









TOTAL E&P PNG LIMITED

PAPUA LNG

Upstream Environmental Impact Statement

Volume 2: Environmental and Social Baseline

Part 9
Seabed and Coastal Geomorphology Baseline Report

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"Where will our knowledge take you?"



Papua LNG Project

Seabed and Coastal Geomorphology Baseline Report

August 2017

Prepared for Total Exploration and Production PNG Limited

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Papua LNG Project - Seabed and Coastal Geomorphology Baseline Report

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Executive Summary

Background

Total E&P PNG Limited (TEP PNG), a wholly owned subsidiary of TOTAL S.A. (TOTAL), is the largest partner in a joint venture to develop the Elk-Antelope gas field, located in Petroleum Retention License 15 (PRL-15) in Gulf Province, Papua New Guinea. This Project, known as the Papua LNG Project, will comprise upstream production well development and associated infrastructure at the gas field within PRL-15, construction of an upstream central processing facility (CPF) and delivery of gas and condensate via onshore and offshore export pipelines to a LNG plant site at Caution Bay, Central Province, 20 km northwest of Port Moresby.

This technical report provides the findings of a baseline study in relation to seabed and coastal geomorphology in the study area. This technical report forms part of the Environmental and Social Baseline Study (ESBS) for the Project Environmental Impact Statement/Environmental, Social and Health Impact Assessment (EIS/ESHIA). The study area encompasses three sub-areas, namely (1) Orokolo Bay and parts of the Purari River delta (collectively known as Orokolo Bay), (2) the nominal offshore export pipeline corridor through the Gulf of Papua (offshore export pipeline corridor), and (3) relevant parts of Caution Bay (Caution Bay).

The key objectives of the ESBS for seabed and coastal geomorphology are to:

- Identify the national, international and corporate regulatory and policy framework for assessment of impacts to seabed and coastal geomorphology, including the technical elements required to conduct an EIS/ESHIA.
- On the basis of a review of previous studies and data collection, describe seabed and coastal geomorphology baseline for the study area.

This report provides baseline seabed and coastal geomorphology information which adheres to Papua New Guinea national standards, International environmental guidelines, including the International Finance Corporation (IFC) Performance Standards and TOTAL company environmental performance specifications.

Study Approach

Existing information was reviewed to characterize the seabed and coastal geomorphology of the study area and to identify key information gaps requiring further assessment. Key information gaps included:

- Orokolo Bay – No existing information describing geomorphological processes or formations, other than Admiralty Charts.
- Caution Bay – Baseline descriptions and mapping of benthic features and coastal land; little information describing actual geomorphological processes.
- Offshore export pipeline corridor - Limited baseline benthic feature descriptions for the offshore export pipeline corridor to the junction with the PNG LNG subsea pipeline (due south of Orokolo Bay).

In order to supplement information gaps, two targeted field surveys were undertaken during nominal dry (20 June to 9 July 2016) and wet (12 and 31 January 2017) seasons. The surveys involved:

(1) Acoustic data collection to identify and map benthic features, including different substrate types.

(2) Sampling of sediment for further assessment of particle size distribution (PSD), as well as visual observation of benthic sediment (without subsequent analysis).

(3) Visual observation of coastal and seabed geomorphological features.

Field surveys were not intended to provide a complete coverage of the entire study area but provide a representation of the seabed and coastal geomorphology environment for the study area sufficient for the purposes of the EIS/ESHIA.

Study Findings

The key findings of the baseline characterization are as follows:

- The coastal environment of Orokolo Bay consists of two main geomorphological units: brackish and saltwater tidal flats, associated with the Purari River delta, and beach ridges and beach plains between Alele Passage and Vailala River.
- Visual observations and analysis of sediment samples at the Purari River delta and Orokolo Bay show a seabed composed predominantly of silts and clays.
- The sediment composition along the offshore export pipeline corridor is more than 90% silts and clays.
- Acoustic mapping indicates that the seabed in Orokolo Bay is relatively smooth with the only significant geomorphological feature being a rocky reef in the south-eastern part of the bay.
- Large volumes of terrigenous (i.e. derived from erosion of rocks on land) sediment are delivered to the coastline near Orokolo Bay by the Purari and Vailala rivers. Most of this sediment is deposited in shallow areas directly offshore but may be remobilized by wave-current bed shear stress, particularly during the southeast trade winds season.
- Net sediment transport offshore is likely to be directed towards the southeast along the offshore export pipeline corridor due to the prevailing currents, particularly during the southeast trade winds season.
- Shoreline sediment transport rates within Orokolo Bay are likely to be significant (driven by incident south-easterly waves) and a lobe of sediment forms a shoreline protrusion in the eastern part of the bay which is progressively migrating from the southeast to the west and elongating in shape.
- The shoreline alignment in Caution Bay is stable and is fringed by mangroves and coral reefs.

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1 Introduction

1.1 Project Overview

Joint venture partners, Total E&P PNG Limited (40.13%), ExxonMobil (37.03% – through SPI (208) Limited (35.48%) and SPI Security Holdings Limited (4.55%)), and Oil Search Limited (22.84 % – though Pac LNG Assets Limited (6.75%), Pac LNG International Limited (5.10%), Pac Overseas Limited (5%), Pac LNG Holdings Limited (3.49%) and Pac LNG Investments Limited (2.50%)) are planning the development of the Elk-Antelope gas fields located in Gulf Province, Papua New Guinea. The gas fields are located within Petroleum Retention License 15 (PRL-15). The Project will include infrastructure development inside PRL-15, and the construction of gas and condensate pipelines (export pipeline) to a liquefied natural gas (LNG) plant site at Caution Bay, 20 km northwest of Port Moresby.

The Project area comprises the physical footprint of the various Project components and associated infrastructure as detailed below (Figure 1-1).

- Production, processing and related facilities (within PRL-15):
  - Wellpads and the associated gathering system (including flowlines and trunkline).
  - Central processing facility (CPF).
  - Logistics base and river offloading facilities, accommodation camps, airstrip, roads and bridges.
  - Quarries, communications infrastructure.
  - Initial section of the onshore export pipeline.
- Onshore pipeline (outside PRL-15):
  - Remainder of the onshore export pipeline to landfall on the Gulf coast including valve stations.
  - Temporary laydown areas and camps.
  - Quarries and communications infrastructure.
- Transport (river) corridors:
  - River transport routes— the Purari, Urika-Ivo and Wame-Varoi rivers.
- Offshore pipeline:
  - Offshore section of the export pipeline to a LNG Plant site at Caution Bay.

