ + W ₂) / 2				
Remarks :				Tested By :	Checked By :		Approved By :					
				Date :	Date :		Date :					

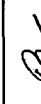
"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Point Load Test Result
(ISRM 1984)

PROJECT/LOCATON :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date: 18.12.23

Borehole No	Depth Range of Sample (m)	Sample No	Rock Name		Relation of weak plane to Loading Axis (°)	'D' of Sample (mm)	Type of Test (i / d / a)	Equivalent Core Diameter D _e (mm)	Failure Load (kN)	Uncorrected Point Load Strength I _s (MN/m ²)	Correction Factor	Point Load Strength Index I _{sg(50)} (MN/m ²)	Sample Condition Before Test
BH-13	15.50-16.50	CR10	Light grey and yellowish brown SILTSTONE		0	51	d	51	2.85	1.10	1.01	1.11	*
d = Diametral Test hrc=Hairline Crack Present				a = Axial Test *No Noticeable Adverse Condition Present				W - width = (W ₁ + W ₂)/2					
i=Irregular Lump (Block Sample) fri=Fracture Line Present				Tested By : 				Checked By : 		Approved By : 			
Remarks :				Date : 18.12.23		Date : 20.12.23			Date : 27.12.23				

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Point Load Test Result
(ISRM 1984)

PROJECT/LOCATION :

Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Date : 8.01.24

[illegible]

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Point Load Test Result
(ISRM 1984)

PROJECT/LOCATION : Soil Investigation Works for proposed Development At Plot 6 At Keppel Island Date : 18.12.23

Borehole No	Depth Range of Sample (m)	Sample No	Rock Name	Relation of weak plane to Loading Axis (°)	'D' of Sample (mm)	Type of Test (i / d / a)	Equivalent Core Diameter D _e (mm)	Failure Load (KN)	Uncorrected Point Load Strength Index I _s (MN/m ²)	Correction Factor	Point Load Strength Index I _{s(50)} (MN/m ²)	Sample Condition Before Test
BH-16	16.00-17.00	CR6	Light grey and yellowish brown SANDSTONE	0	51	d	51	4.21	1.62	1.01	1.63	*

d = Diametral Test i=Irregular Lump (Block Sample) a = Axial Test W - width = (W₁+ W₂)/2
 hrc=Hairline Crack Present fri=Fracture Line Present *No Noticeable Adverse Condition Present

Remarks :	Tested By :	Checked By :	Approved By :
	Date :	Date :	Date :

18.12.23 26.12.23 27.12.23

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS"

Chemical Test

Determination of pH value
BS 1377 : PART 3 : 2018

PROJECT/LOCATION : Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Borehole No	Sample No	Sample Type	Depth (m)	pH Value 1 st Reading	pH Value 2 nd Reading	pH Value Average	pH Value Unit
BH-1		Water		8.89	8.92	8.91	8.9
Tested By : 				Approved By : 			
Date : 30.12.23				Date : 09.01.24			

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS."

TEST REPORT

CLIENT NAME : ELEMENT GEOLAB (S) PTE LTD

ADDRESS : 215 KAKI BUKIT AVENUE 1
#02-00 SHUN LI INDUSTRIAL PARK
SINGAPORE 416042

ATTENTION TO : MS SAN SAN

ACCOUNT CHARGEABLE TO : ELEMENT GEOLAB (S) PTE LTD

PROJECT CODE : PT09499

PROJECT TITLE : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT
PLOT 6 AT KEPPEL ISLAND

SUBJECT & TEST METHODS : 1) SULPHATE CONTENT : BS 1377-3:2018+A1:2021,
CLAUSE 7.8
2) CHLORIDE CONTENT : BS 1377-3:2018+A1:2021,
CLAUSE 9.2

JOB REF. : T23-49890 (A)

SAMPLE REFERENCE : WATER SAMPLE FROM BOREHOLE NO:
BH-1
1. WATER

DATE RECEIVED : 27-Dec-2023

DATE TESTED : 28-Dec-2023 TO 02-Jan-2024

DATE OF REPORT : 05-Jan-2024

TOTAL PAGES : 2 (including cover page)

TEST RESULTS

CLIENT'S NAME : ELEMENT GEOLAB (S) PTE LTD
SAMPLE REF : WATER SAMPLE FROM BOREHOLE NO:
 BH-1

BOREHOLE NO.		BH-1	
SAMPLE NO.		WATER	
CHEMICAL TESTS	Sulphate Content	28	mg/L
	Chloride Content	29	mg/L

PREPARED BY



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**SIGNED FOR AND ON BEHALF OF
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Determination of pH value

BS 1377 : PART 3 : 2018

PROJECT/LOCATION : Soil Investigation Works for proposed Development At Plot 6 At Keppel Island

Borehole No	Sample No	Sample Type	Depth (m)	pH Value 1 st Reading	pH Value 2 nd Reading	pH Value Average	pH Value Unit
BH-5		Water		6.28	6.32	6.30	6.3
Tested By : 				Approved By : 			
Date : 30.12.23				Date : 03.01.24			

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS."

TEST REPORT

CLIENT NAME : ELEMENT GEOLAB (S) PTE LTD

ADDRESS : 215 KAKI BUKIT AVENUE 1
#02-00 SHUN LI INDUSTRIAL PARK
SINGAPORE 416042

ATTENTION TO : MS SAN SAN

ACCOUNT CHARGEABLE TO : ELEMENT GEOLAB (S) PTE LTD

PROJECT CODE : PT09499

PROJECT TITLE : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT
PLOT 6 AT KEPPEL ISLAND

SUBJECT & TEST METHODS : 1) SULPHATE CONTENT : BS 1377-3:2018+A1:2021,
CLAUSE 7.8
2) CHLORIDE CONTENT : BS 1377-3:2018+A1:2021,
CLAUSE 9.2

JOB REF. : T23-49890 (B)

SAMPLE REFERENCE : WATER SAMPLE FROM BOREHOLE NO:
BH-5
1. WATER

DATE RECEIVED : 27-Dec-2023

DATE TESTED : 28-Dec-2023 TO 02-Jan-2024

DATE OF REPORT : 05-Jan-2024

TOTAL PAGES : 2 (including cover page)

TEST RESULTS

CLIENT'S NAME : ELEMENT GEOLAB (S) PTE LTD
SAMPLE REF : WATER SAMPLE FROM BOREHOLE NO:
BH-5

BOREHOLE NO.		BH-5	
SAMPLE NO.		WATER	
CHEMICAL TESTS	Sulphate Content	3	mg/L
	Chloride Content	1	mg/L

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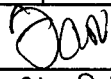
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Determination of pH value
BS 1377 : PART 3 : 2018

PROJECT/LOCATION : **Soil Investigation Works for proposed Development At Plot 6 At Keppel Island**

Borehole No	Sample No	Sample Type	Depth (m)	pH Value 1 st Reading	pH Value 2 nd Reading	pH Value Average	pH Value Unit
BH-7		Water		7.24	7.28	7.26	7.3
Tested By : 				Approved By : 			
Date : 30.12.23				Date : 08.01.24			

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS."

TEST REPORT

CLIENT NAME : ELEMENT GEOLAB (S) PTE LTD

ADDRESS : 215 KAKI BUKIT AVENUE 1
#02-00 SHUN LI INDUSTRIAL PARK
SINGAPORE 416042

ATTENTION TO : MS SAN SAN

ACCOUNT CHARGEABLE TO : ELEMENT GEOLAB (S) PTE LTD

PROJECT CODE : PT09499

PROJECT TITLE : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND

SUBJECT & TEST METHODS : 1) SULPHATE CONTENT : BS 1377-3:2018+A1:2021, CLAUSE 7.8
2) CHLORIDE CONTENT : BS 1377-3:2018+A1:2021, CLAUSE 9.2

JOB REF. : T23-49890 (C)

SAMPLE REFERENCE : WATER SAMPLE FROM BOREHOLE NO:
BH-7
1. WATER

DATE RECEIVED : 27-Dec-2023

DATE TESTED : 28-Dec-2023 TO 02-Jan-2024

DATE OF REPORT : 05-Jan-2024

TOTAL PAGES : 2 (including cover page)

TEST RESULTS

CLIENT'S NAME : ELEMENT GEOLAB (S) PTE LTD
SAMPLE REF : WATER SAMPLE FROM BOREHOLE NO: BH-7

BOREHOLE NO.		BH-7	
SAMPLE NO.		WATER	
CHEMICAL TESTS	Sulphate Content	0	mg/L
	Chloride Content	8	mg/L

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ELEMENT CONSTRUCTION TESTING (S) PTE LTD**

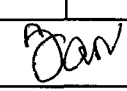
may

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Determination of pH value

BS 1377 : PART 3 : 2018

PROJECT/LOCATION : **Soil Investigation Works for proposed Development At Plot 6 At Keppel Island**

Borehole No	Sample No	Sample Type	Depth (m)	pH Value 1 st Reading	pH Value 2 nd Reading	pH Value Average	pH Value Unit
BH-10	TW1	Soil	3.00-3.90	6.88	6.89	6.89	6.9
Tested By : 				Approved By : 			
Date : 30.12.23				Date : 03-01-24			

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TEST REPORT

CLIENT NAME : ELEMENT GEOLAB (S) PTE LTD

ADDRESS : 215 KAKI BUKIT AVENUE 1
#02-00 SHUN LI INDUSTRIAL PARK
SINGAPORE 416042

ATTENTION TO : MS SAN SAN

ACCOUNT CHARGEABLE TO : ELEMENT GEOLAB (S) PTE LTD

PROJECT CODE : PT09499

PROJECT TITLE : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT
PLOT 6 AT KEPPEL ISLAND

SUBJECT & TEST METHODS : 1) ORGANIC MATTER CONTENT : BS 1377-3:2018+A1:2021,
CLAUSE 4
2) ACID SOLUBLE SULPHATE : BS 1377-3:2018+A1:2021,
CLAUSE 7.6 & 7.9
3) CHLORIDE CONTENT : BS 1377-3:2018+A1:2021,
CLAUSE 9.2

JOB REF. : T24-01400

SAMPLE REFERENCE : SOIL SAMPLES FROM BOREHOLE NO:
BH-10
1. TW-1

DATE RECEIVED : 08-Jan-2024

DATE TESTED : 09-Jan-2024 TO 11-Jan-2024

DATE OF REPORT : 11-Jan-2024

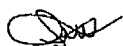
TOTAL PAGES : 2 (including cover page)

TEST RESULTS

CLIENT'S NAME : ELEMENT GEOLAB (S) PTE LTD
SAMPLE REF : SOIL SAMPLES FROM BOREHOLE NO:
 BH-10

BOREHOLE NO.		BH-10	
SAMPLE NO.		TW-1	
DEPTH (m)		3.00 3.90	Unit
CHEMICAL TESTS	Organic Matter Content	0.1	%
	Acid Soluble Sulphate	0.03	%
	Chloride Content	< 0.01	%

PREPARED BY



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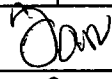
SIGNED FOR AND ON BEHALF OF
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 Email: Maysoe.moe@element.com

Determination of pH value
BS 1377 : PART 3 : 2018

PROJECT/LOCATION : **Soil Investigation Works for proposed Development At Plot 6 At Keppel Island**

Borehole No	Sample No	Sample Type	Depth (m)	pH Value 1 st Reading	pH Value 2 nd Reading	pH Value Average	pH Value Unit
BH-11		Water		7.76	7.79	7.78	7.8
Tested By : 				Approved By : 			
Date : 30.12.23				Date : 03.01.24			

"The results reported herein have been performed in accordance with the laboratory's terms of accreditation under the SAC-SINGLAS."

TEST REPORT

CLIENT NAME : ELEMENT GEOLAB (S) PTE LTD

ADDRESS : 215 KAKI BUKIT AVENUE 1
#02-00 SHUN LI INDUSTRIAL PARK
SINGAPORE 416042

ATTENTION TO : MS SAN SAN

ACCOUNT CHARGEABLE TO : ELEMENT GEOLAB (S) PTE LTD

PROJECT CODE : PT09499

PROJECT TITLE : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT
PLOT 6 AT KEPPEL ISLAND

SUBJECT & TEST METHODS : 1) SULPHATE CONTENT : BS 1377-3:2018+A1:2021,
CLAUSE 7.8
2) CHLORIDE CONTENT : BS 1377-3:2018+A1:2021,
CLAUSE 9.2

JOB REF. : T23-49890 (D)

SAMPLE REFERENCE : WATER SAMPLE FROM BOREHOLE NO:
BH-11
1. WATER

DATE RECEIVED : 27-Dec-2023

DATE TESTED : 28-Dec-2023 TO 02-Jan-2024

DATE OF REPORT : 05-Jan-2024

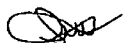
TOTAL PAGES : 2 (including cover page)

TEST RESULTS

CLIENT'S NAME : ELEMENT GEOLAB (S) PTE LTD
SAMPLE REF : WATER SAMPLE FROM BOREHOLE NO:
 BH-11

BOREHOLE NO.		BH-11	
SAMPLE NO.		WATER	
CHEMICAL TESTS	Sulphate Content	3	mg/L
	Chloride Content	2	mg/L

PREPARED BY



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APPENDIX E

Core Samples Photograph





CLIENT - KEPPEL LAND PROJECT - SI WORK AT KEPPEL ISLAND LOCATION - KEPPEL ISLAND BH NO - 01 BOX NO - 3 OF 3 DATE 21.09.2023 CIRN 11 DEPTH 29.50,30.00 TOR% 50 SCR% 10 RQD% 00									
			BH-01			CR11			
CLIENT : KEPPEL BAY PTE LTD									
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND									

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	26.10.23	1	09.80-10.80	100	30	10
LOCATION	KEPPEL ISLAND	11	2	10.80-11.80	100	75	45
BH NO	BH 2	11	3	11.80-12.80	100	35	0
BOX NO	1 OF 3	11	4	12.80-13.80	0	0	0
		27.10.23	5	17.00-18.00	100	25	0

10.80	10.80
10.80	11.80
11.80	12.80
12.80	13.80
17.00	18.00

BH-02		CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH (M)	TCR%	SCR%	RQD%
PROJECT	SIWORK AT KEPPEL ISLAND	27.10.23	6	18.00-19.00	100	50	0
LOCATION	KEPPEL ISLAND	11	7	19.00-20.00	100	70	20
BH NO	BH 2	28.10.23	8	20.00-21.00	100	80	38
BOX NO	2 OF 3	11	9	21.00-22.00	100	84	46
		11	10	22.00-23.00	100	15	0

BH-02

CR6 to CR10

CLIENT : KEPPEL BAY PTE LTD

PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND

						BH-02		CR11 to CR12	
CLIENT : KEPPEL BAY PTE LTD									
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND									
CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH (M)	TCR%	SCR%	RQD%		
PROJECT	SI WORK AT KEPPEL ISLAND	28/0.23	11	23.00-24.00	100	30	0		
LOCATION	KEPPEL ISLAND	11	12	24.00-25.00	100	20	0		
BH NO	BH2								
BOX NO	3 OF 3								
									

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	17.10.23	1	2.00-3.00	100	05	00
LOCATION	KEPPEL ISLAND	11	2	3.00-4.00	100	10	00
BH NO.	BH - 3	11	3	4.00-5.00	100	50	20
BOX NO.	1 OF 3	11	4	5.00-6.00	100	55	15
		11	5	6.00-7.00	100	25	00

2.00

3.00

4.00

5.00

6.00

3.00

4.00

5.00

6.00

7.00

</



CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TOP	AREA	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	18.10.23	6	7.00-8.00	100	20	0
LOCATION	KEPPEL ISLAND	11	7	8.00-9.00	100	40	15
BH NO.	BH-3	11	8	9.00-10.00	100	45	30
BOX NO.	2 OF 3	11	9	10.00-11.00	100	15	0
		11	10	11.00-12.00	100	50	25

BH-03		CR6 to CR10
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR/	SCR/	RJD
PROJECT	SI WORK AT KEPPEL ISLAND	18.10.23	11	12.00-13.00	100	50	13
LOCATION	KEPPEL ISLAND	11	12	13.00-14.00	100	65	55
BH NO.	BH - 3	11	13	14.00-15.00	100	50	40
BOX NO.	3 OF 3						

12.00

13.00

14.00

15.00



BH-03

CR11 to CR13

CLIENT : KEPPEL BAY PTE LTD

PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TOR/%	SCR/%	RQD/%
PROJECT	SI WORK AT KEPPEL ISLAND	05.10.23	1	10.00-11.00	100	73	12
LOCATION	KEPPEL ISLAND		2	11.00-12.00	100	67	00
BH. NO.	BH - 4		3	12.00-13.00	100	76	00
BOX NO.	1 OF 4		4	13.00-14.00	100	70	00
			5	14.00-15.00	100	78	00

10.00	11.00	12.00	13.00	14.00	15.00
					

	BH-04	CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C - RUN	DEPTH(M)	TOR/%	SCR/%	RQD/%
PROJECT	SF WORK AT KEPPEL ISLAND	06.10.23	6	15.00 - 16.00	100	51	15
LOCATION	KEPPEL ISLAND	"	7	16.00 - 17.00	100	80	39
BH NO.	3H-4	"	8	17.00 - 18.00	100	75	21
BOX NO.	2 OF 4	"	9	18.00 - 19.00	100	85	00
		"	10	19.00 - 20.00	100	90	00

15.00	16.00	17.00	18.00	19.00	20.00
					

	BH-04	CR6 to CR10
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C.RUN	DEPTH	TCR%	SCR%	RCD%
PROJECT	SI WORK AT KEPPEL ISLAND	23.09.2023	1	2.00-3.00	100	30	00
LOCATION	KEPPEL ISLAND	"	2	3.00-4.00	100	65	00
BH NO	05	"	3	4.00-5.00	100	70	00
BOX NO	1 OF 4	"	4	5.00-6.00	100	90	45
		"	5	6.00-7.00	100	35	28

200	300	400	500	600	700
-----	-----	-----	-----	-----	-----

BH-05		CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	25.09.23	6	7.00-8.00	100	20	12
LOCATION	KEPPEL ISLAND		7	8.00-9.00	100	25	15
BH NO.	BH-5		8	9.00-10.00	100	50	25
BOX NO.	2 OF 4		9	10.00-11.00	100	40	13
			10	11.00-12.00	100	40	10
							
				BH-05			
				CR6 to CR10			
CLIENT : KEPPEL BAY PTE LTD							
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND							

element

CLIENT	KEPPEL LAND	DATE	C-RUN DEPTH(M)	TCR%	SCR%	RQD%	
PROJECT	SI WORK AT KEPPEL ISLAND	26.09.23	11	12.00-13.00	100	35	00
LOCATION	KEPPEL ISLAND	11	12	13.00-14.00	100	50	15
BH NO.	BH - 5	11	13	14.00-15.00	100	70	20
BOX NO.	3 OF 4	11	14	15.00-16.00	100	65	00
		11	15	16.00-17.00	100	45	28
12.00							13.00
13.00							14.00
14.00							15.00
15.00							16.00
16.00							17.00
			BH-05		CR11 to CR15		
			CLIENT : KEPPEL BAY PTE LTD				
			PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND				

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	26.09.23	16	17.00-18.00	100	50	20
LOCATION	KEPPEL ISLAND		17	18.00-19.00	100	40	0
BH NO.	BH - 5		18	19.00-20.00	100	30	0
BOX NO.	4 OF 4	27.09.23	19	20.00-21.00	100	40	12
			20	21.00-22.00	100	30	10

17.00	18.00	19.00	20.00	21.00	22.00

	BH-05	CR16 to CR20
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C RUN	DEPTH(M)	TCR/	SCR/	ROD/
PROJECT	SI WORK AT KEPPEL ISLAND	21/10/23	1	02.00-03.00	100	50	30
LOCATION	KEPPEL ISLAND	"	2	03.00-04.00	100	45	0
BH NO	BH 6	"	3	04.00-05.00	100	30	24
BOX NO	1 OF 3	"	4	05.00-06.00	100	50	35
		23/10/23	5	06.00-07.00	100	65	40



BH-06		CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		



CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TOR%	SCR%	RQID%
PROJECT	SI WORK AT KEPPEL ISLAND	23.10.23	6	0700-08.00	100	55	0
LOCATION	KEPPEL ISLAND	11	7	0800-09.00	100	70	35
BH NO.	BH - 6	11	8	0900-10.00	100	60	0
BOX NO.	2 OF 3	11	9	10.00-11.00	100	50	0
		24.10.23	10	11.00-12.00	100	60	0
07.00							
08.00							
09.00							
10.00							
11.00							
				BH-06			
				CR6 to CR10			
				CLIENT : KEPPEL BAY PTE LTD			
				PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND			
							

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	RAID%
PROJECT	SIWORK AT KEPPEL ISLAND	24.10.23	11	12.00-13.00	100	55	30
LOCATION	KEPPEL ISLAND	11	12	13.00-14.00	100	50	20
BH NO	BH 6	11	13	14.00-15.00	100	60	0
BOX NO	3 OF 3	25.10.23	14	15.00-15.50	100	70	0

BH-06

CR11 to CR14

CLIENT : KEPPEL BAY PTE LTD

PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND

CLIENT - KEPPEL LAND								
PROJECT- SI WORK AT KEPPEL ISLAND								
LOCATION- KEPPEL ISLAND								
BH NO_ 07								
BOX NO_ 01								
DATE				C-RUN	DEPTH	TCR%	SCR%	RQD%
12.09.2023				1	2.80-3.80	80	65	30
"				2	3.80-4.80	90	60	15
"				3	4.80-5.80	100	85	00
13.09.2023				4	5.80-6.80	100	50	30
"				5	6.80-7.80	95	70	52

CLIENT - KEPPEL LAND		DATE	C-RUN	DEPTH	TCR%	SCR%	RQD%
PROJECT - SI WORK AT KEPPEL ISLAND		13.09.2023	6	7.80-8.80	100	90	46
LOCATION - KEPPEL ISLAND		"	7	8.80-9.80	100	42	27
BH NO - 07		"	8	9.80-10.80	100	26	00
BOX NO - 02		14.09.2023	9	10.80-11.80	100	78	00
		"	10	11.80-12.80	100	33	10

CLIENT - KEPPEL LAND											
PROJECT- SI WORK AT KEPPEL ISLAND					DATE	C.RUN	DEPTH	TCR%	SCR%	RQD%	
LOCATION- KEPPEL ISLAND					14.09.2023	11	12.80-13.80	100	12	12	
					"	12	13.80-14.80	100	70	55	
					"	13	14.80-15.80	100	80	12	
BH NO - 07					15.09.2023	14	15.80-16.80	100	30	00	
BOX NO - 3					"	15	16.80-17.80	100	72	33	
											
 element											
BH-07						CR11 to CR15					
CLIENT : KEPPEL BAY PTE LTD											
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND											

CLIENT - KEPPEL LAND				TOR%				SCR%				RQD%															
PROJECT - SI WORK FOR KEPPEL ISLAND				16				1780 - 1880				100				70				35							
LOCATION - KEPPEL ISLAND				"				17				1880 - 1980				100				80				00			
BH NO - 07				"				18				1980 - 2080				100				53				10			
BOX NO - 4				16.09.2023				19				2080 - 2180				100				77				20			
				"				20				2180 - 2300				120				95				28			

2180	2080	1980	1880	1780

BH-07		CR16 to CR20	
CLIENT : KEPPEL BAY PTE LTD			
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND			

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(MCD)	TOR\	SCR\	RQD\
PROJECT	SI WORK AT KEPPEL ISLAND	20.10.23	1	-(14.30-15.30)	100	40	10
LOCATION	KEPPEL ISLAND		2	-(15.30-16.30)	100	0	0
BH NO.	BH-8		3	-(16.30-17.30)	100	20	0
BOX NO.	1 OF 3		4	-(17.30-18.30)	100	35	0
			5	-(18.30-19.30)	100	85	60

-14.30	-15.30	-16.30	-17.30	-18.30	-19.30
					

	BH-08	CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(MCD)	TCRA	SCRA	RQDA
PROJECT	SI WORK AT KEPPEL ISLAND	21.10.23	6	-(19.30-20.30)	100	55	12
LOCATION	KEPPEL ISLAND		7	-(20.30-21.30)	100	50	22
BH NO.	BH-8		8	-(21.30-22.30)	100	30	0
BOX NO.	2 OF 3		9	-(22.30-23.30)	100	20	0
			10	-(23.30-24.30)	100	40	15

BH-08		CR6 to CR10
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		



CLIENT		KEPPEL LAND		DATE	C-RUN	DEPTH(MCD)	TCR\	SCR\	RQDA\
PROJECT		SI WORK AT KEPPEL ISLAND		23.10.23	11	-(24.30-24.50)	100	75	0
LOCATION		KEPPEL ISLAND							
BH NO.		BH-8							
BOX NO.		3 OF 3							
									
-24.30									
-24.50									
									
		BH-08 CR11							
CLIENT : KEPPEL BAY PTE LTD									
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND									

CLIENT	KEPPEL LAND	DATE	CIRUN	DEPTH(M)	TOP	SCRT	RQD(%)
PROJECT	SI WORK AT KEPPEL ISLAND	25.09.23	1	7.00-8.00	100	40	25
LOCATION	KEPPEL ISLAND		2	8.00-9.00	100	45	30
BH NO.	9	26.09.23	3	9.00-10.00	100	40	10
BOX NO	1 OF 3		4	10.00-11.00	100	50	45
			5	11.00-12.00	100	80	70
7.00							
8.00							
9.00							
10.00							
11.00							
12.00							
				BH-09			
				CR1 to CR5			
CLIENT : KEPPEL BAY PTE LTD							
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND							

CLIENT	KEPPEL	LAND	DATE	C RUN	DEPTH(M)	TCR	SCR	ROD	
PROJECT	SI	WORK AT KEPPEL ISLAND	26.09.23	6	12.00-13.00	100	60	0	
LOCATION	KEPPEL	ISLAND	11	7	13.00-14.00	100	50	18	
BH NO.	BH-9		11	8	14.00-15.00	100	30	0	
BOX NO.	2	OF 3	11	9	15.00-16.00	100	70	45	
			11	10	16.00-17.00	100	60	30	
12.00									13.00
13.00									14.00
14.00									15.00
15.00									16.00
16.00									17.00
				BH-09		CR6 to CR10			
CLIENT : KEPPEL BAY PTE LTD									
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND									

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	27.09.23	11	17.00-18.00	100	75	15
LOCATION	KEPPEL ISLAND	11	12	18.00-19.00	100	60	35
BH NO.	BH-9	11	13	19.00-20.00	100	60	15
BOX NO.	3 OF 3						
							
				BH-09			
CLIENT : KEPPEL BAY PTE LTD				CR11 to CR13			
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND							

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	RQD %
PROJECT	SI WORKS AT KEPPEL ISLAND	17.10.23	1	12.00-13.00	100	25	00
LOCATION	KEPPEL ISLAND	11	2	13.00-14.00	100	70	20
BH NO.	10	11	3	14.00-15.00	100	75	65
BOX NO.	1 OF 5	11	4	15.00-16.00	100	80	10
		11	5	16.00-17.00	100	75	65

12.00	13.00	14.00	15.00	16.00	17.00

	BH-10	CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	POD%
PROJECT	SI WORK AT KEPPEL ISLAND	18.10.23	6	17.00-18.00	100	35	
LOCATION	KEPPEL ISLAND	"	7	18.00-19.00	100	45	
BH NO.	BH - 10	"	8	19.00-20.00	100	65	
BOX NO.	2 OF 5	"	9	20.00-21.00	100	70	
		"	10	21.00-22.00	100	75	
17.00							18.00
18.00							19.00
19.00							20.00
20.00							21.00
21.00							22.00

	BH-10	CR6 to CR10
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	RCD%
PROJECT	SI WORK AT KEPPEL ISLAND	181023	11	22.00-23.00	100	60	20
LOCATION	KEPPEL ISLAND	191023	12	23.00-24.00	100	00	00
BH NO.	BH - 10	11	13	24.00-25.00	100	00	00
BOX NO.	3 OF 5	11	14	25.00-26.00	100	25	00
		11	15	26.00-27.00	100	50	15
22.00							
23.00							
24.00							
25.00							
26.00							
27.00							
		BH-10		CR11 to CR15			
		CLIENT : KEPPEL BAY PTE LTD					
		PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND					

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TOR/%	SCR/%	RQD/%
PROJECT	SI WORK AT KEPPEL ISLAND	19.10.23	16	27.00-28.00	100	40	00
LOCATION	KEPPEL ISLAND	"	17	28.00-29.00	100	15	00
BH NO.	BH - 10	"	18	29.00-30.00	100	30	10
BOX NO.	4 OF 5	20.10.23	19	30.00-31.00	100	70	10
		"	20	31.00-32.00	100	75	00
27.00							28.00
28.00							29.00
29.00							30.00
30.00							31.00
31.00							32.00
			BH-10		CR16 to CR20		
CLIENT : KEPPEL BAY PTE LTD							
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND							

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TCR%	SCR%	RODY
PROJECT	SI WORK AT KEPPEL ISLAND	2010.23	21	32.00-33.00	100	35	10
LOCATION	KEPPEL ISLAND	11	22	33.00-34.00	100	75	10
BH NO	BH - 10	11	23	34.00-35.00	100	80	00
BOX NO.	5 OF 5	11	24	35.00-36.00	100	65	00
32.00							33.00
33.00							34.00
34.00							35.00
35.00							36.00
			BH-10				
			CR21 to CR24				
			CLIENT : KEPPEL BAY PTE LTD				
			PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND				
							

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TOR/%	SCR/%	ROAD/%
PROJECT	SI WORK AT KEPPEL ISLAND	17.10.23	1	10.00-11.00	100	55	10
LOCATION	KEPPEL ISLAND	11	2	11.00-12.00	100	85	00
BH NO.	BH - 11	11	3	12.00-13.00	100	55	00
BOX NO.	1 OF 2	11	4	13.00-14.00	100	35	00
		11	5	14.00-15.00	100	50	00

10.00	11.00	12.00	13.00	14.00	15.00

	BH-11	CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(M)	TOR/%	SCR/%	RQD/%
PROJECT	SI WORK AT KEPPEL ISLAND	18.10.23	6	15.00-16.00	100	25	20
LOCATION	KEPPEL ISLAND	"	7	16.00-17.00	100	45	00
BH NO.	BH - 11	"	8	17.00-18.00	100	60	25
BOX NO.	2 OF 2	"	9	18.00-19.00	100	40	10
		"	10	19.00-20.00	100	75	50

15.00	16.00	17.00	18.00	19.00	20.00
					
16.00	17.00	18.00	19.00	20.00	

	BH-11	CR6 to CR10
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		



CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(MCD)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	18-11-23	1	-(2.30-3.30)	100	0	0
LOCATION	KEPPEL ISLAND	11	2	-(3.30-4.30)	100	0	0
BH NO	BH-12	20-11-23	3	-(4.30-5.30)	100	50	27
BOX NO	1 OF 3	11	4	-(5.30-6.30)	100	90	38
		11	5	-(6.30-7.30)	100	75	0



BH-12		CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		



CLIENT : KEPPEL LAND		DATE	C RUN	DEPTH(MOD)	TCRZ	SCRZ	RQDZ
PROJECT : SJ WORK AT KEPPEL ISLAND		2/11/23	6	07.30-08.30	100	55	0
LOCATION : KEPPEL ISLAND		"	7	08.30-09.30	100	80	28
BH NO : BH-12		"	8	09.30-10.30	100	85	25
BOX NO : 2 OF 3		"	9	10.30-11.30	100	85	35
		"	10	11.30-12.30	100	30	0
		BH-12					
		CR6 to CR10					
		CLIENT : KEPPEL BAY PTE LTD					
		PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND					
							

CLIENT : KEPPEL LAND		DATE	C-RUN	DEPTH(MCID)	TCR%	SCR%	RQD%
PROJECT : SI WORK AT KEPPEL ISLAND		22/11/23	11	-(12.30-13.30)	100	80	0
LOCATION : KEPPEL ISLAND		-	12	-(13.30-14.30)	100	90	0
BH NO. : BH-12		-	13	-(14.30-15.30)	100	78	0
BOX NO. : 3 OF 3		-	14	-(15.30-16.30)	100	0	0
		-	15	-(16.30-17.30)	100	0	0
		TERMINATED AT -17.30 MCD					

12.30	13.30	14.30	15.30	16.30	17.30

BH-12		CR11 to CR15
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT	KEPPEL	LAND	DATE	C-RUN	DEPTH(MCD)	TCR%	SCR%	RQD%
PROJECT	SJ WORK AT KEPPEL ISLAND		09.11.23	1	-(6.50-7.50)	100	25	0
LOCATION	KEPPEL ISLAND		11	2	-(7.50-8.50)	100	20	0
BH NO.	BH-13		11	3	-(8.50-9.50)	100	35	0
BOX NO.	1	OF 3	11	4	-(9.50-10.50)	100	45	23
			11	5	-(10.50-11.50)	100	20	0

-6.50	-7.50	-8.50	-9.50	-10.50
-7.50	-8.50	-9.50	-10.50	-11.50

BH-13		CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		





CLIENT : KEPPEL LAND	DATE	C-RUN	DEPTH(MCN)	TCR%	SLR%	RDY%
PROJECT : SI WORK AT KEPPEL ISLAND	22.11.23	1	-03.00-14.00	60	0	0
LOCATION : KEPPEL ISLAND	11	2	-(14.00-15.00)	50	20	10
BH NO : BH-14	11	3	-(15.00-16.00)	70	40	20
BOX NO. : 1 OF 5	11	4	-(16.00-17.00)	50	20	10
	23.11.23	5	-(17.00-18.00)	100	50	30

-13.00	CORE	LOSS	-14.00
-14.00			-15.00
-15.00		CORE LOSS	-16.00
-16.00	CORE	LOSS	-17.00
-17.00			-18.00

BH-14	CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD	
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND	

element

CLIENT : KEPPEL LAND	DATE	C-RUN	DEPTH(MCD)	TORY	SCRY	RQDX
PROJECT : SI WORK AT KEPPEL ISLAND	24.11.23	11	-(23.00-24.00)	100	80	50
LOCATION : KEPPEL ISLAND	11	12	-(24.00-25.00)	100	40	20
BH NO. : BH-14	11	13	-(25.00-26.00)	100	60	10
BOX NO. : 3 OF 5	11	14	-(26.00-27.00)	100	40	10
	25.11.23	15	-(27.00-28.00)	100	55	45

23.00	24.00	25.00	26.00	27.00	28.00
					

BH-14		CR11 to CR15
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		
		

CLIENT	KEPPEL	LAND	DATE	CRUN	DEPTH(MCD)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT	KEPPEL ISLAND	25.11.23	16	-(28.00-29.00)	100	80	40
LOCATION	KEPPEL	ISLAND		17	-(29.00-30.00)	100	90	25
BH NO.	BH-14			18	-(30.00-31.00)	100	75	30
BOX NO.	4	OF 5	20.12.23	19	-(31.00-32.00)	100	12	12
				20	-(32.00-33.00)	100	0	0
								
			BH-14		CR16 to CR20			
			CLIENT : KEPPEL BAY PTE LTD					
			PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND					

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(MCD)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	21.12.23	21	-(33.00-34.00)	100	0	0
LOCATION	KEPPEL ISLAND		22	-(34.00-35.00)	100	25	0
BH NO	14		23	-(35.00-36.00)	100	30	0
BOX NO,	5 OF 5		24	-(36.00-37.00)	100	65	40
		22.12.23	25	-(37.00-38.00)	100	50	20

		BH-14	CR21 to CR25
CLIENT : KEPPEL BAY PTE LTD			
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND			

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(MCD)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	04.11.23	6	-(14.50-15.50)	100	40	15
LOCATION	KEPPEL ISLAND		7	-(15.50-16.50)	100	50	0
BH NO.	BH-15	06.11.23	8	-(16.50-17.50)	100	45	0
BOX NO.	2 OF 3		9	-(17.50-18.50)	100	30	0
			10	-(18.50-19.50)	100		

-14.50	-15.50	-16.50	-17.50	-18.50	-19.50
					
BH-15			CR6 to CR10		
CLIENT : KEPPEL BAY PTE LTD					
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND					


element

CLIENT	KEPPEL LAND	DATE	C-RUN	DEPTH(MCD)	TCR%	SCR%	RQD%
PROJECT	SI WORK AT KEPPEL ISLAND	27.10.23	1	-(11.00-12.00)	100	10	0
LOCATION	KEPPEL ISLAND		2	-(12.00-13.00)	100	45	15
BH NO.	BH-16		3	-(13.00-14.00)	100	25	0
BOX NO.	1 OF 3		4	-(14.00-15.00)	100	30	0
		28.10.23	5	-(15.00-16.00)	100	75	30

-11.00	-12.00	-13.00	-14.00	-15.00	-16.00

BH-16		CR1 to CR5
CLIENT : KEPPEL BAY PTE LTD		
PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND		

CLIENT :KEPPEL LAND	DATE	C-RUN	DEPTH(MCD)	TCR%	SCR%	RQD%
PROJECT :SI WORK AT KEPPEL ISLAND	28.10.23	6	-(16.00-17.00)	100	65	35
LOCATION:KEPPEL ISLAND		7	-(17.00-18.00)	100	60	40
BH NO. BH-16		8	-(18.00-19.00)	100	60	25
BOX NO. 2 OF 3		9	-(19.00-20.00)	100	45	15
		10	-(20.00-21.00)	100	50	15

-16.00	-17.00	-18.00	-19.00	-20.00
				
-16.00	-17.00	-18.00	-19.00	-20.00

CLIENT: KEPPEL LAND		DATE	C-RUN	DEPTH(MCD)	TOR	SCR	RQID
PROJECT: SI WORK AT KEPPEL ISLAND		30.10.23	11	-(21.00-22.00)	100	45	14
LOCATION: KEPPEL ISLAND		11	12	-(22.00-23.00)	100	70	0
BH NO	BH-16	31.10.23	13	-(23.00-24.00)	100	75	20
BOX NO	3 OF 3						
							
		BH-16 CR11 to CR13					
		 element CLIENT : KEPPEL BAY PTE LTD					
		PROJECT : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND					

APPENDIX G

Hammer Calibration Reports



The results herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council – Singapore Laboratory Accreditation Scheme

CALIBRATION SITE: CWRP

TEST REPORT

STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT (SPT HAMMER – EGTA-SPT-01)

TEST REPORT

09 January 2023

CLIENT

M/s **ELEMENT GEOTECHNICAL TESTING (S) PTE. LTD.**

Submitted by



APS ASIA PDA ENTERPRISE PTE LTD

10 January 2023

REPORT REF. NO : APS/SPT/2023/063

No. 65 Ubi Crescent #02-1 Holo Centre Singapore 408559 Tel (65) 68968926 Fax: (65) 62212003

The results reported herein have been performed in accordance with the terms of accreditation under the Singapore Accreditation Council. The reports shall not be reproduced except in full, unless the management representative of APS ASIA PDA Enterprise Pte Ltd has given approval in writing.

CONTENTS

1. INTRODUCTION
2. TEST EQUIPMENT
3. SUMMARY
4. RESULTS

APPENDIX I SPT HAMMER ENERGY MEASUREMENT RESULTS

1. INTRODUCTION

This report the results of the standard penetration test, SPT, hammer energy measurement using the Pile Driving Analyzer, PDA, carried out for APS ASIA PDA Enterprise Pte Ltd on 09 January 2023. The aim of testing was to provide an estimate of the hammer energy transferred by the SPT hammer in accordance to American Standard Test Method ASTM D4633-16.

The SPT testing was performed at CWRP.

The SPT hammer tested was identified as EGTA-SPT-01 and was operated by Hanjin (D&B -10KD) drilling machine (RIG-05).

2. TEST EQUIPMENT

Pile Driving Analyser (Model PAX)	: Serial No. 5319LE
Instrumented Rod	: Serial No. 587BW (Length 600mm)
Strain Transducers	: Serial Nos. 587BW - Bridge 1 & 2
Accelerometers	: Serial Nos. K2478 & K2480

3. SUMMARY

SPT Hammer Serial No.	-	EGTA-SPT-01
Calibration Site	-	CWRP
Borehole	-	BH-03
	-	Diameter : - 100 mm
	-	Depth : 54.00 m
Drilling Rig	-	RIG-05
Drilling Operator	-	Nyi Nyi Swe
Drill Rod Type	-	BW
Shoe Type / Length	-	Split Spoon Sampler /600mm
Instrumented Rod/Length	-	600 mm
Drill Rod Segments	-	3 m x 18 + 0.6 + 0.6
Total Length	-	55.20 m (Instrumented Rod Top to Shoe Base)
SPT Ram Mass	-	63.60 kg
SPT Anvil Mass	-	21.40 kg
SPT Total Mass	-	85.00 kg
SPT Ram Drop Height	-	761 mm
Theoretical Energy	-	0.4748 kN-m

4. RESULTS (SPT HAMMER ENERGY MEASUREMENT)

No. Of Blow = 10

Min. / Max. EMX Value = 0.3690 kN-m / 0.3950 kN-m

Mean Measured Energy = 0.3832 kN-m

Standard Deviation = 0.0071 kN-m

Energy Ratio, Er = Mean Measured Energy / Theoretical Energy
= 0.81 (81 %)

Report prepared by

Wee Hui Hui
Approved Signatory



APPENDIX I

SPT HAMMER ENERGY MEASUREMENT RESULTS

SPT HAMMER ENERGY MEASUREMENT

Conducted By : APS Asia PDA Enterprise Pte Ltd (Theft Tin Soe)

Conducted For : Element Geotechnical Testing (S) Pte. Ltd. (Hammer :EGTA-SPT-01)

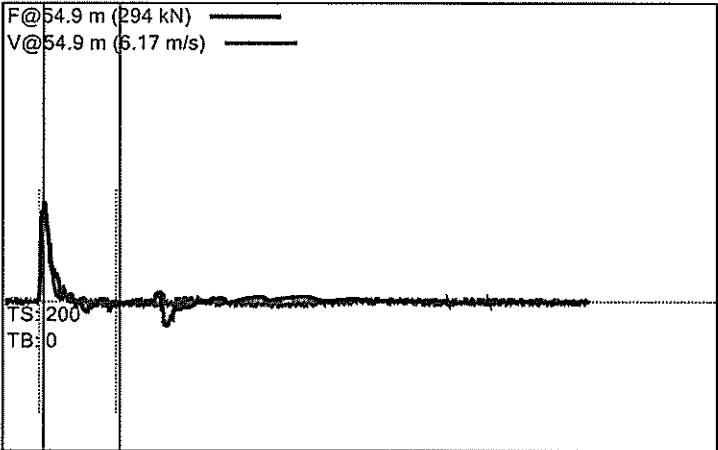
BLOW NO.	EMX	EF2	DMX	FMX	TSX	CSX	VMX	AMX
5	0.3820	0.3520	7	93	13.9	78.6	2.05	512
6	0.3850	0.3560	7	93	14.1	78.4	1.99	418
7	0.3950	0.3630	17	95	13.8	80.1	2.08	481
8	0.3880	0.3570	13	94	15.1	79.6	2.07	511
9	0.3870	0.3550	10	93	13.1	78.6	2.04	444
10	0.3790	0.3500	12	91	13.6	77.3	2.05	445
11	0.3880	0.3550	12	92	12.8	78.3	2.05	437
12	0.3810	0.3470	7	91	12.9	76.9	2.06	442
13	0.3780	0.3500	7	90	13.5	76.0	2.02	360
14	0.3690	0.3440	7	88	13.1	74.2	1.97	363
MINIMUM	0.3690	0.3440	7.0	88	12.80	74.20	1.97	360
MAXIMUM	0.3950	0.3630	17	95	15.1	80.1	2.08	512
AVERAGE	0.3832	0.3529	9.9	92	13.6	77.8	2.04	441
STANDARD DEV.	0.0071	0.0055	3.51	2	0.7	1.8	0.03	52

OUTPUT QUANTITIES

EMX	maximum energy transmitted past the transducers.
EF2	maximum energy transmitted past the transducers from integral of force squared.
DMX	maximum downward displacement at the transducers' location.
FMX	maximum compressive force at the transducers' location.
CSX	maximum compressive stress at transducers' location.
TSX	maximum tensile stress along the length of rod.
VMX	maximum velocity at the transducers' location.
AMX	maximum acceleration at the transducers' location.