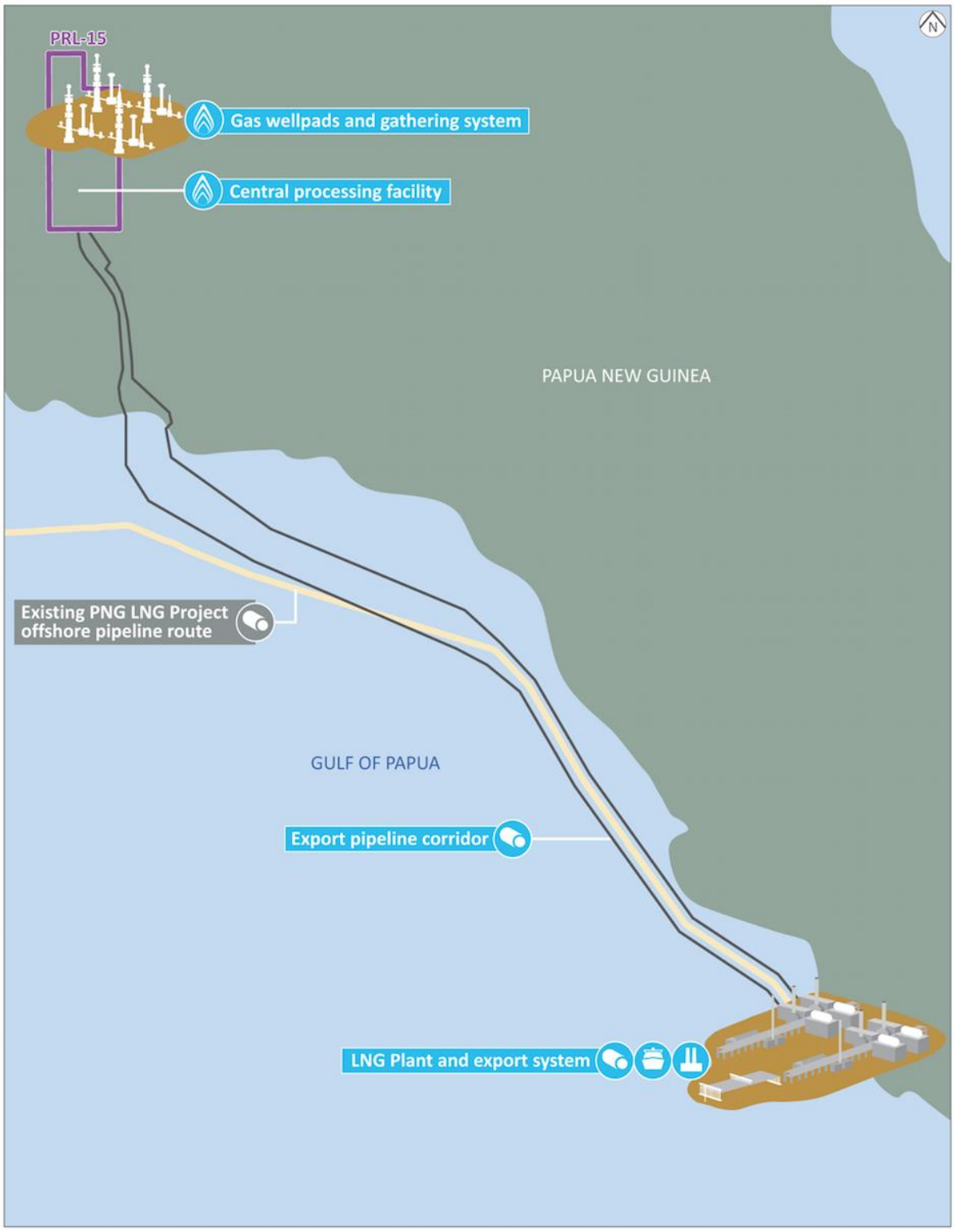


Figure 1-1 Schematic of the Project

1.2 Study and Objectives

This technical report describes the seabed and coastal geomorphology of areas potentially affected by the Project. This report is part of the seabed and coastal geomorphology study for the Environmental Impact Statement, and the Environmental, Social and Health Impact Assessment (EIS/ESHIA) for the Project. In particular, this report forms part of the Environmental and Social Baseline Study (ESBS) component of the EIS/ESHIA.

The study objectives of the seabed and coastal geomorphology study are to:

- Characterize seabed and coastal morphology and processes in the study area.
- Inform the mapping of marine habitat types in the study area, undertaken as part of the Marine Biodiversity study.
- Characterize potential sensitivities of coastal processes (e.g. subsea sand movements, beach/dune erosional processes) at the pipeline landfall sites.
- Inform development of sediment transport conceptual and numerical models to a level suitable for impact assessment.
- Undertake seabed mapping of marine habitat types to inform the Marine Biodiversity study and Marine Fisheries and Resources study and provide support in assessing potential impacts on seabed benthic and coral reef resource uses (ecosystem services).
- Plan and execute baseline studies to collect sufficient data to underpin assessment of potential project impacts to satisfy International Finance Corporation environment and social performance standards and to meet Papua New Guinea requirements under the *Environment Act 2000*.

Within the context of these study objectives, this ESBS technical report achieves the following:

- Identifies the national, international and corporate regulatory and policy framework for assessment of impacts to seabed and coastal geomorphology, including the technical elements required to conduct an EIS/ESHIA.
- On the basis of a review of previous studies and data collected through field survey, describes the seabed and coastal geomorphology baseline for the study area.

2 Regulatory Framework and Standards

The Project is regulated primarily under the *Environment Act 2000* and the *Oil and Gas Act 1998* together with aspects of the suite of recently introduced Marine Pollution Acts. In addition, TEP PNG will be guided by company environmental performance specifications and international guidelines for the purposes of the EIS/ESHIA. Therefore, there are three sets of performance standards applicable to the EIS/ESHIA:

- Papua New Guinea legislation, including Conservation and Environmental Protection Authority (CEPA) operational procedures and codes of practice under the *Environment Act 2000*.
- International environmental and social guidelines, including the IFC Performance Standards on Environmental and Social Sustainability.
- TOTAL company standards and commitments.