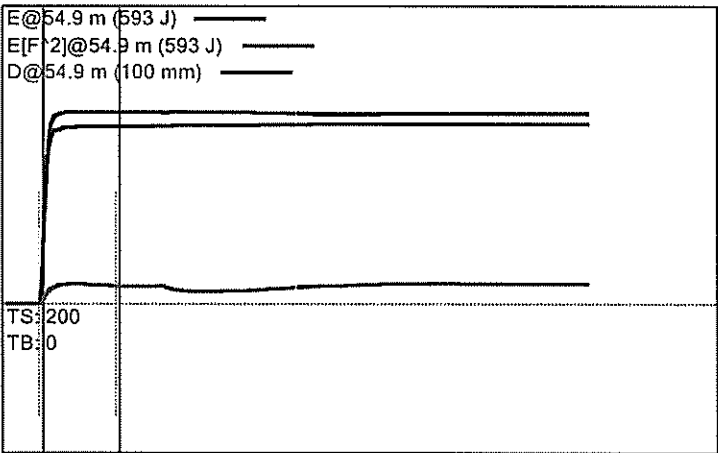
Pile Dynamics, Inc.
CWRP (090123)
EGTA-SPT-01
APS
PDA Operator: APS

Pile Driving Analyzer ® (PDA)
Version: 2021.34



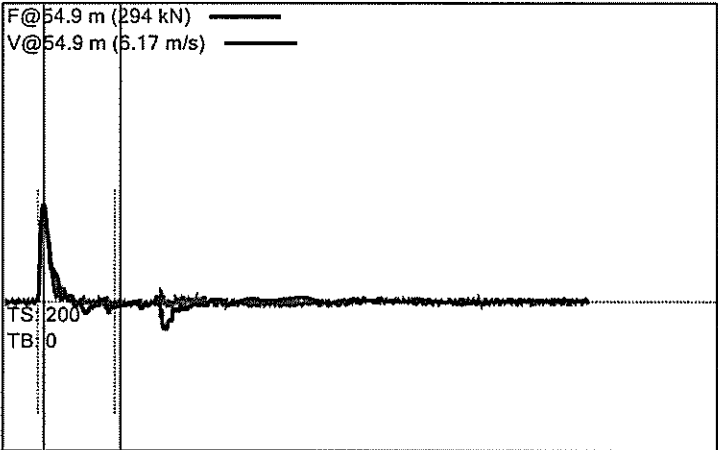
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EMX	382 J
EF2	352 J
DMX	7 mm
FMX	93 kN
TSX	13.9 MPa
CSX	78.6 MPa
VMX	2.05 m/s
AMX	512 g's
LE	54.9 m
AR	11.81 cm^2
EM	206843 MPa
SP	77.3 kN/m3
WS	5123.0 m/s
WC	5121.3 m/s
JC	0.90
JF	1.00



Pile Dynamics, Inc.
CWRP (090123)
EGTA-SPT-01
APS
PDA Operator: APS

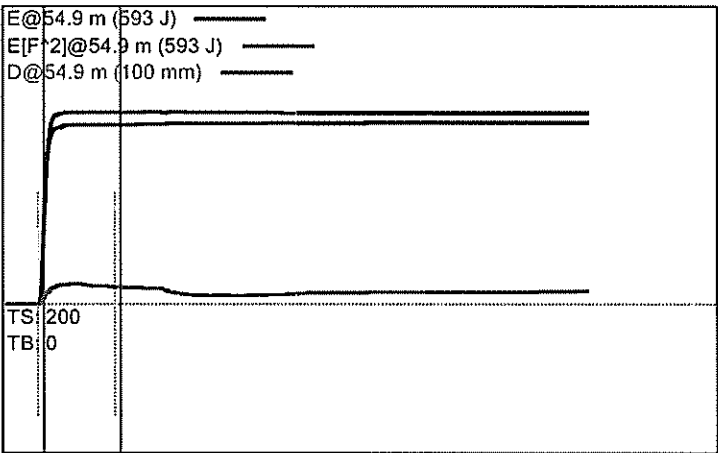
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Version: 2021.34



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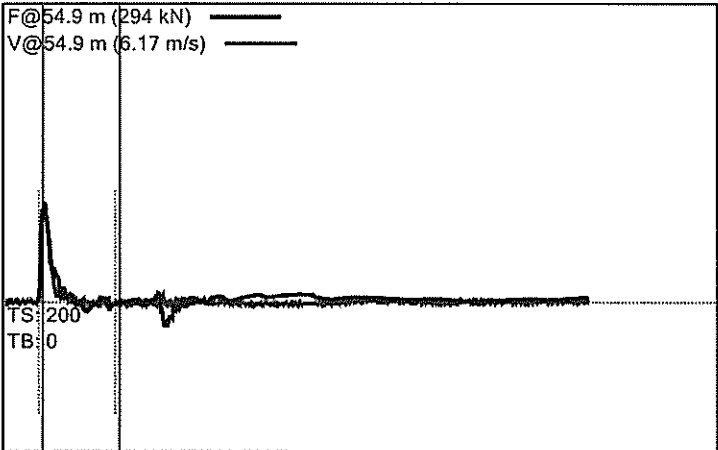
EMX 385 J
EF2 356 J
DMX 7 mm
FMX 93 kN
TSX 14.1 MPa
CSX 78.4 MPa
VMX 1.99 m/s
AMX 418 g's

LE 54.9 m
AR 11.81 cm^2
EM 206843 MPa
SP 77.3 kN/m3
WS 5123.0 m/s
WC 5121.3 m/s
JC 0.90
JF 1.00



Pile Dynamics, Inc.
CWRP (090123)
EGTA-SPT-01
APS
PDA Operator: APS

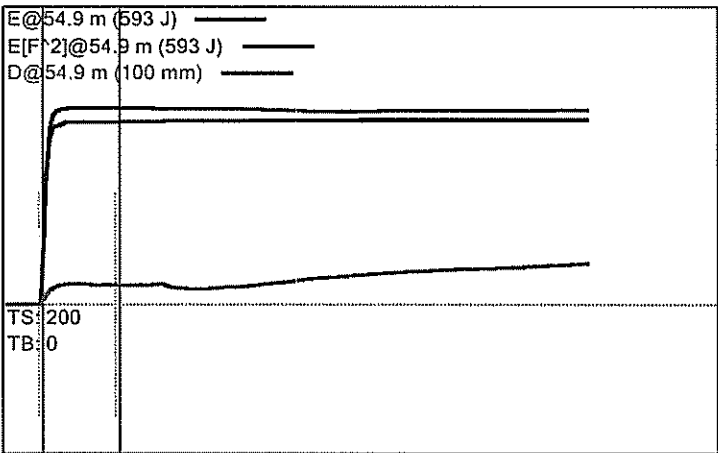
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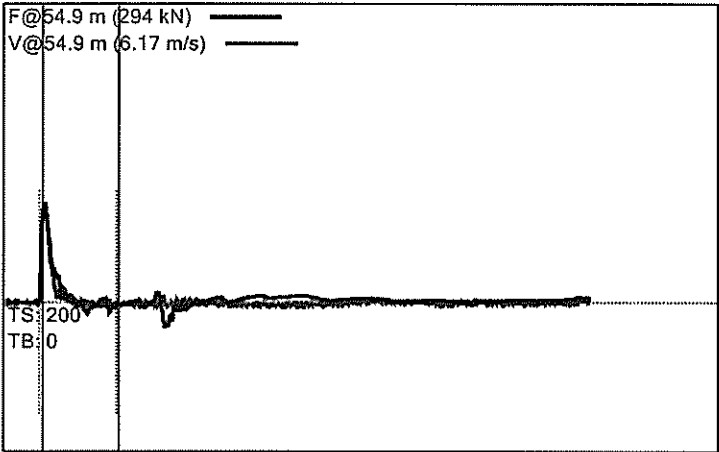
EMX 395 J
EF2 363 J
DMX 17 mm
FMX 95 kN
TSX 13.8 MPa
CSX 80.1 MPa
VMX 2.08 m/s
AMX 481 g's

LE 54.9 m
AR 11.81 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
WC 5121.3 m/s
JC 0.90
JF 1.00



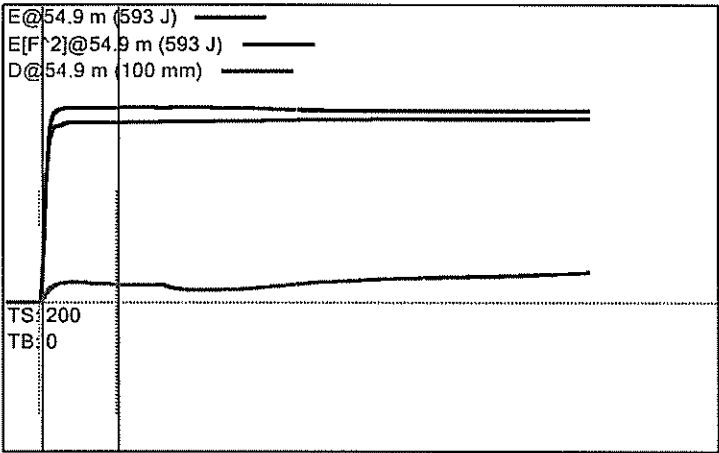
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CWRP (090123)
EGTA-SPT-01
APS
PDA Operator: APS

Pile Driving Analyzer ® (PDA)
Version: 2021.34



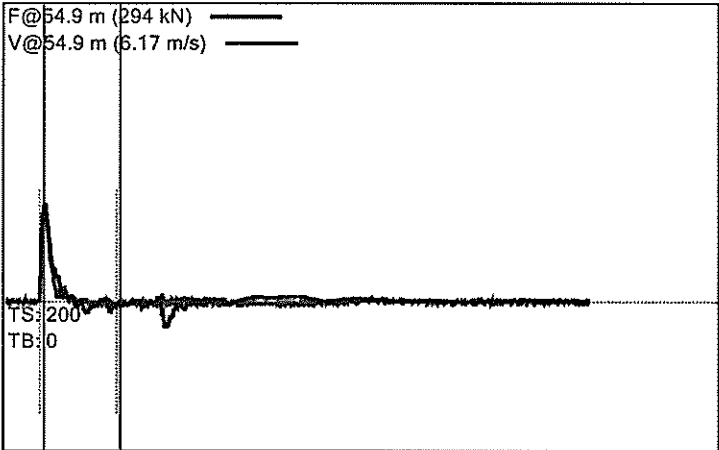
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EMX	388 J
EF2	357 J
DMX	13 mm
FMX	94 kN
TSX	15.1 MPa
CSX	79.6 MPa
VMX	2.07 m/s
AMX	511 g's
LE	54.9 m
AR	11.81 cm ²
EM	206843 MPa
SP	77.3 kN/m ³
WS	5123.0 m/s
WC	5121.3 m/s
JC	0.90
JF	1.00



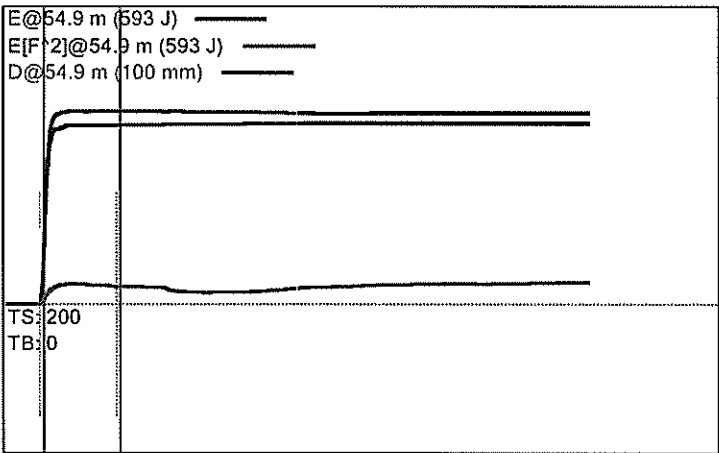
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CWRP (090123)
EGTA-SPT-01
APS
PDA Operator: APS

Pile Driving Analyzer® (PDA)
Version: 2021.34



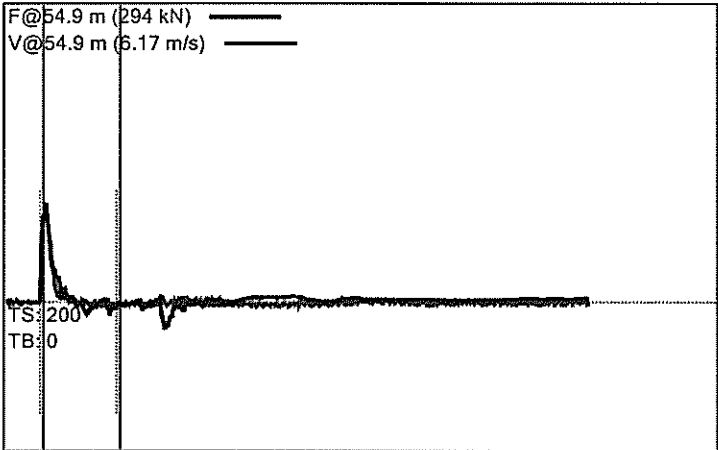
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EMX	387 J
EF2	355 J
DMX	10 mm
FMX	93 kN
TSX	13.1 MPa
CSX	78.6 MPa
VMX	2.04 m/s
AMX	444 g's
LE	54.9 m
AR	11.81 cm^2
EM	206843 MPa
SP	77.3 kN/m3
WS	5123.0 m/s
WC	5121.3 m/s
JC	0.90
JF	1.00



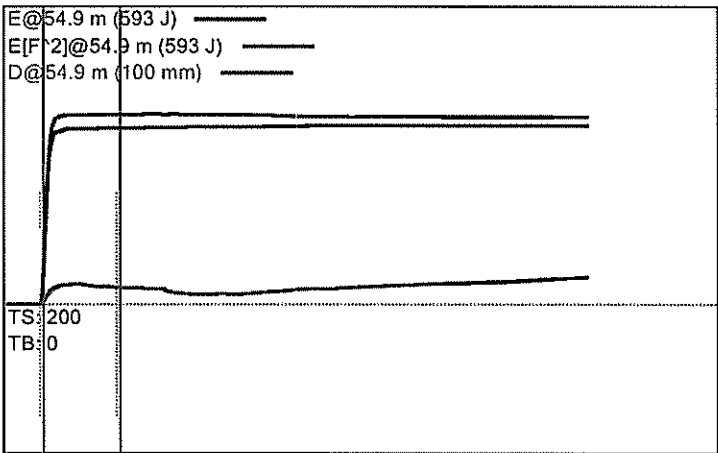
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CWRP (090123)
EGTA-SPT-01
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PDA Operator: APS

Pile Driving Analyzer® (PDA)
Version: 2021.34



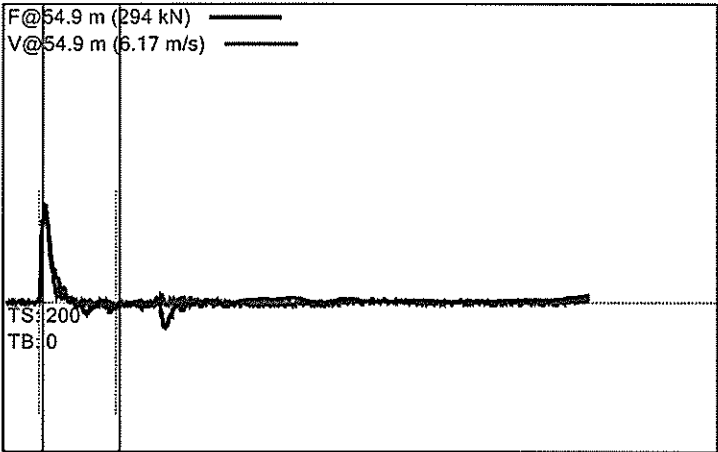
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EMX	379 J
EF2	350 J
DMX	12 mm
FMX	91 kN
TSX	13.6 MPa
CSX	77.3 MPa
VMX	2.05 m/s
AMX	445 g's
LE	54.9 m
AR	11.81 cm ²
EM	206843 MPa
SP	77.3 kN/m ³
WS	5123.0 m/s
WC	5121.3 m/s
JC	0.90
JF	1.00



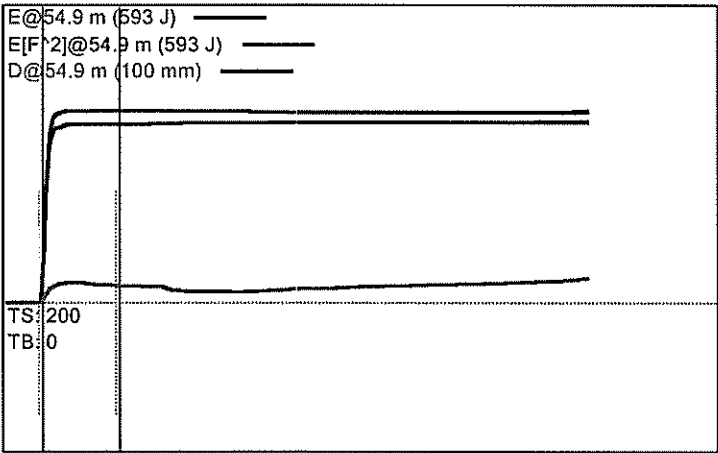
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EGTA-SPT-01
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PDA Operator: APS

Pile Driving Analyzer® (PDA)
Version: 2021.34



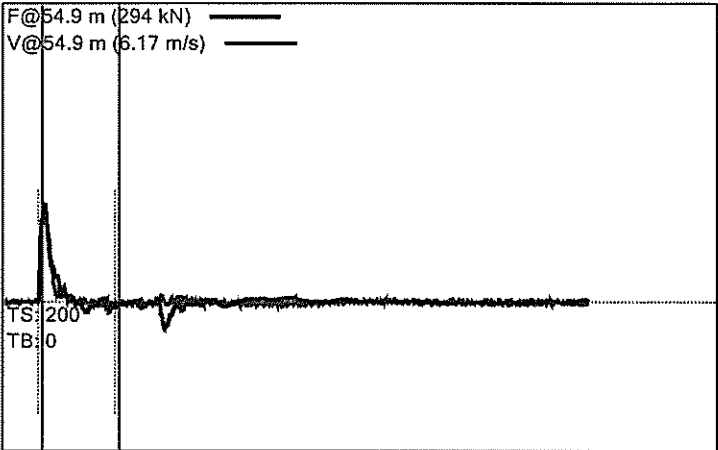
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EMX	388 J
EF2	355 J
DMX	12 mm
FMX	92 kN
TSX	12.8 MPa
CSX	78.3 MPa
VMX	2.05 m/s
AMX	437 g's
LE	54.9 m
AR	11.81 cm^2
EM	206843 MPa
SP	77.3 kN/m3
WS	5123.0 m/s
WC	5121.3 m/s
JC	0.90
JF	1.00



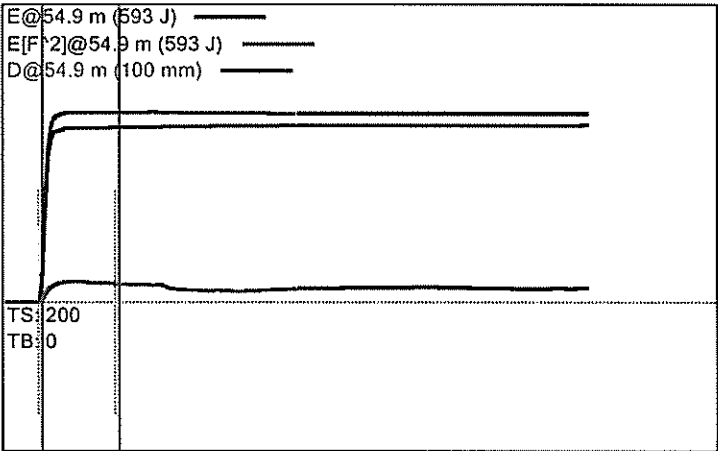
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CWRP (090123)
EGTA-SPT-01
APS
PDA Operator: APS

Pile Driving Analyzer ® (PDA)
Version: 2021.34



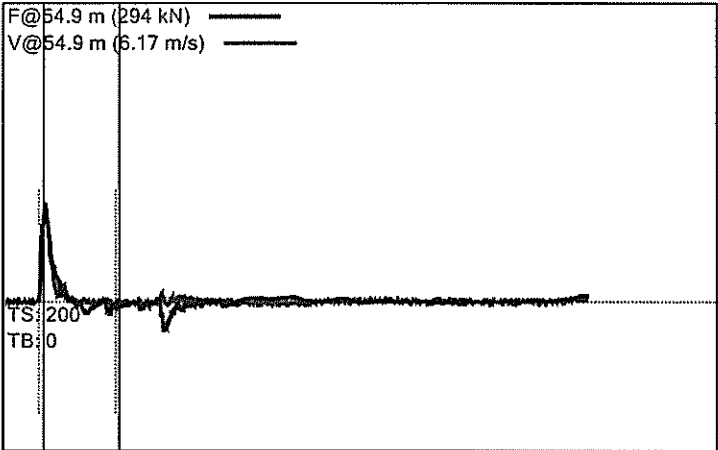
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EMX	381 J
EF2	347 J
DMX	7 mm
FMX	91 kN
TSX	12.9 MPa
CSX	76.9 MPa
VMX	2.06 m/s
AMX	442 g's
LE	54.9 m
AR	11.81 cm^2
EM	206843 MPa
SP	77.3 kN/m3
WS	5123.0 m/s
WC	5121.3 m/s
JC	0.90
JF	1.00



Pile Dynamics, Inc.
CWRP (090123)
EGTA-SPT-01
APS
PDA Operator: APS

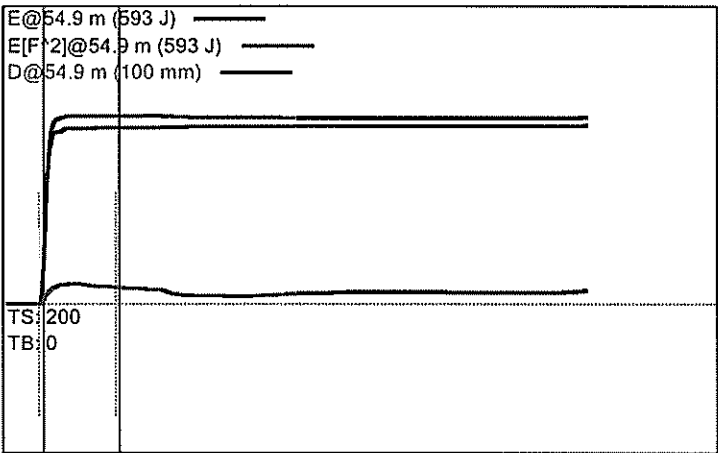
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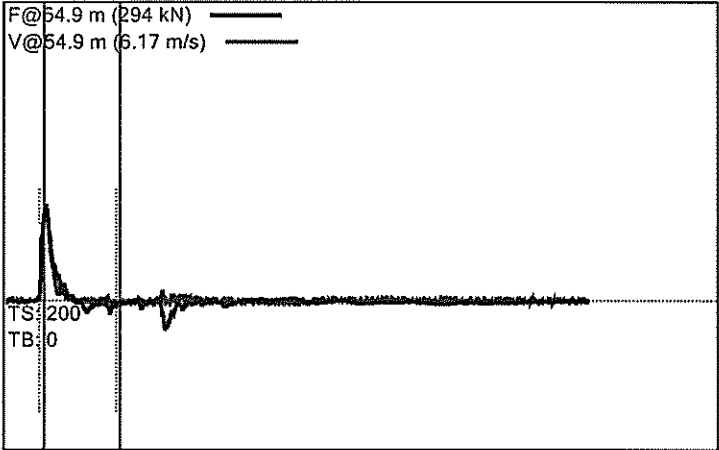
EMX 378 J
EF2 350 J
DMX 7 mm
FMX 90 kN
TSX 13.5 MPa
CSX 76.0 MPa
VMX 2.02 m/s
AMX 360 g's

LE 54.9 m
AR 11.81 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
WC 5121.3 m/s
JC 0.90
JF 1.00



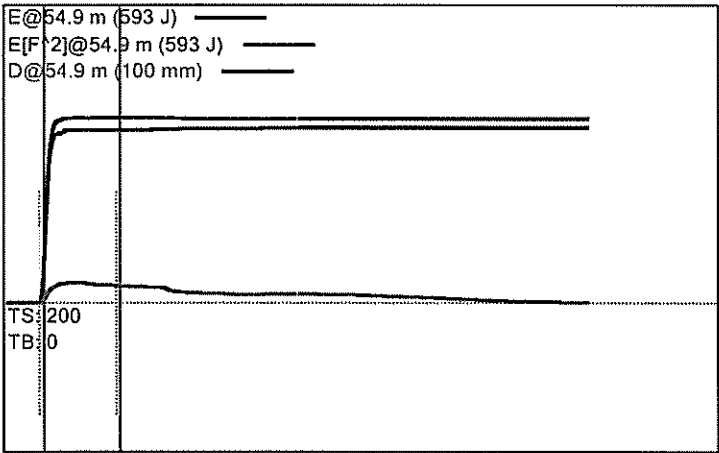
Pile Dynamics, Inc.
CWRP (090123)
EGTA-SPT-01
APS
PDA Operator: APS

Pile Driving Analyzer ® (PDA)
Version: 2021.34



BN 14
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EMX	369 J
EF2	344 J
DMX	7 mm
FMX	88 kN
TSX	13.1 MPa
CSX	74.2 MPa
VMX	1.97 m/s
AMX	363 g's
LE	54.9 m
AR	11.81 cm ²
EM	206843 MPa
SP	77.3 kN/m ³
WS	5123.0 m/s
WC	5121.3 m/s
JC	0.90
JF	1.00





APS ASIA PDA ENTERPRISE PTE LTD

FIELD SHEET - STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT

Test Date : 09/01/2023 Test Ref No: _____
 Client : Element Geotechnical Testing (S) Pte Ltd
 Project Title : AT CNRP.

Calibration Details

Analyser	Weighing Scale	Strain Gauge	Serial Number	Calibration Factor (GV)	Accelerometer	Serial Number	Calibration Factor (GV)
PAX	Teraeiko	F3	587 BW 2	208.71	A3	K12480	431.99
5319LE	20150821116	F4	587 BW 1	208.53	A4	K12478	442.35

Test Details

SPT Hammer Serial No.	EGTA- SPT- 01	
Borehole No.	BH- 3	
Borehole Diameter	φ 100	
Borehole Depth	54.0	
Drilling Rig.	Rig- 05	
Drilling Operator	Nyi Nyi Swe	
Drill Rod Type	BW	
Shoe Type/Length	SS/ 600mm.	
Drill Rod Segments	3m x 18 + 0.60 + 0.60	
Total Length	55.20	
Total Length From Gauge	54.90	
SPT Ram Mass (kg)	68.60	
SPT Anvil Mass (kg)	21.40	
SPT Total Mass (kg)	85.00	
SPT Ram Drop Height	761 mm	
Type Of Machine	Hanjin	
Model	D&B - 10KD	

Results

No. of Blows		
Min. Measured Energy (KN-m)	0.369	
Max. Measured Energy (KN-m)	0.414	

Tested & Checked By: _____
 Signed by SPT Operator

Witness By: A-Mari Muthu, 09/1/23
 Sign & Name Of (R.T.O./RE/Client's Rep)



APS ASIA PDA ENTERPRISE PTE LTD

No. 65 Ubi Crescent, #02-01 Hola Centre

Singapore 408559

Tel: 68968926 Email: info@aps-instrument.com

Co. Registration No. : 200601680E



CERTIFICATE OF CALIBRATION

Certificate Number : APS/SPT/063/2023

Instrument	: Standard Penetration Test (SPT)
Client	: Element Geotechnical Testing (S) Pte Ltd
Serial No	: EGTA-SPT-01
SPT Ram Energy Transfer Ratio	: 81%
Calibration Date	: 09 January 2023
Recalibration Date	: 08 January 2024

Calibration Remarks:

Please refer to Calibration Test Report : APS/SPT/2023/063 for detailed summary and analysis.

This Certificate shall not be reproduced except in full, without the written approval of the laboratory.



The results herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council – Singapore Laboratory Accreditation Scheme

CALIBRATION SITE: LOYANG AVENUE

TEST REPORT

STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT (SPT HAMMER – FTA-SPT-01)

TEST REPORT

10th January 2022

CLIENT

M/s **FOSTA PTE LTD**

Submitted by



APS ASIA PDA ENTERPRISE PTE LTD

11th JANUARY 2022

REPORT REF. NO : APS/SPT/2022/001

No. 65 Ubi Crescent #02-1 Holo Centre Singapore 408559 Tel (65) 68968926 Fax: (65) 62212003

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3. SUMMARY
4. RESULTS

APPENDIX I SPT HAMMER ENERGY MEASUREMENT RESULTS

1. INTRODUCTION

This report the results of the standard penetration test, SPT, hammer energy measurement using the Pile Driving Analyzer, PDA, carried out for APS ASIA PDA Enterprise Pte Ltd on 10 January 2022. The aim of testing was to provide an estimate of the hammer energy transferred by the SPT hammer in accordance to American Standard Test Method ASTM D4633-16.

The SPT testing was performed at Loyang Avenue.

The SPT hammer tested was identified as FTA-SPT-01 and was operated by Hanjin D&B 10KD drilling machine (Rig-5).

2. TEST EQUIPMENT

Pile Driving Analyser (Model PAX)	: Serial No. 4192L
Instrumented Rod	: Serial No. 462BW (Length 600mm)
Strain Transducers	: Serial Nos. 462BW - Bridge 1 & 2
Accelerometers	: Serial Nos. K3439 & K3430

3. SUMMARY

SPT Hammer Serial No.	-	FTA-SPT-01
Calibration Site	-	Loyang Avenue
Borehole	-	BH-9
	-	Diameter : - 100 mm
	-	Depth : 8.05 m
Drilling Rig	-	Rig-5
Drilling Operator	-	Ranansamy
Drill Rod Type	-	BW
Shoe Type / Length	-	Split Spoon Sampler /600mm
Instrumented Rod/Length	-	600 mm
Drill Rod Segments	-	6 + 2 + 0.6 + 0.6
Total Length	-	9.20 m (Instrumented Rod Top To Shoe Base)
SPT Ram Mass	-	63.60 kg
SPT Anvil Mass	-	21.40 kg
SPT Total Mass	-	85.00 kg
SPT Ram Drop Height	-	761 mm
Theoretical Energy	-	0.4748 kN-m

4. RESULTS (SPT HAMMER ENERGY MEASUREMENT)

No. Of Blow = 10

Min. / Max. EMX Value = 0.2674 kN-m / 0.3487 kN-m

Mean Measured Energy = 0.3201 kN-m

Standard Deviation = 0.0287 kN-m

Energy Ratio, Er = Mean Measured Energy / Theoretical Energy
= 0.67 (67 %)

Report prepared by

Cheng Chung Yin Chris
Approved Signatory

APPENDIX I

SPT HAMMER ENERGY MEASUREMENT RESULTS

SPT HAMMER ENERGY MEASUREMENT

Conducted By : APS Asia PDA Enterprise Pte Ltd (Joseph Ling Ka Jun)

Conducted For : Fosta Pte Ltd (Machine : RIG - Rig 5 / SPT : FTA-SPT-01)

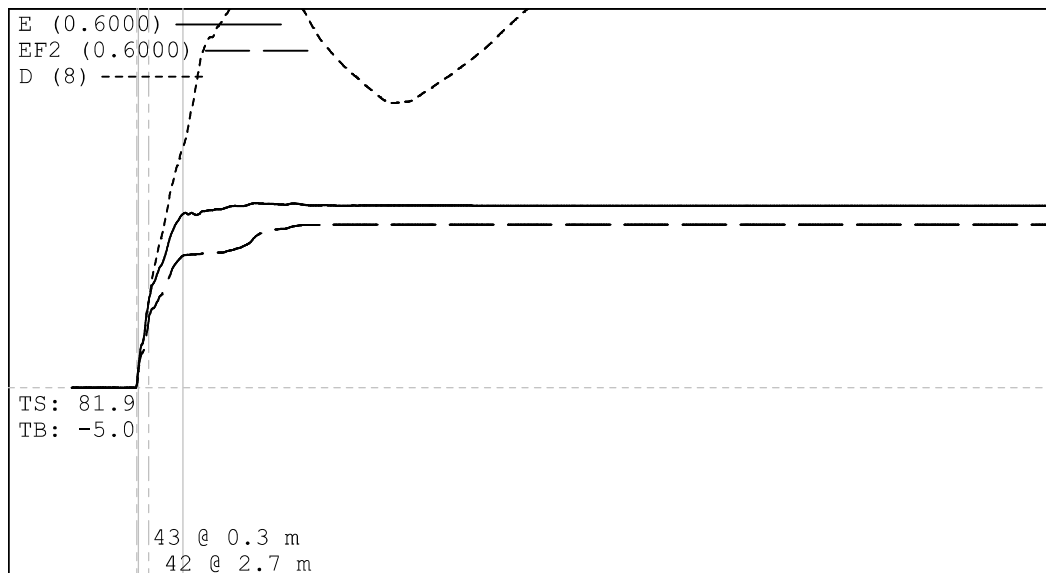
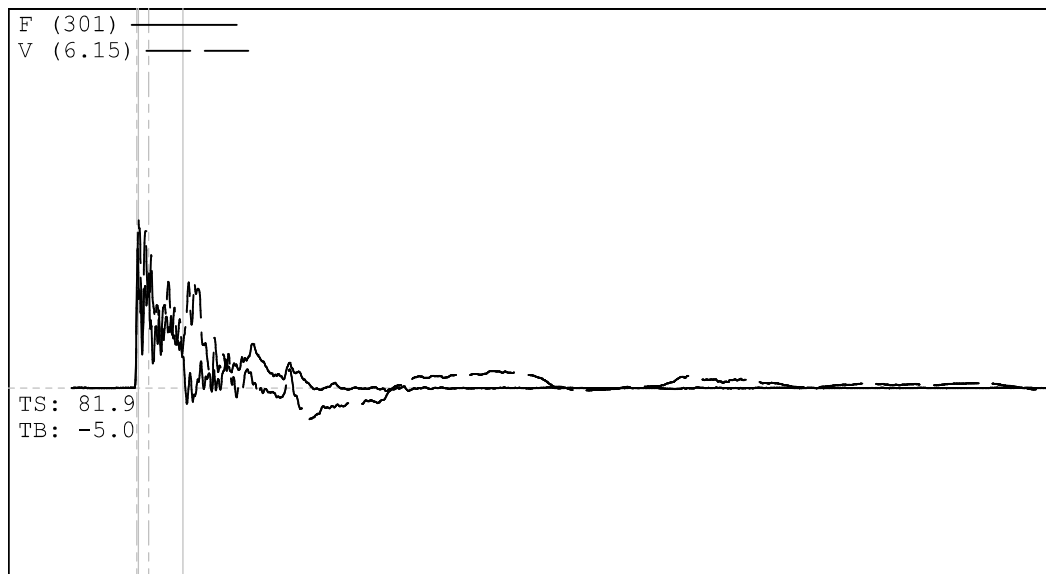
BLOW NO.	EMX	EF2	DMX	FMX	TSX	CSX	VMX	AMX
2	0.2916	0.2096	10	110	18.2	91.1	2.73	1443
3	0.3281	0.2340	12	137	23.2	112.70	2.92	1593
4	0.3487	0.2555	13	129	25.6	106.00	3.04	1737
5	0.2880	0.2239	8	135	18.7	111.00	3.12	1722
6	0.3452	0.2900	8	152	22.4	125.20	3.66	1915
7	0.3434	0.2595	9	135	20.7	111.40	3.03	1940
8	0.3339	0.2212	15	132	21.5	109.10	3.14	1581
9	0.3130	0.2296	11	136	31.3	112.30	2.96	1658
10	0.3421	0.2435	11	136	22.3	112.30	2.91	1589
11	0.2674	0.1802	8	105	11.7	86.70	2.89	1344
MINIMUM	0.2674	0.1802	8.0	105	11.70	86.70	2.73	1344
MAXIMUM	0.3487	0.2900	15	152	31.3	125.2	3.66	1940
AVERAGE	0.3201	0.2347	10.5	131	21.6	107.8	3.04	1652
STANDARD DEV.	0.0287	0.0300	2.37	14	5.1	11.2	0.25	187

OUTPUT QUANTITIES

EMX	maximum energy transmitted past the transducers.
EF2	maximum energy transmitted past the transducers from integral of force squared.
DMX	maximum downward displacement at the transducers' location.
FMX	maximum compressive force at the transducers' location.
CSX	maximum compressive stress at transducers' location.
TSX	maximum tensile stress along the length of rod.
VMX	maximum velocity at the transducers' location.
AMX	maximum acceleration at the transducers' location.

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
PILE NAME: FTA-SPT-01
DESCR: APS
OPERATOR: APS
FILE: FTA-SPT-01
10/1/2022 4:19:09 pm
Blow Number 2

Quantity Results

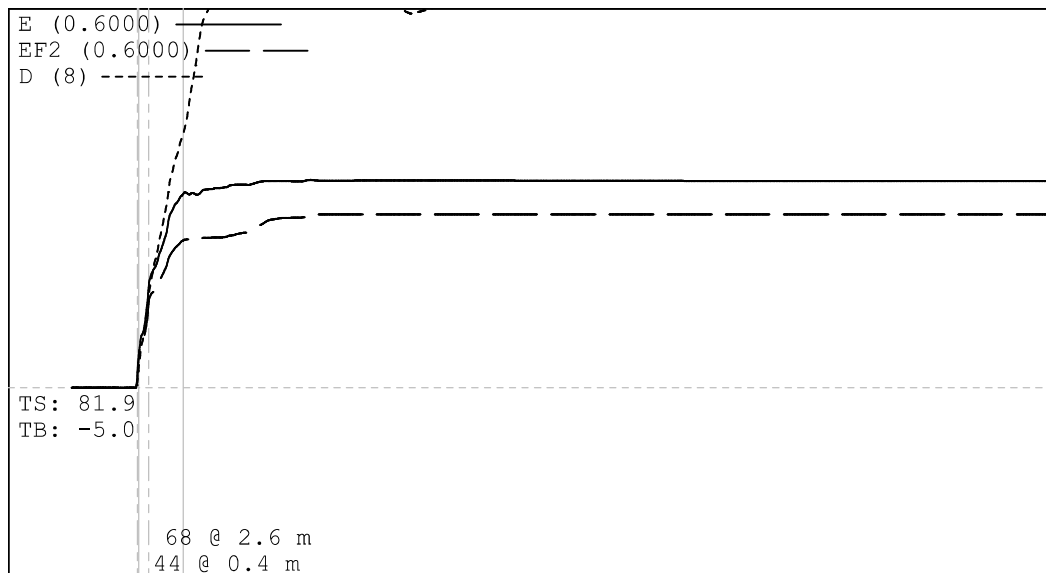
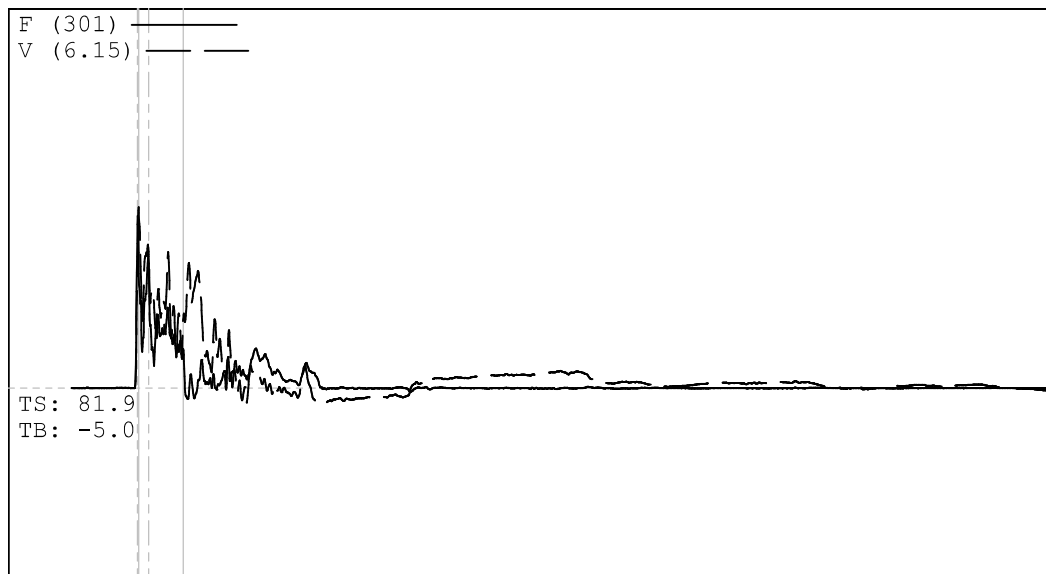
EMX 0.2916 kN-m
EF2 0.2096 kN-m
DMX 10 mm
FMX 110 kN
TSX 18.2 MPa
CSX 91.1 MPa
VMX 2.73 m/s
AMX 1443 g's
RX5 kN

Pile Properties

LE 8.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.48 ms
JC []

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
PILE NAME: FTA-SPT-01
DESCR: APS
OPERATOR: APS
FILE: FTA-SPT-01
10/1/2022 4:19:17 pm
Blow Number 3

Quantity Results

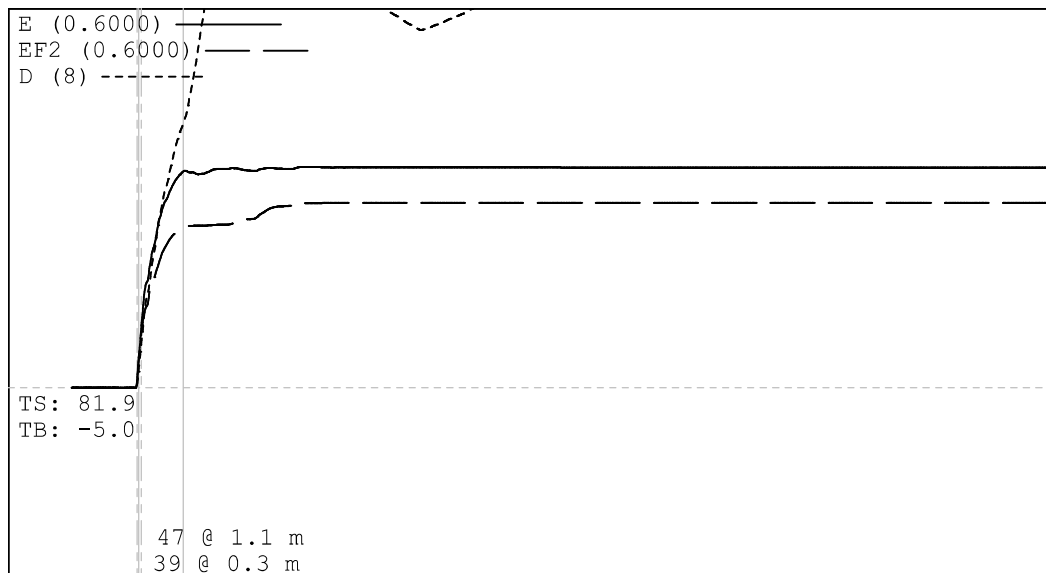
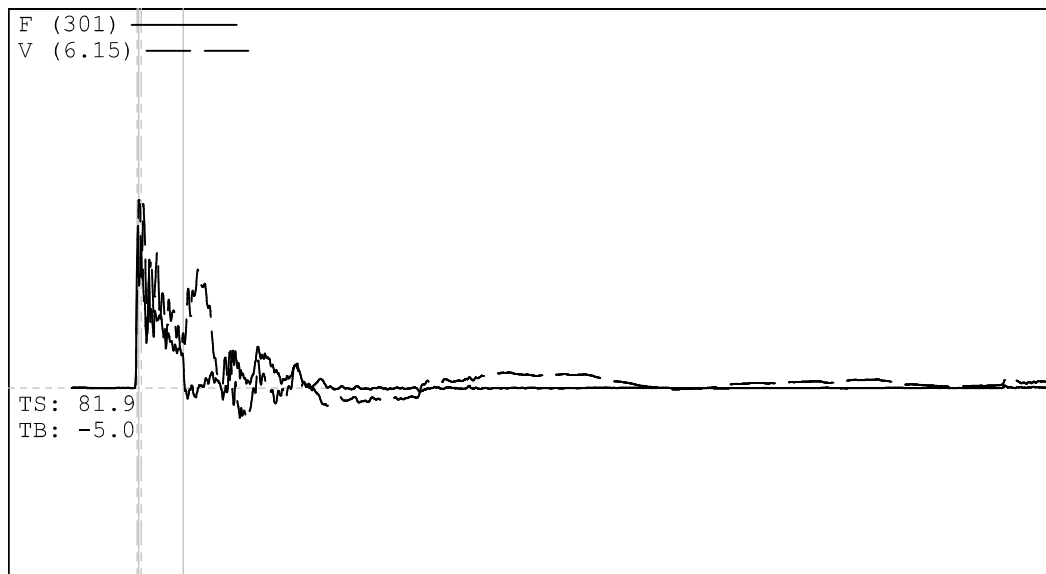
EMX 0.3281 kN-m
EF2 0.2340 kN-m
DMX 12 mm
FMX 137 kN
TSX 23.2 MPa
CSX 112.7 MPa
VMX 2.92 m/s
AMX 1593 g's
RX5 kN