2.1 Papua New Guinean Authorities and Legislation

The following Papua New Guinean legislation is considered relevant for the purposes of the Project EIS/ESHIA:

- *Environment Act 2000*, including regulations and operational procedures/information guidelines
- *Oil and Gas Act 1998*
- Marine Pollution Acts, including:
  - *Marine Pollution (Preparedness and Response) Act 2013*
  - *Marine Pollution (Sea Dumping) Act 2013* and Marine Pollution (Sea Dumping) Regulation
  - *Marine Pollution: Ships and Installations Act 2013*.

These instruments identify critical aspects of the EIS process.

An EIS in Papua New Guinea is required under the *Environment Act 2000* in order to assess and understand the potential environmental impacts of significant activities prior to the issue of an Environment Permit. In particular, an EIS is required for Level 3 Activities identified under the Environment (Prescribed Activities) Regulation 2002. The Project is a Level 3 Activity in accordance with Sub-Category 18 of the Regulation. The *Environment Act 2000* and EIS process is administered by CEPA.

Under the *Oil and Gas Act 1998* the issue of licenses for petroleum projects, including Petroleum Development Licenses (PDLs), Pipeline Licenses (PLs) and Petroleum Processing Facility Licenses (PPFLs) require consideration of environmental aspects and management actions. A PDL can only be issued where the Minister administering the Act is satisfied that the project provides for the protection of the environment and welfare of people in the project area. In practice, the Minister relies on the EIS developed under the *Environment Act 2000* in making this assessment. The Minister administering the Act is the Minister of the Department of Petroleum and Energy.

The *Marine Pollution (Sea Dumping) Act 2013* requires a Sea Dumping Permit for the purposes of placement of certain waste material within marine waters. This includes dredged material but only

where material meets the contaminant guidelines set under the Marine Pollution (Sea Dumping) Regulation 2013. Non-compliant material is required to be placed on land. An application for a Sea Dumping Permit is considered separately to the application for an Environment Permit, though the assessment of dredged material contamination levels can be undertaken as part of an EIS. This process is administered by the National Maritime Safety Authority (NMSA).

The discharge of pollutants from installations and ships in the marine environment is prohibited under the *Marine Pollution (Ships and Installations) Act 2013* unless approved under an Environment Permit under the *Environment Act 2000*, assessed by CEPA.

In preparing an EIS and applying for an Environment Permit, a proponent is required to follow the process set out in operational procedures and guidelines prepared by CEPA. These include the following:

- Operational Procedure (2013): *Information Requirements for Permit Application & Registration of Intention to Carry Out Preparatory Works*.
- Information Guideline GL-ENV/02/2004: *Guideline for Conduct of Environmental Impact Assessment & Preparation of Environmental Impact Statement*.
- Information Guideline GL-ENV/03/2004: *Guideline for Submission of an Application for an Environment Permit to Discharge Waste.*
- Technical Guideline IB-ENV/04/2004: *Water & Land Discharges*.

In addition to the requirements of these guidelines, the *Marine Pollution (Prevention and Response) Act 2013* requires proponents for new petroleum-related facilities to undertake a marine pollution risk assessment as part of an EIS. This allows for marine pollution risks to be assessed as part of an Environment Permit application. A detailed marine pollution contingency plan must then be developed after the approval of the installation.

2.2 International Standards and Guidelines

TEP PNG has committed to preparing an EIS/ESHIA for the Project consistent with a number of international standards and guidelines. These are:

- Equator Principles and World Bank Safeguards.
- IFC Performance Standards.
- Organization for Economic Cooperation and Development (OECD) Common Approaches.
- International Petroleum Industry Environmental Conservation Association (IPIECA) Guidelines.
- Any international convention ratified by the Government of Papua New Guinea (that has not been given effect under legislation listed above).

Preparation of an ESHIA for the purposes of environmental due diligence is required under the World Bank Safeguards, Equator Principles and OECD Common Approaches. The IFC Performance Standards provide specific guidance on the ESHIA process.

IFC Performance Standard (PS) 1 establishes the framework for preparing an ESHIA in order to assess and manage the impacts from a particular activity. The remaining Performance Standards (PS2 to PS8) provide more detail on the assessment and management of impacts in particular areas, including pollution/discharges to the environment (PS3) and biodiversity conservation (PS6). The IFC Performance Standards are supplemented by Environmental, Health and Safety (EHS) guidelines which provide examples of good international industry practice (GIIP) for certain activities.

In accordance with the IFC Performance Standards an ESHIA is required to consider the risk of an activity to the environment within the activity's 'area of influence'. This includes consideration of the impacting processes in the relevant industry-specific EHS Guidelines.

Under PS3, the ESHIA is required to describe the ambient environment conditions in the area of influence, including the assimilative capacity. This then forms the basis of assessing potential pollution impacts and for the setting of impact criteria. Performance Standard 6 requires the ESHIA to include a distinction between 'modified', 'natural' and 'critical' habitat in order to appropriately quantify and manage impacts to biodiversity and ecosystems services.

The IPIECA has prepared a number of guidelines for the petroleum industry to advise proponents on best practice related to ESHIA processes. These guidelines include a focus on biodiversity and ecosystem services, oil spill preparedness, and water.

The key features of the most relevant guidelines include: locating and assessing sensitive areas (including protected areas, sensitive habitats and rare, threatened or endangered species) as part of project planning; assessing baseline ecological conditions to inform the occurrence of and vulnerability to alien invasive species; and assessing the potential impacts of abstraction of and discharge to naturally-occurring water sources, including cumulative impacts and the effects of climate change.

2.3 TOTAL Company Standards and Commitments

TOTAL has developed the following general specifications for the purpose of environmental impact assessment that are relevant to the Project EIS/ESHIA:

- GS EP ENV 120: Environmental impact assessment of E&P activities.
- GS EP ENV 111: Environmental Baseline and Monitoring Studies: Onshore Sites.
- GS EP ENV 112: Environmental Baseline and Monitoring Studies: Offshore Sites.

GS EP ENV 120 provides details on the process for undertaking an environmental impact assessment and preparing an environmental management plan. The instrument adopts the ISO14001 approach for impact assessment and management. Some relevant specific requirements of the specification include:

- Identification of the physical, biological and socio-economic context of a project, including sensitivities of the environment.
- Assessment of impacts within an 'area of influence'.
- Use of a modeling study (if relevant) to assess liquid effluent discharges dispersion.

The specifications also identify a methodology for impact assessment and contents of an environmental management plan (including oil spill contingency plan).

GS EP ENV 111 and GS EP ENV 112 specify the type of data to be collected for baseline purposes. These include physicochemical properties of marine sediment and water, rare and endangered species, and flora and fauna bioindicators.