Pile Properties

LE 8.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.48 ms
JC []

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
 PILE NAME: FTA-SPT-01
 DESCR: APS
 OPERATOR: APS
 FILE: FTA-SPT-01
 10/1/2022 4:19:25 pm
 Blow Number 4

Quantity Results

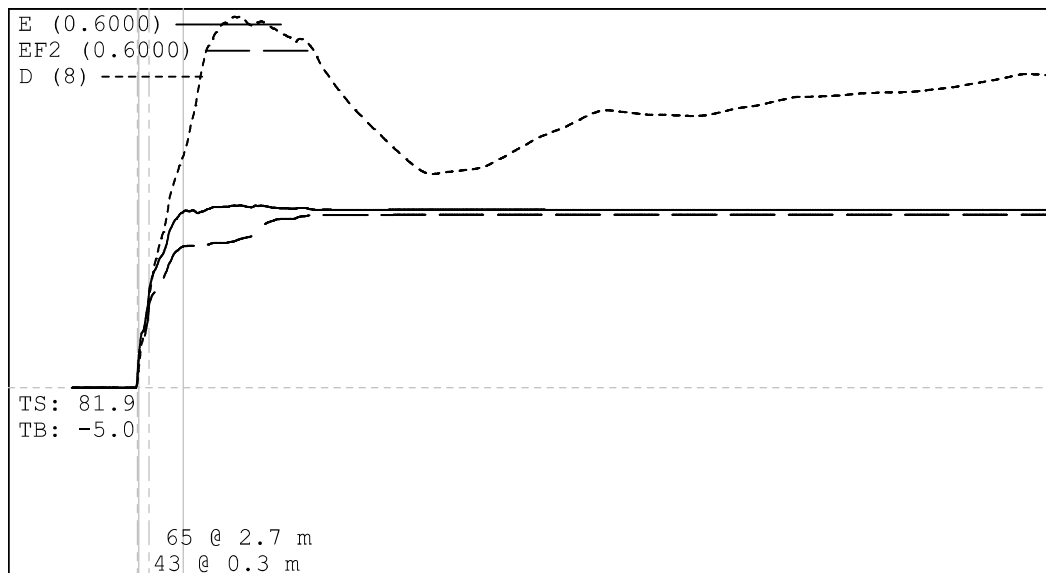
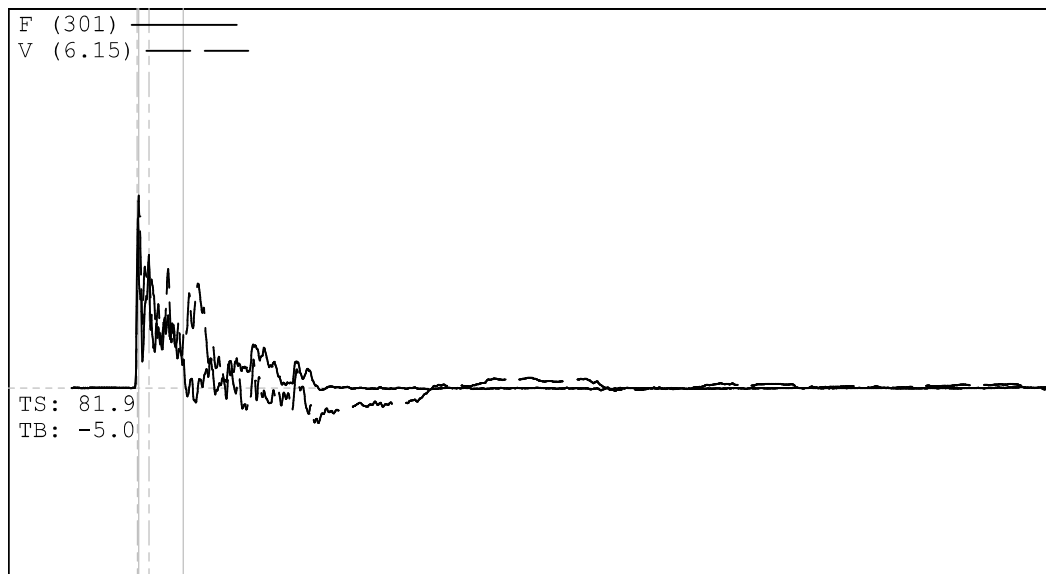
EMX 0.3487 kN-m
 EF2 0.2555 kN-m
 DMX 13 mm
 FMX 129 kN
 TSX 25.6 MPa
 CSX 106.0 MPa
 VMX 3.04 m/s
 AMX 1737 g's
 RX5 kN

Pile Properties

LE 8.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.48 ms
 JC []

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
PILE NAME: FTA-SPT-01
DESCR: APS
OPERATOR: APS
FILE: FTA-SPT-01
10/1/2022 4:19:33 pm
Blow Number 5

Quantity Results

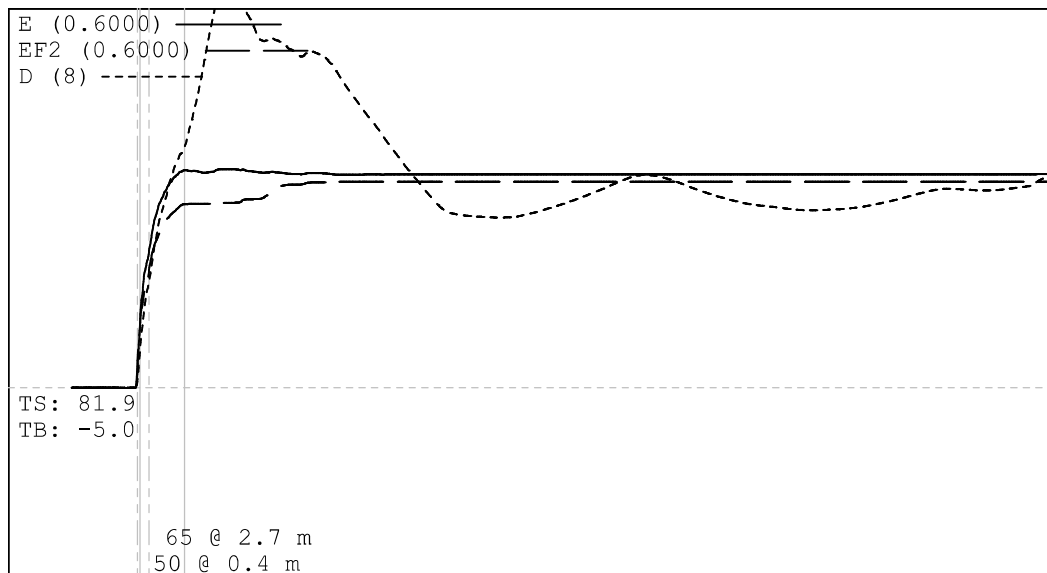
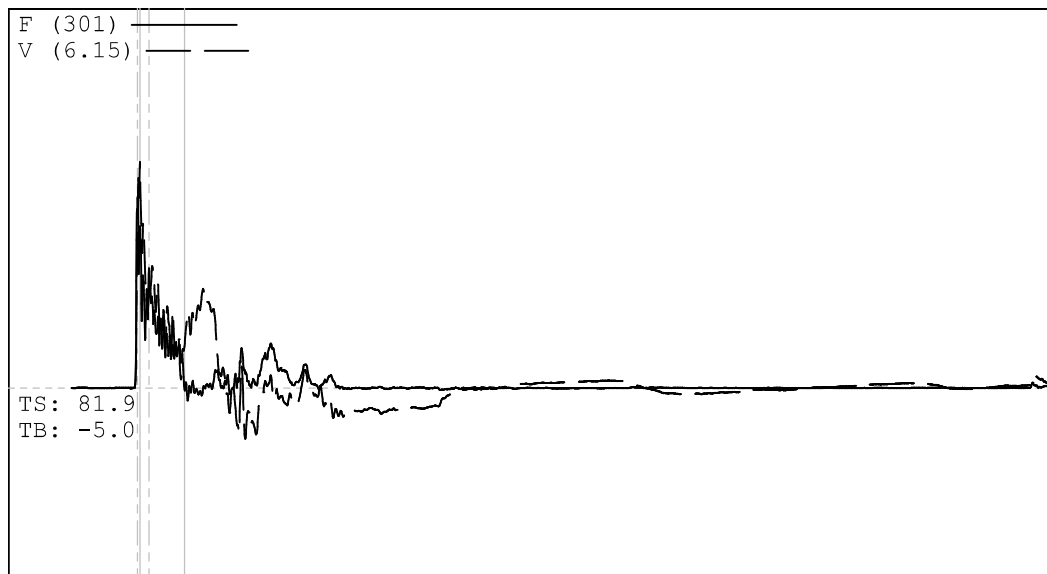
EMX 0.2880 kN-m
EF2 0.2239 kN-m
DMX 8 mm
FMX 135 kN
TSX 18.7 MPa
CSX 111.0 MPa
VMX 3.12 m/s
AMX 1722 g's
RX5 kN

Pile Properties

LE 8.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.48 ms
JC []

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
 PILE NAME: FTA-SPT-01
 DESCR: APS
 OPERATOR: APS
 FILE: FTA-SPT-01
 10/1/2022 4:19:40 pm
 Blow Number 6

Pile Properties

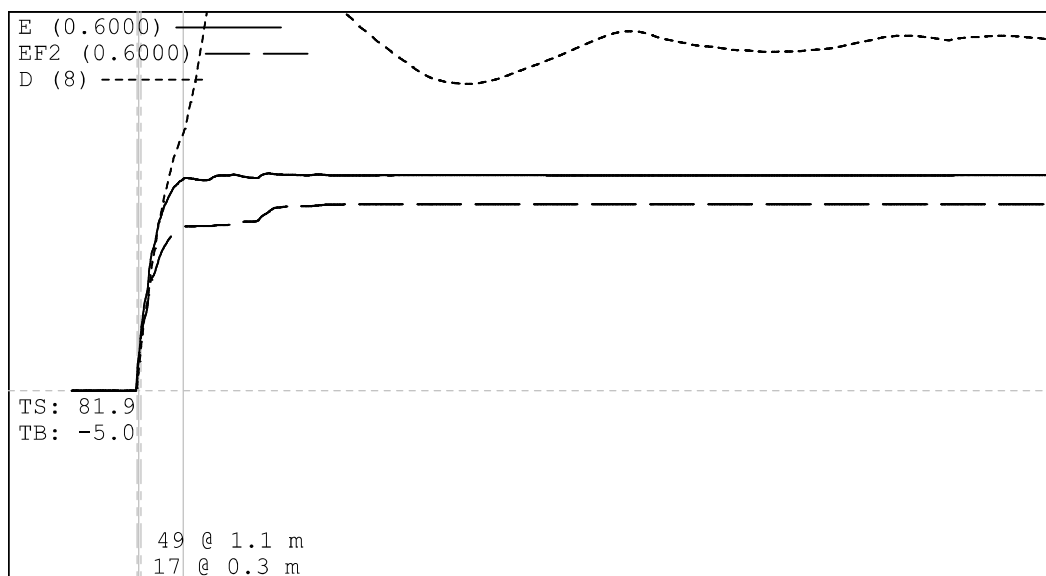
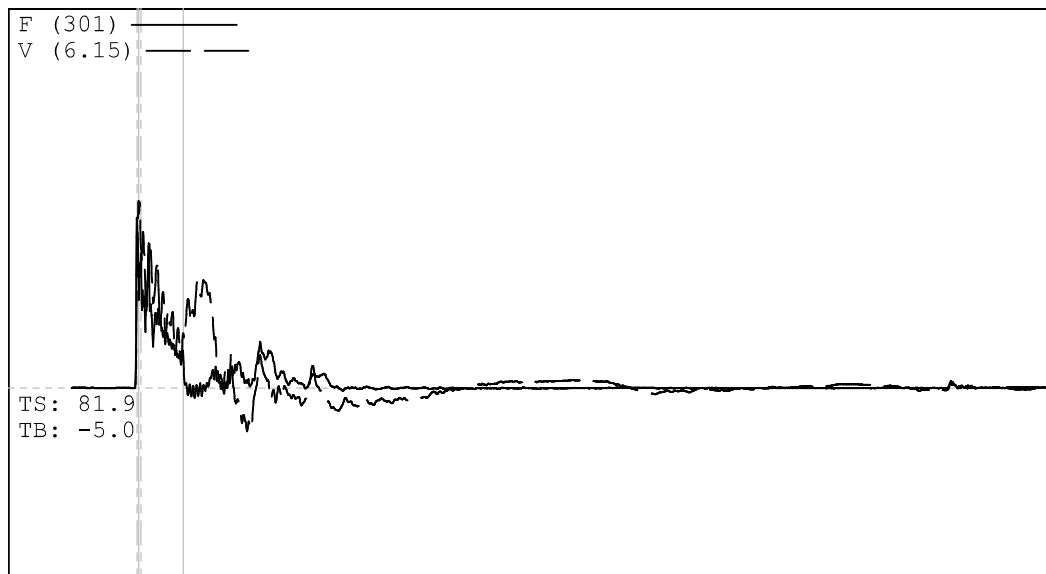
LE 8.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.48 ms
 JC []

Quantity Results

EMX 0.3452 kN-m
 EF2 0.2900 kN-m
 DMX 8 mm
 FMX 152 kN
 TSX 22.4 MPa
 CSX 125.2 MPa
 VMX 3.66 m/s
 AMX 1915 g's
 RX5 kN

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
 PILE NAME: FTA-SPT-01
 DESCR: APS
 OPERATOR: APS
 FILE: FTA-SPT-01
 10/1/2022 4:19:46 pm
 Blow Number 7

Quantity Results

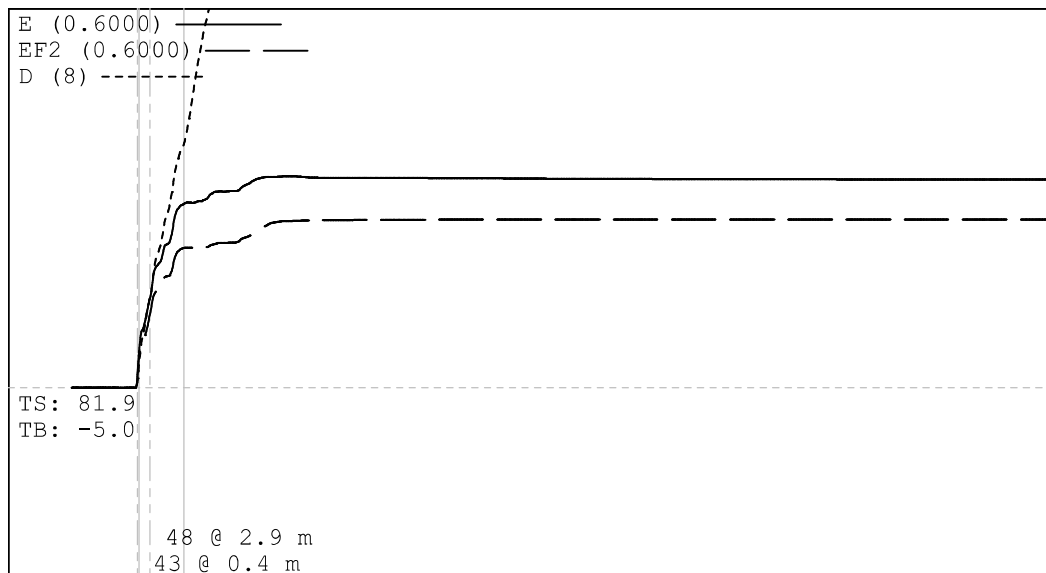
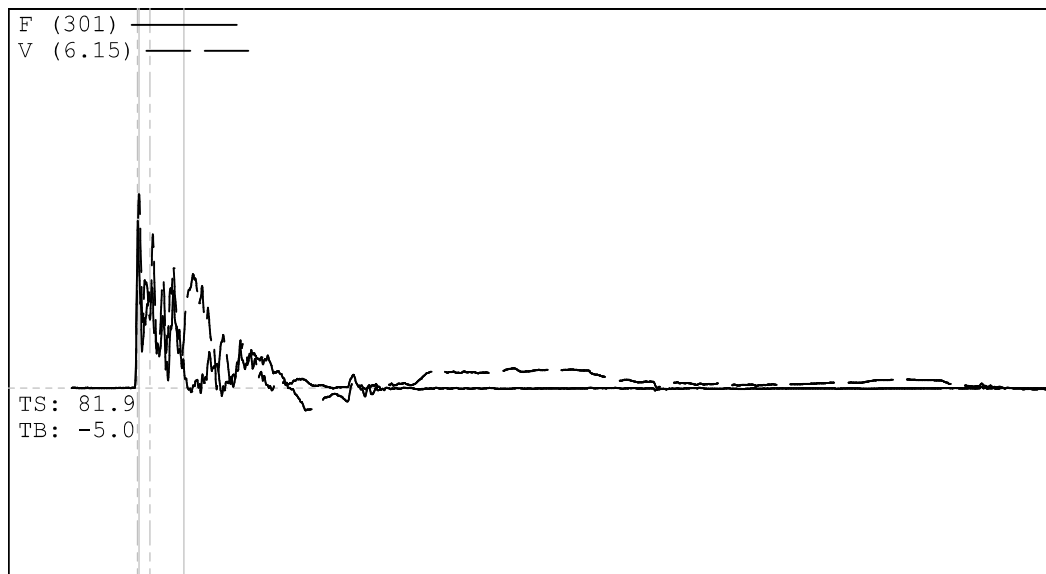
EMX 0.3434 kN-m
 EF2 0.2595 kN-m
 DMX 9 mm
 FMX 135 kN
 TSX 20.7 MPa
 CSX 111.4 MPa
 VMX 3.03 m/s
 AMX 1940 g's
 RX5 kN

Pile Properties

LE 8.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.48 ms
 JC []

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
 PILE NAME: FTA-SPT-01
 DESCR: APS
 OPERATOR: APS
 FILE: FTA-SPT-01
 10/1/2022 4:19:53 pm
 Blow Number 8

Pile Properties

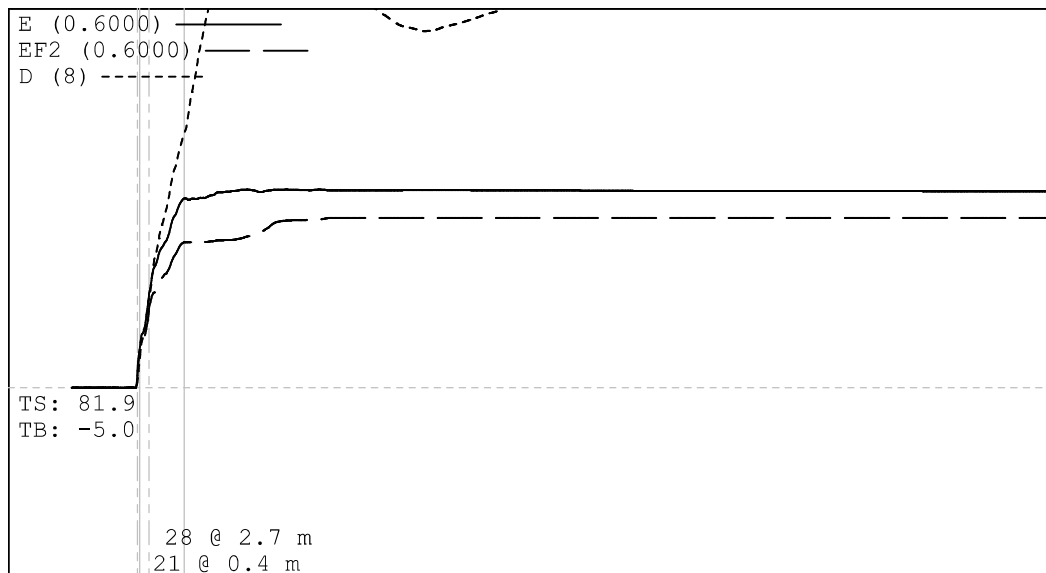
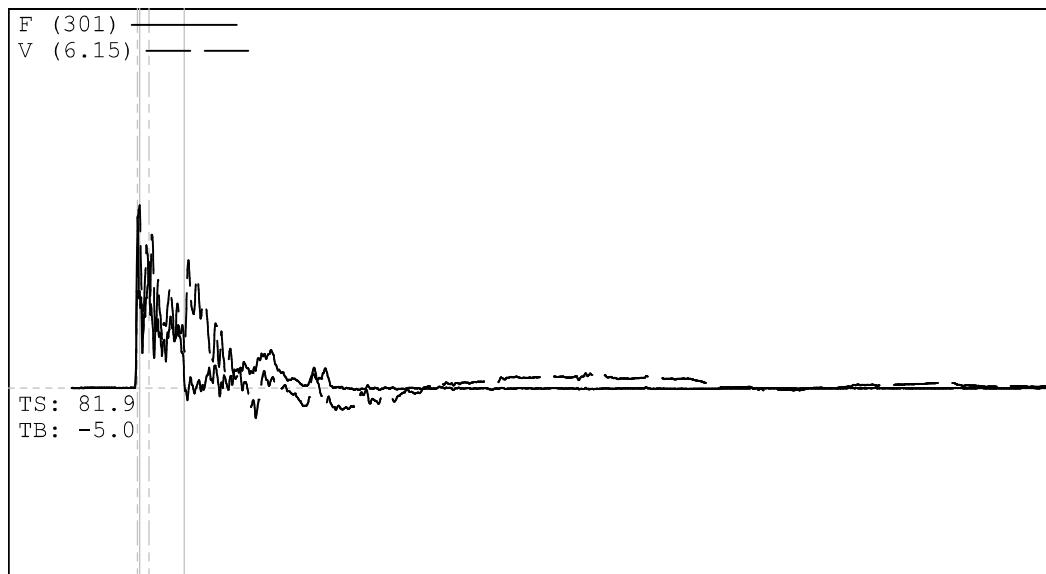
LE 8.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.48 ms
 JC []

Quantity Results

EMX 0.3339 kN-m
 EF2 0.2212 kN-m
 DMX 15 mm
 FMX 132 kN
 TSX 21.5 MPa
 CSX 109.1 MPa
 VMX 3.14 m/s
 AMX 1581 g's
 RX5 kN

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
 PILE NAME: FTA-SPT-01
 DESCR: APS
 OPERATOR: APS
 FILE: FTA-SPT-01
 10/1/2022 4:19:59 pm
 Blow Number 9

Quantity Results

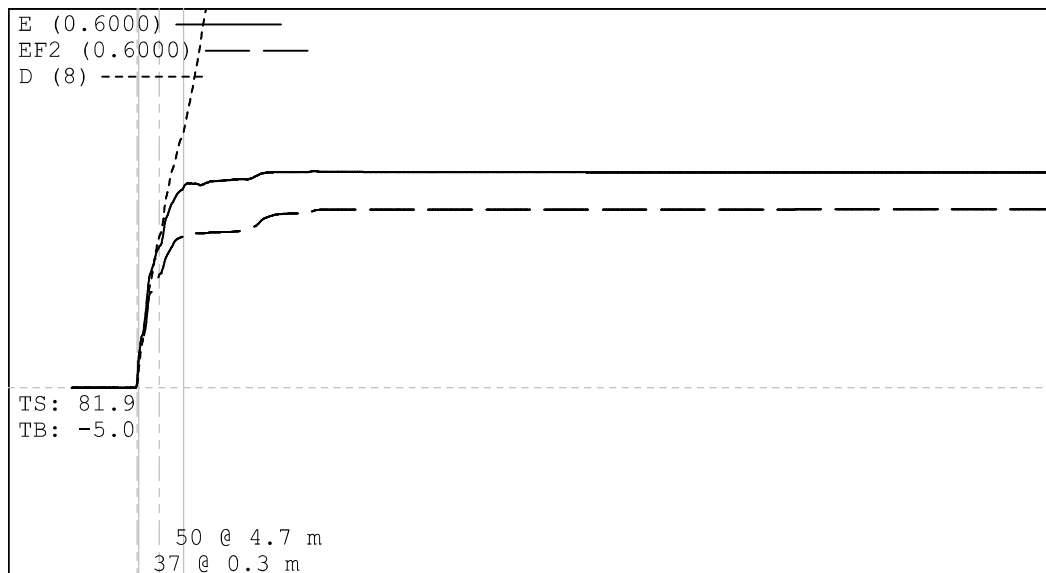
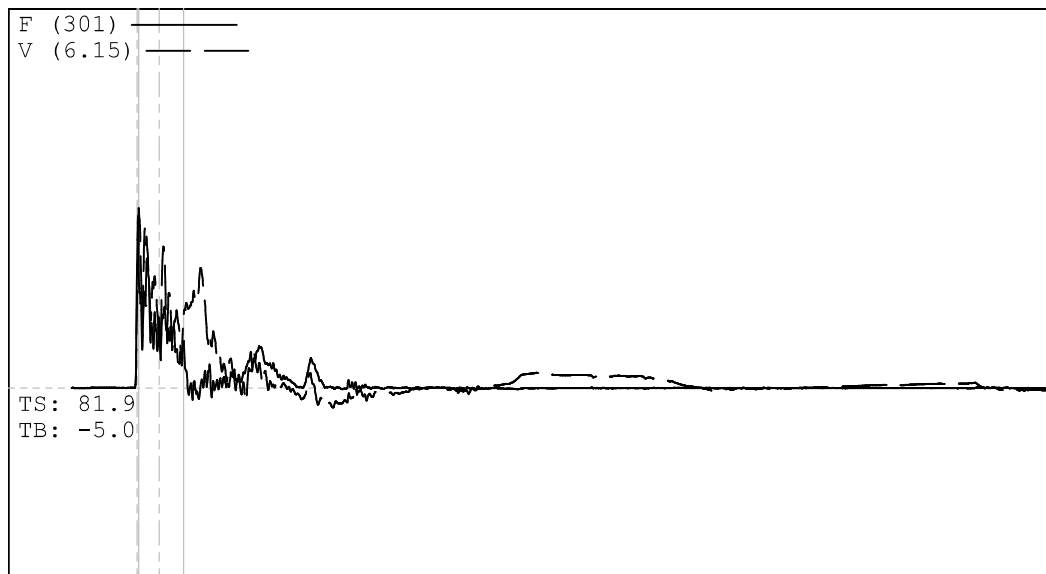
EMX 0.3130 kN-m
 EF2 0.2296 kN-m
 DMX 11 mm
 FMX 136 kN
 TSX 31.3 MPa
 CSX 112.3 MPa
 VMX 2.96 m/s
 AMX 1658 g's
 RX5 kN

Pile Properties

LE 8.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.48 ms
 JC []

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
 PILE NAME: FTA-SPT-01
 DESCR: APS
 OPERATOR: APS
 FILE: FTA-SPT-01
 10/1/2022 4:20:06 pm
 Blow Number 10

Pile Properties

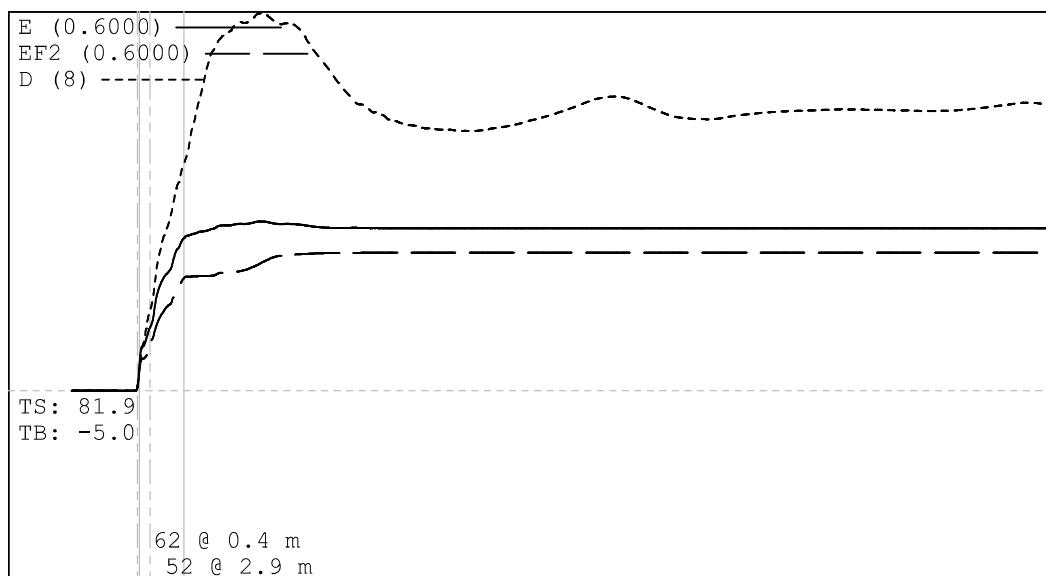
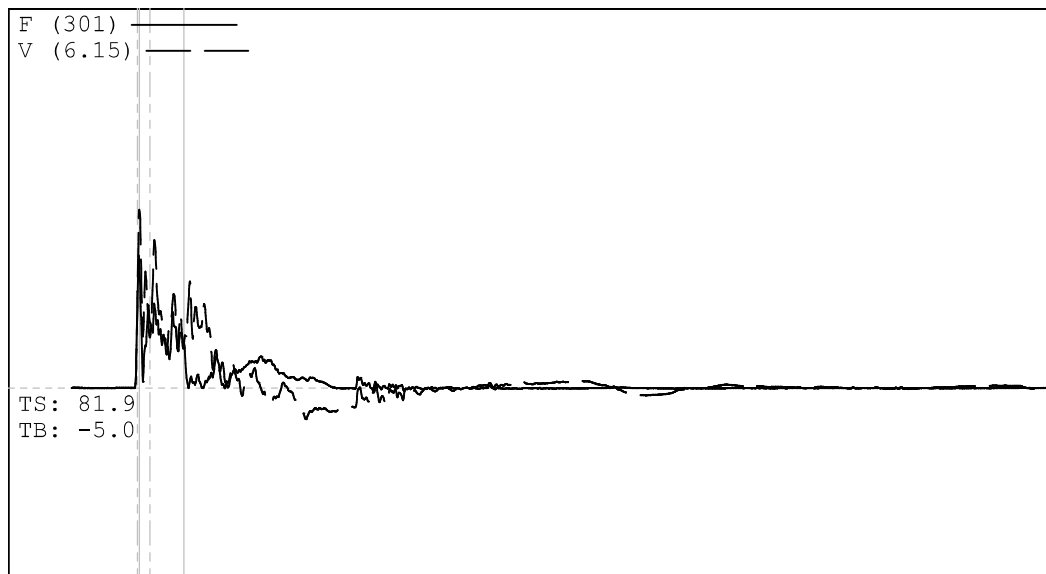
LE 8.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.48 ms
 JC []

Quantity Results

EMX 0.3421 kN-m
 EF2 0.2435 kN-m
 DMX 11 mm
 FMX 136 kN
 TSX 22.3 MPa
 CSX 112.3 MPa
 VMX 2.91 m/s
 AMX 1589 g's
 RX5 kN

LOYANG AVE(100122)

FTA-SPT-01

Project Information

PROJECT: LOYANG AVE(100122)
 PILE NAME: FTA-SPT-01
 DESCR: APS
 OPERATOR: APS
 FILE: FTA-SPT-01
 10/1/2022 4:20:13 pm
 Blow Number 11

Quantity Results

EMX 0.2674 kN-m
 EF2 0.1802 kN-m
 DMX 8 mm
 FMX 105 kN
 TSX 11.7 MPa
 CSX 86.7 MPa
 VMX 2.89 m/s
 AMX 1344 g's
 RX5 kN

Pile Properties

LE 8.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.48 ms
 JC []



APS ASIA PDA ENTERPRISE PTE LTD

No. 65 Ubi Crescent, #02-01 Holo Centre

Singapore 408559

Tel: 68968826 Email: info@aps-instrument.com

Co. Registration No. : 200601680E



CERTIFICATE OF CALIBRATION

Certificate Number : APS/SPT/0001/2022

Instrument : Standard Penetration Test (SPT)

Manufacturer : Hanjin D&B 10KD Drilling Machine

Serial No : FTA-SPT-01

SPT Ram Energy Transfer Ratio : 67%

Calibration Date : 10 January 2022

Recalibration Date : 09 January 2023

Calibration Remarks:

Please refer to Calibration Test Report : APS/SPT/2022/001 for detailed summary and analysis.

This Certificate shall not be reproduced except in full, without the written approval of the laboratory.



APS ASIA PDA ENTERPRISE PTE LTD

FIELD SHEET - STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT

Test Date : 10/01/2022 Test Ref No: _____
 Client : Festa Engineering Pte
 Project Title : Loyang Avenue

Calibration Details

Analyser	Weighing Scale	Strain Gauge	Serial Number	Calibration Factor (G/V)	Accelerometer	Serial Number	Calibration Factor (G/V)
PAX	Teraseiko	F3	462 BW B1	210.92	A3	K3439	303.6
PAX4192LA	20150821116	F4	462 BW B2	210.63	A4	K3430	379.6

Test Details

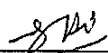
SPT Hammer Serial No.	FTAH-SPT-01 FTA-SPT-01
Borehole No.	BH-9
Borehole Diameter	φ100mm
Borehole Depth	8.05m
Drilling Rig.	Rig-5
Drilling Operator	Ramliumy
Drill Rod Type	BW
Shoe Type/Length	SS / 600
Drill Rod Segments	6 + 2 + 0.6 + 0.6
Total Length	9.20
Total Length From Gauge	8.90
SPT Ram Mass (kg)	63.6
SPT Anvil Mass (kg)	21.4
SPT Total Mass (kg)	85.0
SPT Ram Drop Height	761
Type Of Machine	Hanjin
Model	DB 10kn

Results

No. of Blows	10
Min. Measured Energy (ton-m)	0.029
Max. Measured Energy (ton-m)	0.036

Tested & Checked By: 

Signed by SPT Operator

Witness By: 

Sign & Name Of (R.T.O./RE/Client's Rep)



APS ASIA PDA ENTERPRISE PTE LTD

No. 65 Ubi Crescent #02-01 Holo Centre Singapore 408559

Tel : (65) 6896 8926 Email : info@aps-instrument.com

Singapore Accredited Laboratory : LA-2006-0353-B

Co Reg. No : 200601680E GST Reg. No : 200601680E

DELIVERY ORDER

Client : Fosta Engineering Pte

DO No : PDA/ 406576

Contact Person : _____

Date : 10/01/12

Project Title : Loyang Aene

☐ Dynamic Pile Test

☐ Pile Integrity Test

☐ Vibration / Noise

☐ Plate Bearing Test

☐ Sonic Logging Test

☒ Others

Item No.	Job Details	Quantity
01	SPT Test	04
	FTA-SPT-01, FTA-SPT-02, FTA-SPT-03,	
	FTA-SPT-04,	

Equipment Details	Serial No	Equipment Details	Serial No

Remarks :

- Note : 1. All Instruments are installed in good condition.
2. Client shall be fully responsible/liable for our equipment & instrument.
3. All cost of repair/replacement of damage/stolen equipment will be borne by the client.

Prepared by

Client's Representative

APS ASIA PDA ENTERPRISE PTE LTD

Name & Signature

Date :



The results herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council – Singapore Laboratory Accreditation Scheme

CALIBRATION SITE: PUB TELOK BLANGAH

TEST REPORT

STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT (SPT HAMMER – FTAH-SPT-02)

TEST REPORT

18th November 2021

CLIENT

M/s **FOSTA PTE LTD**

Submitted by



APS ASIA PDA ENTERPRISE PTE LTD

19th NOVEMBER 2021

REPORT REF. NO : APS/SPT/2021/182

No. 65 Ubi Crescent #02-1 Holo Centre Singapore 408559 Tel (65) 68968926 Fax: (65) 62212003

The results reported herein have been performed in accordance with the terms of accreditation under the Singapore Accreditation Council. The reports shall not be reproduced except in full, unless the management representative of APS ASIA PDA Enterprise Pte Ltd has given approval in writing.

C O N T E N T S

1. INTRODUCTION
2. TEST EQUIPMENT
3. SUMMARY
4. RESULTS

APPENDIX I SPT HAMMER ENERGY MEASUREMENT RESULTS

1. INTRODUCTION

This report the results of the standard penetration test, SPT, hammer energy measurement using the Pile Driving Analyzer, PDA, carried out for APS ASIA PDA Enterprise Pte Ltd on 18 November 2021. The aim of testing was to provide an estimate of the hammer energy transferred by the SPT hammer in accordance to American Standard Test Method ASTM D4633-16.

The SPT testing was performed at PUB Telok Blangah.

The SPT hammer tested was identified as FTAH-SPT-02 and was operated by Hanjin D&B 10KD drilling machine (Rig-Rig-2).

2. TEST EQUIPMENT

Pile Driving Analyser (Model PAX)	: Serial No. 4192L
Instrumented Rod	: Serial No. 462BW (Length 600mm)
Strain Transducers	: Serial Nos. 462BW - Bridge 1 & 2
Accelerometers	: Serial Nos. K1582 & K0361

3. SUMMARY

SPT Hammer Serial No.	- FTAH-SPT-02
Calibration Site	- PUB Telok Blangah
Borehole	- RX1512009 - Diameter : - 100 mm - Depth : 9.07 m
Drilling Rig	- Rig-2
Drilling Operator	- Chinniyah
Drill Rod Type	- BW
Shoe Type / Length	- Split Spoon Sampler /600mm
Drill Rod Segments	- 3m x 3 + 0.6 + 0.6
Total Length	- 10.20 m (Instrumented Rod Top To Shoe Base)
SPT Ram Mass	- 63.50 kg
SPT Anvil Mass	- 7.40 kg
SPT Total Mass	- 70.90 kg
SPT Ram Drop Height	- 762 mm
Theoretical Energy	- 0.4747 kN-m

4. **RESULTS (SPT HAMMER ENERGY MEASUREMENT)**

No. Of Blow = 10

Min. / Max. EMX Value = 0.3049 kN-m / 0.3407 kN-m

Mean Measured Energy = 0.3221 kN-m

Standard Deviation = 0.0119 kN-m

Energy Ratio, E_r = Mean Measured Energy / Theoretical Energy
 = 0.68 (68 %)

Report prepared by



Cheng Chung Yin Chris
 Approved Signatory

APPENDIX I

SPT HAMMER ENERGY MEASUREMENT RESULTS

SPT HAMMER ENERGY MEASUREMENT

Conducted By : APS Asia PDA Enterprise Pte Ltd (Joseph Ling Ka Jun)

Conducted For : Fosta Pte Ltd (Machine : RIG - Rig 2 / SPT : FTAH-SPT-02)

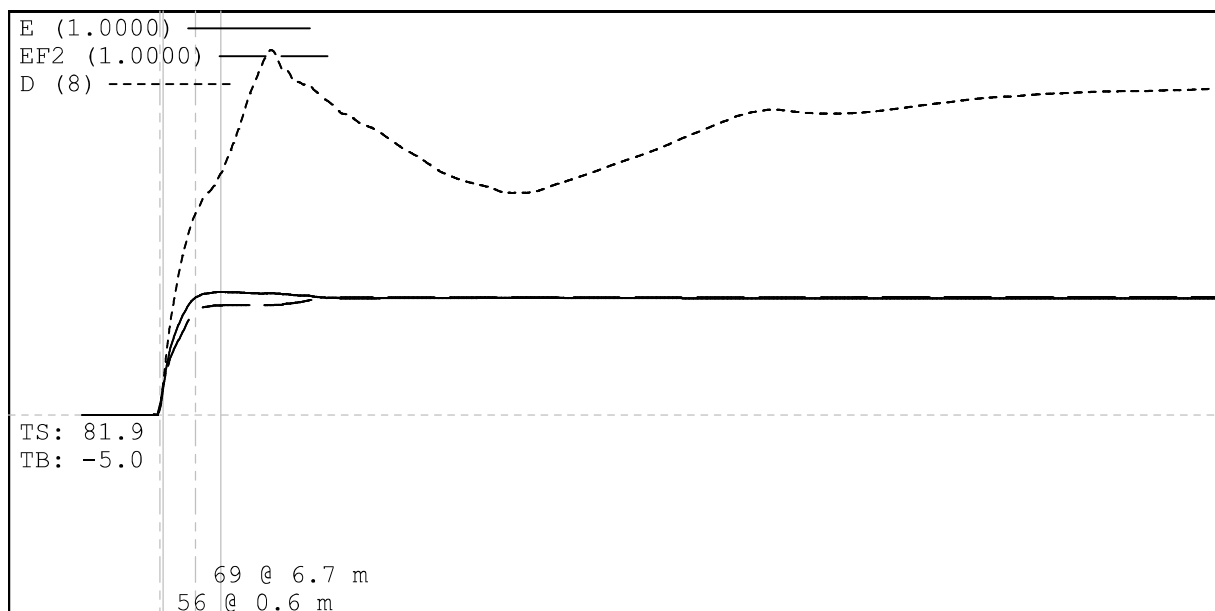
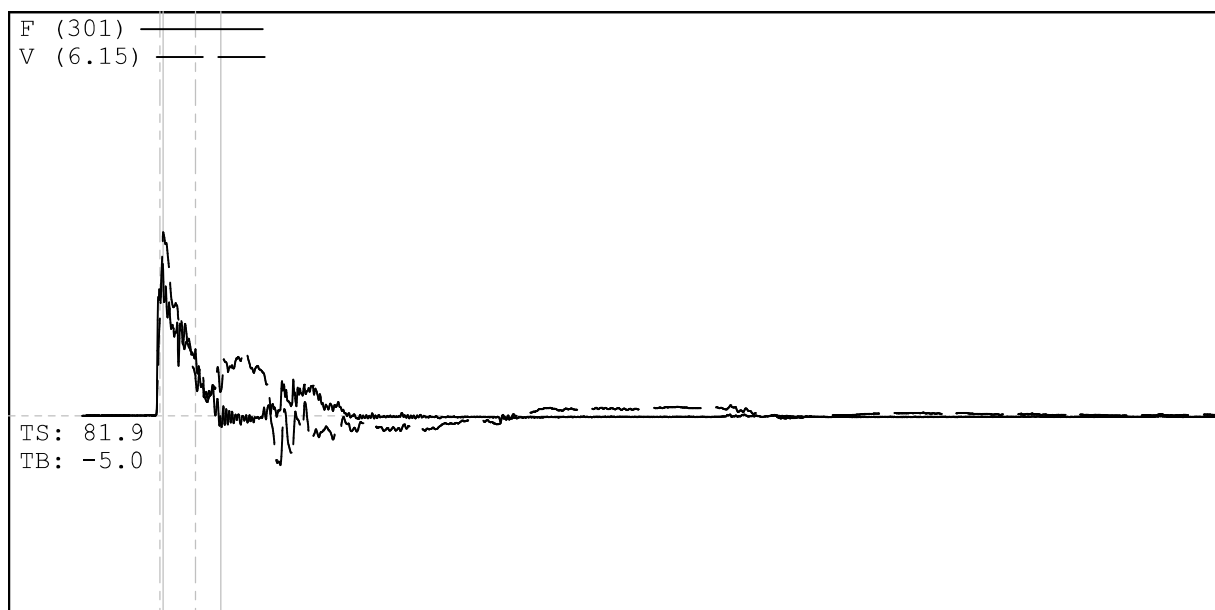
BLOW NO.	EMX	EF2	DMX	FMX	TSX	CSX	VMX	AMX
2	0.3049	0.2715	7	113	17.0	93.2	2.79	900
3	0.3157	0.2741	7	117	17.8	96.20	3.01	883
4	0.3117	0.2676	7	110	18.5	90.90	2.83	959
5	0.3249	0.2756	8	117	16.2	96.10	2.95	1012
6	0.3072	0.2754	7	120	15.9	99.30	2.72	939
7	0.3343	0.2812	7	116	18.4	95.80	3.05	1125
8	0.3233	0.2889	7	118	17.9	97.50	2.81	993
9	0.3407	0.2915	7	118	21.4	97.10	3.05	1082
10	0.3288	0.2927	7	114	22.3	94.20	2.78	1010
11	0.3298	0.2914	7	115	15.3	94.60	2.82	975
MINIMUM	0.3049	0.2676	7.0	110	15.30	90.90	2.72	883
MAXIMUM	0.3407	0.2927	8	120	22.3	99.3	3.05	1125
AVERAGE	0.3221	0.2810	7.1	116	18.1	95.5	2.88	988
STANDARD DEV.	0.0119	0.0094	0.32	3	2.3	2.4	0.12	75

OUTPUT QUANTITIES

EMX	maximum energy transmitted past the transducers.
EF2	maximum energy transmitted past the transducers from integral of force squared.
DMX	maximum downward displacement at the transducers' location.
FMX	maximum compressive force at the transducers' location.
CSX	maximum compressive stress at transducers' location.
TSX	maximum tensile stress along the length of rod.
VMX	maximum velocity at the transducers' location.
AMX	maximum acceleration at the transducers' location.