3 Study Area

The Project occurs across the northern and eastern ends of the Gulf of Papua, as shown in Figure 1-1. Studies are being undertaken across much of this area as part of the EIS/ESHIA. For the purposes of this ESBS, the 'study area' includes only the marine elements of the Project and surrounding area.

Figure 3-1 provides an overview of the study area. This includes the following three subsets:

- Coastal and nearshore environments at Orokolo Bay and offshore the Purari River delta, located at and adjacent to the upstream segment of the export pipeline corridor and offshore potential riverine transport routes along Wame-Varoi, Urika-Ivo and Purari rivers. This area is located in the Gulf Province.
    - Orokolo Bay refers to the bay embayment between the eastern-most mouth of the Purari River delta and the mouth of the Vailala River.
    - Purari River delta represents the area between the Purari and Wame-Varoi river mouths.
- Offshore environments in the Gulf of Papua at and adjacent to the offshore segment of the export pipeline corridor (offshore export pipeline corridor). The western sediment of the offshore export pipeline corridor is located offshore from the Gulf Province whereas the eastern segment is located offshore from the Central Province.
- Coastal nearshore environments at and adjacent to Caution Bay at the downstream end of the export pipeline corridor (Caution Bay study area). This area is located in the Central Province region.

The waters in the study area include nearshore and offshore waters. For the purposes of this report, 'nearshore' waters are those between mean high water springs and the 15 m depth contour. 'Offshore' waters represent all waters seaward of the 15 m depth contour.

Figure 3-2 through Figure 3-4 show parts of Orokolo Bay, the Purari River delta and Caution Bay.



Title:

Seabed and Coastal Geomorphology Study Area

Figure: 3-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Approx. Scale

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Figure 3-2 Approach to Purari River Delta (June-July 2016)



Figure 3-3 Orokolo Bay (June-July 2016)



Figure 3-4 Caution Bay – View Northwest from Shore South of PNG LNG Project Jetty (June-July 2016)

3.1 Climate

The following provides an overview of the climatic setting of the study area. More detailed climatic and meteorological information is provided in the Upstream Hydrology and Meteorology Baseline Report (BMT WBM, 2017a; Part 2 of ESBS Dossier) and the Physical Oceanography Baseline Report (BMT WBM, 2017b; Part 10 of ESBS Dossier).

3.1.1 Orokolo Bay, Purari River Delta and Western Offshore Export Pipeline Corridor (Gulf Province)

Seasonal wind patterns in the Gulf Province are the occurrence of strong southeast trade winds from April to November and lighter northwest monsoon winds from December to March. In contrast to Caution Bay, rainfall at Kerema (to the east of the study area) is not as strongly seasonal, with mean monthly totals ranging from 209 to 437 mm. May to October represent the wetter months with mean rainfall totals 299 mm and above. The mean annual rainfall is 3,612 mm and mean evaporation rate 1,420 mm (Evesson, 1983).

The coolest month is August which has mean daily maximum and minimum temperatures of 27ºC and 22ºC respectively. The warmest months are December and January with a mean daily maximum temperature of 31ºC. There is little variation in the mean daily minimum (±1ºC) and maximum (±3.5ºC) temperatures throughout the year (Evesson, 1983).

The Gulf Province coast is north of the main cyclone belt.

3.1.2 Caution Bay and Eastern Offshore Export Pipeline Corridor (Central Province)

The main seasonal climate patterns of Caution Bay, within the Central Province, consist of:

- Dry season from May to October, with prevailing southeast trade winds.
- Wet season from December to March, when the lighter northwest monsoon winds prevail. Approximately 80% of the mean annual rainfall of 1,200 mm occurs during the wet season.
- Transition periods during April and November, when winds are generally calmer.

Monsoon surges with strong northwest winds have been observed in the region. These short-lived squalls of about one hour's duration with wind speeds of 55 to 65 km/hr are locally known as *gubas*.

The coolest months are July and August when the mean daily maximum and minimum temperatures are 28ºC and 23ºC respectively. The warmest months are December and January when the mean daily maximum and minimum temperatures are 32ºC and 24ºC respectively. There is little variation in the mean daily minimum (±1ºC) and maximum (±4ºC) temperatures throughout the year (CNS, 2009).

Caution Bay (i.e. the location of the LNG Plant and downstream supporting infrastructure) is north of the main cyclone belt and occurrence of such events in the Gulf of Papua is rare, with only five named cyclones in 15 years entering the gulf, all situated well south of Caution Bay. Cyclones generally occur from February to April.

3.2 Anthropogenic Setting

The following provides an overview of the anthropogenic setting of the study area, including population distribution and marine-based activities. More detailed information is provided in the Upstream Community and Demographics Baseline Report (Finlayson, 2017; Part 14 of ESBS Dossier), Marine Fisheries and Resources Baseline Report (ERIAS Group, 2017a; Part 13 of ESBS Dossier), and Marine and River Traffic and Transport Baseline Report (ERIAS Group, 2017b; Part 22 of ESBS Dossier).

3.2.1 Orokolo Bay and Purari River Delta (Gulf Province)

Population patterns across Orokolo Bay and the Purari River delta are marked by a generally low inland population scattered or concentrated in small villages along riverbanks, and a much denser population in large villages and hamlets across the coastal strip. The principal villages in the Purari/Orokolo area are:

- Purari River delta: Akoma, Aivei and Apiope.
- Orokolo Bay: Harevavo and Hororo.

All coastal communities engage in subsistence fishing activities in nearshore and offshore waters, with some limited commercial fishing also occurring. These activities tend to occur in the coastal zone out to three nautical miles, beyond which commercial trawling occurs as part of the Gulf of Papua Prawn Fishery (see below). Fishing activities typically use small outrigger canoes and y-nets, with canoes primarily used to set gill nets but also to fish in deeper water with hook-and-line.

Subsistence and artisanal fishing activities are strongly seasonal, with fishing from outrigger canoes more restricted during the southeast trade winds due to the generation of dangerous sea conditions.

Limited shipping traffic occurs in Orokolo Bay and offshore of the Purari River delta as it is outside of existing commercial shipping channels, with the exception of boats from local villages (ERIAS Group, 2017b).

3.2.2 Offshore Export Pipeline Corridor

The offshore export pipeline corridor includes areas within the Gulf of Papua Prawn Fishery, regulated by the National Fisheries Authority (NFA). This fishery occurs at least three nautical miles offshore, in waters up to about 40 m depth, and extends east from the Purari River delta as far as the village of Iokea (near the border of Gulf and Central provinces).

An artisanal dive fishery for rock lobsters occurs on the coastal reefs around Yule Island where lobster annually migrate from the Torres Strait to spawn during November to April.

Various shipping traffic occurs within the Gulf of Papua, including a number of coastal vessels that cross the offshore export pipeline corridor. These include cargo, tanker and passenger vessels, as well as logging ships transiting between ports at Port Moresby, Baimuru, Kumul terminal, Kikori and Daru.

3.2.3 Caution Bay (Central Province)

Along the coastal strip of Caution Bay there are four villages: Lea Lea, Papa, Boera and Porebada. Each of these villages are populated by mixed populations of people from the Koita and Motu people groups. The population density across the area is 10 persons/km^2.

In addition to these villages, the ExxonMobil LNG Plant, part of the PNG LNG project, occupies part of the coastal strip between Papa and Boera. This facility includes an LNG jetty and wharf that extend out into Caution Bay. Brine from a desalination plant is discharged into the bay from a pipeline attached to this jetty, while hydrotest water (produced during construction phase only) was discharged to nearshore waters north of the LNG jetty.

Artisanal fisheries in Caution Bay are considered important for subsistence and income purposes for Lea Lea, Papa, Boera and Porebada. Fishing is primarily undertaken on inshore fringing reefs and shallow shoals, but is also undertaken in mangrove communities and at barrier reefs. Fishing in offshore areas is restricted by sea conditions but is less limited in sheltered inshore areas. There is a high dependence in local communities on coastal and marine resources. Subsequent to the development of the LNG plant, a 500 m exclusion zone is maintained around the LNG jetty, restricting fishing activities in this area.

Most boat traffic in Caution Bay is associated with the local villages or with operations of the LNG plant. Commercial shipping traffic, including commercial fishing vessels, generally occurs beyond the outer reef, outside of the bay (ERIAS Group, 2017b).

4 Existing Information

The following section describes the previous studies that are considered relevant to the study area. The actual content of this literature has been integrated, as relevant, into the findings described in Section 6.

4.1 Prior Studies within the Study Area

4.1.1 Published Reports

Table 4-1 summarizes all the significant previous environmental impact assessment studies conducted within the study area (and neighboring regions). These represent a significant body of existing information relevant to the study area which has been used in the preparation of this Seabed and Coastal Geomorphology Baseline Report.

NOTE: This sections considers only published reports; unpublished reports are discussed in Section 4.1.2.

The survey sites from previous studies that overlap with the study area are shown in the following figures:

- Figure 4-1 – seabed survey sites for offshore export pipeline corridor (CNS, 2008a)
- Figure 4-2 – seabed survey sites for Caution Bay (CNS, 2008b)

Most of the studies undertaken as part of the 1979 Purari Hydroelectric Project EIS have been reported in Petr (1983), *The Purari: Tropical environment of a high rainfall river basin*. Chapter 4 of Part I of this book, 'Geomorphology of the Purari Delta' (Thom and Wright, 1983) is considered relevant to the seabed and coastal geomorphology study. Geomorphology sampling sites in the Purari River delta reported in Thom and Wright (1983) are shown in Figure 4-3.

Table 4-1 Summary of Previous Relevant Environmental Assessment Studies

Project/study	Year	Author	Geographic overlap	Relevance to ESBS	Relevant reports
PNG LNG Project EIS (prepared for Esso Highlands Limited)	2009	Coffey Natural Systems	Offshore export pipeline corridor and Caution Bay	Detailed seabed and coastal geomorphology information for Caution Bay and offshore export pipeline corridor Regional and comparative seabed and coastal geomorphology information	PNG LNG Project Environmental Impact Statement (2009) Offshore Impact Assessment (2008) Nearshore Marine Impact Assessment (2008)
Purari River (Wabo) Hydroelectric Scheme Environmental Studies	1979	Papua New Guinea Government	Uncertain, though results of EIS are mostly reported in Petr (1983)		