TELOK BLANGAH(181121)

FTAH-SPT02

Project Information

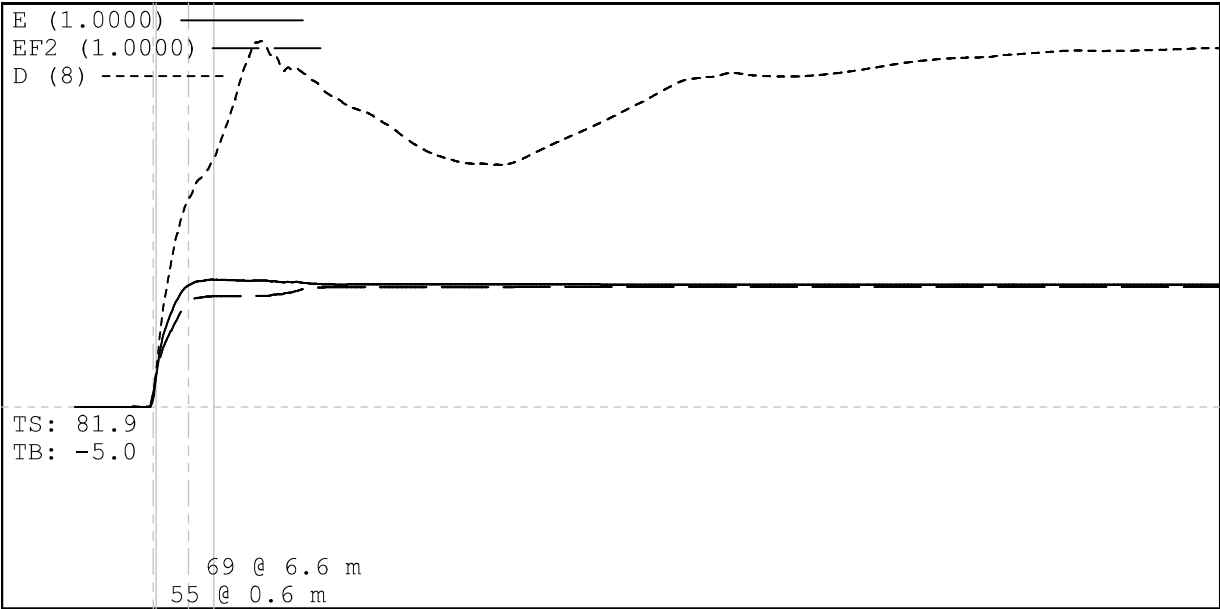
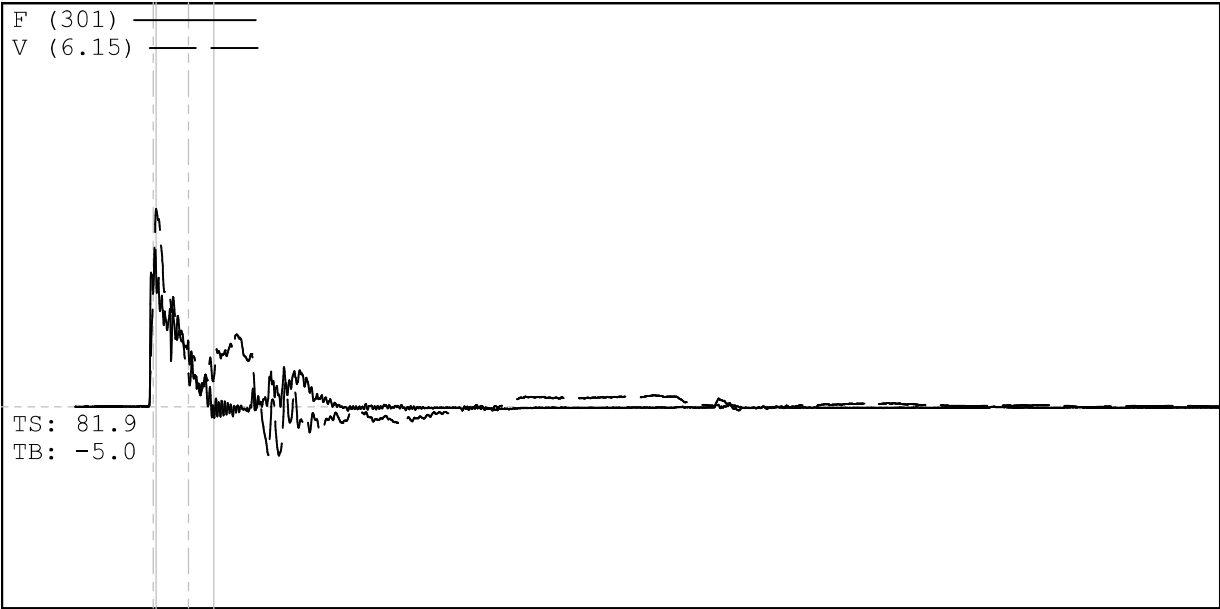
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 PILE NAME: FTAH-SPT02
 DESCR: APS
 OPERATOR: APS
 FILE: FTAH-SPT-02
 18/11/2021 11:11:19 am
 Blow Number 2

Quantity Results

EMX 0.3049 kN-m
 EF2 0.2715 kN-m
 DMX 7 mm
 FMX 113 kN
 TSX 17.0 MPa
 CSX 93.2 MPa
 VMX 2.79 m/s
 AMX 900 g's
 RX5 kN

Pile Properties

LE 9.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.88 ms
 JC []



Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT02
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT-02
18/11/2021 11:11:29 am
Blow Number 3

Quantity Results

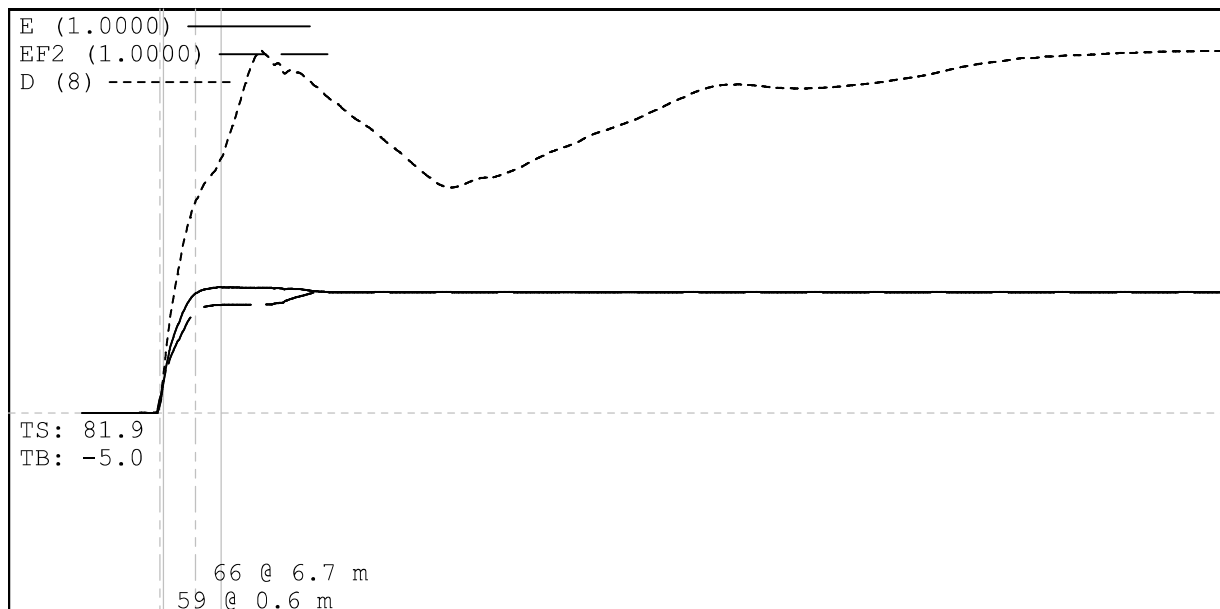
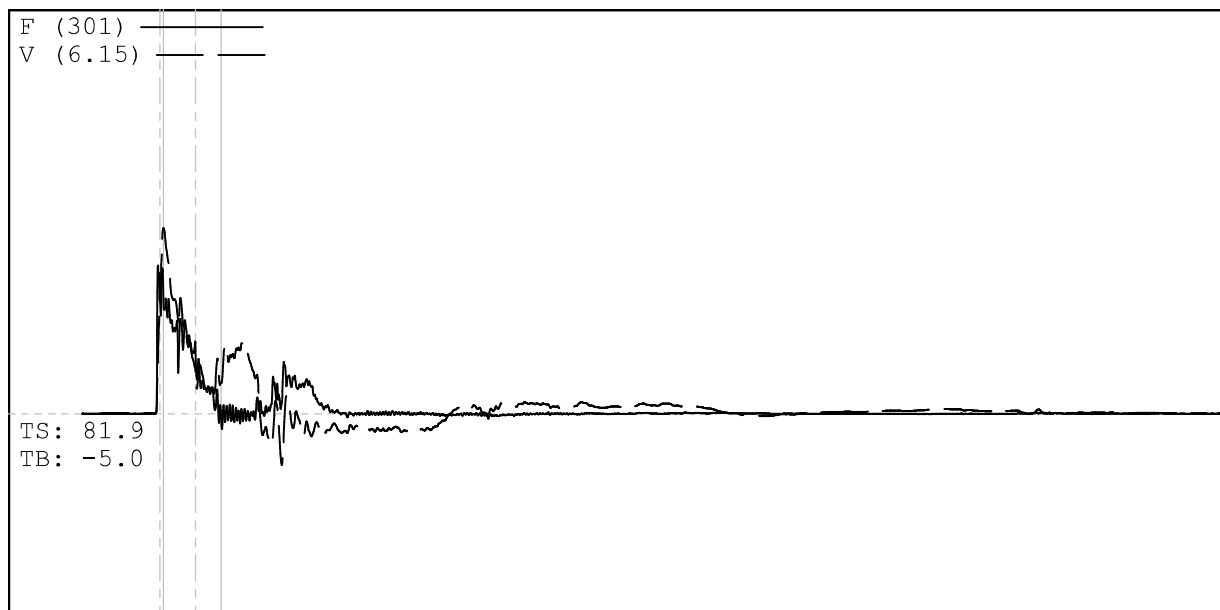
EMX 0.3157 kN-m
EF2 0.2741 kN-m
DMX 7 mm
FMX 117 kN
TSX 17.8 MPa
CSX 96.2 MPa
VMX 3.01 m/s
AMX 883 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT02

Project Information

PROJECT: TELOK BLANGAH(181121)

PILE NAME: FTAH-SPT02

DESCR: APS

OPERATOR: APS

FILE: FTAH-SPT-02

18/11/2021 11:11:34 am

Blow Number 4

Quantity Results

EMX 0.3117 kN-m

EF2 0.2676 kN-m

DMX 7 mm

FMX 110 kN

TSX 18.5 MPa

CSX 90.9 MPa

VMX 2.83 m/s

AMX 959 g's

RX5 kN

Pile Properties

LE 9.9 m

AR 12.13 cm²

EM 206843 MPa

SP 77.3 kN/m³

WS 5123.0 m/s

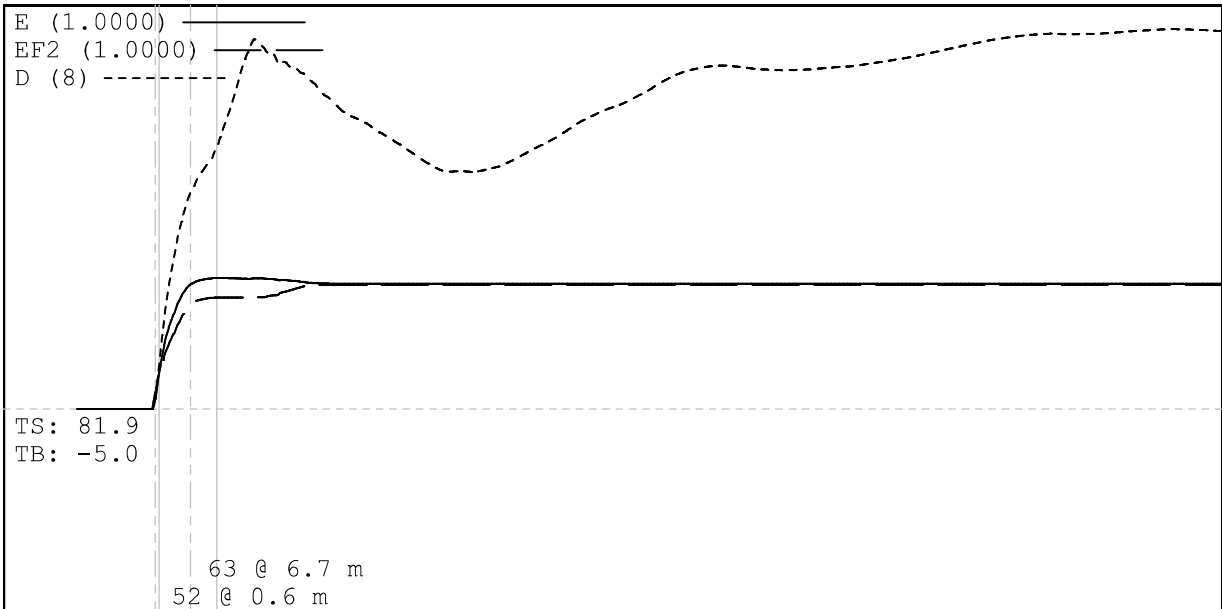
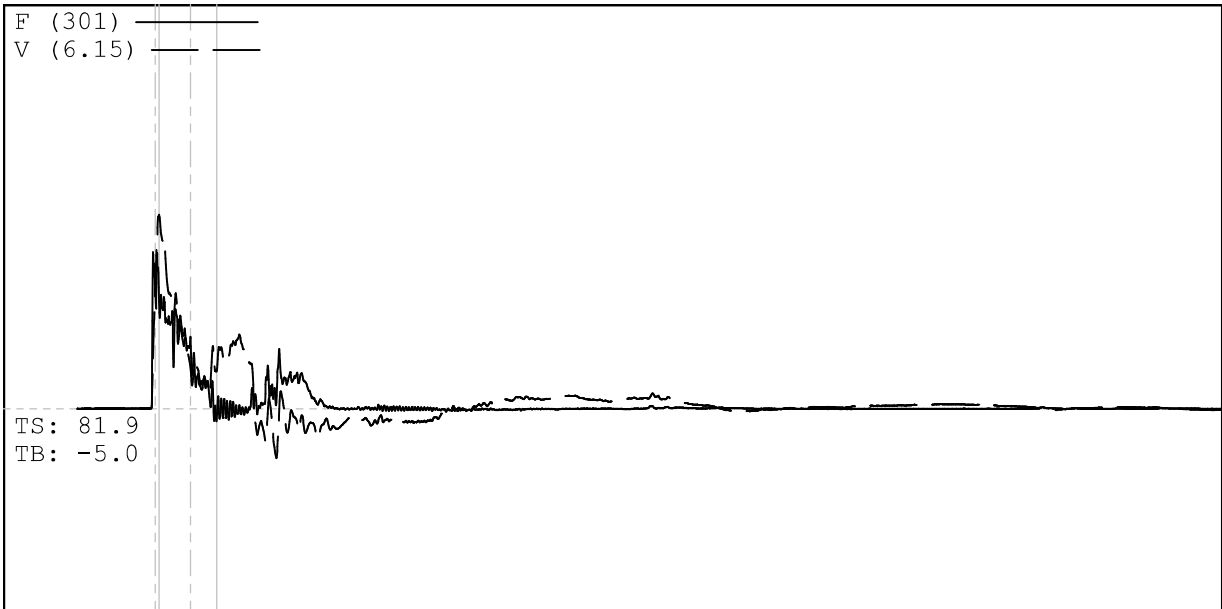
EA/C 49 kN-s/m

2L/C 3.88 ms

JC []

TELOK BLANGAH(181121)

FTAH-SPT02



Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT02
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT-02
18/11/2021 11:11:38 am
Blow Number 5

Quantity Results

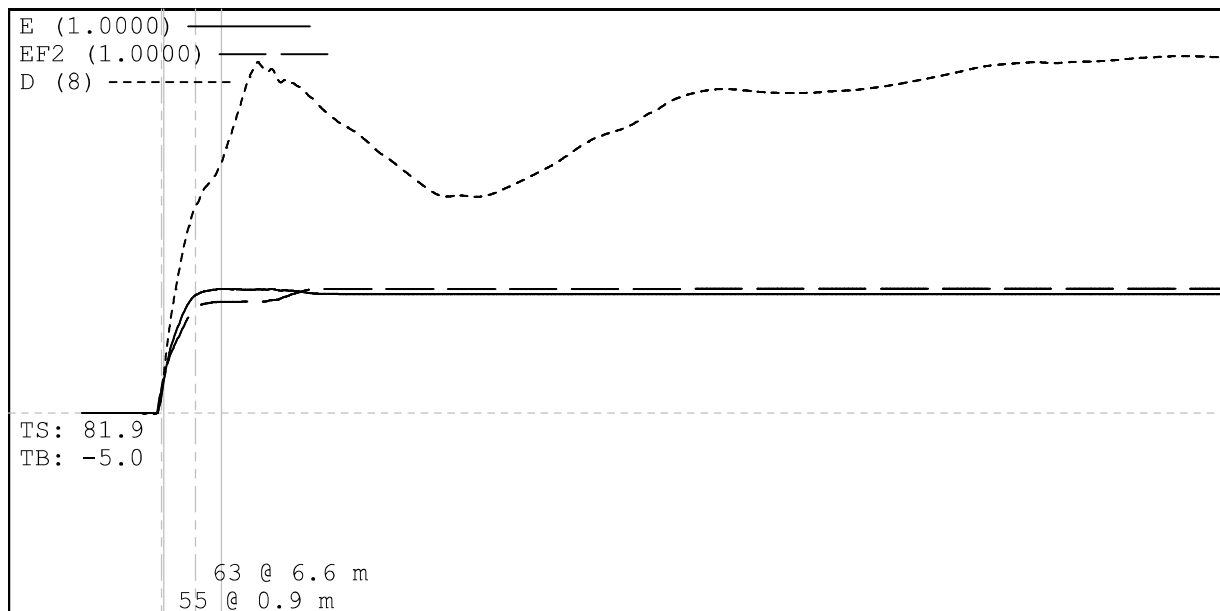
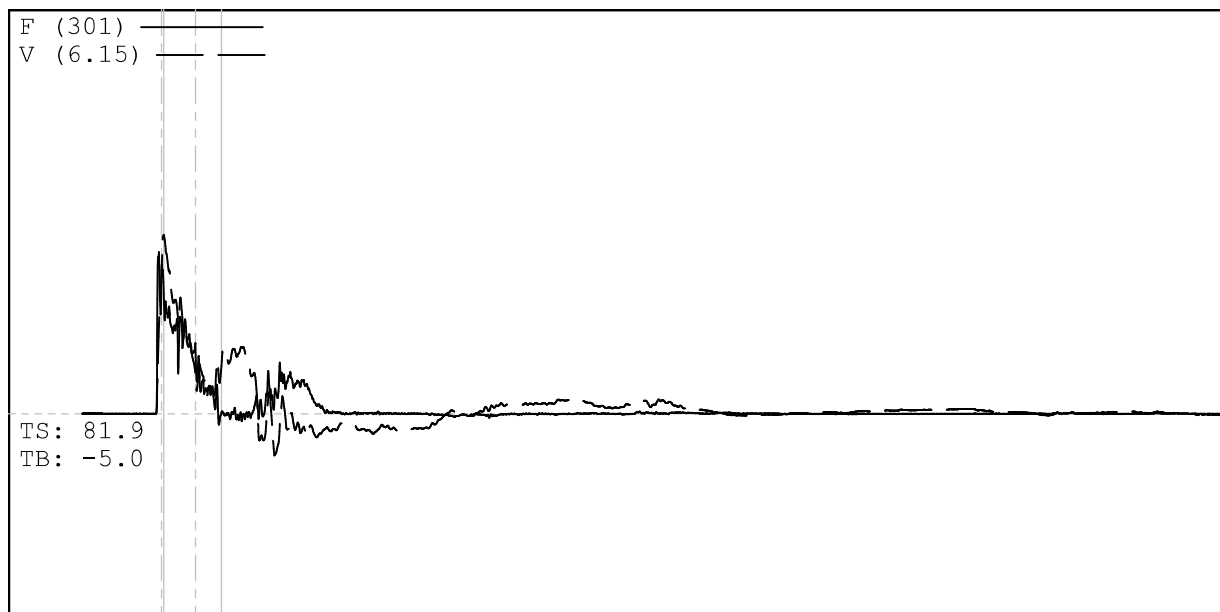
EMX 0.3249 kN-m
EF2 0.2756 kN-m
DMX 8 mm
FMX 117 kN
TSX 16.2 MPa
CSX 96.1 MPa
VMX 2.95 m/s
AMX 1012 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT02

Project Information

PROJECT: TELOK BLANGAH(181121)
 PILE NAME: FTAH-SPT02
 DESCR: APS
 OPERATOR: APS
 FILE: FTAH-SPT-02
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 Blow Number 6

Quantity Results

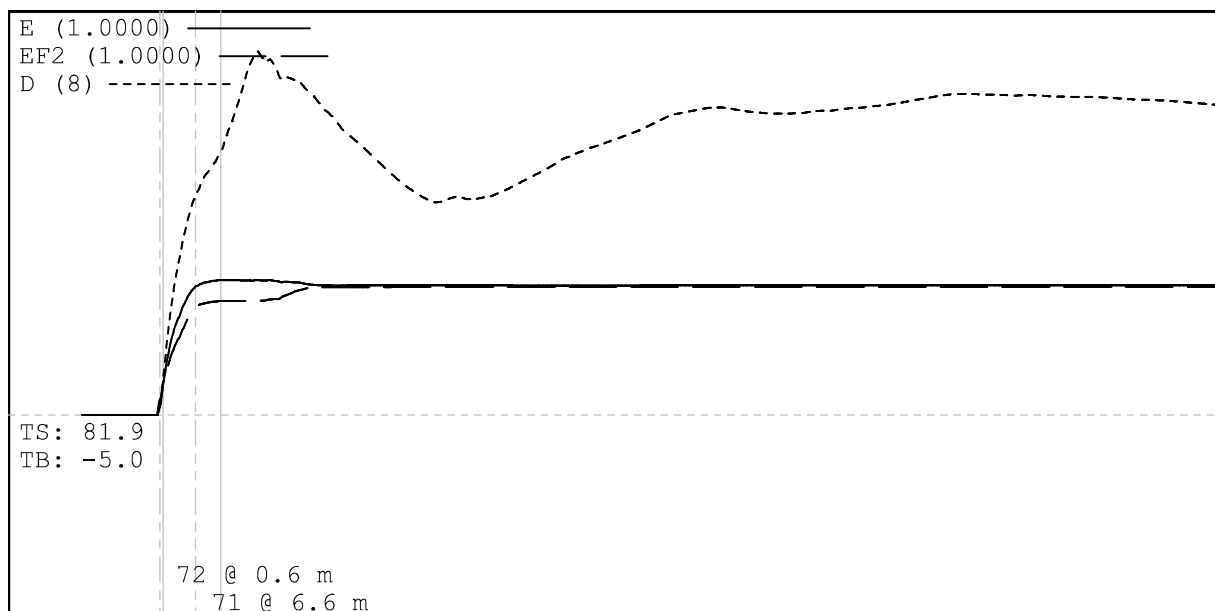
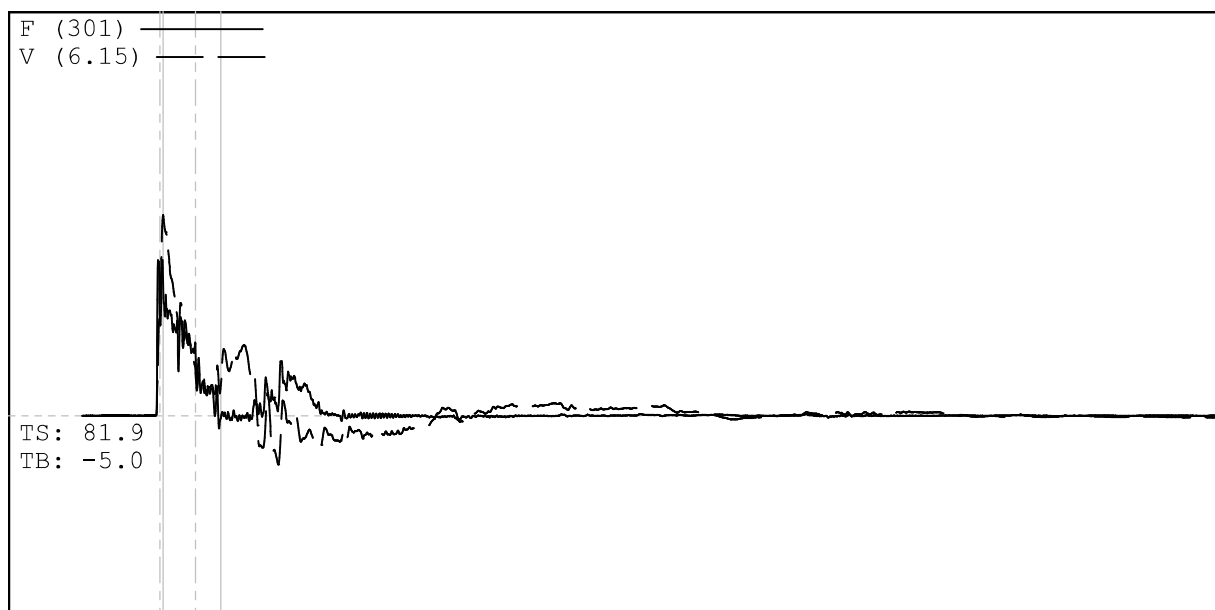
EMX 0.3072 kN-m
 EF2 0.2754 kN-m
 DMX 7 mm
 FMX 120 kN
 TSX 15.9 MPa
 CSX 99.3 MPa
 VMX 2.72 m/s
 AMX 939 g's
 RX5 kN

Pile Properties

LE 9.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.88 ms
 JC []

TELOK BLANGAH(181121)

FTAH-SPT02

Project Information

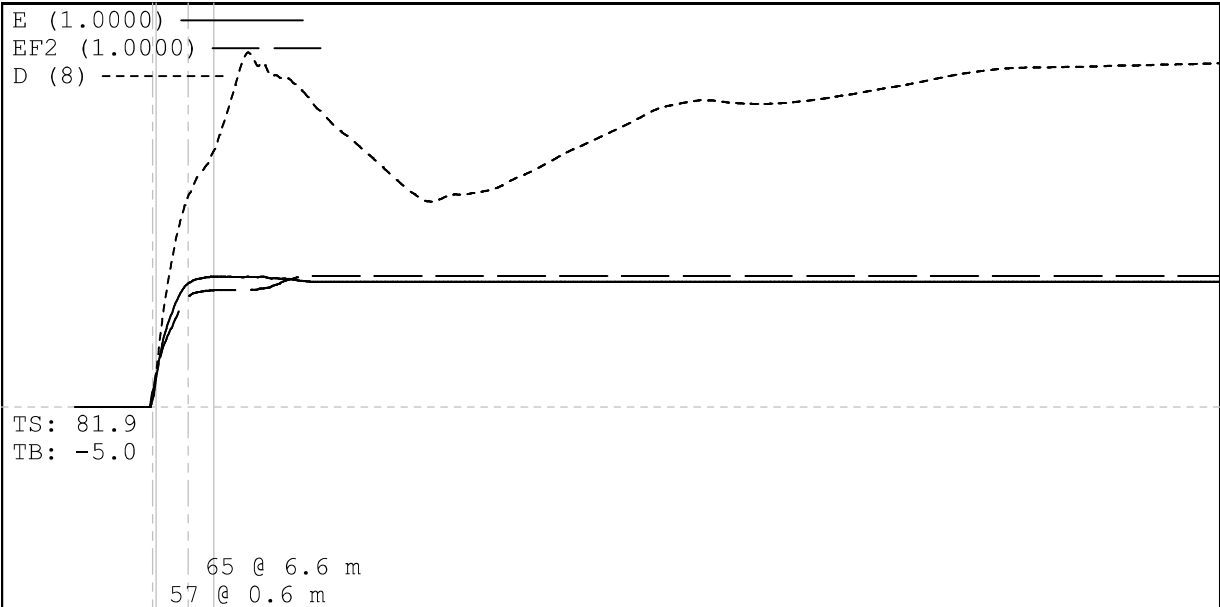
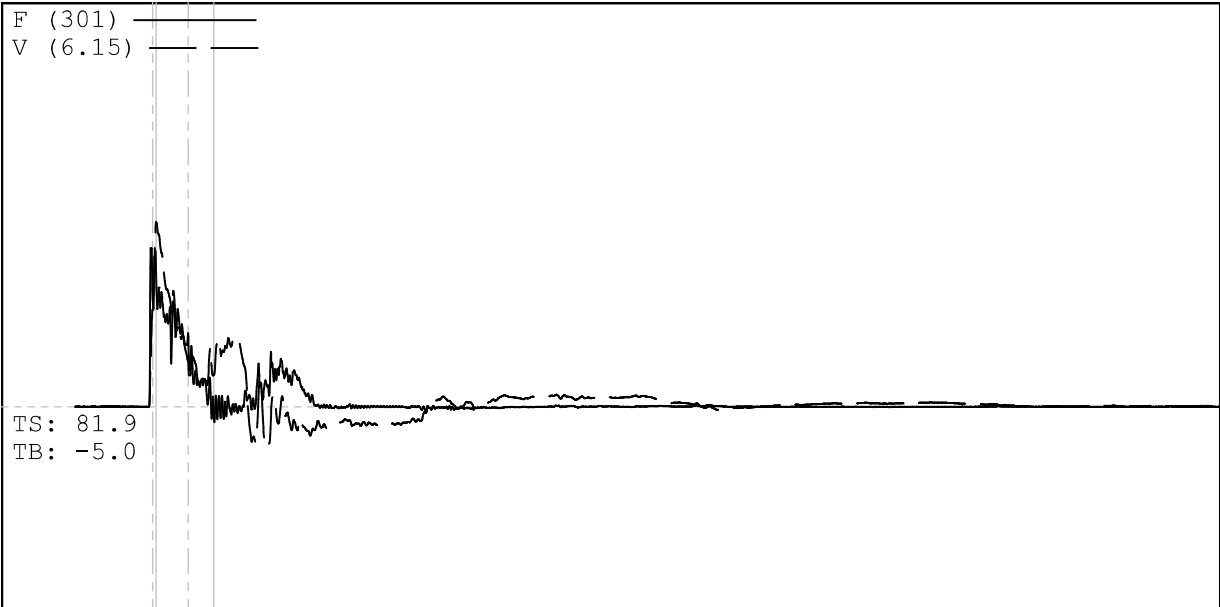
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 PILE NAME: FTAH-SPT02
 DESCR: APS
 OPERATOR: APS
 FILE: FTAH-SPT-02
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 Blow Number 7

Quantity Results

EMX 0.3343 kN-m
 EF2 0.2812 kN-m
 DMX 7 mm
 FMX 116 kN
 TSX 18.4 MPa
 CSX 95.8 MPa
 VMX 3.05 m/s
 AMX 1125 g's
 RX5 kN

Pile Properties

LE 9.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.88 ms
 JC []



Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT02
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT-02
18/11/2021 11:11:48 am
Blow Number 8

Quantity Results

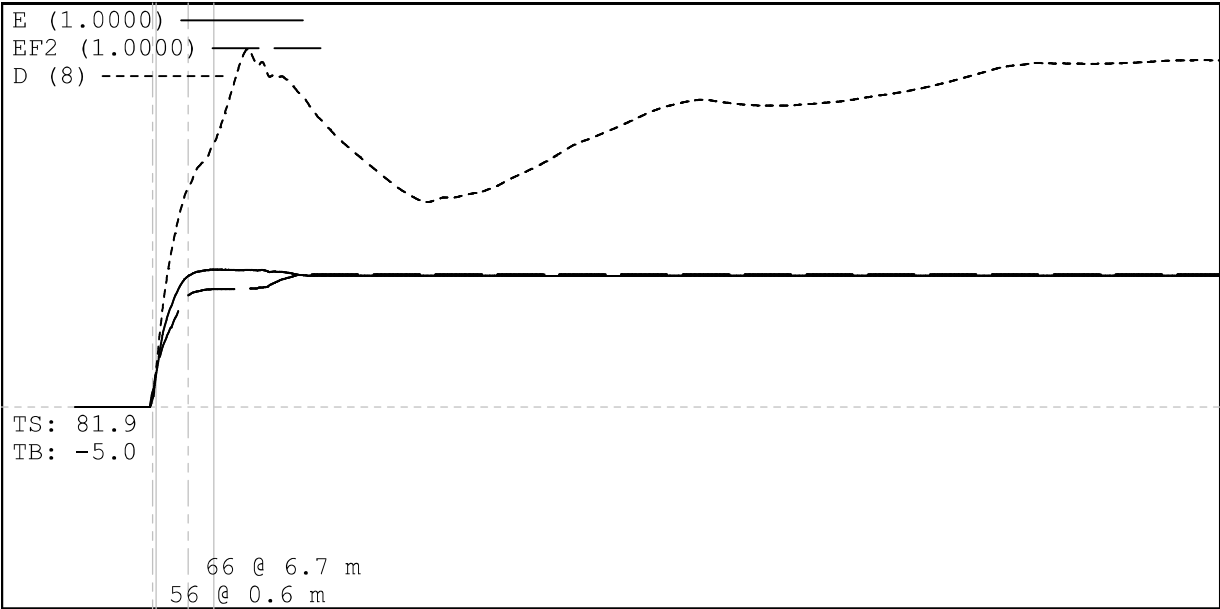
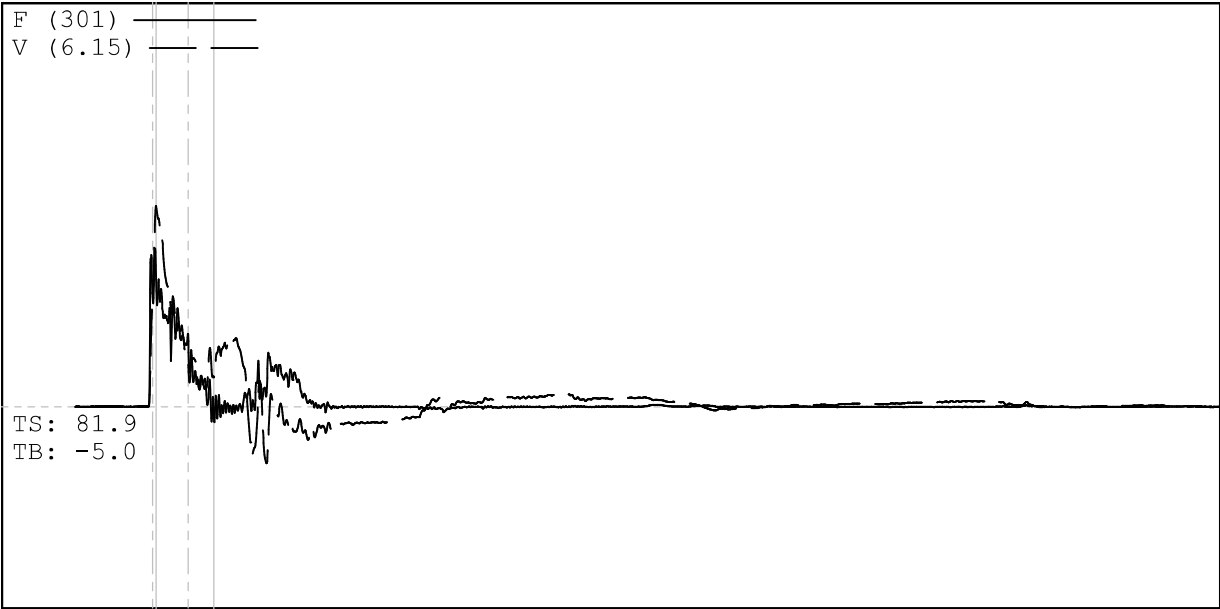
EMX 0.3233 kN-m
EF2 0.2889 kN-m
DMX 7 mm
FMX 118 kN
TSX 17.9 MPa
CSX 97.5 MPa
VMX 2.81 m/s
AMX 993 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm^2
EM 206843 MPa
SP 77.3 kN/m3
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT02



Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT02
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT-02
18/11/2021 11:11:50 am
Blow Number 9

Quantity Results

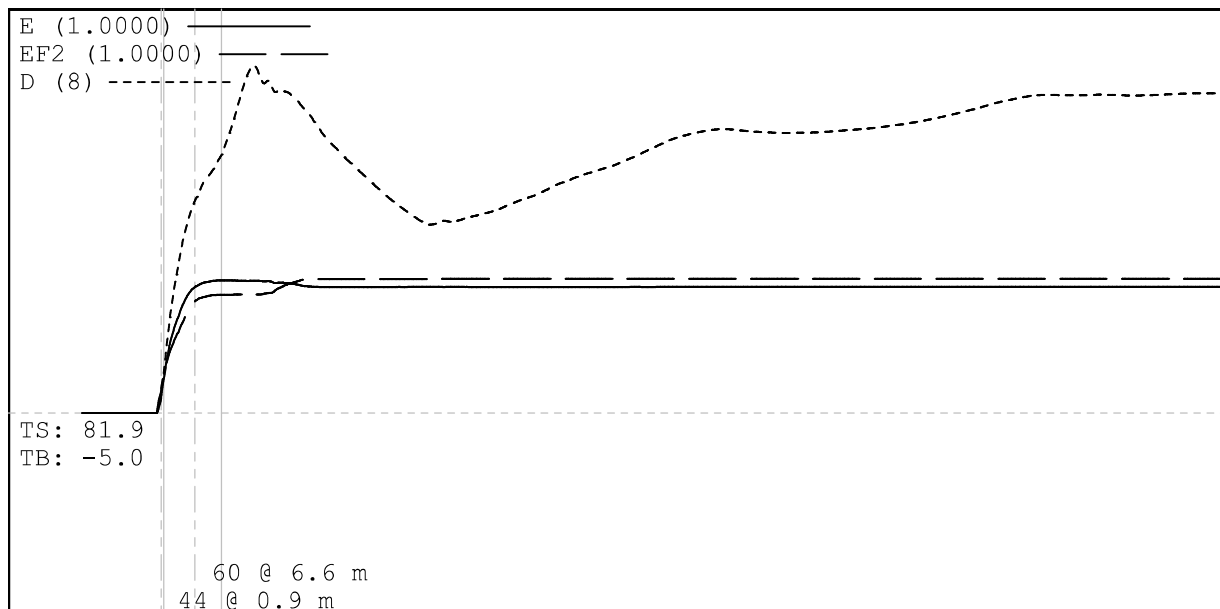
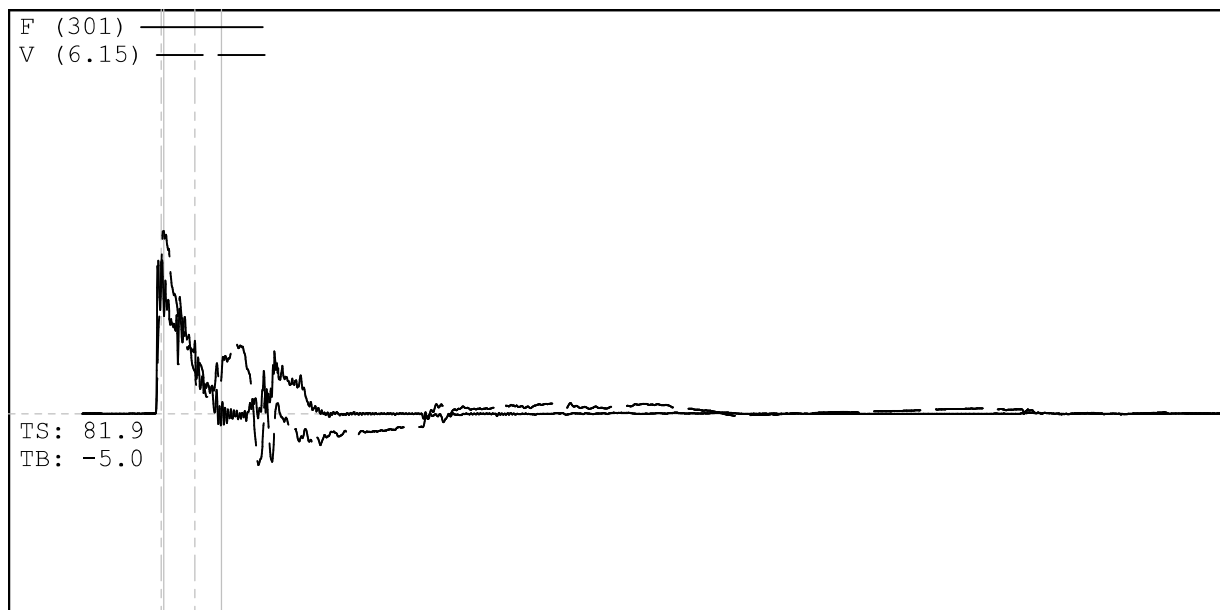
EMX 0.3407 kN-m
EF2 0.2915 kN-m
DMX 7 mm
FMX 118 kN
TSX 21.4 MPa
CSX 97.1 MPa
VMX 3.05 m/s
AMX 1082 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT02

Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT02
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT-02
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Blow Number 10