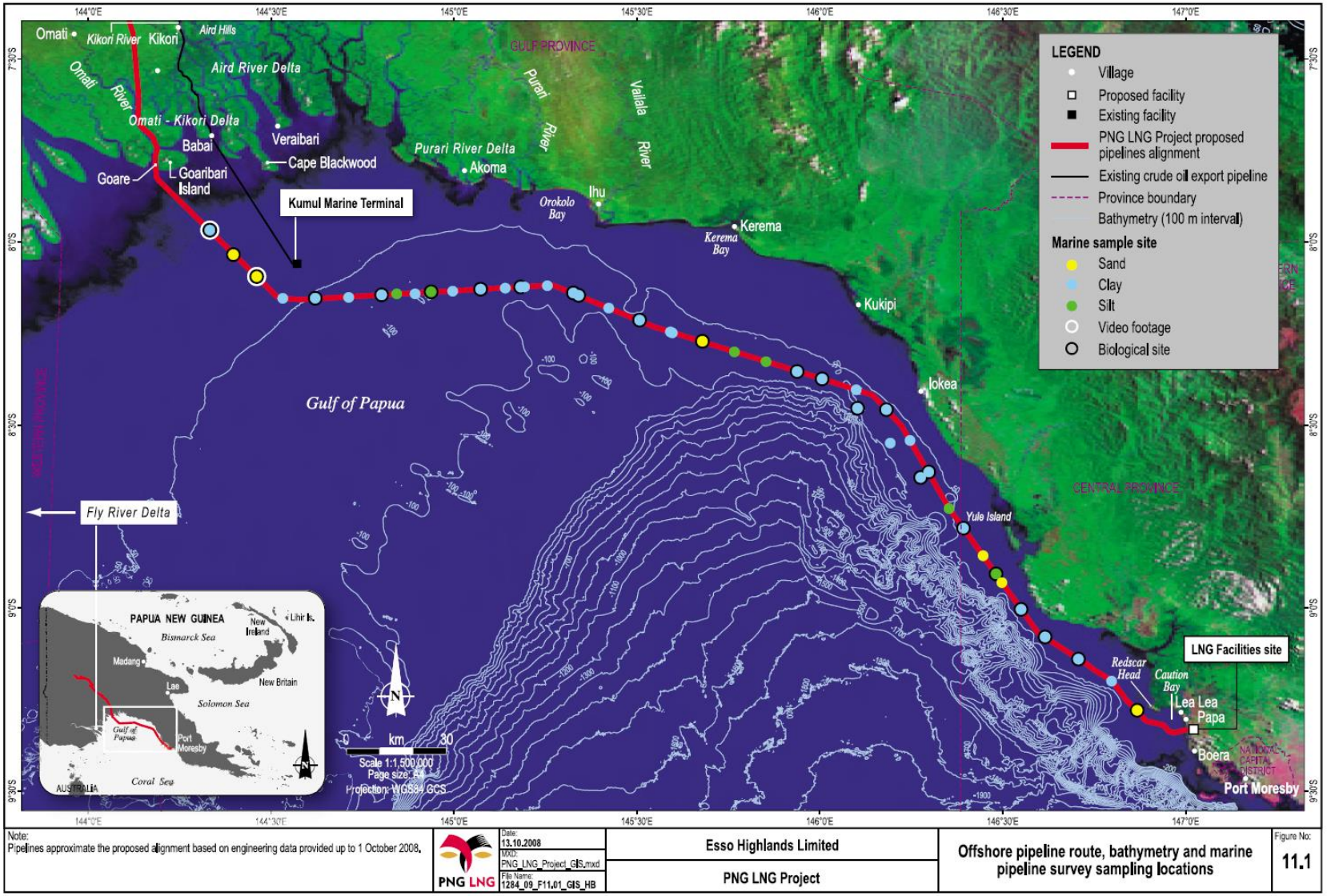


Figure 4-1 Offshore Export Pipeline Corridor Seabed Survey Sites – PNG LNG Project EIS (CNS, 2008a)

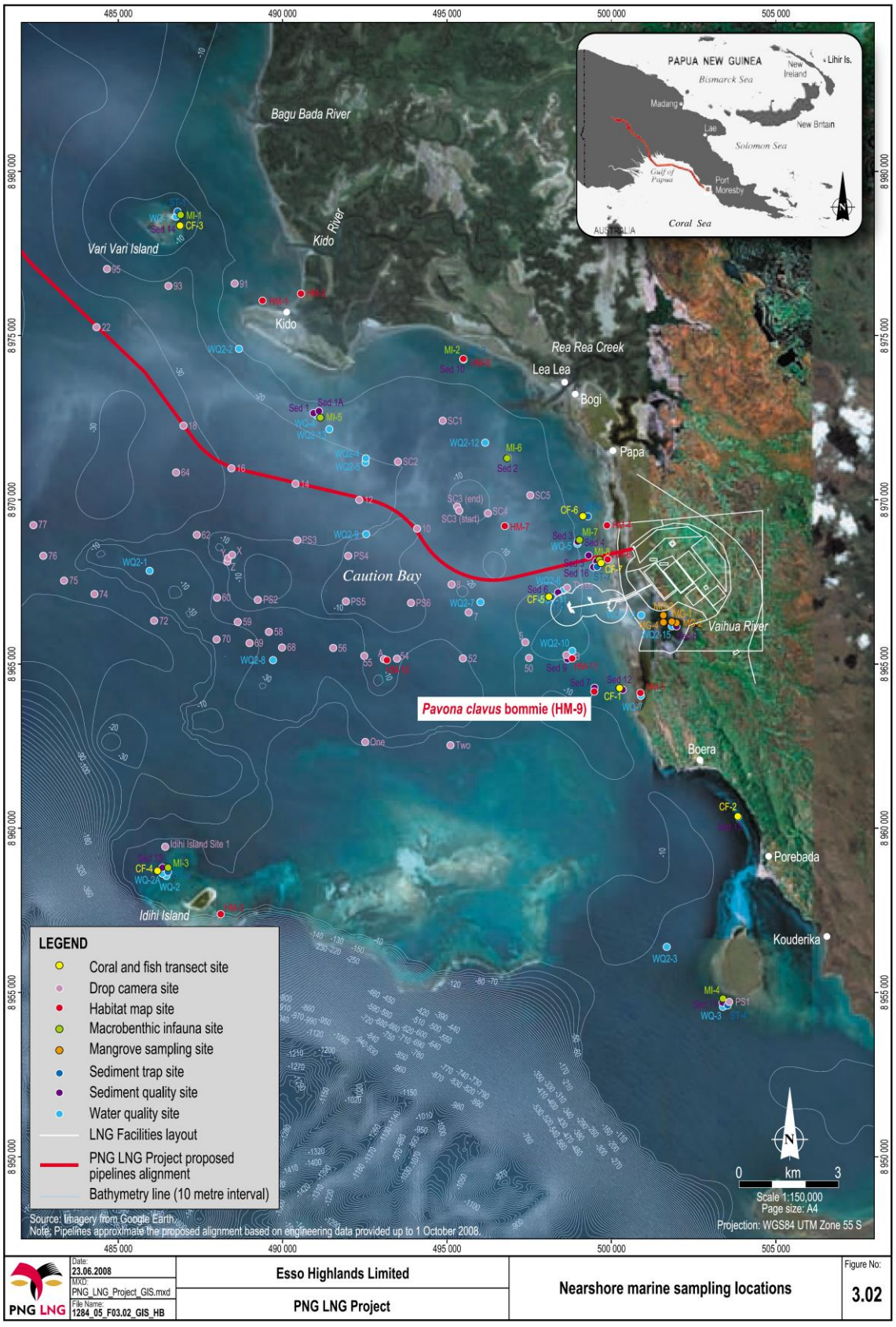


Figure 4-2 Caution Bay Seabed Survey Sites – PNG LNG Project EIS (CNS, 2008b)