Quantity Results

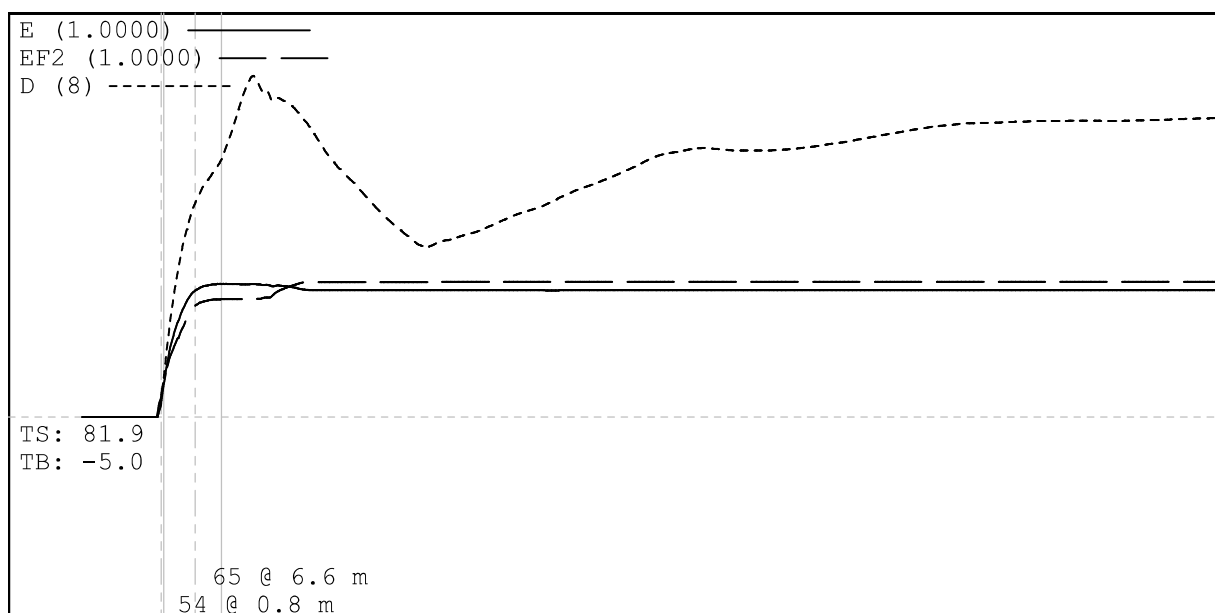
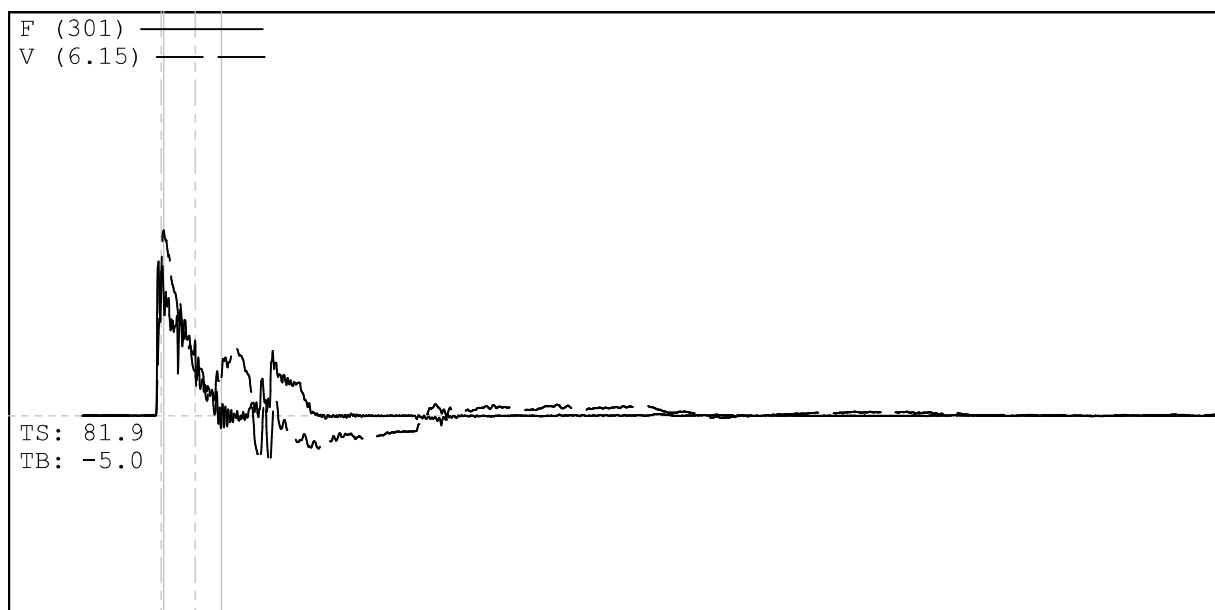
EMX 0.3288 kN-m
EF2 0.2927 kN-m
DMX 7 mm
FMX 114 kN
TSX 22.3 MPa
CSX 94.2 MPa
VMX 2.78 m/s
AMX 1010 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT02

Project Information

PROJECT: TELOK BLANGAH(181121)
 PILE NAME: FTAH-SPT02
 DESCR: APS
 OPERATOR: APS
 FILE: FTAH-SPT-02
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 Blow Number 11

Quantity Results

EMX 0.3298 kN-m
 EF2 0.2914 kN-m
 DMX 7 mm
 FMX 115 kN
 TSX 15.3 MPa
 CSX 94.6 MPa
 VMX 2.82 m/s
 AMX 975 g's
 RX5 kN

Pile Properties

LE 9.9 m
 AR 12.13 cm²
 EM 206843 MPa
 SP 77.3 kN/m³
 WS 5123.0 m/s
 EA/C 49 kN-s/m
 2L/C 3.88 ms
 JC []



APS ASIA PDA ENTERPRISE PTE LTD

FIELD SHEET - STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT

Test Date : 18/11/2021 Test Ref No: _____
 Client : Forta P/L
 Project Title : PUB Telok Blangah

Calibration Details

Analyser	Weighing Scale	Strain Gauge	Serial Number	Calibration Factor (G/V)	Accelerometer	Serial Number	Calibration Factor (G/V)
PAX	Teraseiko	F3	462 BW B1	210.92	A3	K1582	368.5
PAX4192LA	20150821116	F4	462 BW B2	210.63	A4	K0361	353.7

Test Details

SPT Hammer Serial No.	<u>FTAH-SPT02</u> <u>Hanjin-2 m H-2 (Hanjin)</u>
Borehole No.	<u>RX1512009</u>
Borehole Diameter	<u>φ100mm</u>
Borehole Depth	<u>9.07</u>
Drilling Rig.	<u>Rig-2</u>
Drilling Operator	<u>Clinical</u>
Drill Rod Type	<u>BW</u>
Shoe Type/Length	<u>SJ/600</u>
Drill Rod Segments	<u>3m x 3 + 0.6 + 0.6</u>
Total Length	<u>10.20</u>
Total Length From Gauge	<u>9.90</u>
SPT Ram Mass (kg)	<u>63.50</u>
SPT Anvil Mass (kg)	<u>7.40</u>
SPT Total Mass (kg)	<u>70.90</u>
SPT Ram Drop Height	<u>762</u>
Type Of Machine	<u>Hanjin</u>
Model	<u>DA B1060</u>

* Ram Weight & Anvil Weight Given By Client

Results

No. of Blows	<u>10</u>
Min. Measured Energy (ton-m)	<u>0.031</u>
Max. Measured Energy (ton-m)	<u>0.035</u>

Tested & Checked By:

Signed by SPT Operator

Witness By:

Sign & Name Of (R.T.O./RE/Client's Rep)



APS ASIA PDA ENTERPRISE PTE LTD

No. 65 Ubi Crescent, #02-01 Hola Centre

Singapore 408559

Tel: 68988826 Email: info@aps-instrument.com

Co. Registration No. : 200601680E



CERTIFICATE OF CALIBRATION

Certificate Number : APS/SPT/0182/2021

Instrument : Standard Penetration Test (SPT)

Manufacturer : Hanjin D&B 10KD Drilling Machine

Serial No : FTAH-SPT-02

SPT Ram Energy Transfer Ratio : 68%

Calibration Date : 18 November 2021

Recalibration Date : 17 November 2022

Calibration Remarks:

Please refer to Calibration Test Report : APS/SPT/2021/182 for detailed summary and analysis.

This Certificate shall not be reproduced except in full, without the written approval of the laboratory.



The results herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council – Singapore Laboratory Accreditation Scheme

CALIBRATION SITE: 45 CARMICHAEL ROAD

TEST REPORT

STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT (SPT HAMMER – FTAH-SPH-03)

TEST REPORT

25th February 2022

CLIENT

M/s **FOSTA PTE LTD**

Submitted by



APS ASIA PDA ENTERPRISE PTE LTD

26th FEBRUARY 2022

REPORT REF. NO : APS/SPT/2022/018

No. 65 Ubi Crescent #02-1 Holo Centre Singapore 408559 Tel (65) 68968926 Fax: (65) 62212003

The results reported herein have been performed in accordance with the terms of accreditation under the Singapore Accreditation Council. The reports shall not be reproduced except in full, unless the management representative of APS ASIA PDA Enterprise Pte Ltd has given approval in writing.

C O N T E N T S

1. INTRODUCTION
2. TEST EQUIPMENT
3. SUMMARY
4. RESULTS

APPENDIX I SPT HAMMER ENERGY MEASUREMENT RESULTS

1. INTRODUCTION

This report the results of the standard penetration test, SPT, hammer energy measurement using the Pile Driving Analyzer, PDA, carried out for APS ASIA PDA Enterprise Pte Ltd on 25 February 2022. The aim of testing was to provide an estimate of the hammer energy transferred by the SPT hammer in accordance to American Standard Test Method ASTM D4633-16.

The SPT testing was performed at 45 Carmichael Road.

The SPT hammer tested was identified as FTAH-SPH-03 and was operated by Hanjin D&B 10KD drilling machine (Hanjin-03).

2. TEST EQUIPMENT

Pile Driving Analyser (Model PAX)	: Serial No. 4192L
Instrumented Rod	: Serial No. 462BW (Length 600mm)
Strain Transducers	: Serial Nos. 462BW - Bridge 1 & 2
Accelerometers	: Serial Nos. K1582 & K0361

3. SUMMARY

SPT Hammer Serial No.	-	FTAH-SPH-03
Calibration Site	-	45 Carmichael Road
Borehole	-	BH-55A
	-	Diameter : - 100 mm
	-	Depth : 19.50 m
Drilling Rig	-	Hanjin-03
Drilling Operator	-	Zhenthai
Drill Rod Type	-	BW
Shoe Type / Length	-	Split Spoon Sampler /600mm
Instrumented Rod/Length	-	600 mm
Drill Rod Segments	-	3m x 6 + 1.50 + 0.6 + 0.7
Total Length	-	20.80 m (Instrumented Rod Top To Shoe Base)
SPT Ram Mass	-	63.40 kg
SPT Anvil Mass	-	8.50 kg
SPT Total Mass	-	71.90 kg
SPT Ram Drop Height	-	762 mm
Theoretical Energy	-	0.4739 kN-m

4. **RESULTS (SPT HAMMER ENERGY MEASUREMENT)**

No. Of Blow = 10

Min. / Max. EMX Value = 0.3551 kN-m / 0.4157 kN-m

Mean Measured Energy = 0.3906 kN-m

Standard Deviation = 0.0160 kN-m

Energy Ratio, Er = Mean Measured Energy / Theoretical Energy
= 0.82 (82 %)

Report prepared by

Cheng Chung Yin Chris
Approved Signatory

APPENDIX I

SPT HAMMER ENERGY MEASUREMENT RESULTS

SPT HAMMER ENERGY MEASUREMENT

Conducted By : APS Asia PDA Enterprise Pte Ltd (Joseph Ling Ka Jun)

Conducted For : Fosta Pte Ltd (Machine : RIG - Hanjin-03 / SPT : FTAH-SPT-03)

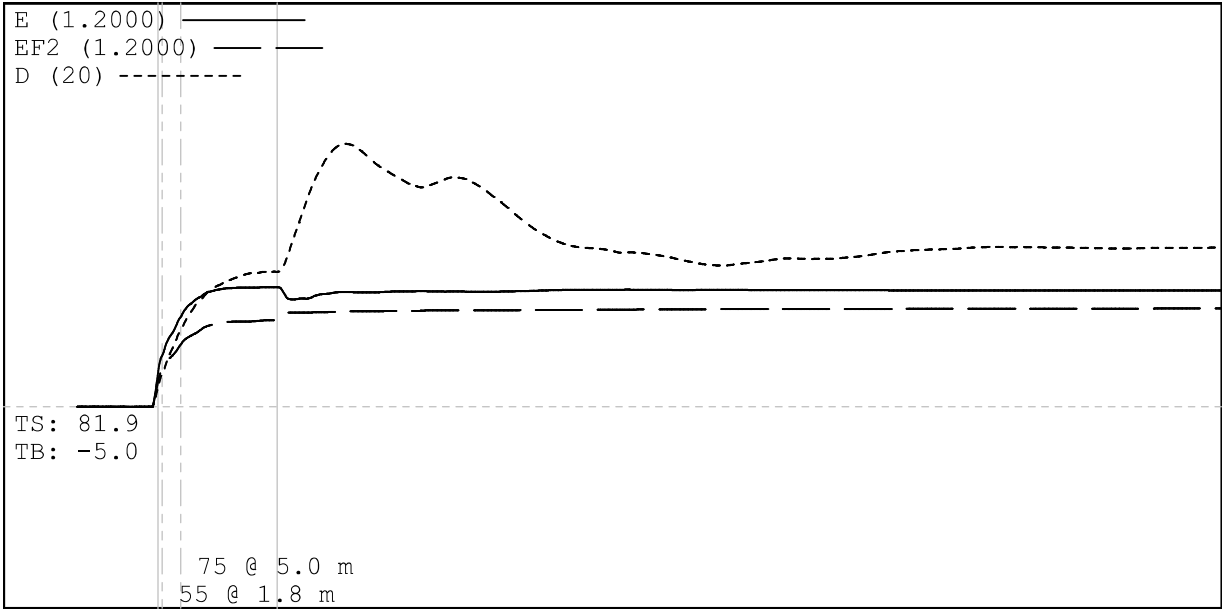
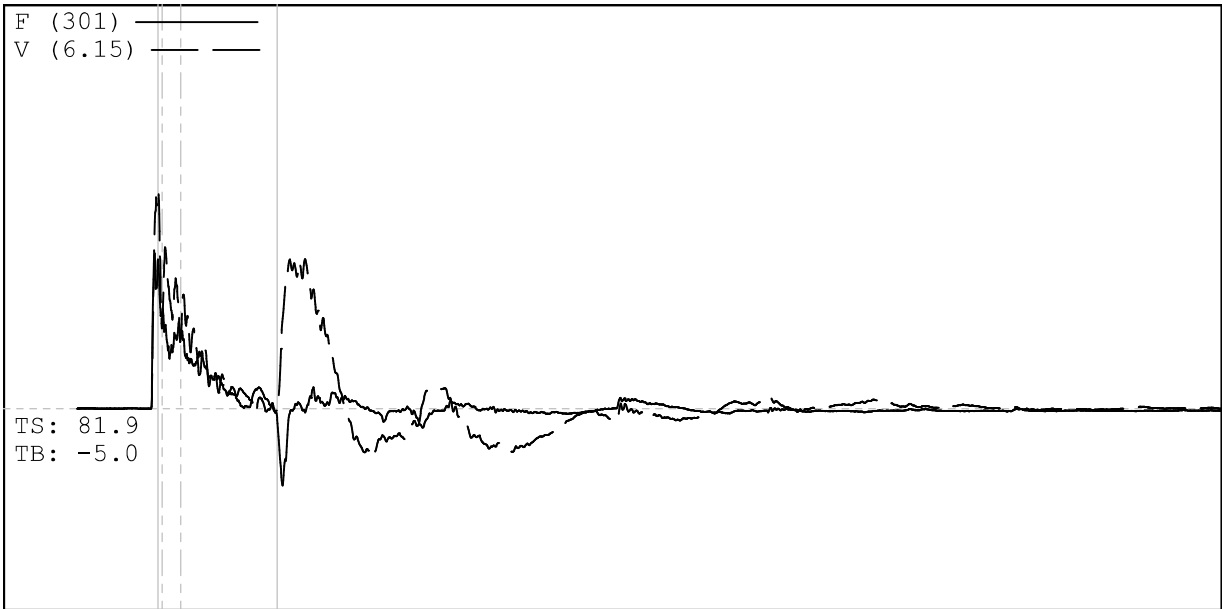
BLOW NO.	EMX	EF2	DMX	FMX	TSX	CSX	VMX	AMX
2	0.3551	0.2571	13	116	60.1	95.4	3.30	1874
3	0.3798	0.2662	13	121	65.4	99.40	3.57	2617
4	0.3858	0.2668	14	129	64.8	106.20	3.57	2836
5	0.3915	0.2677	14	128	64.1	105.80	3.67	2986
6	0.3900	0.2680	14	126	66.6	104.20	3.74	3093
7	0.3896	0.2665	14	124	64.9	102.20	3.76	2980
8	0.3962	0.2676	15	115	65.6	95.20	3.72	3002
9	0.4006	0.2663	15	116	64.7	95.60	3.77	3010
10	0.4019	0.2673	15	117	64.9	96.20	3.79	2965
11	0.4157	0.2692	16	120	65.3	99.20	3.80	3002
MINIMUM	0.3551	0.2571	13.0	115	60.10	95.20	3.30	1874
MAXIMUM	0.4157	0.2692	16	129	66.6	106.2	3.80	3093
AVERAGE	0.3906	0.2663	14.3	121	64.6	99.9	3.67	2837
STANDARD DEV.	0.0160	0.0033	0.95	5	1.7	4.4	0.15	363

OUTPUT QUANTITIES

EMX	maximum energy transmitted past the transducers.
EF2	maximum energy transmitted past the transducers from integral of force squared.
DMX	maximum downward displacement at the transducers' location.
FMX	maximum compressive force at the transducers' location.
CSX	maximum compressive stress at transducers' location.
TSX	maximum tensile stress along the length of rod.
VMX	maximum velocity at the transducers' location.
AMX	maximum acceleration at the transducers' location.

45 CARMICHAEL RD(25022

FTAH-SPH-03



Project Information

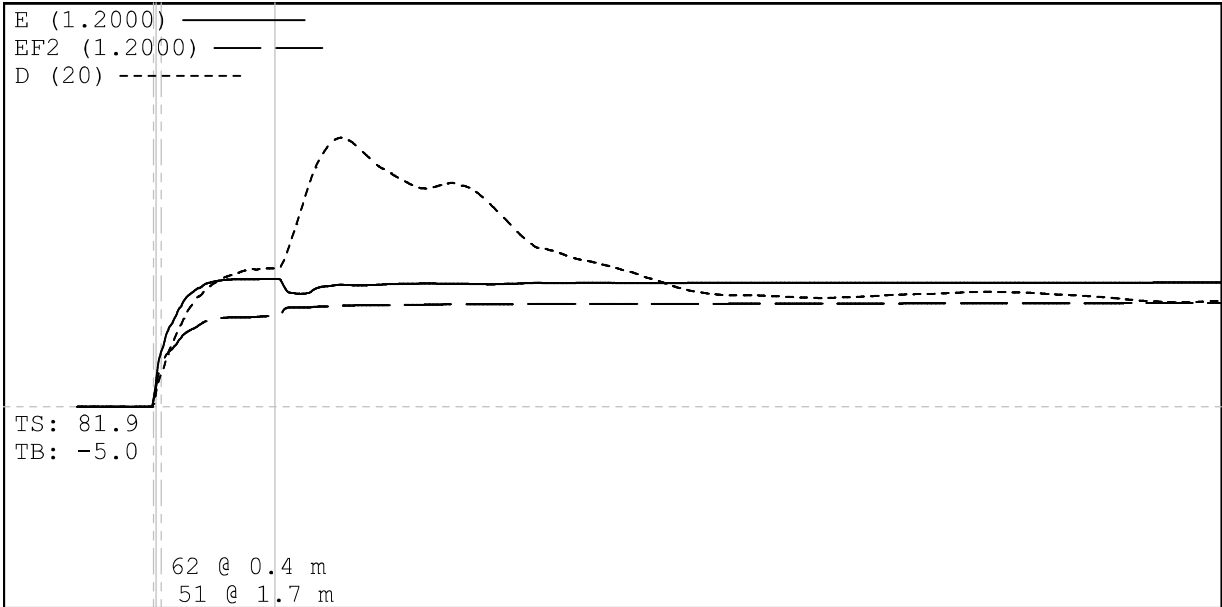
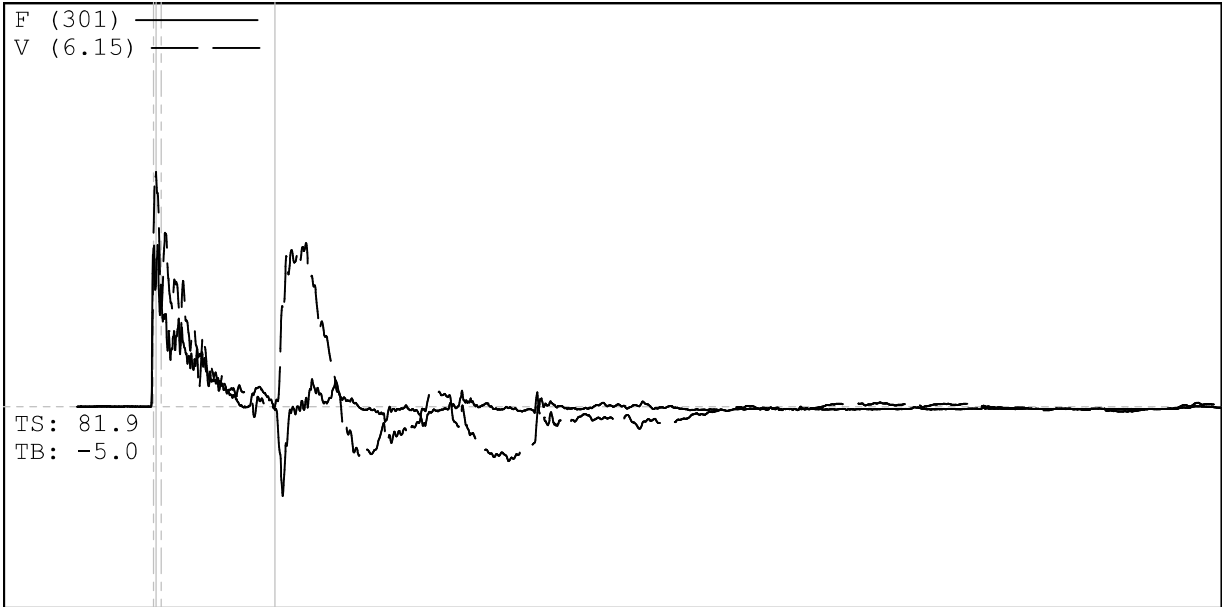
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DESCR: APS
OPERATOR: APS
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Blow Number 2

Quantity Results

EMX 0.3551 kN-m
EF2 0.2571 kN-m
DMX 13 mm
FMX 116 kN
TSX 60.1 MPa
CSX 95.4 MPa
VMX 3.30 m/s
AMX 1874 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm^2
EM 206843 MPa
SP 77.3 kN/m3
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []



Project Information

PROJECT: 45 CARMICHAEL RD(25022
PILE NAME: FTAH-SPH-03
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPH-03.W01
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Blow Number 3

Quantity Results

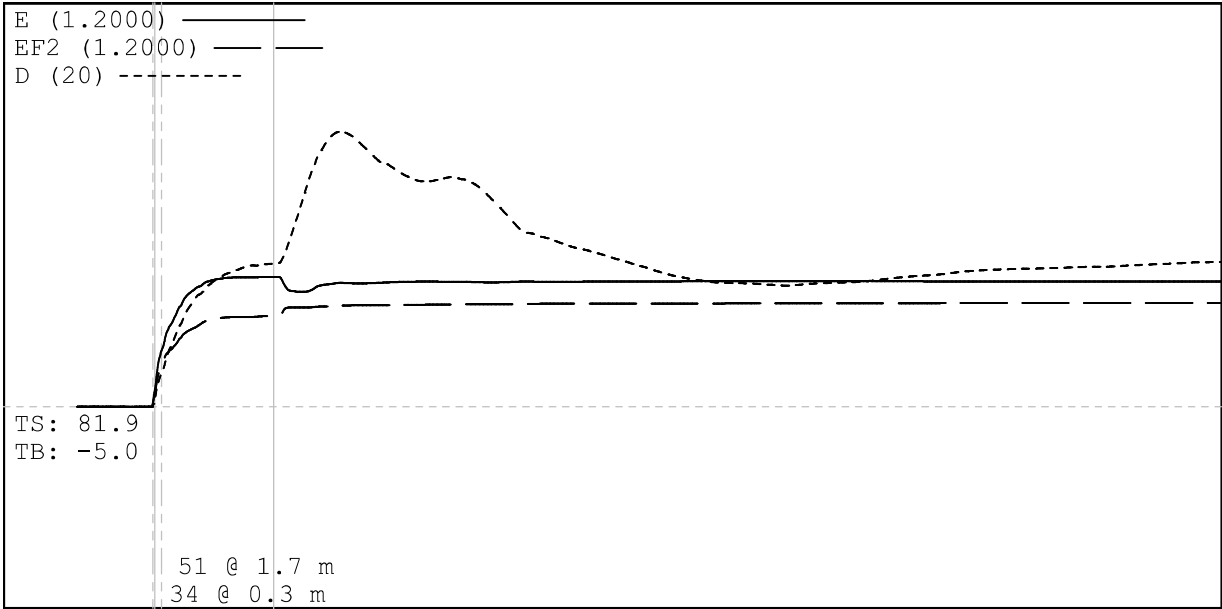
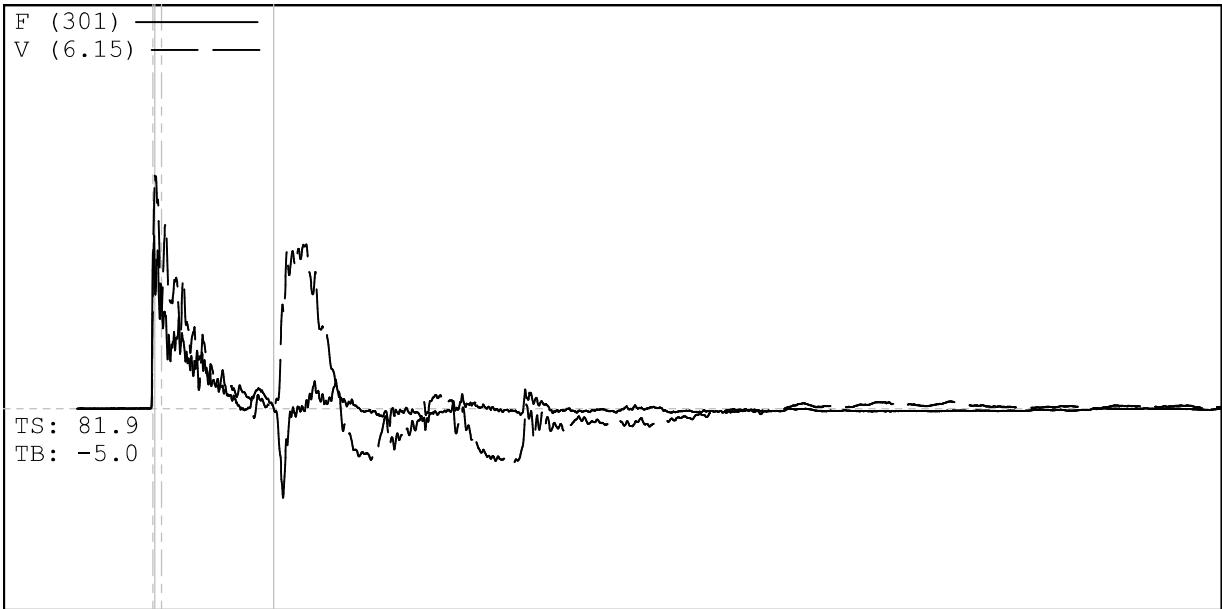
EMX 0.3798 kN-m
EF2 0.2662 kN-m
DMX 13 mm
FMX 121 kN
TSX 65.4 MPa
CSX 99.4 MPa
VMX 3.57 m/s
AMX 2617 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []

45 CARMICHAEL RD(25022

FTAH-SPH-03



Project Information

PROJECT: 45 CARMICHAEL RD(25022
PILE NAME: FTAH-SPH-03
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OPERATOR: APS
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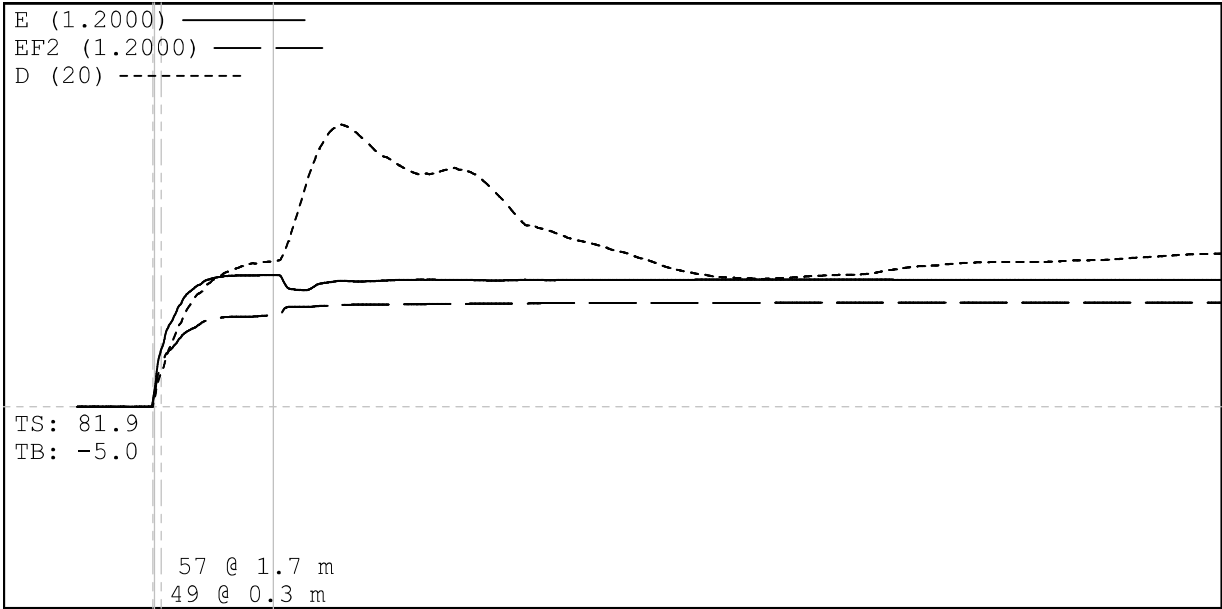
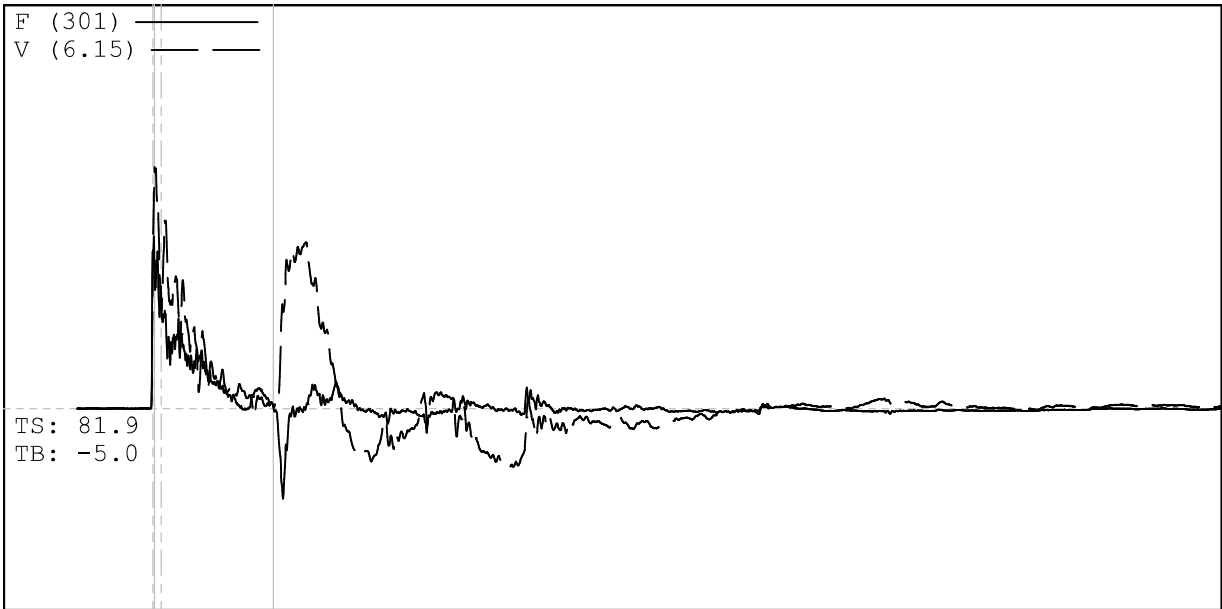
EMX 0.3858 kN-m
EF2 0.2668 kN-m
DMX 14 mm
FMX 129 kN
TSX 64.8 MPa
CSX 106.2 MPa
VMX 3.57 m/s
AMX 2836 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []

45 CARMICHAEL RD(25022

FTAH-SPH-03



Project Information

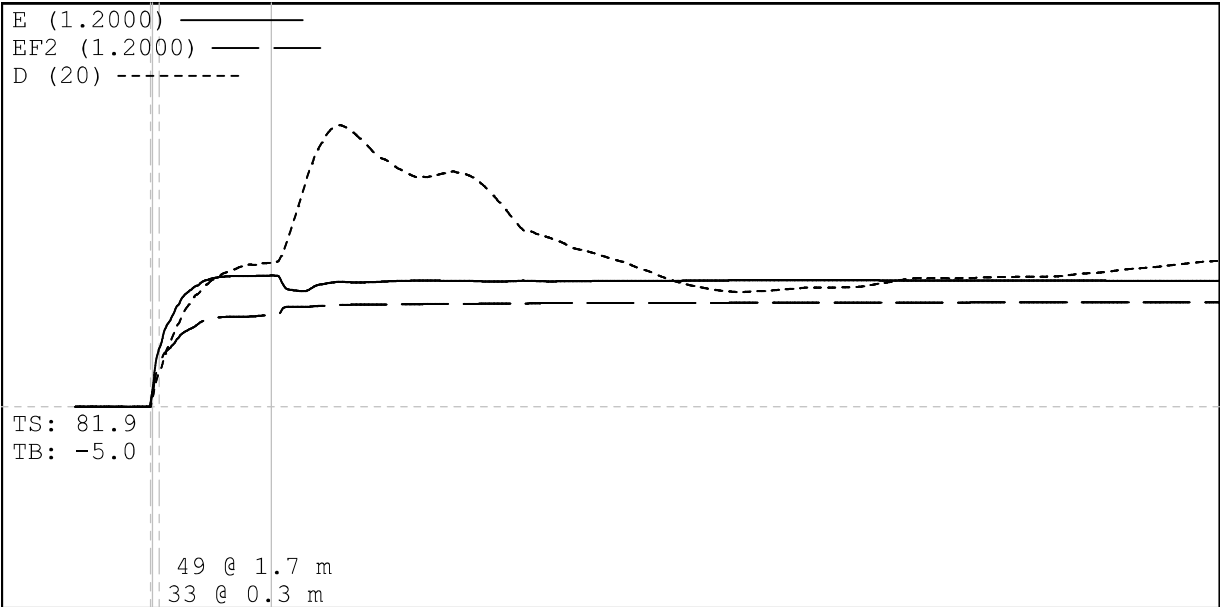
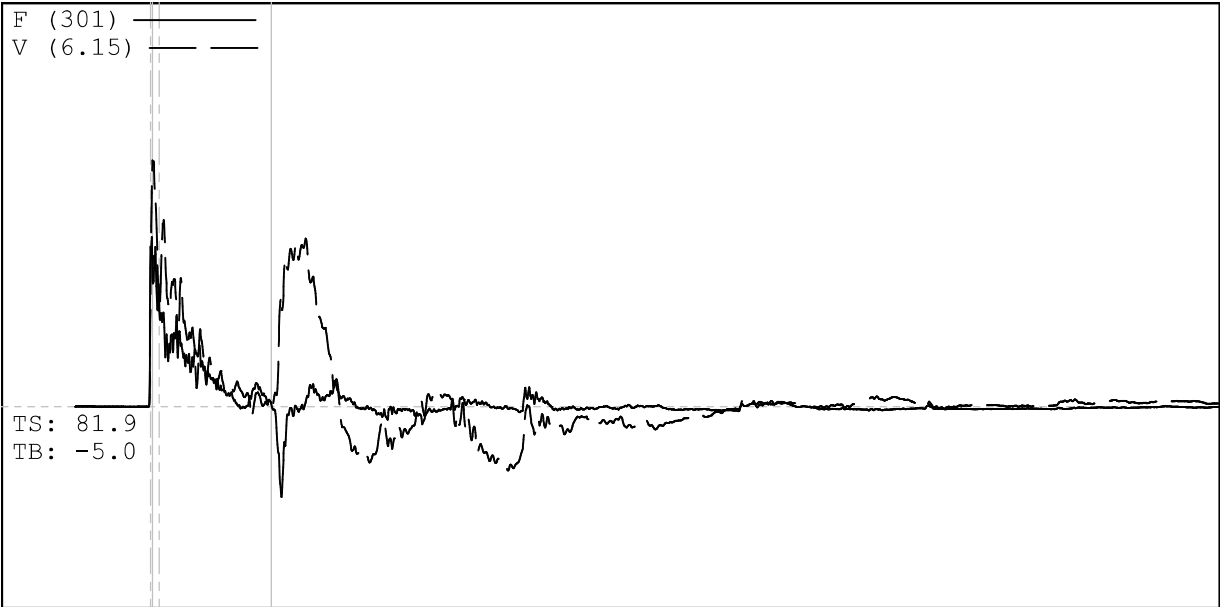
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DESCR: APS
OPERATOR: APS
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Blow Number 5

Quantity Results

EMX 0.3915 kN-m
EF2 0.2677 kN-m
DMX 14 mm
FMX 128 kN
TSX 64.1 MPa
CSX 105.8 MPa
VMX 3.67 m/s
AMX 2986 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []



Project Information

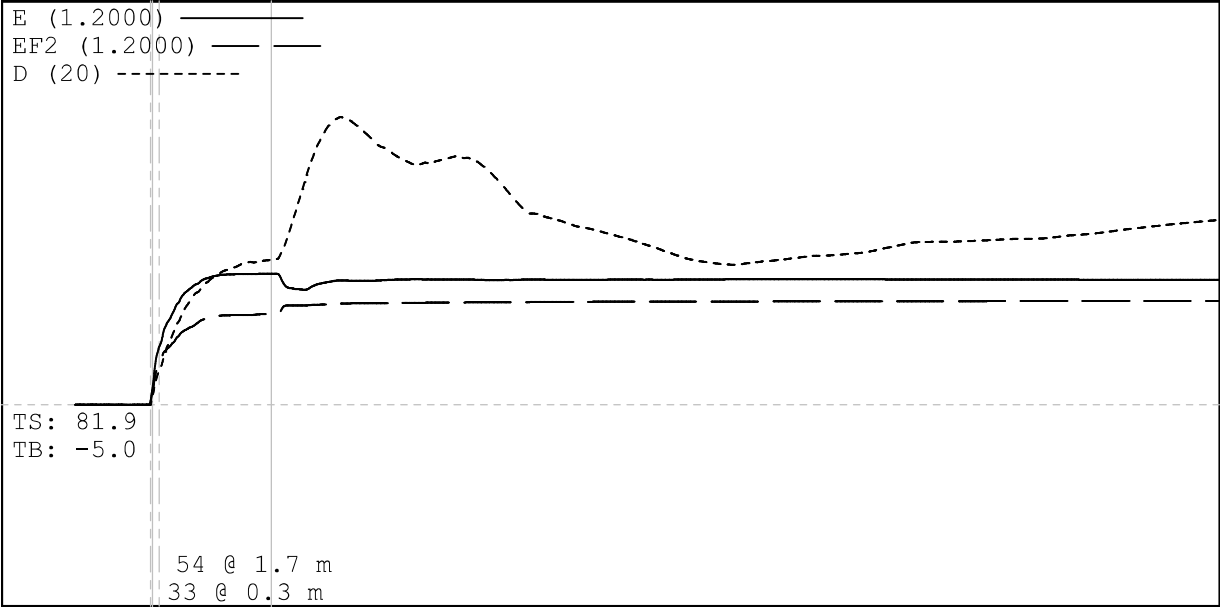
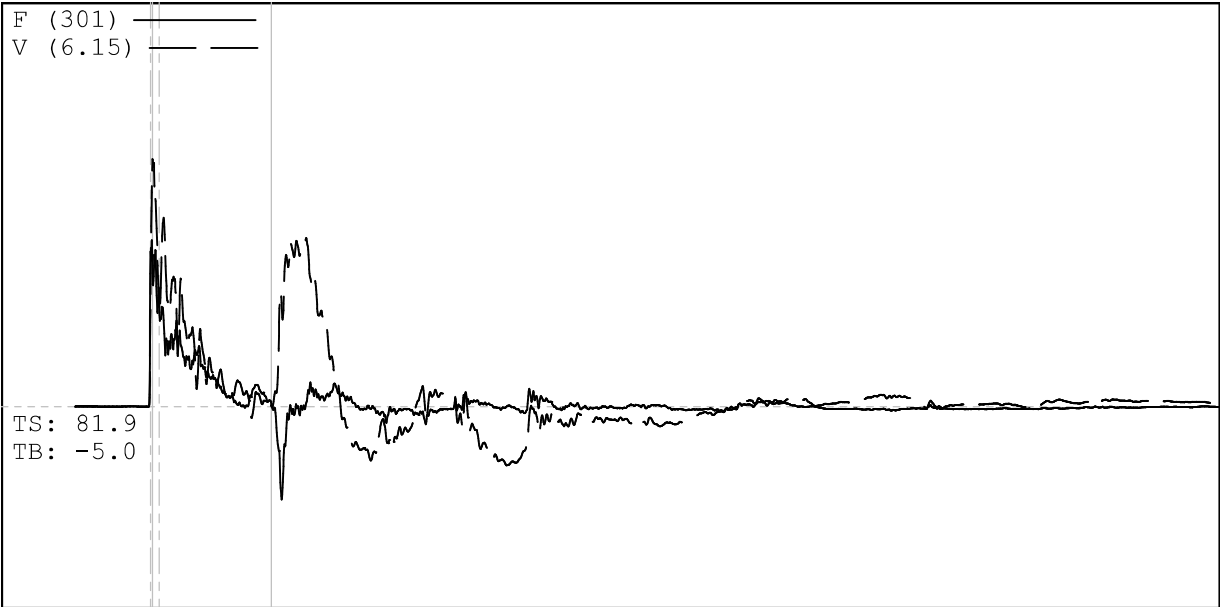
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PILE NAME: FTAH-SPH-03
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPH-03.W01
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Blow Number 6

Quantity Results

EMX 0.3900 kN-m
EF2 0.2680 kN-m
DMX 14 mm
FMX 126 kN
TSX 66.6 MPa
CSX 104.2 MPa
VMX 3.74 m/s
AMX 3093 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []



Project Information

PROJECT: 45 CARMICHAEL RD(25022
PILE NAME: FTAH-SPH-03
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPH-03.W01
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Quantity Results