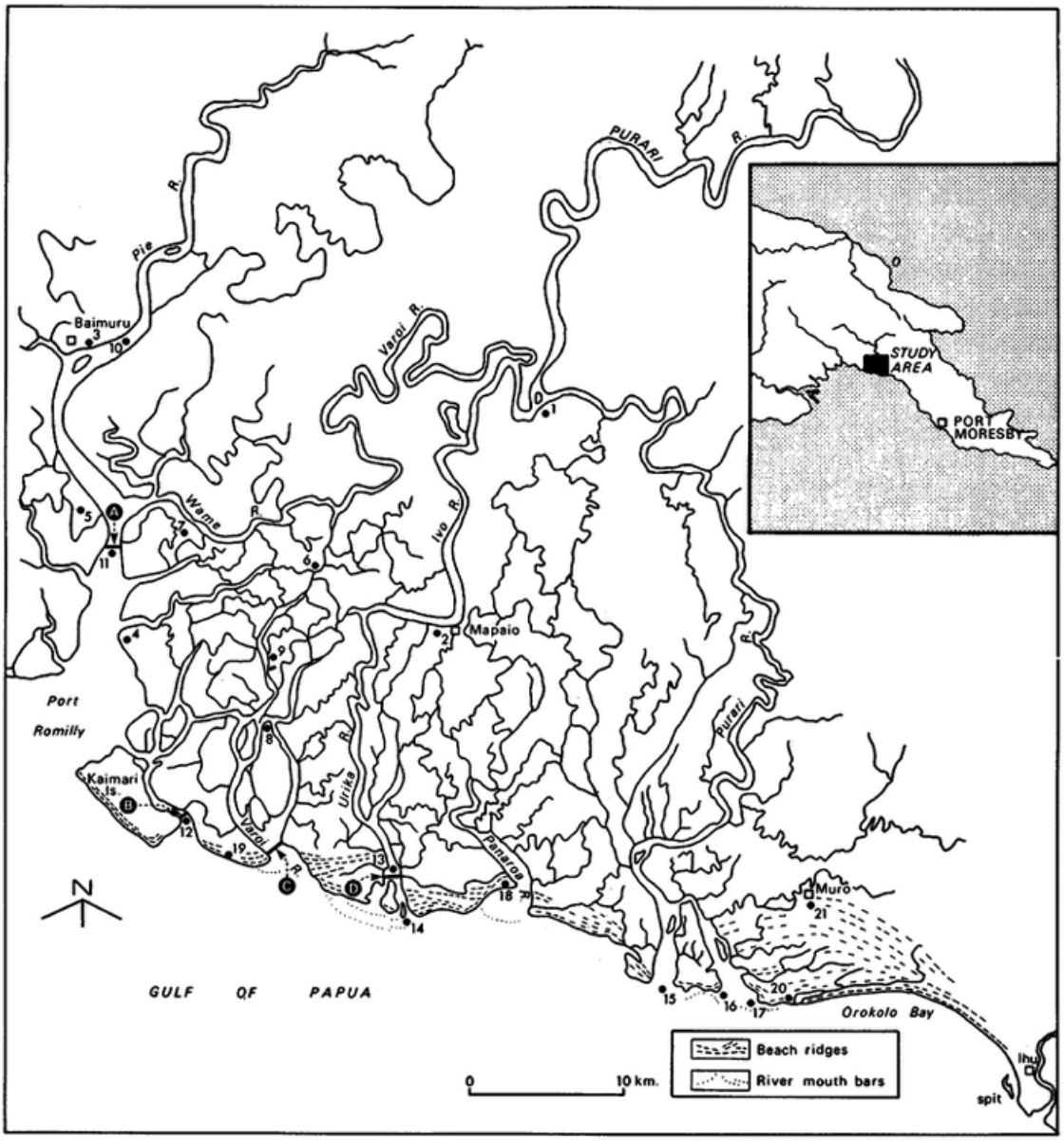


Figure 4-3 Purari River Delta Geomorphology Sampling (Thom and Wright, 1983)

4.1.2 Unpublished Reports

In addition to the published reports discussed in Section 4.1.1, the other studies known to have occurred in the study area, but which have not been published, consist of:

- Acoustic habitat/seafloor mapping conducted for a corridor between Kerema and Port Moresby
- Coastal processes and geomorphology assessments in Kerema Bay.

The information from these studies has been used, as where relevant, in the preparation of this baseline report.

4.2 Studies in Neighboring Regions

The PNG LNG Project EIS (CNS, 2009) covers an area that extends beyond the present study area. As a result, assessments have been undertaken in neighboring areas, i.e. the Kikori River delta and parts of the western Gulf of Papua. This provides a contextual understanding of the coastal processes and geomorphology in these locations.

4.3 Summary

Based on the studies cited above, the following information is known to be available for the study area:

- Qualitative coastal processes and geomorphology data for the Purari River delta and Orokolo Bay, with some quantitative data in the form of sediment descriptions in the delta.
- Seabed classification for much of the offshore export pipeline corridor, together with some areas of acoustic seabed mapping at the eastern end of the corridor (where it enters Caution Bay). There is also extensive literature available regarding the coastal processes that operate within the gulf, together with bathymetry.
- High level description of coastal processes and seabed classification for Caution Bay, although this was prior to the construction of the PNG LNG plant and associated marine facilities (e.g. berths, jetty) which may have caused some morphological changes to the existing environment within the immediate vicinity of these facilities (e.g. accumulation of sediment transported by coastal processes). Some areas of Caution Bay (western side) have also been subject to acoustic seabed mapping.

Regional/adjoining information is available from western gulf (i.e. Kikori River delta and surrounds). This provides some relevant information that can be used to contextualize the study area and/or can be extrapolated to assist with characterization of the study area.

5 Approach and Methods

This section provides a summary of the methods adopted for desktop studies, data collection and numerical modeling. A complete description of the methodology and justification for field-based studies is provided within the scope and methods ('rationale') report for marine studies (ERIAS Group, 2016a) and relevant addendum (ERIAS Group, 2016b).

5.1 General Approach

The study approach was based on a review and analysis of existing information, together with targeted field surveys to address identified gaps and detailed numerical modeling. Two field sampling events were completed between 20 June and 9 July 2016 and between 12 and 31 January 2017. Desktop review, field surveys and modeling focused on obtaining the following information:

- Physical characteristics of seabed sediments (e.g. grain size) and identification of geomorphological features within the supra-, inter- and sub-tidal zones of the study area – this provides the baseline environment in terms of existing physical features.
- Physical processes that drive morphological changes in the coastal/marine environment (e.g. longshore drift) – this provides the baseline environment in terms of actual processes that impact on physical features.

Modeling activities undertaken for this baseline study consisted of the use of the same numerical modeling system established for the physical oceanography study to provide an understanding of physical processes. Further description of this modeling system is provided within the Physical Oceanography Baseline Report (BMT WBM, 2017b).

5.2 Data Sources

The key data source utilized for the desktop assessment was the publicly available data for the PNG LNG Project EIS. In addition, overlapping and regional studies described in Sections 4 provide context for the study area.

5.3 Field Surveys

Two field surveys were undertaken in order to supplement existing information on seabed and coastal geomorphology and to provide data necessary for numerical modeling. These surveys were undertaken in June-July 2016 and January 2017. The methodology for these field activities is described in the marine studies scope and methods ('rationale') (ERIAS Group, 2016a) and addendum (ERIAS Group, 2016b).