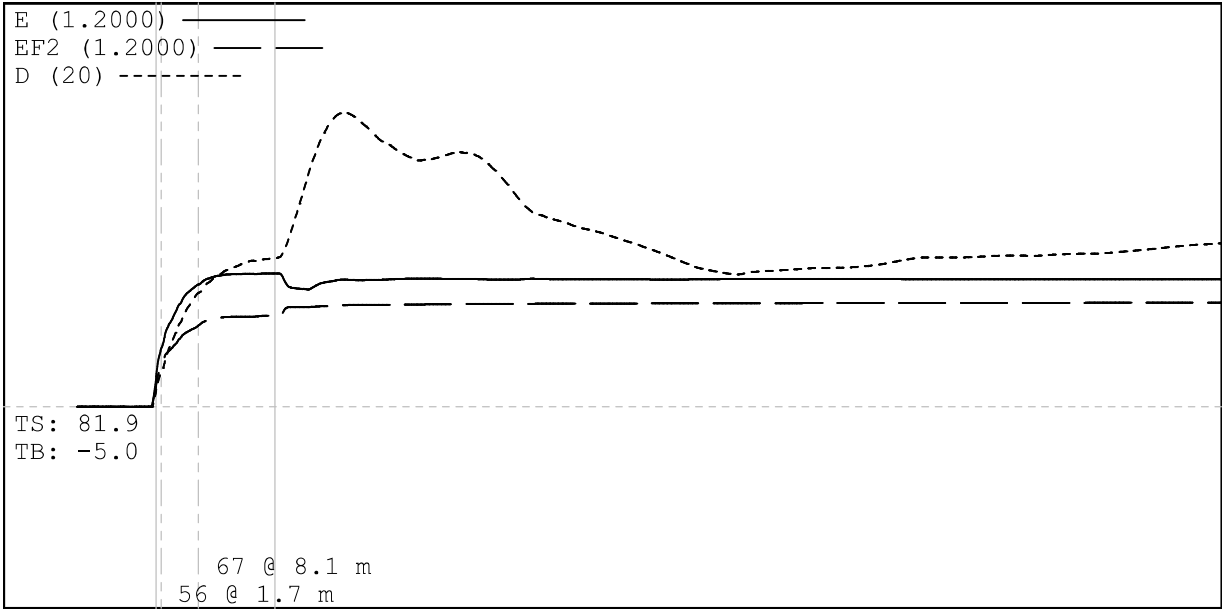
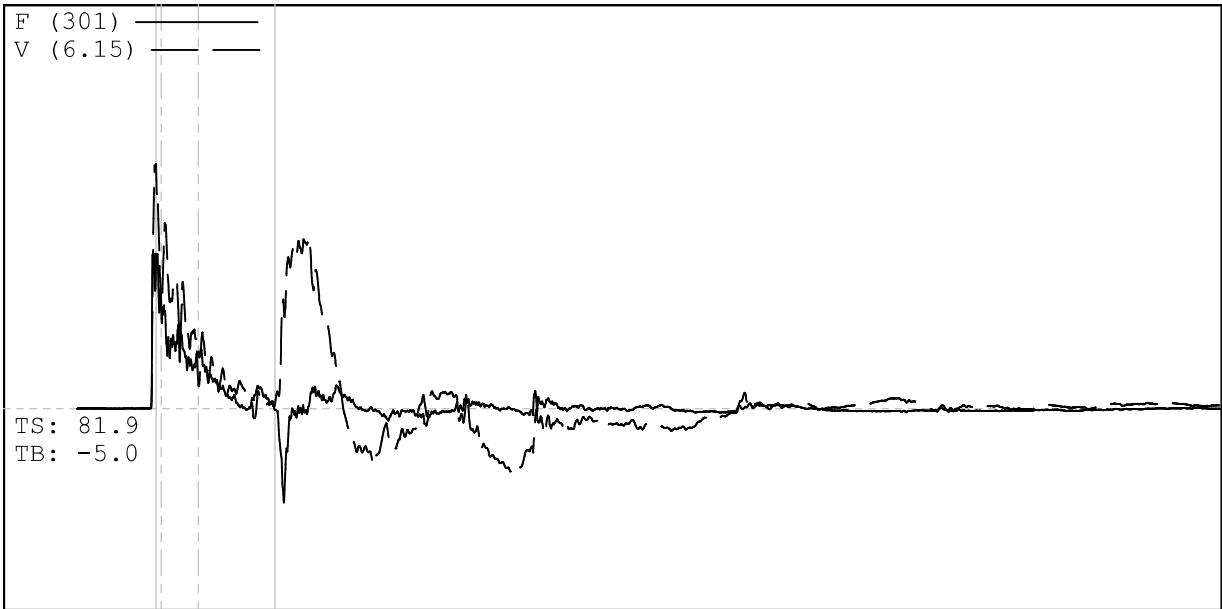
EMX 0.3896 kN-m
EF2 0.2665 kN-m
DMX 14 mm
FMX 124 kN
TSX 64.9 MPa
CSX 102.2 MPa
VMX 3.76 m/s
AMX 2980 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []

45 CARMICHAEL RD(25022

FTAH-SPH-03



Project Information

PROJECT: 45 CARMICHAEL RD(25022
PILE NAME: FTAH-SPH-03
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPH-03.W01
25/2/2022 3:13:55 pm
Blow Number 8

Quantity Results

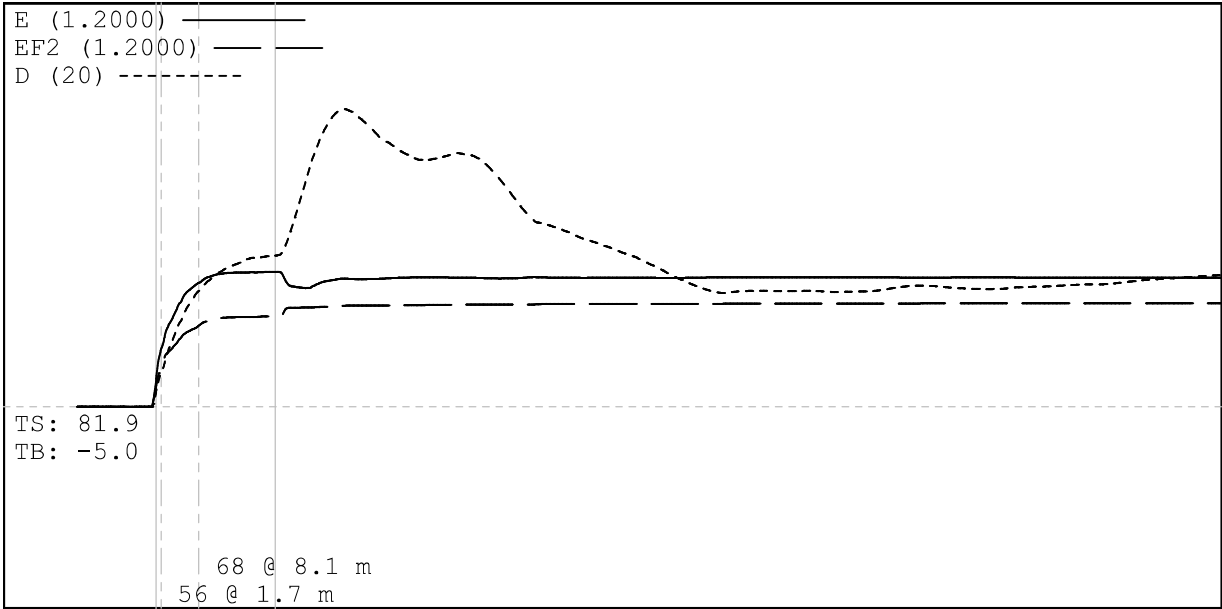
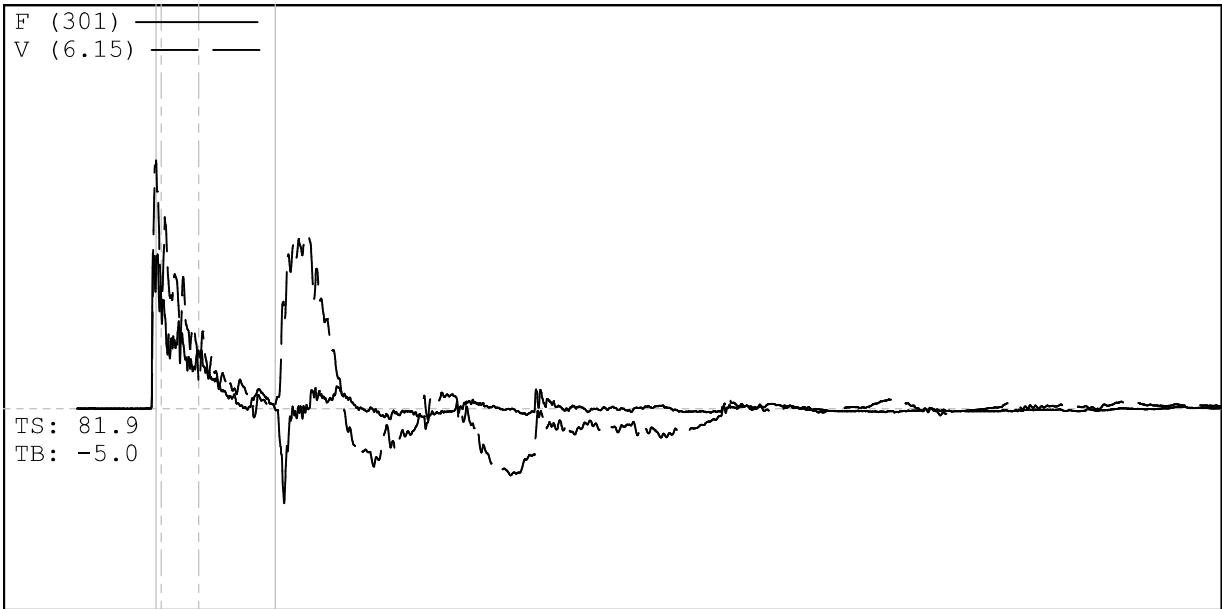
EMX 0.3962 kN-m
EF2 0.2676 kN-m
DMX 15 mm
FMX 115 kN
TSX 65.6 MPa
CSX 95.2 MPa
VMX 3.72 m/s
AMX 3002 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []

45 CARMICHAEL RD(25022

FTAH-SPH-03



Project Information

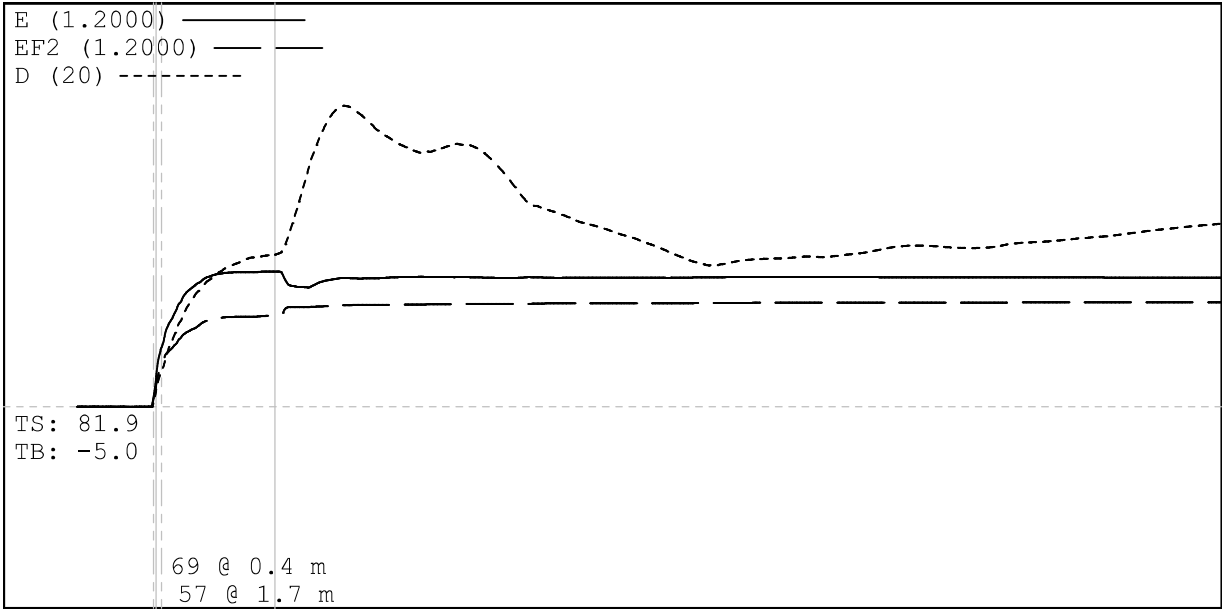
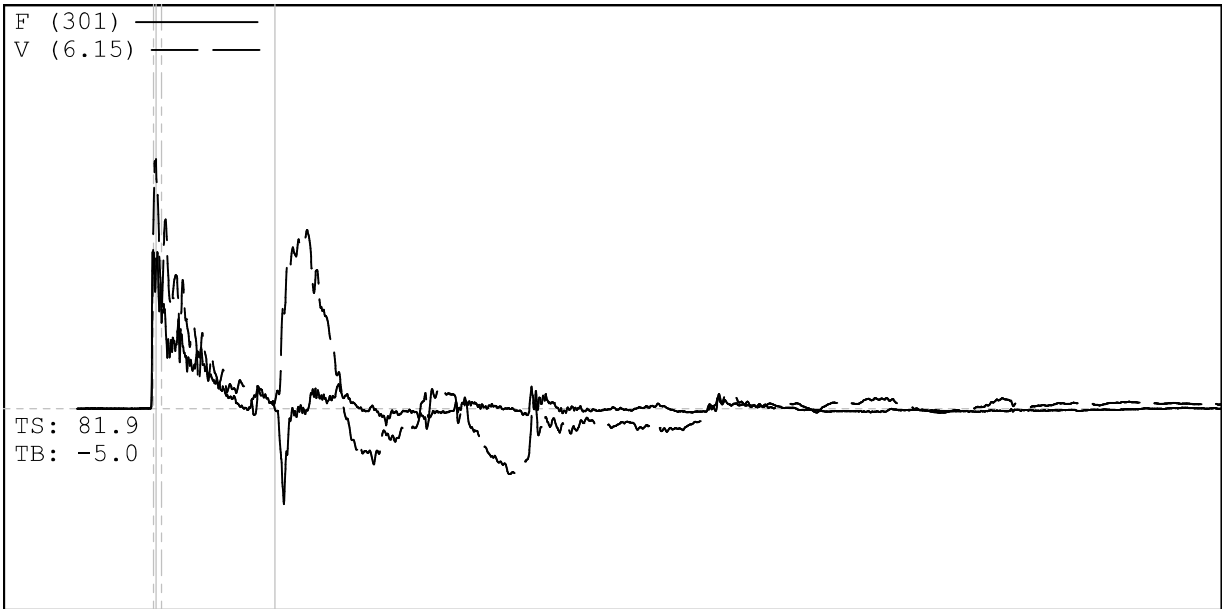
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PILE NAME: FTAH-SPH-03
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPH-03.W01
25/2/2022 3:13:59 pm
Blow Number 9

Quantity Results

EMX 0.4006 kN-m
EF2 0.2663 kN-m
DMX 15 mm
FMX 116 kN
TSX 64.7 MPa
CSX 95.6 MPa
VMX 3.77 m/s
AMX 3010 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []



Project Information

PROJECT: 45 CARMICHAEL RD(25022
PILE NAME: FTAH-SPH-03
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPH-03.W01
25/2/2022 3:14:04 pm
Blow Number 10

Quantity Results

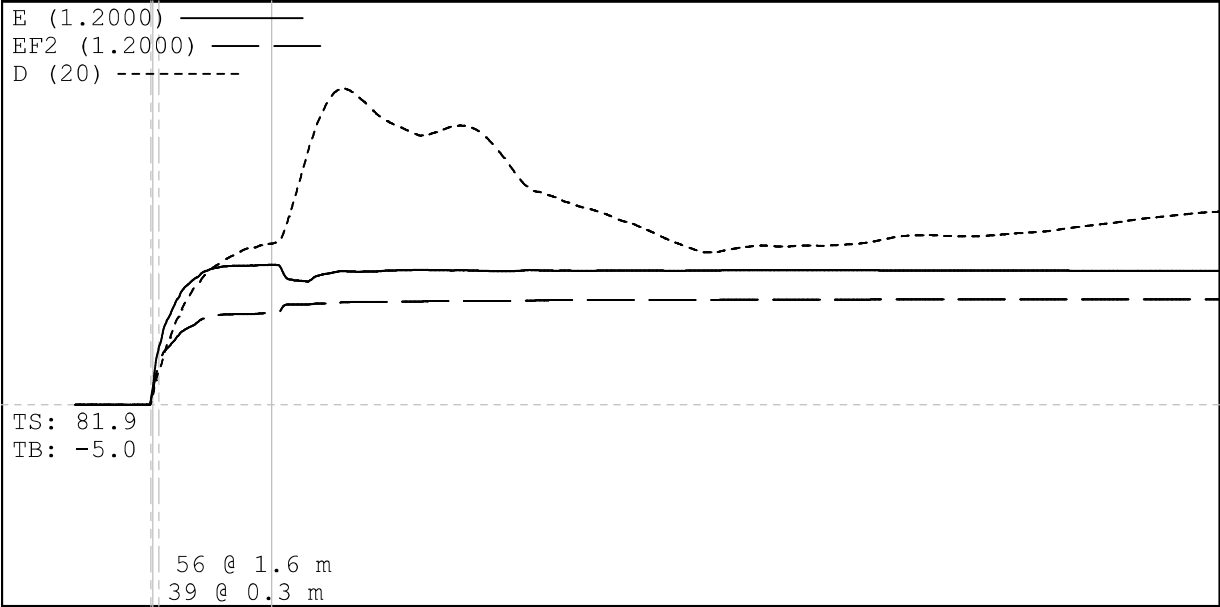
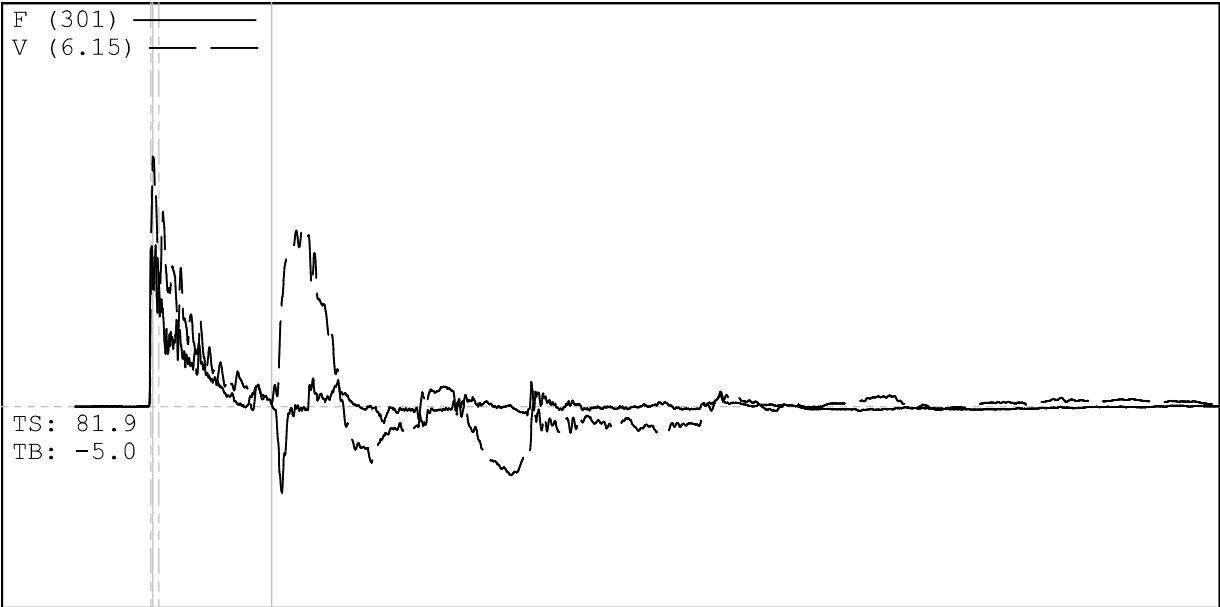
EMX 0.4019 kN-m
EF2 0.2673 kN-m
DMX 15 mm
FMX 117 kN
TSX 64.9 MPa
CSX 96.2 MPa
VMX 3.79 m/s
AMX 2965 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm^2
EM 206843 MPa
SP 77.3 kN/m3
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []

45 CARMICHAEL RD(25022

FTAH-SPH-03



Project Information

PROJECT: 45 CARMICHAEL RD(25022
PILE NAME: FTAH-SPH-03
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPH-03.W01
25/2/2022 3:14:13 pm
Blow Number 11

Quantity Results

EMX 0.4157 kN-m
EF2 0.2692 kN-m
DMX 16 mm
FMX 120 kN
TSX 65.3 MPa
CSX 99.2 MPa
VMX 3.80 m/s
AMX 3002 g's
RX5 kN

Pile Properties

LE 20.5 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 8.00 ms
JC []



APS ASIA PDA ENTERPRISE PTE LTD

FIELD SHEET - STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT

Test Date : 25/02/22 Test Ref No: _____
 Client : Fasten Engineering Pte
 Project Title : 45 Carmichael Road

Calibration Details

Analyser	Weighing Scale	Strain Gauge	Serial Number	Calibration Factor (G/V)	Accelerometer	Serial Number	Calibration Factor (G/V)
PAX	Teraseiko	F3	462 BW B1	210.92	A3	K1582	368.5
PAX4192LA	20150821116	F4	462 BW B2	210.83	A4	K0361	353.7

Test Details

SPT Hammer Serial No.	FTAA-SpA-03
Borehole No.	BA-SSA
Borehole Diameter	Ø170mm
Borehole Depth	19.50
Drilling Rig.	Hangin-03
Drilling Operator	Zhenithi
Drill Rod Type	Bw
Shoe Type/Length	SS/600
Drill Rod Segments	3m x 6 + 1.50 + 0.6 + 0.7
Total Length	20.80
Total Length From Gauge	20.50 20.50
SPT Ram Mass (kg)	63.40
SPT Anvil Mass (kg)	8.50
SPT Total Mass (kg)	71.90
SPT Ram Drop Height	762
Type Of Machine	Hangin
Model	DB10KD

Results

No. of Blows	10
Min. Measured Energy (ton-m)	0.039
Max. Measured Energy (ton-m)	0.042

Tested & Checked By:

Signed by SPT Operator

Witness By:

Sign & Name Of (R.T.O./RE/Client's Rep)



APS ASIA PDA ENTERPRISE PTE LTD

No. 65 Ubi Crescent, #02-01 HOLA Centre

Singapore 408559

Tel: 68968826 Email: info@aps-instrument.com

Co. Registration No. : 200601680E



CERTIFICATE OF CALIBRATION

Certificate Number : APS/SPT/0018/2022

Instrument	:	Standard Penetration Test (SPT)
Manufacturer	:	Hanjin D&B 10KD
Serial No	:	FTAH-SPH-03
SPT Ram Energy Transfer Ratio	:	82%
Calibration Date	:	25 February 2022
Recalibration Date	:	24 February 2023

Calibration Remarks:

Please refer to Calibration Test Report : APS/SPT/2022/018 for detailed summary and analysis.

This Certificate shall not be reproduced except in full, without the written approval of the laboratory.



The results herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council – Singapore Laboratory Accreditation Scheme

CALIBRATION SITE: PUB TELOK BLANGAH

TEST REPORT

STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT (SPT HAMMER – FTAH-SPT06)

TEST REPORT

18th November 2021

CLIENT

M/s **FOSTA PTE LTD**

Submitted by



APS ASIA PDA ENTERPRISE PTE LTD

19th NOVEMBER 2021

REPORT REF. NO : APS/SPT/2021/183

No. 65 Ubi Crescent #02-1 Holo Centre Singapore 408559 Tel (65) 68968926 Fax: (65) 62212003

The results reported herein have been performed in accordance with the terms of accreditation under the Singapore Accreditation Council. The reports shall not be reproduced except in full, unless the management representative of APS ASIA PDA Enterprise Pte Ltd has given approval in writing.

C O N T E N T S

1. INTRODUCTION
2. TEST EQUIPMENT
3. SUMMARY
4. RESULTS

APPENDIX I SPT HAMMER ENERGY MEASUREMENT RESULTS

1. INTRODUCTION

This report the results of the standard penetration test, SPT, hammer energy measurement using the Pile Driving Analyzer, PDA, carried out for APS ASIA PDA Enterprise Pte Ltd on 18 November 2021. The aim of testing was to provide an estimate of the hammer energy transferred by the SPT hammer in accordance to American Standard Test Method ASTM D4633-16.

The SPT testing was performed at PUB Telok Blangah.

The SPT hammer tested was identified as FTAH-SPT06 and was operated by Hanjin D&B 10KD drilling machine (Rig-Rig-6).

2. TEST EQUIPMENT

Pile Driving Analyser (Model PAX)	: Serial No. 4192L
Instrumented Rod	: Serial No. 462BW (Length 600mm)
Strain Transducers	: Serial Nos. 462BW - Bridge 1 & 2
Accelerometers	: Serial Nos. K1582 & K0361

3. SUMMARY

SPT Hammer Serial No.	- FTAH-SPT06
Calibration Site	- PUB Telok Blangah
Borehole	- RX1512009 - Diameter : - 100 mm - Depth : 9.00 m
Drilling Rig	- Rig-6
Drilling Operator	- Chinniyah
Drill Rod Type	- BW
Shoe Type / Length	- Split Spoon Sampler /600mm
Drill Rod Segments	- 3m x 3 + 0.6 + 0.6
Total Length	- 10.20 m (Instrumented Rod Top To Shoe Base)
SPT Ram Mass	- 63.50 kg
SPT Anvil Mass	- 7.80 kg
SPT Total Mass	- 71.30 kg
SPT Ram Drop Height	- 762 mm
Theoretical Energy	- 0.4747 kN-m

4. **RESULTS (SPT HAMMER ENERGY MEASUREMENT)**

No. Of Blow = 10

Min. / Max. EMX Value = 0.3413 kN-m / 0.3625 kN-m

Mean Measured Energy = 0.3536 kN-m

Standard Deviation = 0.0059 kN-m

Energy Ratio, Er = Mean Measured Energy / Theoretical Energy
= 0.74 (74 %)

Report prepared by



Cheng Chung Yin Chris
Approved Signatory

APPENDIX I

SPT HAMMER ENERGY MEASUREMENT RESULTS

SPT HAMMER ENERGY MEASUREMENT

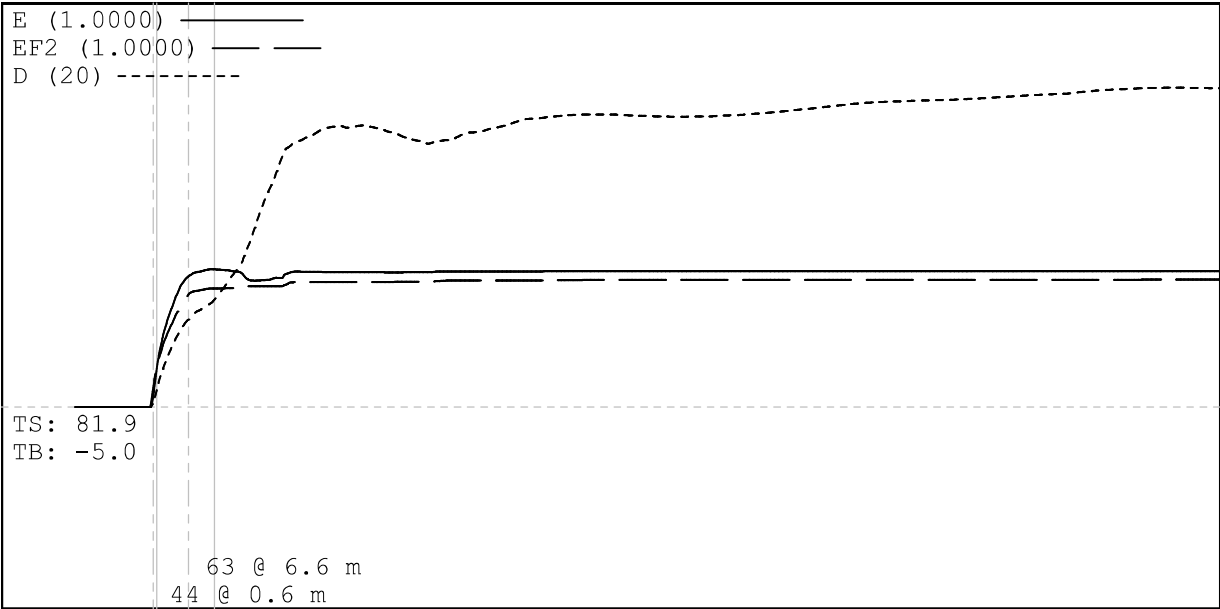
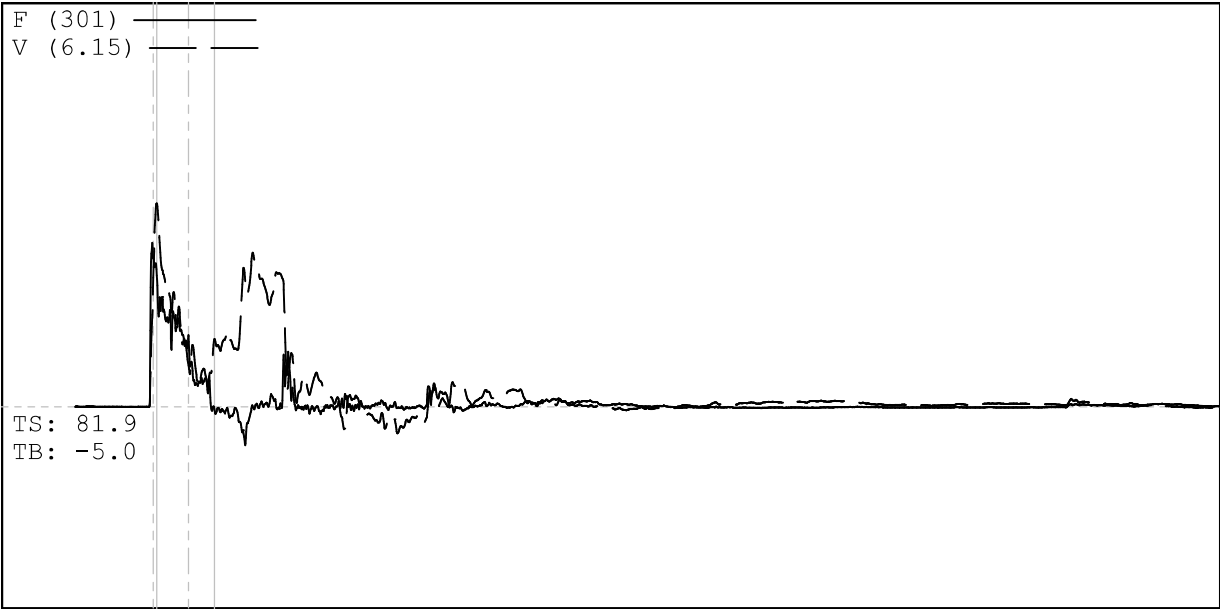
Conducted By : APS Asia PDA Enterprise Pte Ltd (Joseph Ling Ka Jun)

Conducted For : Fosta Pte Ltd (Machine : RIG - Rig 6 / SPT : FTAH-SPT06)

BLOW NO.	EMX	EF2	DMX	FMX	TSX	CSX	VMX	AMX
2	0.3413	0.2939	16	122	41.8	100.7	3.09	1196
3	0.3478	0.2983	15	125	33.5	102.80	3.16	1179
4	0.3568	0.2985	13	123	26.7	101.50	3.26	1146
5	0.3550	0.3027	11	121	22.1	99.70	3.33	1051
6	0.3532	0.2984	10	120	25.0	99.10	3.27	1052
7	0.3625	0.3048	10	123	22.5	101.70	3.39	1110
8	0.3566	0.2976	10	121	23.2	100.00	3.29	1090
9	0.3548	0.2937	9	119	22.7	98.50	3.26	1112
10	0.3577	0.2951	9	119	22.0	97.70	3.23	1058
11	0.3503	0.2953	9	122	20.6	100.80	3.33	987
MINIMUM	0.3413	0.2937	9.0	119	20.60	97.70	3.09	987
MAXIMUM	0.3625	0.3048	16	125	41.8	102.8	3.39	1196
AVERAGE	0.3536	0.2978	11.2	122	26.0	100.3	3.26	1098
STANDARD DEV.	0.0059	0.0036	2.57	2	6.7	1.6	0.09	64

OUTPUT QUANTITIES

EMX	maximum energy transmitted past the transducers.
EF2	maximum energy transmitted past the transducers from integral of force squared.
DMX	maximum downward displacement at the transducers' location.
FMX	maximum compressive force at the transducers' location.
CSX	maximum compressive stress at transducers' location.
TSX	maximum tensile stress along the length of rod.
VMX	maximum velocity at the transducers' location.
AMX	maximum acceleration at the transducers' location.



Project Information

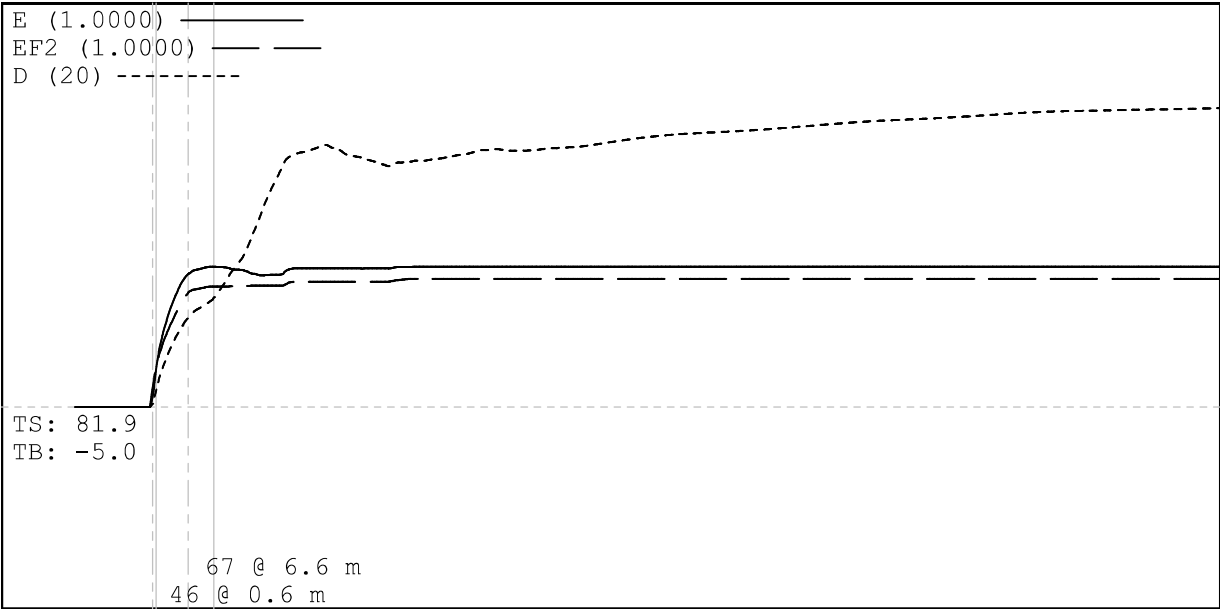
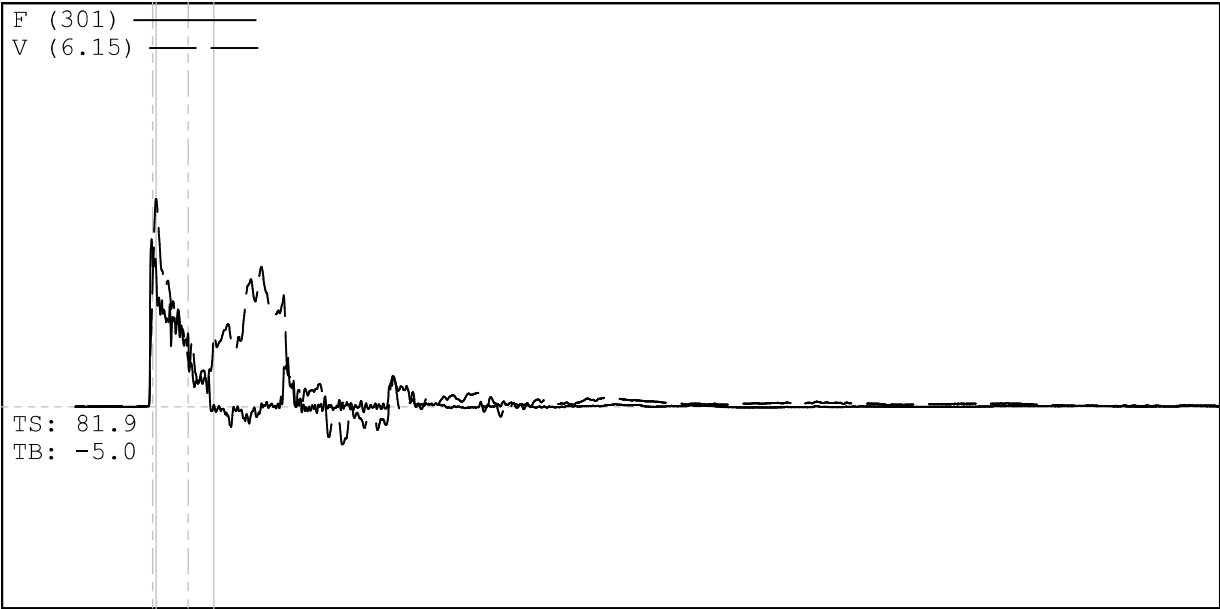
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PILE NAME: FTAH-SPT06
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT06
18/11/2021 10:46:16 am
Blow Number 2

Quantity Results

EMX 0.3413 kN-m
EF2 0.2939 kN-m
DMX 16 mm
FMX 122 kN
TSX 41.8 MPa
CSX 100.7 MPa
VMX 3.09 m/s
AMX 1196 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []



Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT06
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT06
18/11/2021 10:46:17 am
Blow Number 3

Quantity Results

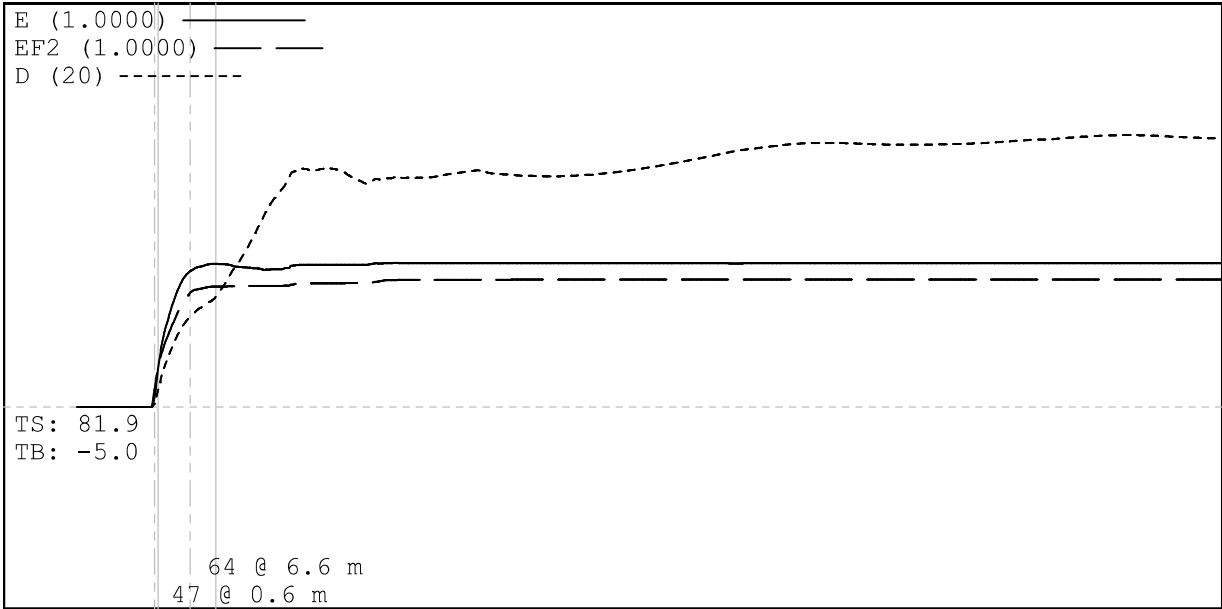
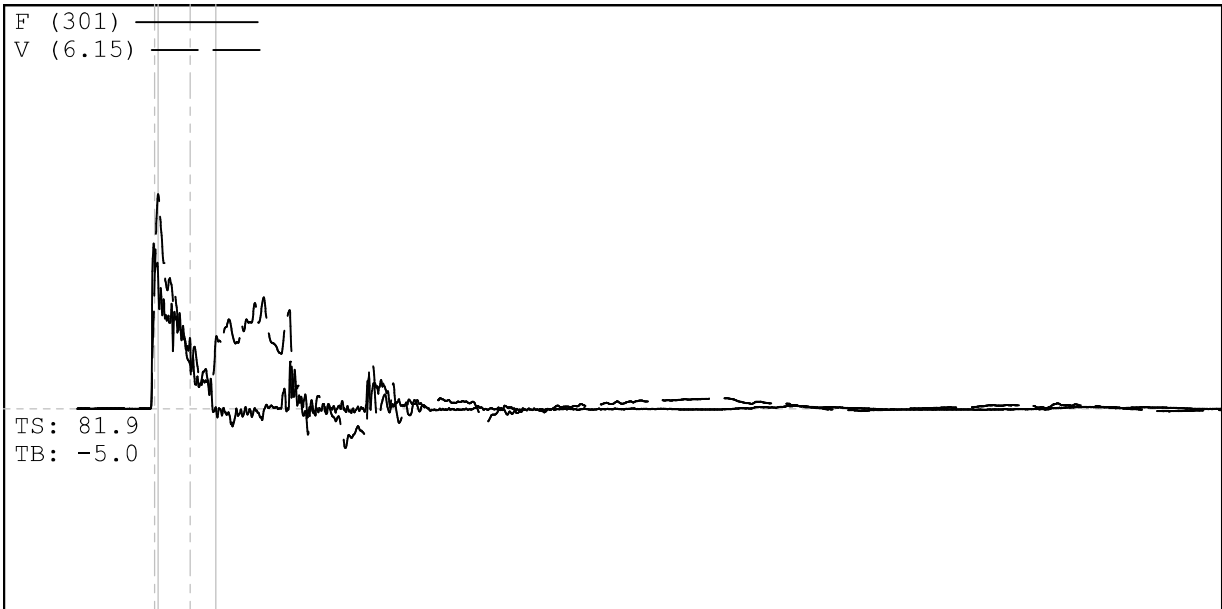
EMX 0.3478 kN-m
EF2 0.2983 kN-m
DMX 15 mm
FMX 125 kN
TSX 33.5 MPa
CSX 102.8 MPa
VMX 3.16 m/s
AMX 1179 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT06



Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT06
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT06
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Blow Number 4

Quantity Results

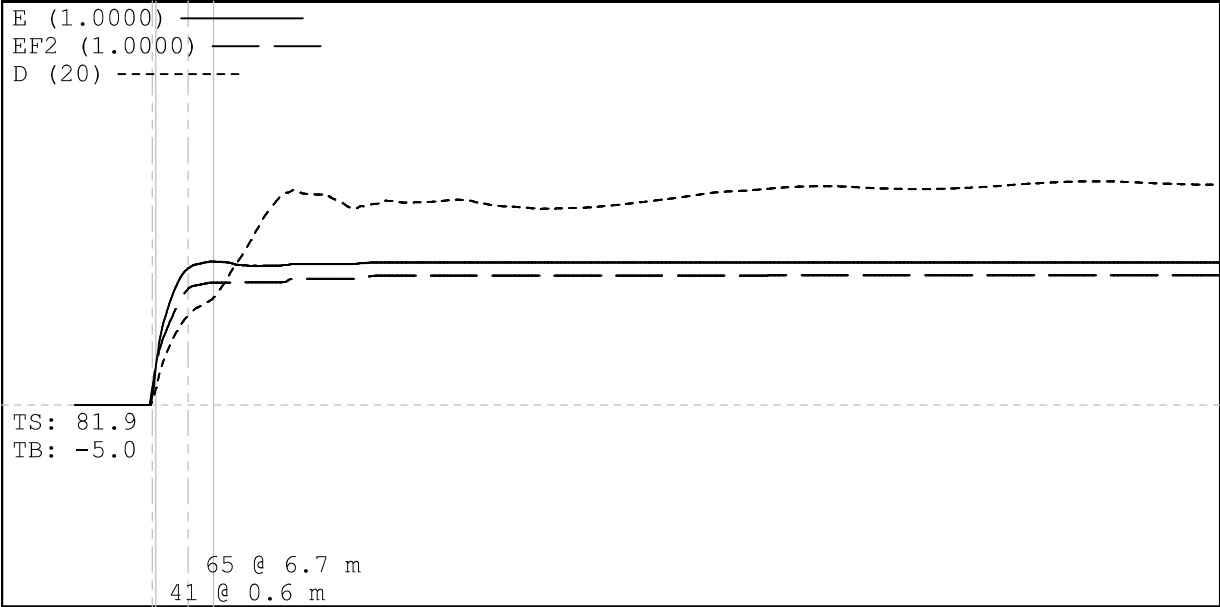
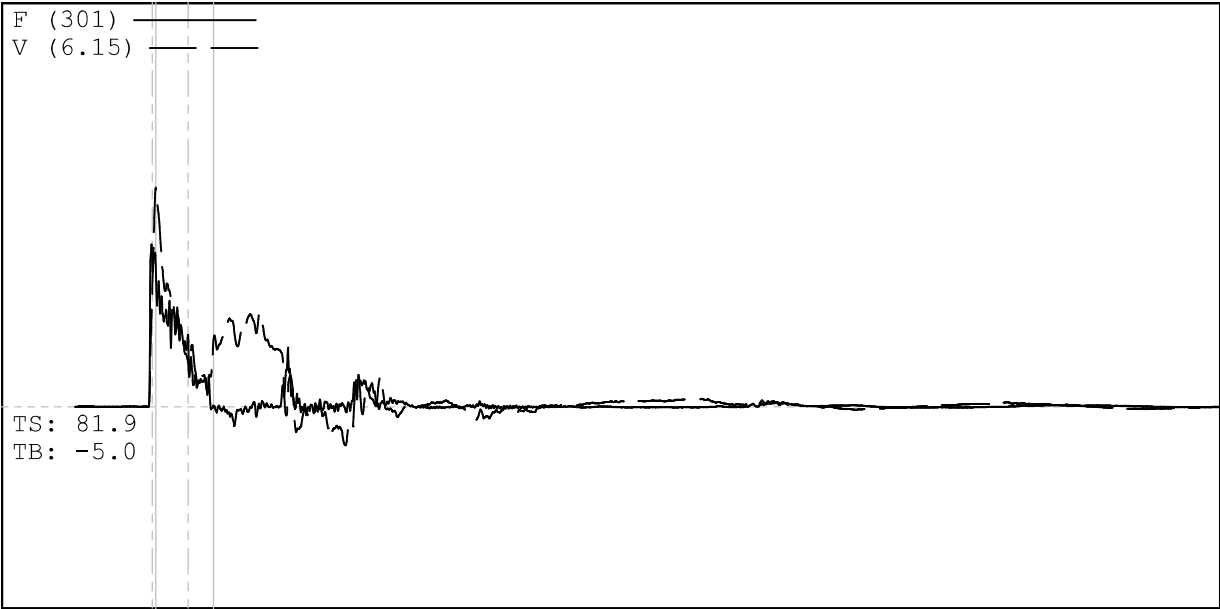
EMX 0.3568 kN-m
EF2 0.2985 kN-m
DMX 13 mm
FMX 123 kN
TSX 26.7 MPa
CSX 101.5 MPa
VMX 3.26 m/s
AMX 1146 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm^2
EM 206843 MPa
SP 77.3 kN/m3
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT06



Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT06
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT06
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Blow Number 5

Quantity Results

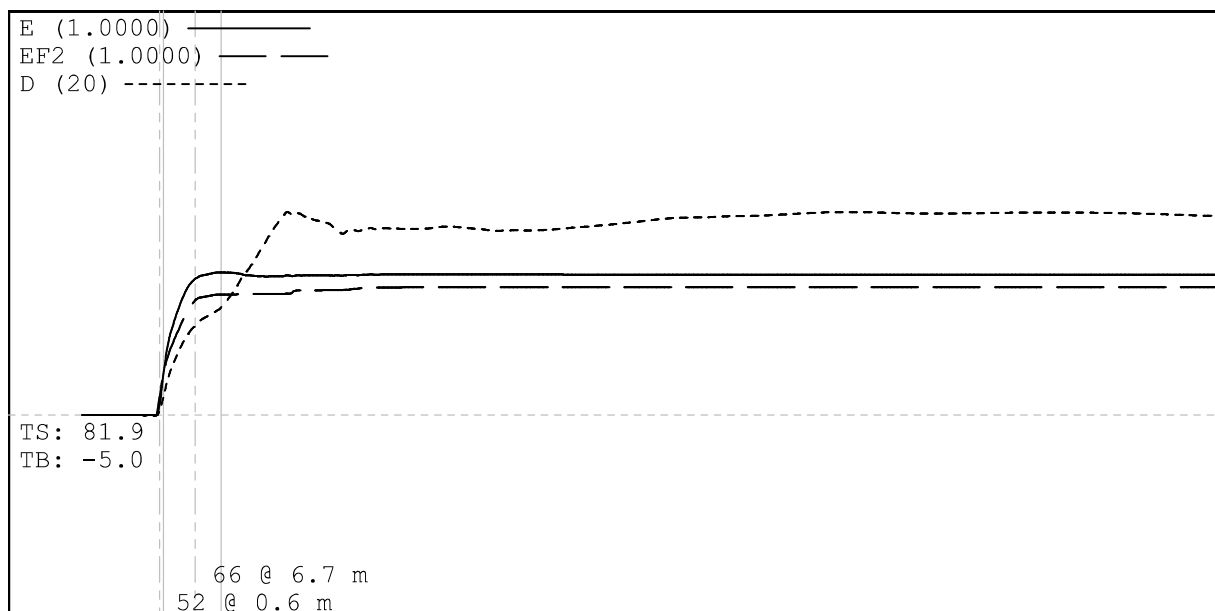
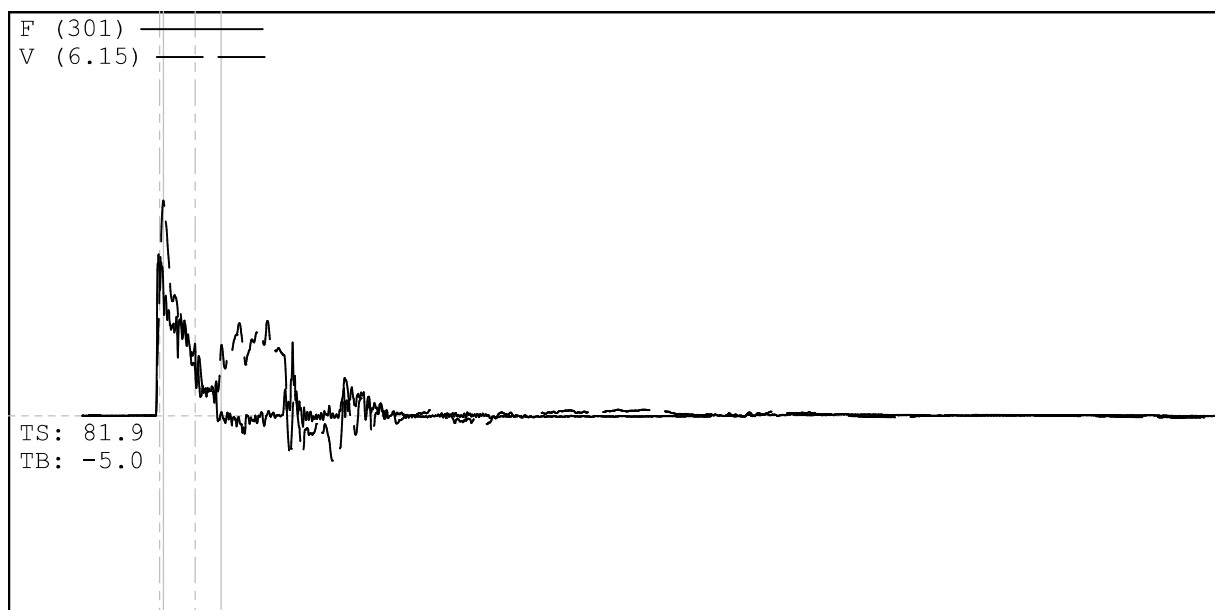
EMX 0.3550 kN-m
EF2 0.3027 kN-m
DMX 11 mm
FMX 121 kN
TSX 22.1 MPa
CSX 99.7 MPa
VMX 3.33 m/s
AMX 1051 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT06

Project Information

PROJECT: TELOK BLANGAH(181121)

PILE NAME: FTAH-SPT06

DESCR: APS

OPERATOR: APS

FILE: FTAH-SPT06

18/11/2021 10:46:21 am

Blow Number 6

Quantity Results

EMX 0.3532 kN-m

EF2 0.2984 kN-m

DMX 10 mm

FMX 120 kN

TSX 25.0 MPa

CSX 99.1 MPa

VMX 3.27 m/s

AMX 1052 g's

RX5 kN

Pile Properties

LE 9.9 m

AR 12.13 cm²

EM 206843 MPa

SP 77.3 kN/m³

WS 5123.0 m/s

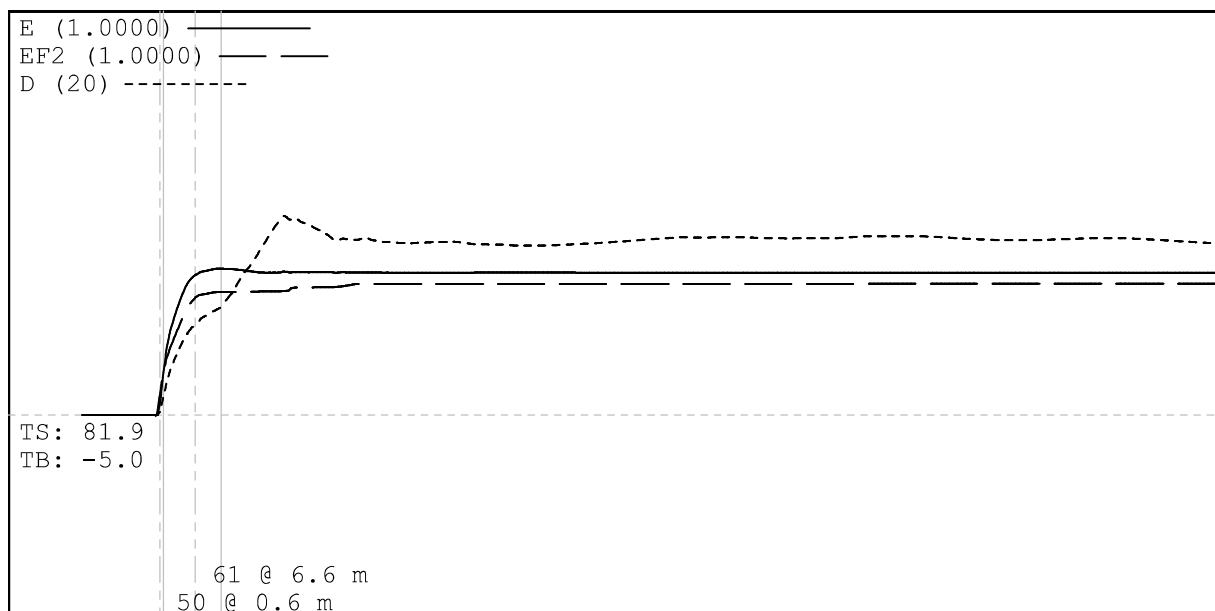
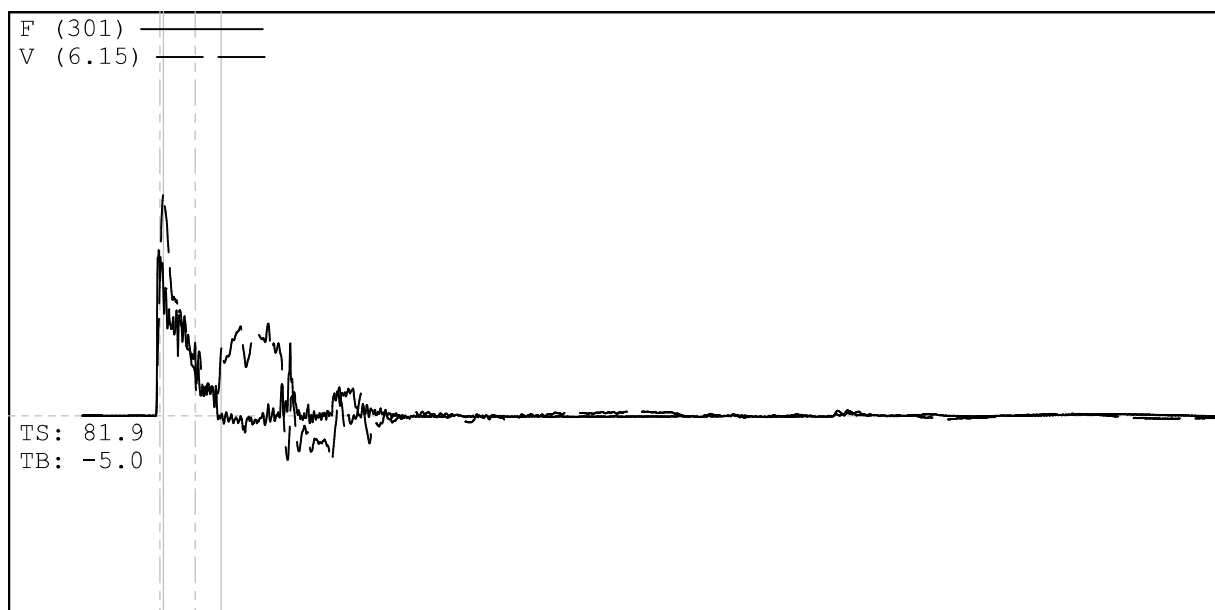
EA/C 49 kN-s/m

2L/C 3.88 ms

JC []

TELOK BLANGAH(181121)

FTAH-SPT06

Project Information

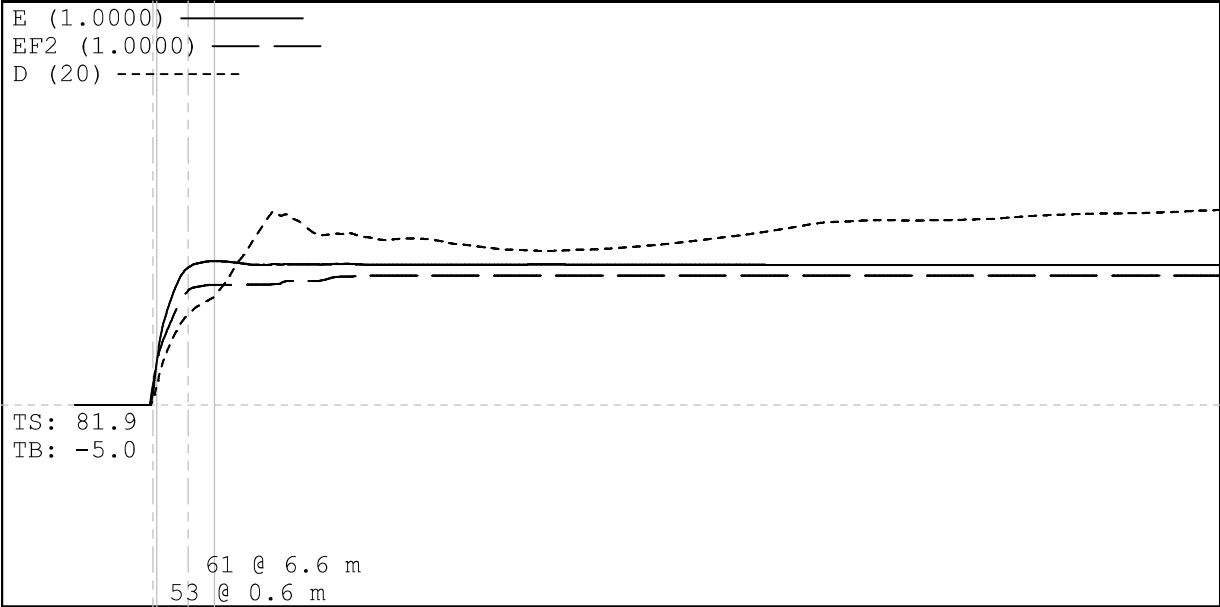
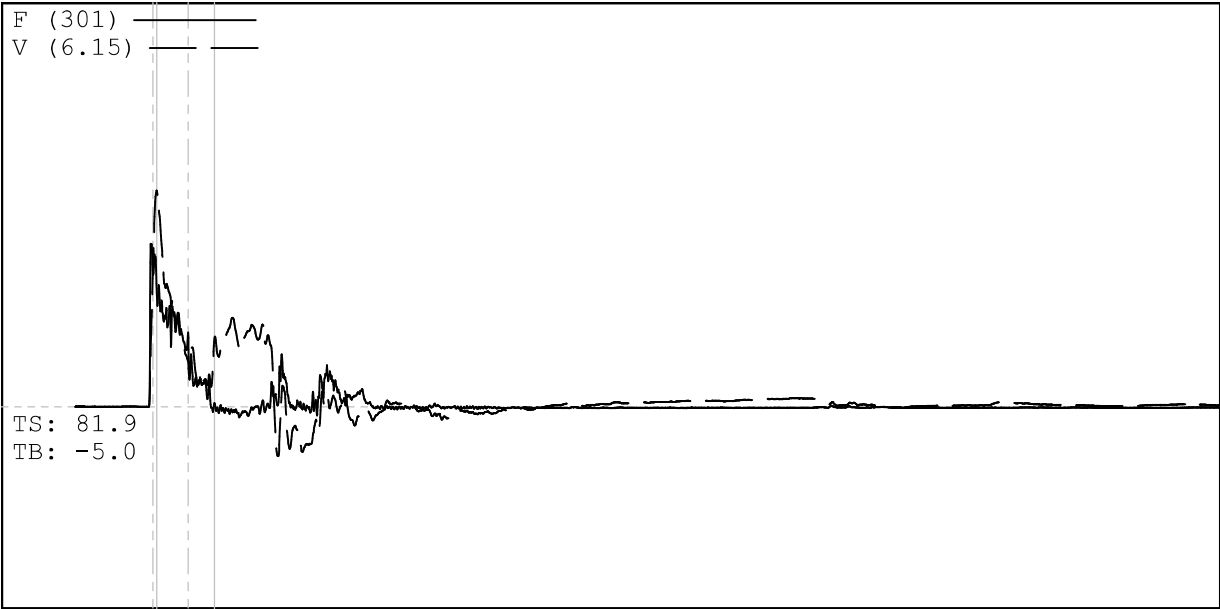
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PILE NAME: FTAH-SPT06
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT06
18/11/2021 10:46:22 am
Blow Number 7

Quantity Results

EMX 0.3625 kN-m
EF2 0.3048 kN-m
DMX 10 mm
FMX 123 kN
TSX 22.5 MPa
CSX 101.7 MPa
VMX 3.39 m/s
AMX 1110 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []



Project Information

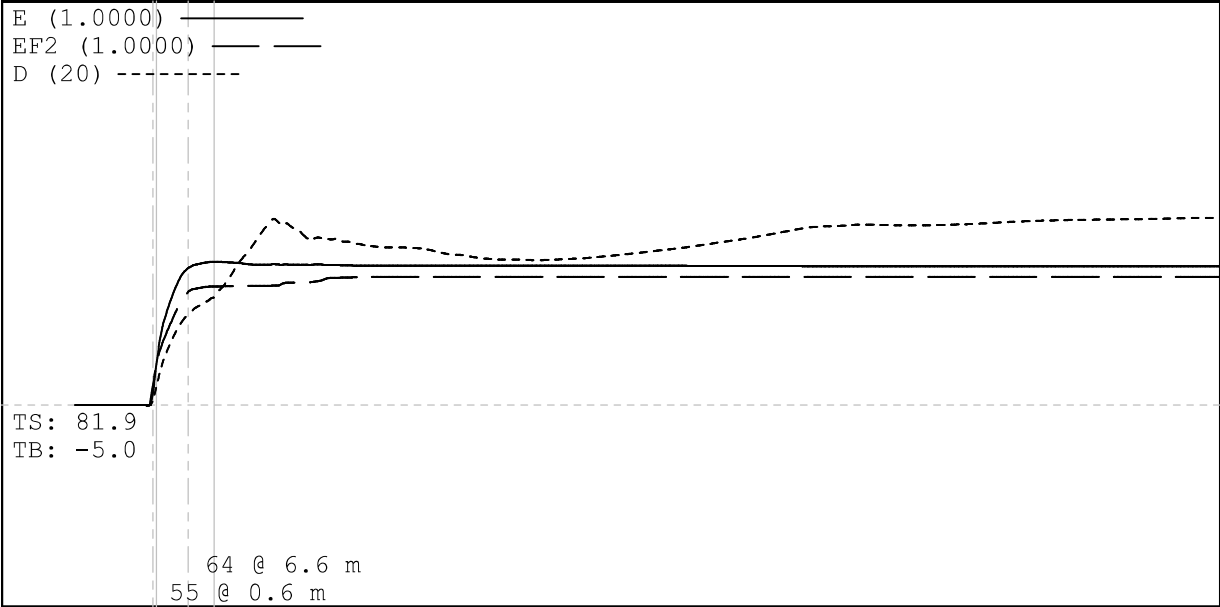
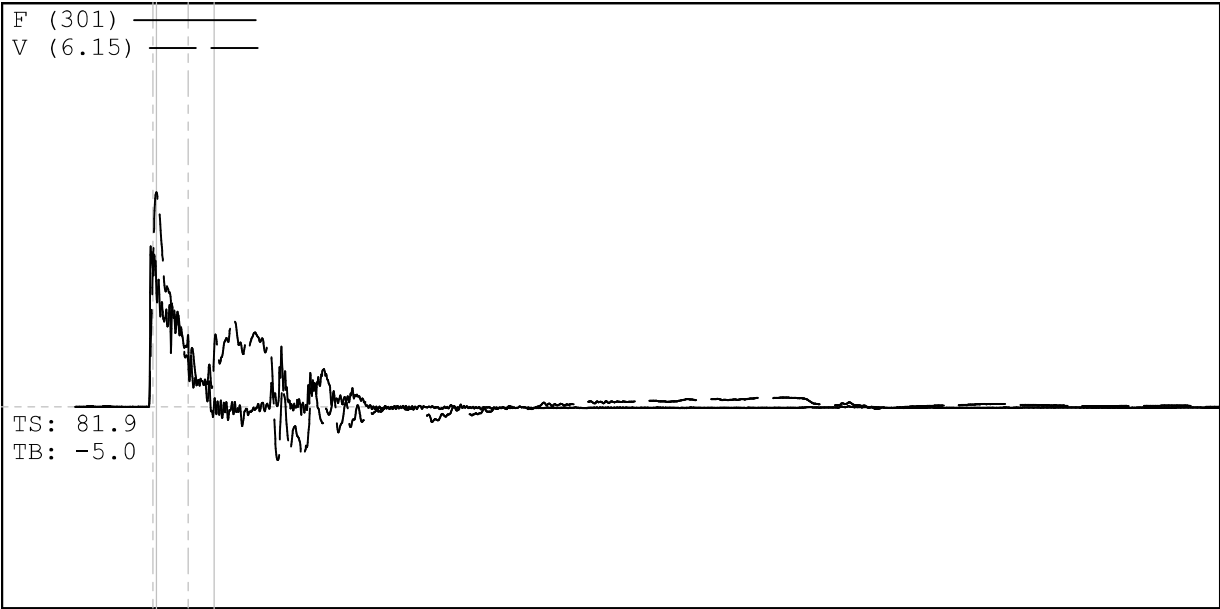
PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT06
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT06
18/11/2021 10:46:23 am
Blow Number 8

Quantity Results

EMX 0.3566 kN-m
EF2 0.2976 kN-m
DMX 10 mm
FMX 121 kN
TSX 23.2 MPa
CSX 100.0 MPa
VMX 3.29 m/s
AMX 1090 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []



Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT06
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT06
18/11/2021 10:46:24 am
Blow Number 9

Quantity Results

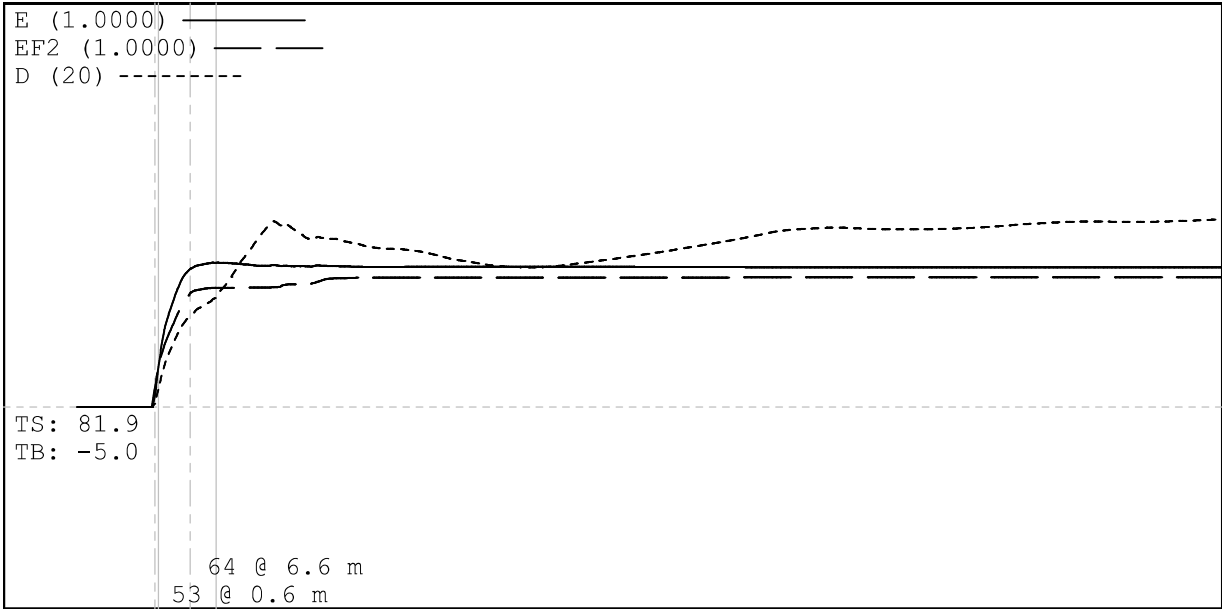
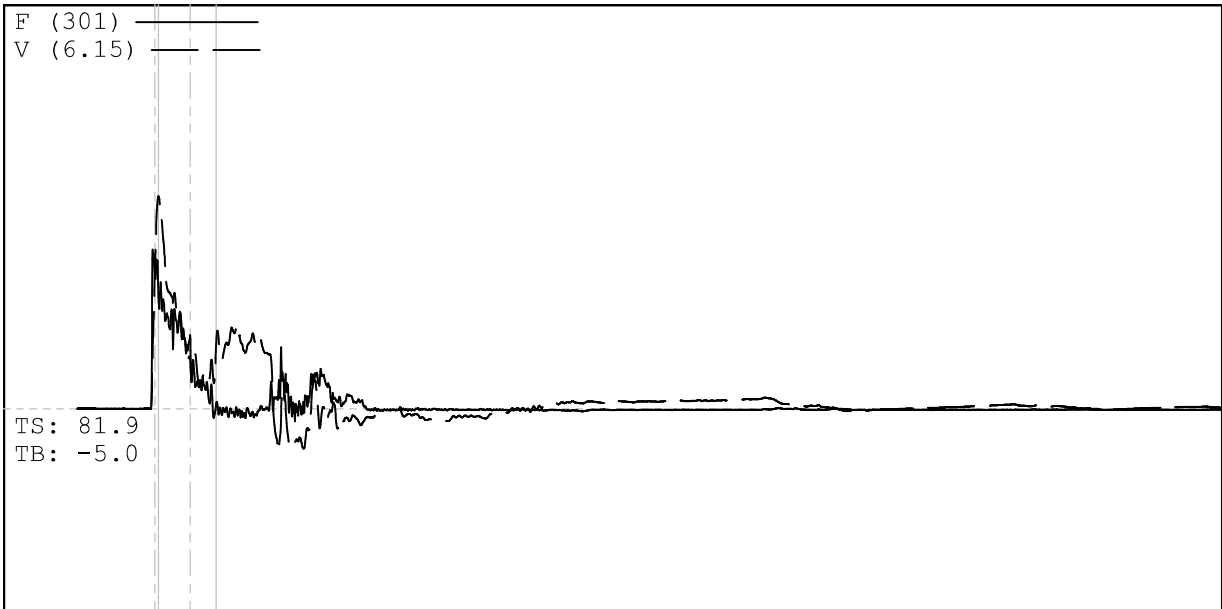
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EF2 0.2937 kN-m
DMX 9 mm
FMX 119 kN
TSX 22.7 MPa
CSX 98.5 MPa
VMX 3.26 m/s
AMX 1112 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT06



Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT06
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT06
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Blow Number 10

Quantity Results

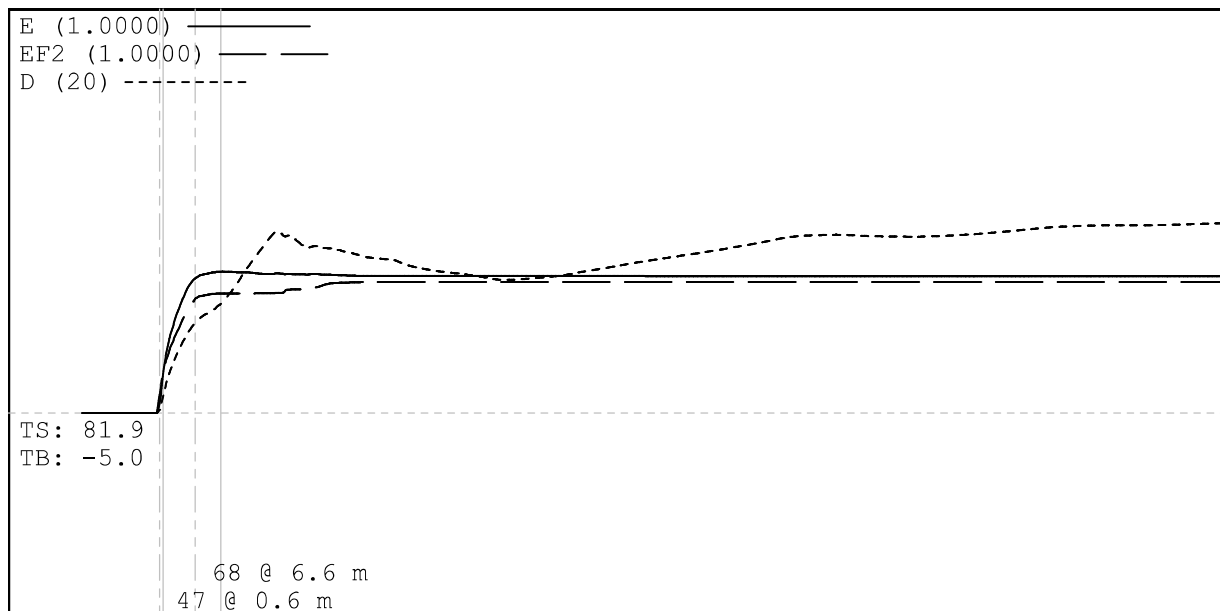
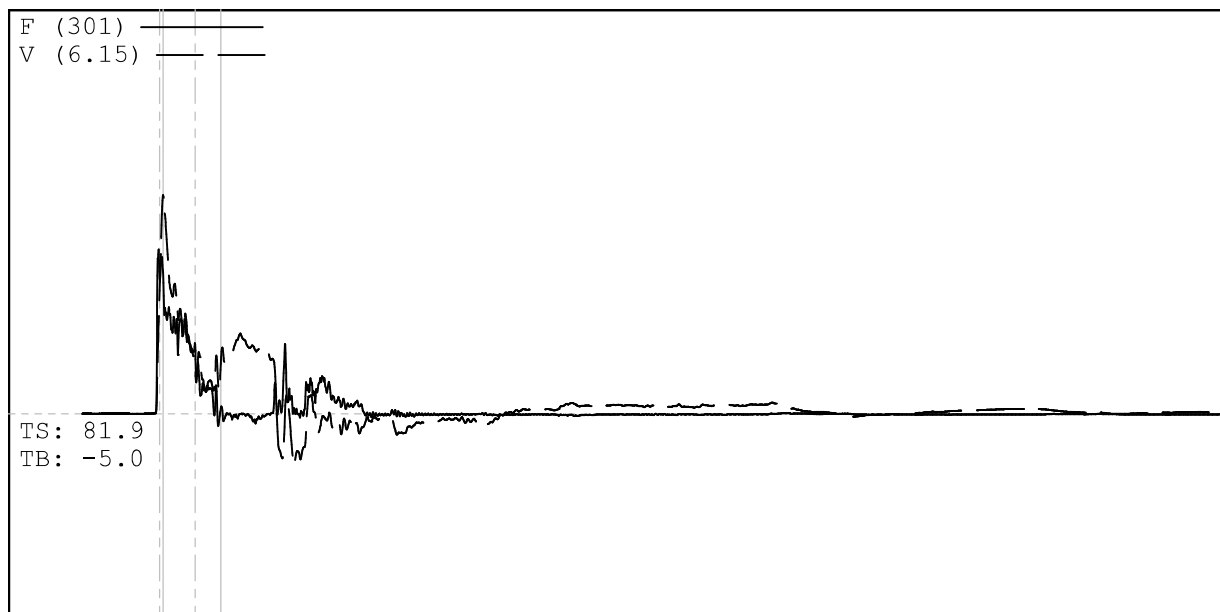
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EF2 0.2951 kN-m
DMX 9 mm
FMX 119 kN
TSX 22.0 MPa
CSX 97.7 MPa
VMX 3.23 m/s
AMX 1058 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []

TELOK BLANGAH(181121)

FTAH-SPT06

Project Information

PROJECT: TELOK BLANGAH(181121)
PILE NAME: FTAH-SPT06
DESCR: APS
OPERATOR: APS
FILE: FTAH-SPT06
18/11/2021 10:46:27 am
Blow Number 11

Quantity Results

EMX 0.3503 kN-m
EF2 0.2953 kN-m
DMX 9 mm
FMX 122 kN
TSX 20.6 MPa
CSX 100.8 MPa
VMX 3.33 m/s
AMX 987 g's
RX5 kN

Pile Properties

LE 9.9 m
AR 12.13 cm²
EM 206843 MPa
SP 77.3 kN/m³
WS 5123.0 m/s
EA/C 49 kN-s/m
2L/C 3.88 ms
JC []



APS ASIA PDA ENTERPRISE PTE LTD

FIELD SHEET - STANDARD PENETRATION TEST (SPT) HAMMER ENERGY MEASUREMENT

Test Date : 18/11/2021 Test Ref No: _____
 Client : Fosta P/C
 Project Title : PAB Telok Blayuh

Calibration Details

Analysers	Weighing Scale	Strain Gauge	Serial Number	Calibration Factor (G/V)	Accelerometer	Serial Number	Calibration Factor (G/V)
PAX	Teraeiko	F3	462 BW B1	210.92	A3	14582	368.5
PAX4192LA	20150821116	F4	462 BW B2	210.63	A4	10361	353.7

Test Details

FAH - SPT 06

SPT Hammer Serial No.	H-6 Hanjin-6
Borehole No.	RX 1512009
Borehole Diameter	Ø100mm
Borehole Depth	9.00
Drilling Rig.	Rig-6
Drilling Operator	Chinniyah
Drill Rod Type	BW
Shoe Type/Length	SS / 600
Drill Rod Segments	3m x 3 + 0.6 + 0.6
Total Length	10.20
Total Length From Gauge	9.90
SPT Ram Mass (kg)	63.50
SPT Anvil Mass (kg)	7.80
SPT Total Mass (kg)	71.30
SPT Ram Drop Height	762
Type Of Machine	Hanjin
Model	DABlokD

* Ram Weight & Anvil Weight Given By Client.

Results

No. of Blows	10
Min. Measured Energy (ton-m)	0.035
Max. Measured Energy (ton-m)	0.037

Tested & Checked By:

Signed by SPT Operator

Witness By:

Sign & Name Of (R.T.O./RE/Client's Rep)

KN Jir 42

[Signature]

YE MANN S MANN



APS ASIA PDA ENTERPRISE PTE LTD

No. 65 Ubi Crescent, #02-01 HOLA Centre

Singapore 408559

Tel: 68988826 Email: info@aps-instrument.com

Co. Registration No. : 200601680E



CERTIFICATE OF CALIBRATION

Certificate Number : APS/SPT/0183/2021

Instrument	:	Standard Penetration Test (SPT)
Manufacturer	:	Hanjin D&B 10KD Drilling Machine
Serial No	:	FTAH-SPT06
SPT Ram Energy Transfer Ratio	:	74%
Calibration Date	:	18 November 2021
Recalibration Date	:	17 November 2022

Calibration Remarks:

Please refer to Calibration Test Report : APS/SPT/2021/183 for detailed summary and analysis.

This Certificate shall not be reproduced except in full, without the written approval of the laboratory.

APPENDIX H

Suspension PS Report

2023



SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND

- SUSPENSION PS LOGGING
(BH-10)

DECEMBER 2023

CLIENT
KEPPEL BAY PTE LTD

MAIN CONTRACTOR
ELEMENT GEOTECHNICAL TESTING (S) PTE LTD
215, KAKI BUKIT AVENUE 1,
SHUN LI INDUSTRIAL PARK,
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GEOPHYSICAL CONTRACTOR
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1. OUTLINE OF THE PROJECT

1.1 Introduction

The purpose of this geophysical investigation is to obtain the geophysical properties of the soil at sites. Geophysical tests were performed to obtain the P-wave and S-wave velocities of the soil strata. These results provide the designer with the information pertinent to the seismic wave velocities of the materials.

1.2 Particulars of the Project

- a) Project title : Soil Investigation Work for Proposed Development at Plot 6 at Keppel Island
- b) Location : Keppel Island
- c) Client : Keppel Bay Pte Ltd
- d) Main Contractor : Element Geotechnical Testing (S) Pte. Ltd.
- e) Geophysical contractor : Pacific Geoscience (S) Pte. Ltd.
 - Personnel involved : Seik Yean Yoong (*Project Manager*)
 - : Aiman Fitri (*Fieldwork*)
 - : Myo Win Htay (*Fieldwork*)
 - : Lingampalli Munindar (*Fieldwork*)
 - : Seik Yean Suang (*Processing and Reporting*)
- f) Period of work : 21th December 2023 (Fieldwork)
22th December 2023 (Processing and Reporting)
- g) Scope of work : Suspension PS Logging Survey
(Quantity of works are shown in Table 1)

Table 1 Quantity of Works – Suspension PS-Logging Survey

No.	Test Point	Test Date	Logging Depth (m)
1.	BH-10	21/12/2023	31.00
Total			31.00

2. SCOPE OF WORK FOR SUSPENSION PS LOGGING

2.1 Suspension PS Wave Logging

The method requires one borehole per test location. The borehole is PVC-cased and grouted to ensure the hole remains open and that the casing is in firm contact with the soil or rock mass. The test consists of lowering a PS probe to a specified depth in the borehole. Suspension P-S velocity logging, or suspension logging for short, is a method for measuring compressional (V_p) and shear (V_s) wave velocities in soils and soft rock formations. Measurements are made in a single, cased, fluid-filled borehole. It is similar to full-waveform sonic logging, but is optimized for low frequency measurements in soil.

A diagram of the suspension logging system setup is shown in Figure 1. A solenoid source generates an acoustic wave in the borehole fluid, which impacts the borehole wall. Both P- and S-waves are generated, which travel radially away from the borehole wall. A portion of the energy travels along the formation as a head wave and radiates energy back into the fluid. These waves are sensed by two receivers on the probe. The receivers separation (distance) divided by the difference in travel time is equal to the average velocity of the formation over that interval.

Commonly, measurements are made at 0.5 to 1.0m intervals, although the data can be processed for higher resolution. The method has been proven at depths up to 2 km.

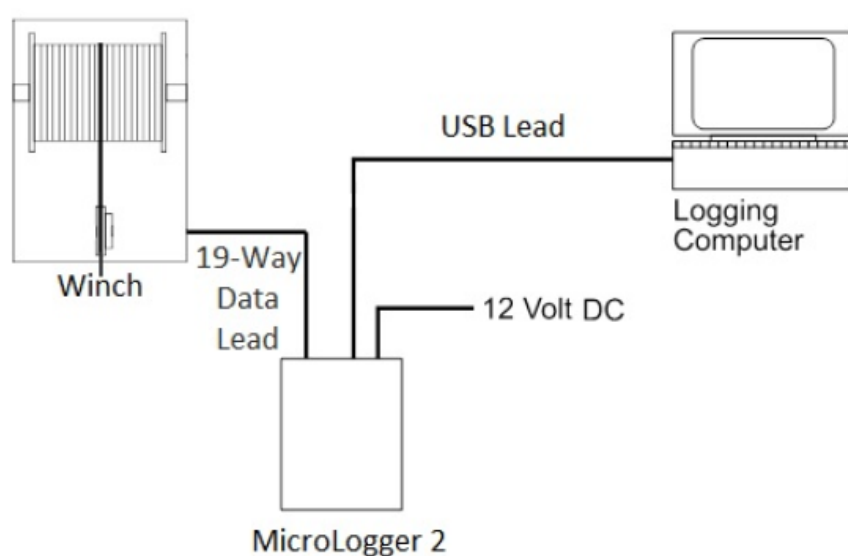


Fig.1 Schematic showing suspension logging system.

2.2 Suspension Geologging Equipment Unit

2.2.1 Micrologger 2 and Laptop

The Micrologger 2 is a small and highly portable single-unit surface interface system for handling logging data acquisition. Table 2 tabulates the physical specifications of Micrologger 2.



Fig. 2 PS Suspension Micrologger 2.

Table 2 : Micrologger 2 Specification.

Physical Specification	
Dimension	240x285x55 mm
Weight	3 kg
Power	12 V DC (regulated supply) at 8 amps (max)
Temperature rating	0-50 °C

2.2.2 Mini Winch

The mini winch is designed specifically for raising and lowering of borehole probes. It is portable, so it may be moved easily from workshop to vehicle or site.

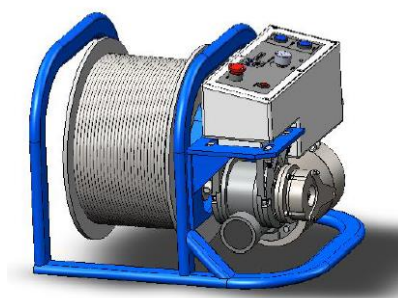


Fig. 3 Mini Winch.

Table 3 : Mini Winch Specification.

Specification	
Capacity	175 m 4.72 cable
Speed	0-17.5 m/min on full drum (12 V DC operation)
Motor	550 W (12-24 V DC)
Size	340 (w) x 400 (l) x 320 (h) mm
Weight	19 kg excluding cable

2.2.3 PS logger Probe

PS Logger probe is a low-frequency acoustic sonde designed to measure V_p and V_s velocities in soils and soft rock formations. The probe contains hammer source and two receivers, separated by acoustic damping tubes. To acquire data, the probe is stopped at the required depth and the source is fired under surface command. Firing causes a solenoid-operated shuttle aligned across the borehole axis to strike plates on opposite sides of the probe in turn, setting up a pressure doublet in the surrounding fluid. The resultant fluid motion produces a tube wave at the borehole wall with velocity close to the shear velocity of the formation together with a compressional wave.

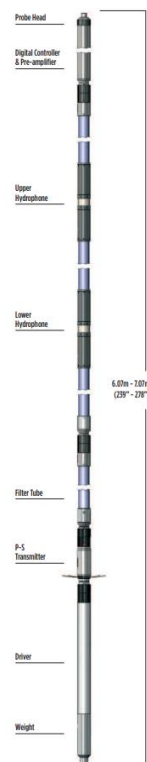


Fig. 4 PS Logger.

Table 4 : PS Logger Specification.

Specification	
Diameter	50mm
Assembled length	6.07 m-7.07 m (1 or 2m filter)
Assembled weight	26.5 kg-28 kg (1 or 2m filter)
Max. temperature	70 °C
Max. pressure	6.5 MPa
Receiver type	3D hydrophone (p), geophone (s)
Receiver spacing	1 m
Transducer type	Solenoid and hammer
Sampling rate	2.5 μ s minimum
Waveform acquisition period	5.12 mS to 409.6 mS
Downhole gain	0 db to 42 db (surface control)

2.3 Data Acquisition

Suspension P-S Logging system consists of a logging computer, PS Logger probe, cable, winch, and Micrologger. The probe length is approximately 6 meters.

The probe consists of a hammer source and two receivers, separated by isolation sections. It is centered in the borehole via the attached nylon whiskers.

The separation between receivers is one meter. As the waves propagate parallel to the borehole axis, they set up corresponding fluid movements that are detected by two neutral buoyancy 3D hydrophone receivers and geophones, allowing the wave velocity to be determined. The probe is connected to the winch on surface by 4-core cable. The cable serves both to support the probe, to transmit activation signals to the source, and to transmit the receiver signals back to the recorder. The depth is measured by the rotary encoder on the winch.

The electronics system activates the source, and records the receiver signals on different channels. Filters may be used in acquisition, but data are usually recorded unfiltered and digitally filtered later during processing.

The measurement procedure is as follows:

- 1) The probe is lowered to the bottom of the borehole to verify total depth and then raised slightly to the first measurement point.
- 2) Once the source is activated, it will acquire a waveform record. The probe will go through several cycles of charging and firing the seismic source to gather a complete set of P and S waveforms.

After the data is stored, the probe is raised to the next depth and the measurement sequence repeated. No filters and amplitude gains should apply during the acquisition in order to see on the screen what is actually being recorded. Digital filters can be used to remove high frequency acoustic noise from waveforms to better allow first arrival picking. These can be applied during processing.

2.4 Data Processing

PS Logging software (PSLog Analysis) displayed the P and S waves on separate channels. Commonly, the first break or first peak is picked on each waveform. If the data are noisy, they can be filtered digitally first. P waves are usually easy to identify as they will be the first arrivals on P traces. For S waves, the left and right traces will show a characteristic reversal (180° phase difference). This aids in identifying the first arrival of the S waves.

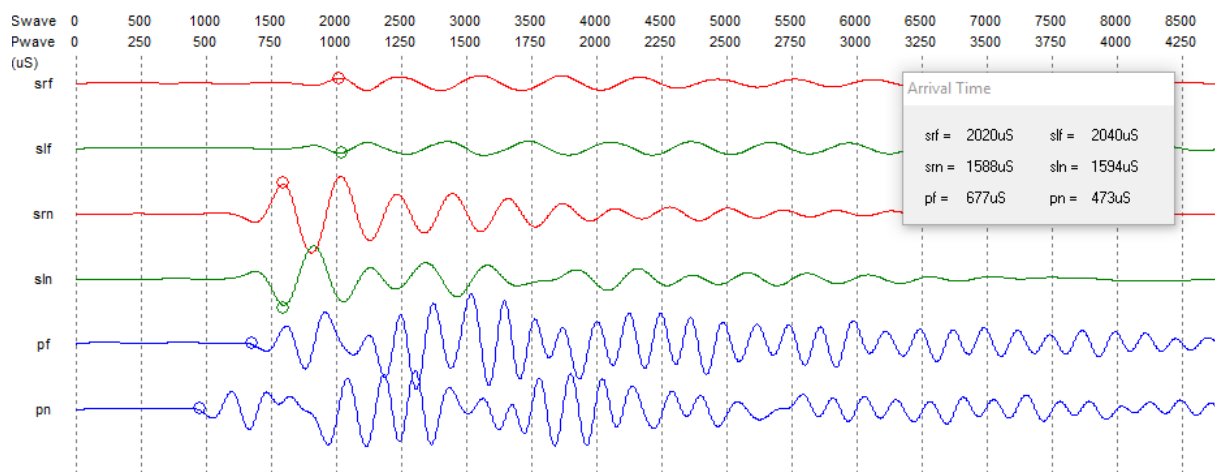


Fig.5 Sample Suspension Logging waveform record.

3. RESULTS OF INVESTIGATION

3.1 Analysis Result of Suspension PS-Logging

The records obtained at each depth are traced up in order of depth. The PS Suspension analysis is attached as appendices.

The average shear velocity V_s in the top 30 m, based on travel time from the surface to a depth of 30 m, is known as V_{s30} , which is the leading parameter for selection of ground type for earthquake engineering design. Its value computed in accordance with the following equation:

$$V_{s,30} = \frac{30}{\sum_{i=1,N} \frac{h_i}{V_i}} \text{-----Equation (1)}$$

where

h_i - Thickness (m)

v_i - Shear velocity V_s

i -th - Formation or layer, in a total of N , existing in the top 30 m.

Building code Eurocode 8 (EC8) introduced five major categories of soil type based on the value of V_{s30} . The classifications are then used to determine the seismic coefficients for earthquake-resistant design.

Conclusive points of ground type classification based on Eurocode 8 from each logging V_{s30} are summarized below:

- BH-10– Type C

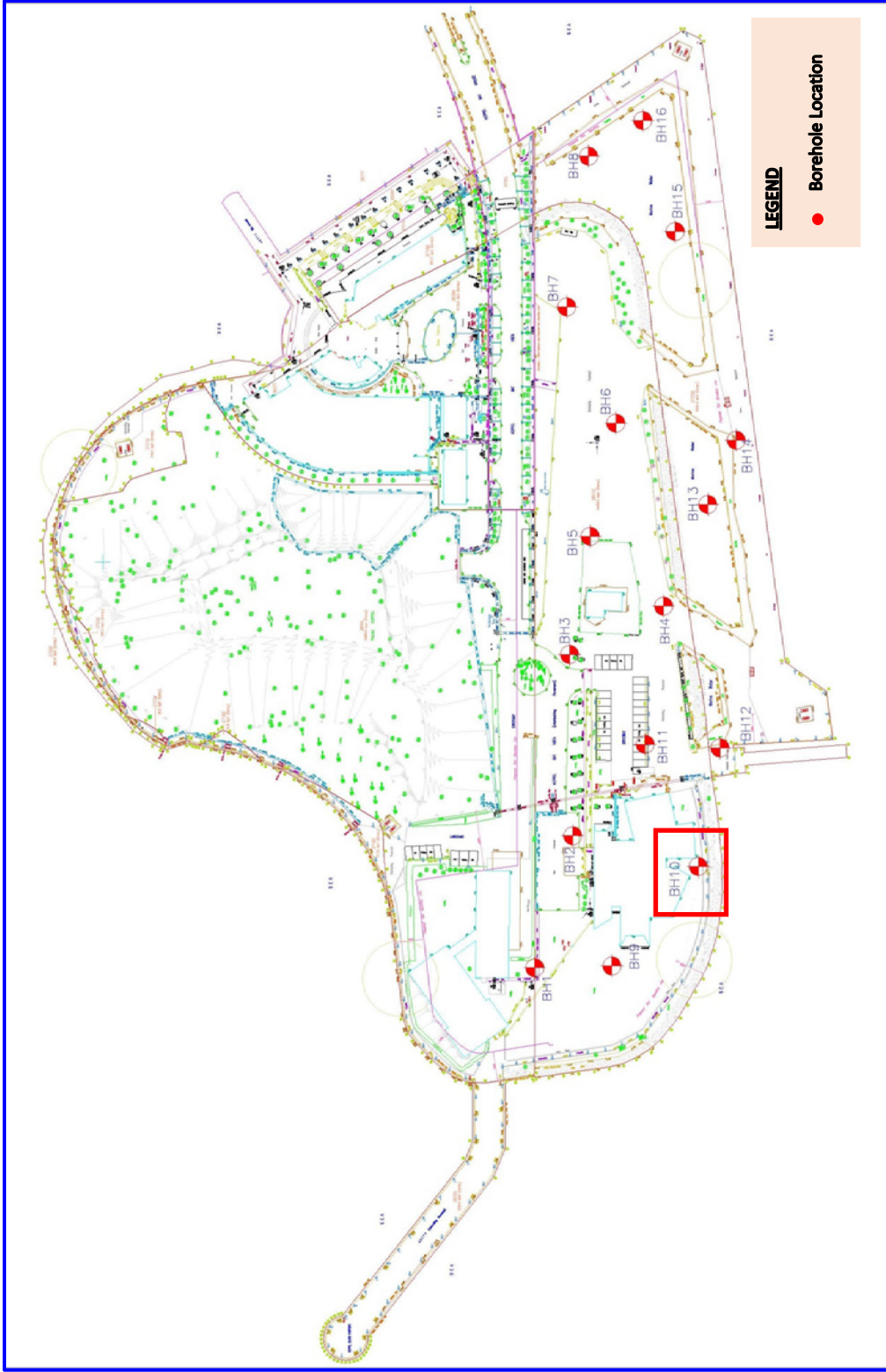
Table 5 : Ground Type

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	–	–
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15 - 50	70 - 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $v_s > 800$ m/s.			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index ($PI > 40$) and high water content	< 100 (indicative)	–	10 - 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1			

Source : (Eduardo C. Carvalho, 2012)

APPENDIX A

LAYOUT PLAN



Project : SOIL INVESTIGATION WORK FOR PROPOSED DEVELOPMENT AT PLOT 6 AT KEPPEL ISLAND

Client : KEPPEL BAY PTE LTD

Location : KEPPEL ISLAND

APPENDIX B

ANALYSIS OF SUSPENSION PS WAVE LOGGING BH-10

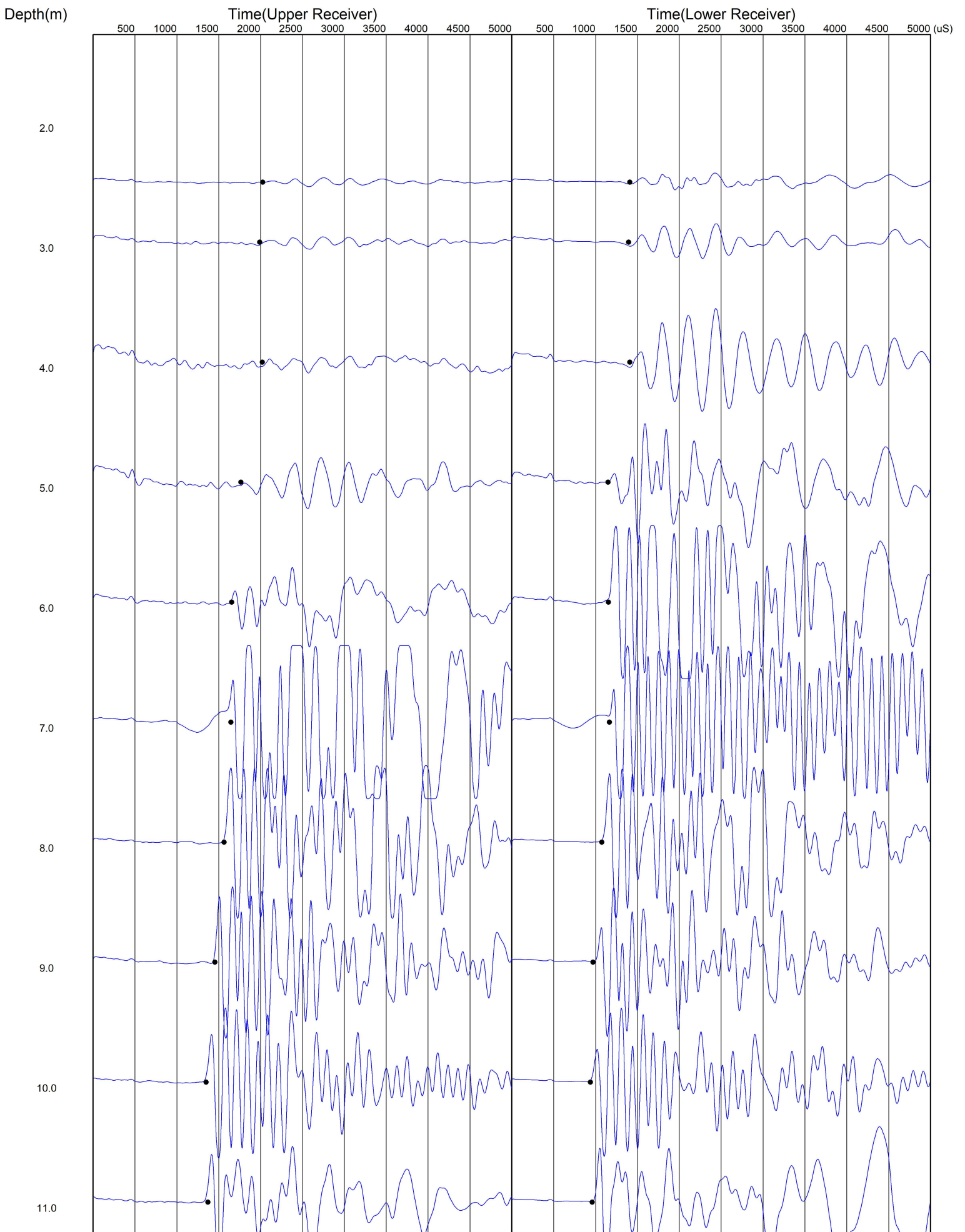
- Suspension PS Wave Logging Result
- Suspension PS Logging Vs30 Result
 - P Waveform Data
 - S Waveform Data
 - P Wave Velocity Log
 - S Wave Velocity Log

Suspension PS Logging Result BH10					
Depth (GL,m)	Vp (m/s)	Vs (m/s)	SPT N-value	RQD (%)	Geological Profile (Depth,m)
0.00					FILL (Fine to coarse Sandy SILT)
1.00					Fine to medium Sandy SILT
2.50	1626.016	196.082			
3.00	1680.672	195.324			Firm, fine to medium Sandy SILT mixed with rock fragments
4.00	1639.344	173.645			
5.00	1626.016	180.527	4		Stiff, fine to medium Sandy SILT mixed with rock fragments
6.00	2000.000	297.661			
7.00	2083.333	304.923	43		Hard, fine to medium Sandy SILT mixed with rock fragments
8.00	2040.816	296.117	100		
9.00	2061.856	287.394			
10.00	2439.024	312.549	100		
11.00	2439.024	306.852	100		
12.00	2500.000	310.571		0	Very weak to weak, fine grained SILSTONE
13.00	2739.726	373.218		20	
14.00	2564.103	400.231		65	
15.00	2500.000	397.226		10	
16.00	2597.403	384.706		65	Moderately strong to moderately weak, fine to medium grained SANDSTONE interbedded with siltstone
17.00	2500.000	434.816		13	Weak to moderately strong, fine to medium grained SILSTONE
18.00	2564.103	420.435		12	Moderately strong to moderately weak, fine to medium grained SILTSTONE
19.00	3174.603	485.483		0	
20.00	3125.000	581.710		35	Moderately strong, fine to medium grained SILSTONE
21.00	3174.603	537.697		45	
22.00	3225.806	510.204		20	
23.00	3225.806	495.098		0	Moderately strong, fine to medium grained SANDSTONE interbedded with siltstone
24.00	3448.276	480.947		0	
25.00	3174.603	495.098		0	Very weak to moderately weak, fine to medium grained SILTSTONE
26.00	3174.603	526.841		30	Moderately weak to moderately strong, fine to medium grained SILTSTONE
27.00	3448.276	490.385		0	Weak to moderately strong, fine to medium grained SILSTONE
28.00	3571.428	495.098		0	Moderately weak to moderately strong, fine to medium grained SILTSTONE
29.00	3508.772	455.902		0	
30.00	3448.276	413.251		0	Moderately weak to moderately strong, fine to medium grained SANDSTONE interbedded with siltstone
31.00	3773.585	581.395		35	

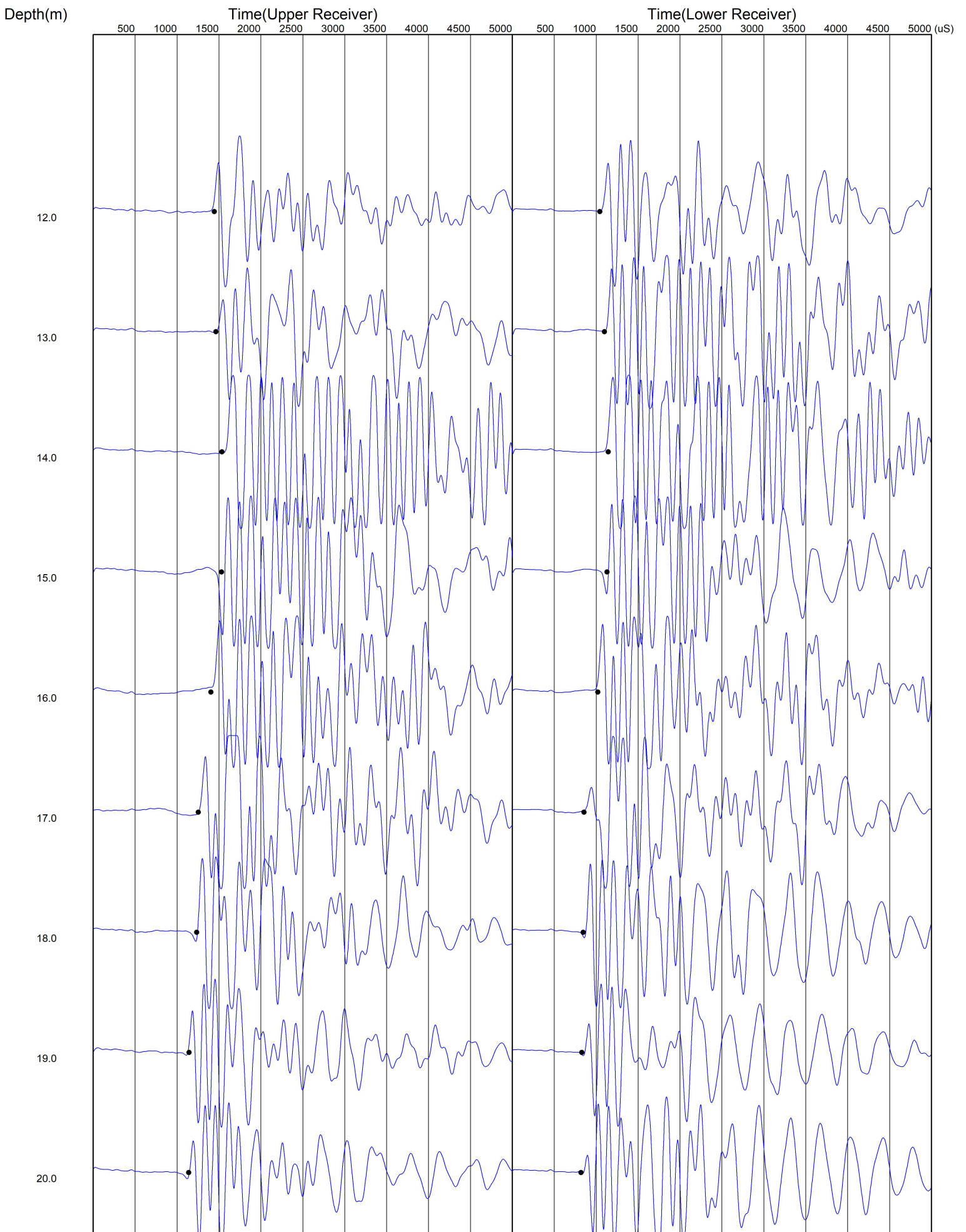
Vs30 for BH-10		
Depth (m)	Vs (m/s)	H/V (soil thickness over s wave velocity)
0.0		
1.0		
2.5	196.082	0.0127
3.0	195.324	0.0026
4.0	173.645	0.0058
5.0	180.527	0.0055
6.0	297.661	0.0034
7.0	304.923	0.0033
8.0	296.117	0.0034
9.0	287.394	0.0035
10.0	312.549	0.0032
11.0	306.852	0.0033
12.0	310.571	0.0032
13.0	373.218	0.0027
14.0	400.231	0.0025
15.0	397.226	0.0025
16.0	384.706	0.0026
17.0	434.816	0.0023
18.0	420.435	0.0024
19.0	485.483	0.0021
20.0	581.710	0.0017
21.0	537.697	0.0019
22.0	510.204	0.0020
23.0	495.098	0.0020
24.0	480.947	0.0021
25.0	495.098	0.0020
26.0	526.841	0.0019
27.0	490.385	0.0020
28.0	495.098	0.0020
29.0	455.902	0.0022
30.0	413.251	0.0024

Sum of H/V : 0.089
Vs30 : 336.92
Ground Type : Type C

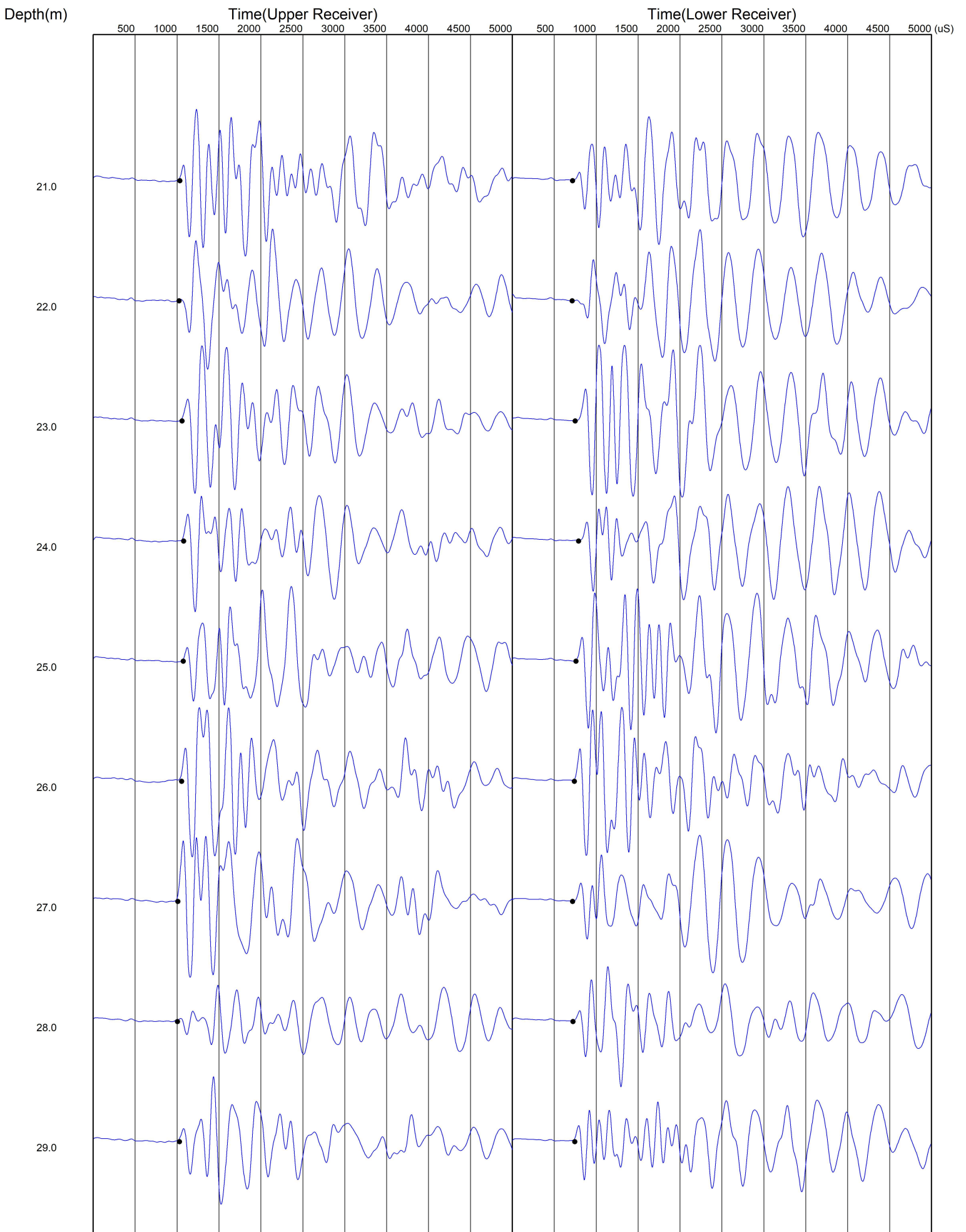
P Wave



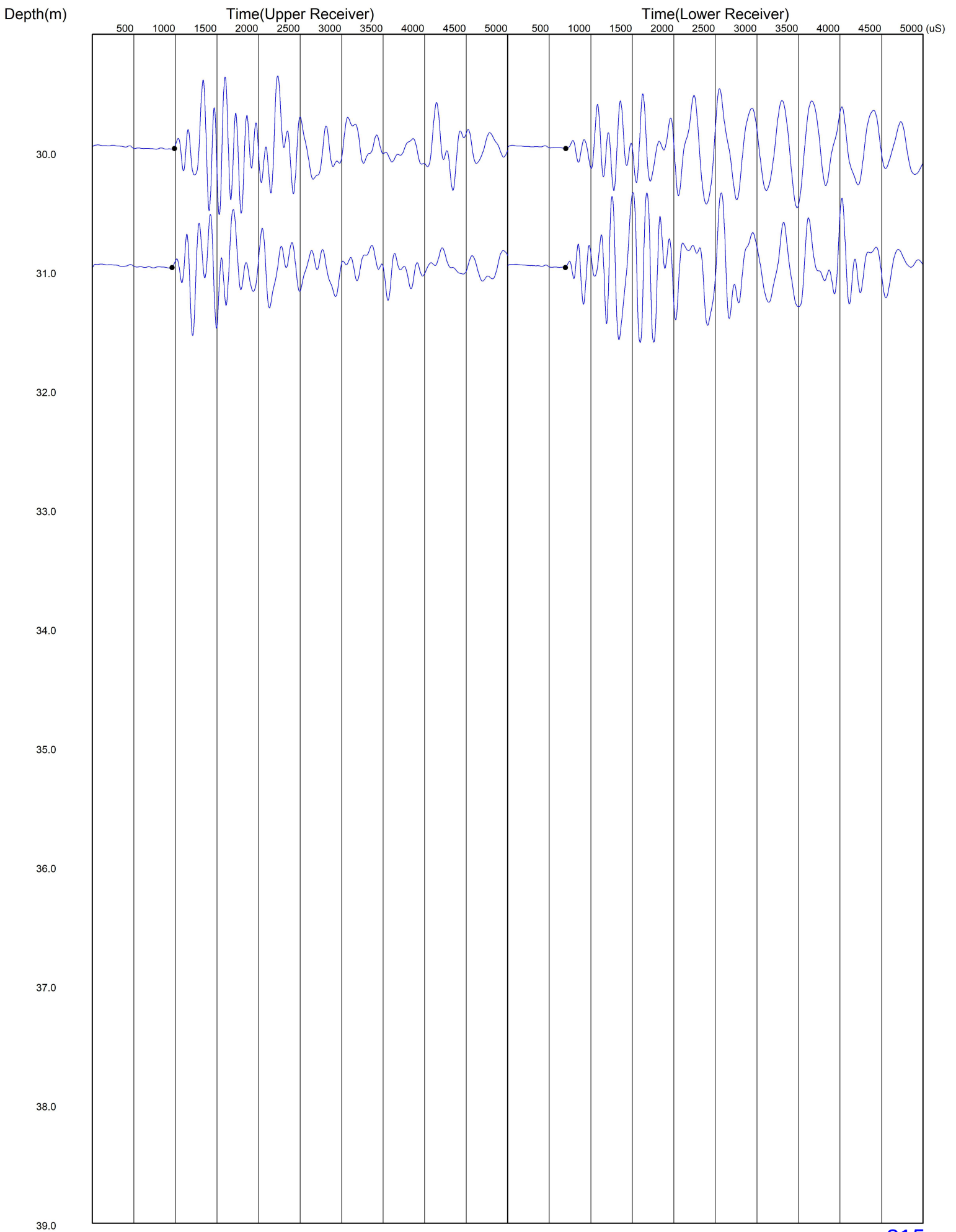
P Wave



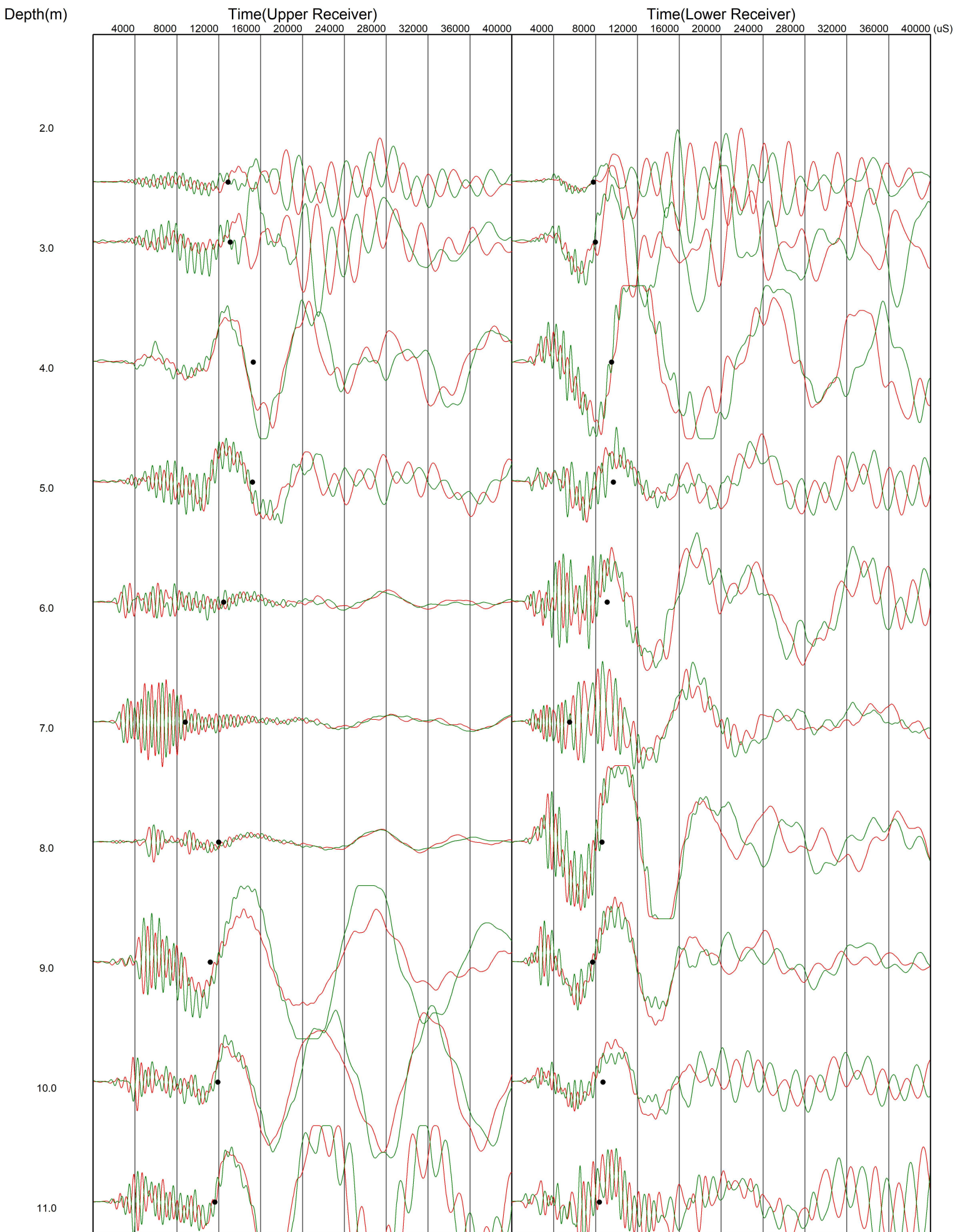
P Wave



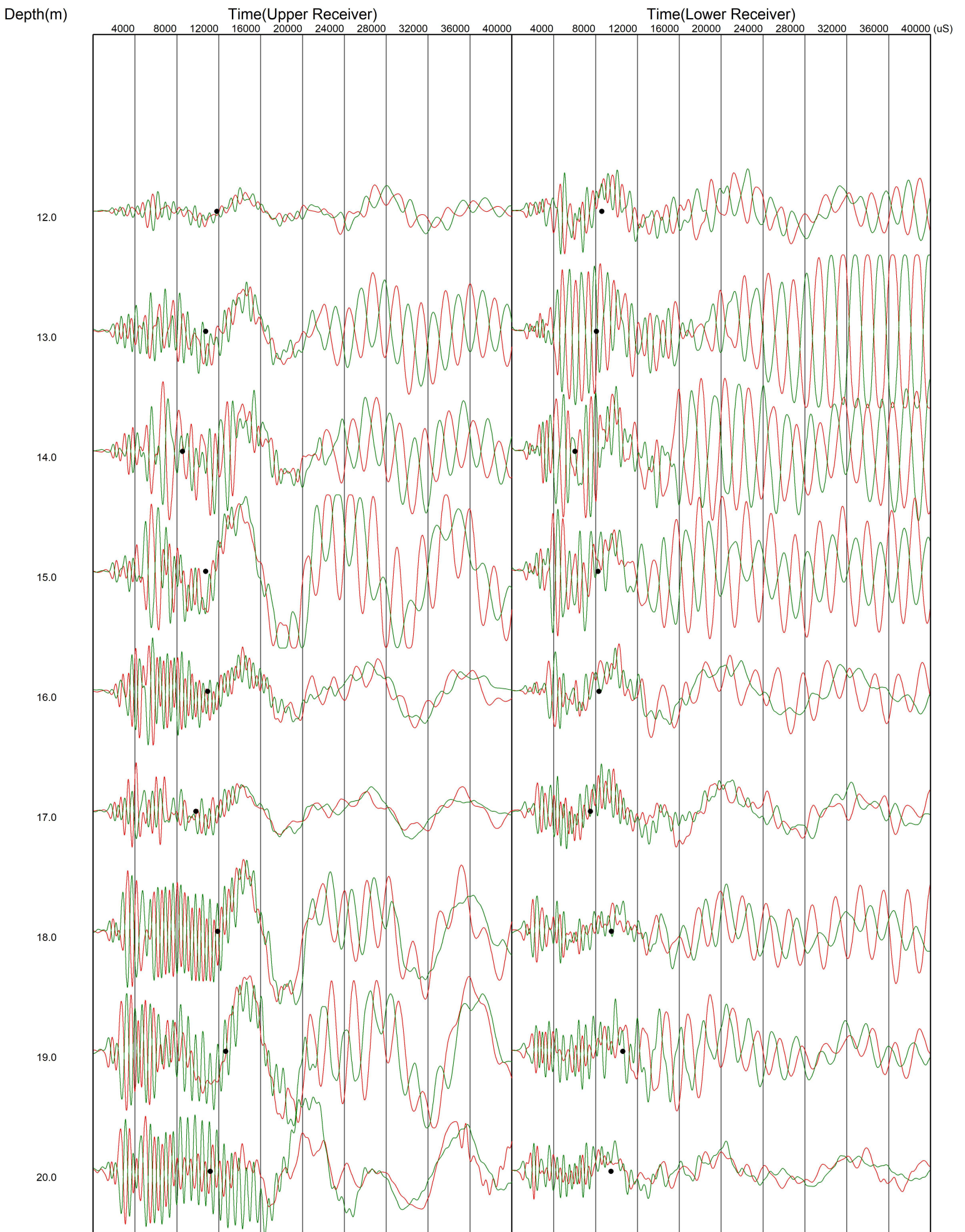
P Wave



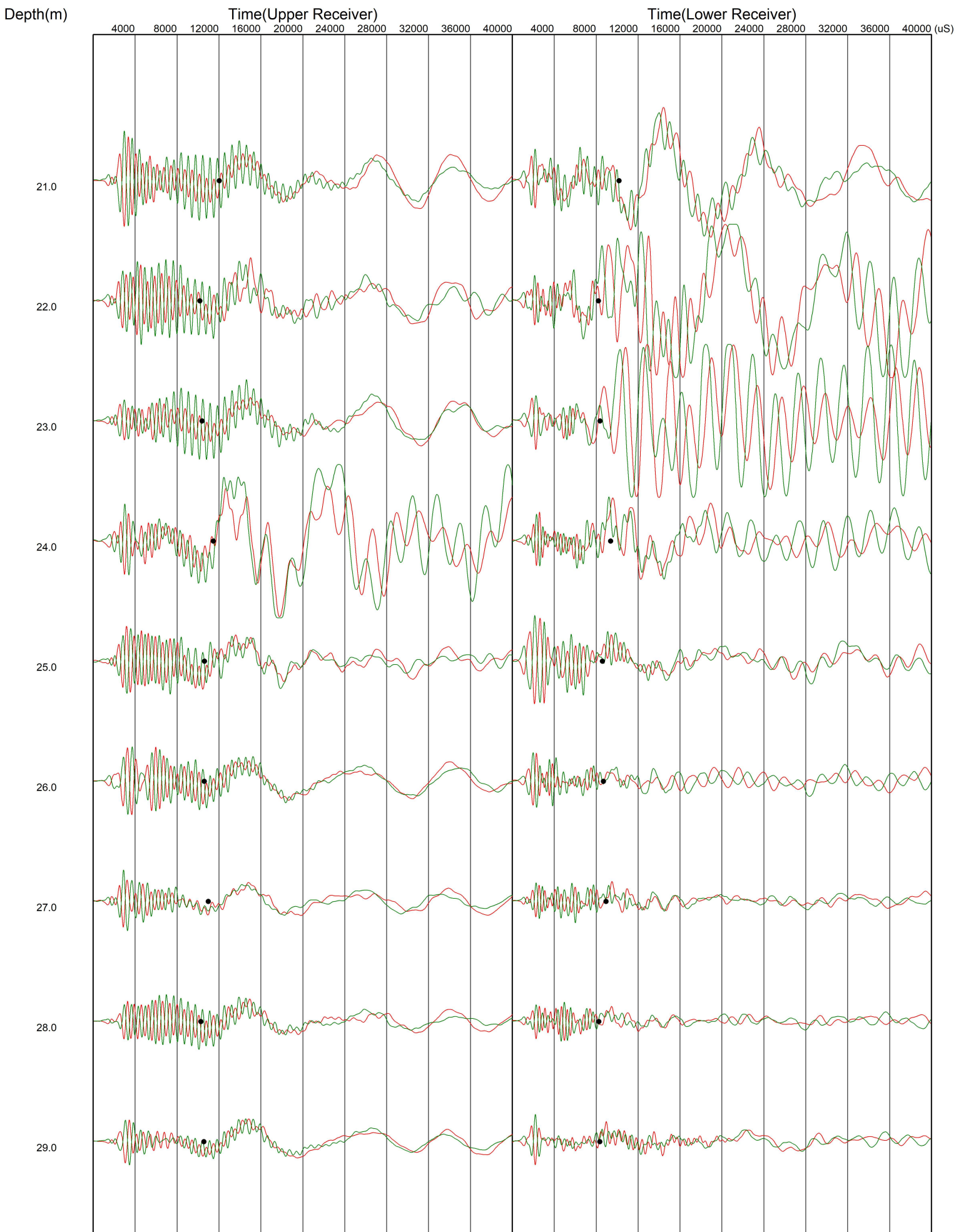
S Wave



S Wave

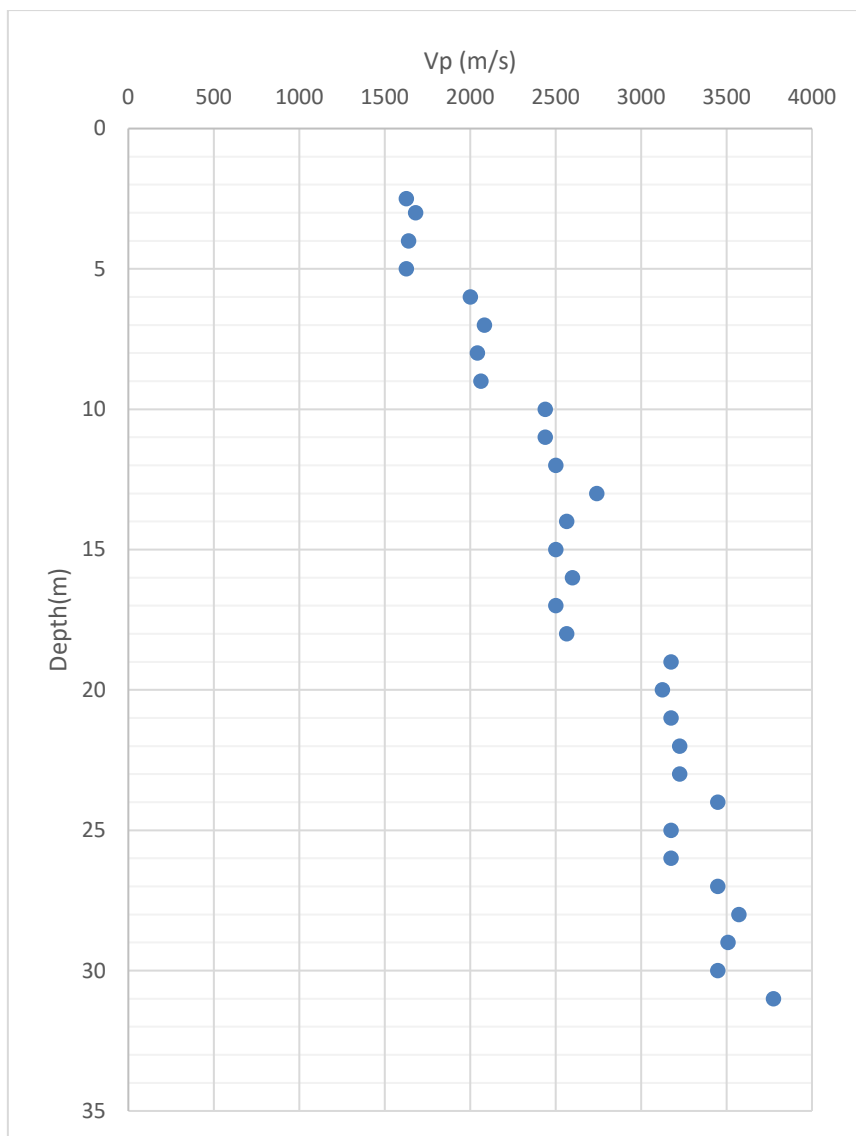


S Wave

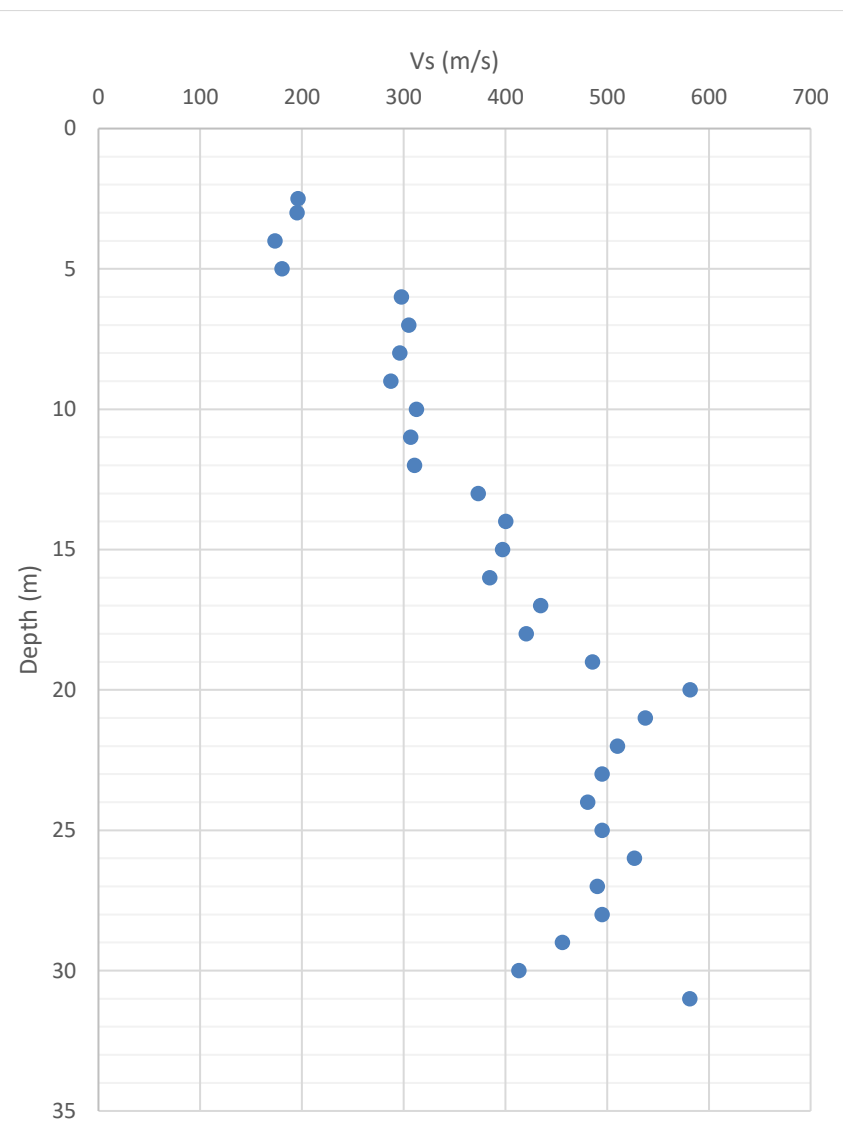


S Wave





BH-10



APPENDIX C

SITE PHOTOGRAPH

BH-10