Sampling activities consisted of the following activities:

- Ground-truthing of maps of intertidal communities and habitat types.
- Visual observations and descriptions of coastal geomorphology features, including location of beaches and dune systems, rocky outcrops, and evidence of coastal processes.
- Collection of surface material samples at points within the intertidal and subtidal zone that represent distinct sediment types, and assessment of particle size distribution (PSD).

- Acoustic habitat mapping using side scan sonar (SSS) and single-beam backscatter data collection, together with ground-truthing by drop-camera and/or sediment grabs.

Figure 5-1 to Figure 5-3 show the location of acoustic habitat mapping and sites where ground-truthing/validation and sediment sampling was undertaken. Table 5-1 summarizes the activities undertaken in each part of the study area. The acoustic mapping methodology is described further in the Marine Biodiversity Baseline Report (BMT WBM, 2017d; Part 12 of ESBS Dossier).

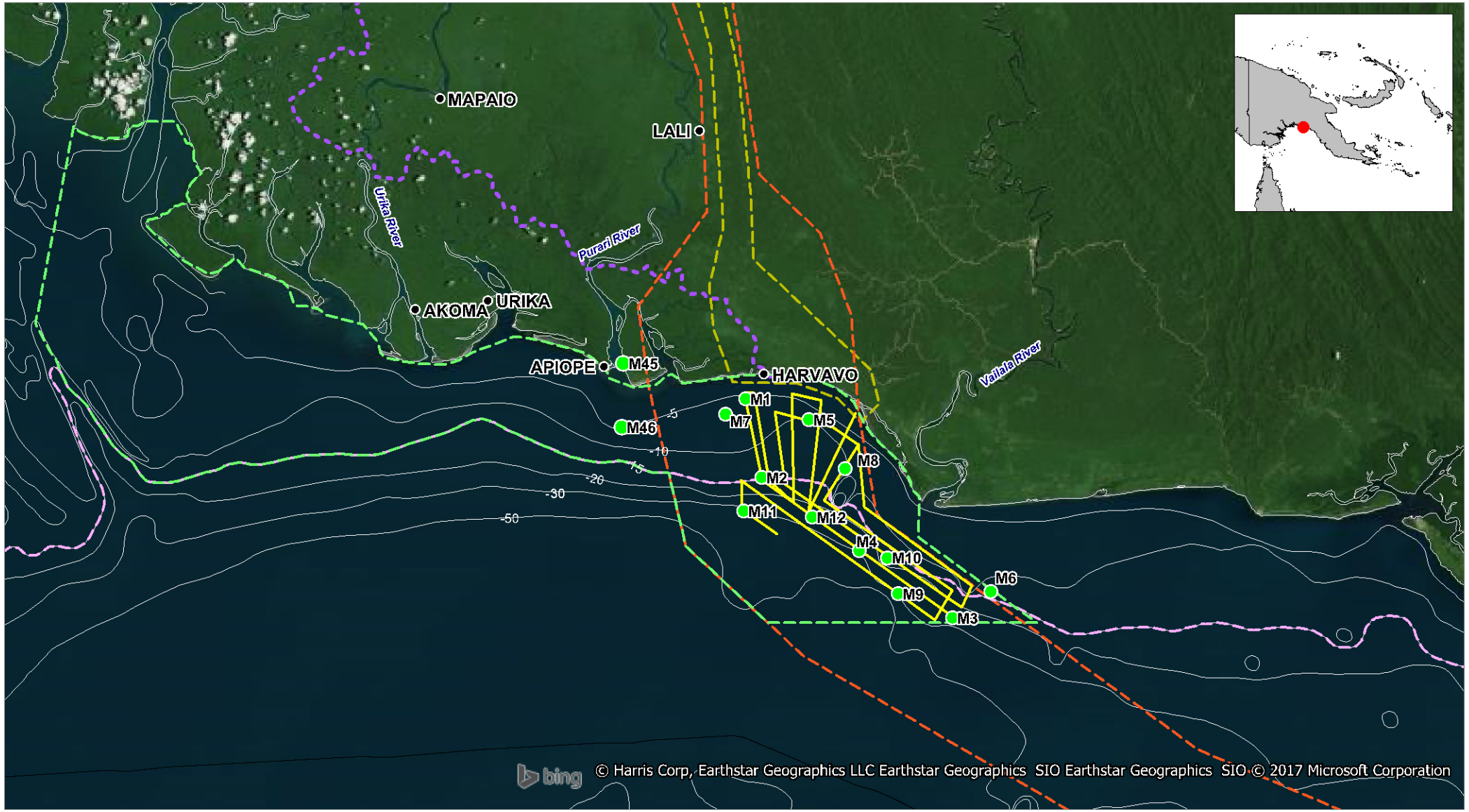
Field surveys were conducted from a live-aboard research vessel, the *Browse Enterprise*.

Table 5-1 Summary of Seabed and Coastal Geomorphology Sampling Activities

Sampling activity	Area	Survey	Notes
Ground-truthing of maps of intertidal communities and habitat types	Orokolo Bay	June-July 2016	
	Caution Bay	June-July 2016	
Visual observations of geomorphology features	Orokolo Bay	June-July 2016 January 2017	
	Caution Bay	June-July 2016 January 2017	
	Offshore Export Pipeline Corridor	June-July 2016 January 2017	
Collection of sediments	Orokolo Bay	June-July 2016	No sediment sampling was possible at Caution Bay due to risk of unexploded ordnances
	Purari River Delta	January 2017	
	Offshore Export Pipeline Corridor	June-July 2016	
Acoustic habitat mapping and ground-truthing	Orokolo Bay	June-July 2016	
	Caution Bay	January 2017	Ground-truthing conducted by drop camera only due to risks to sediment sampling from unexploded ordnances

5.4 Permits Obtained

All sediment quality samples collected during field surveys were tested at Australian laboratories, therefore a Permit to Import was required to import the samples into Australia. The laboratory used for analysis, Australian Laboratory Services (ALS), holds the required Permit to Import and no additional permits were required to be obtained directly by BMT WBM or ERIAS Group.



LEGEND

- Town/Village
- Sampling Sites
- ESBS Study Area
- -5 Contours (m)
- Acoustic Survey Lines
- Nearshore/Offshore Waters Boundary
- Indicative Estuarine/ Freshwater Boundary
- Pipeline Corridor
- Narrowed Onshore Pipeline Corridor

Title:

Location of Study Sites in Orokolo Bay and Purari Delta

Figure: 5-1

Rev: A

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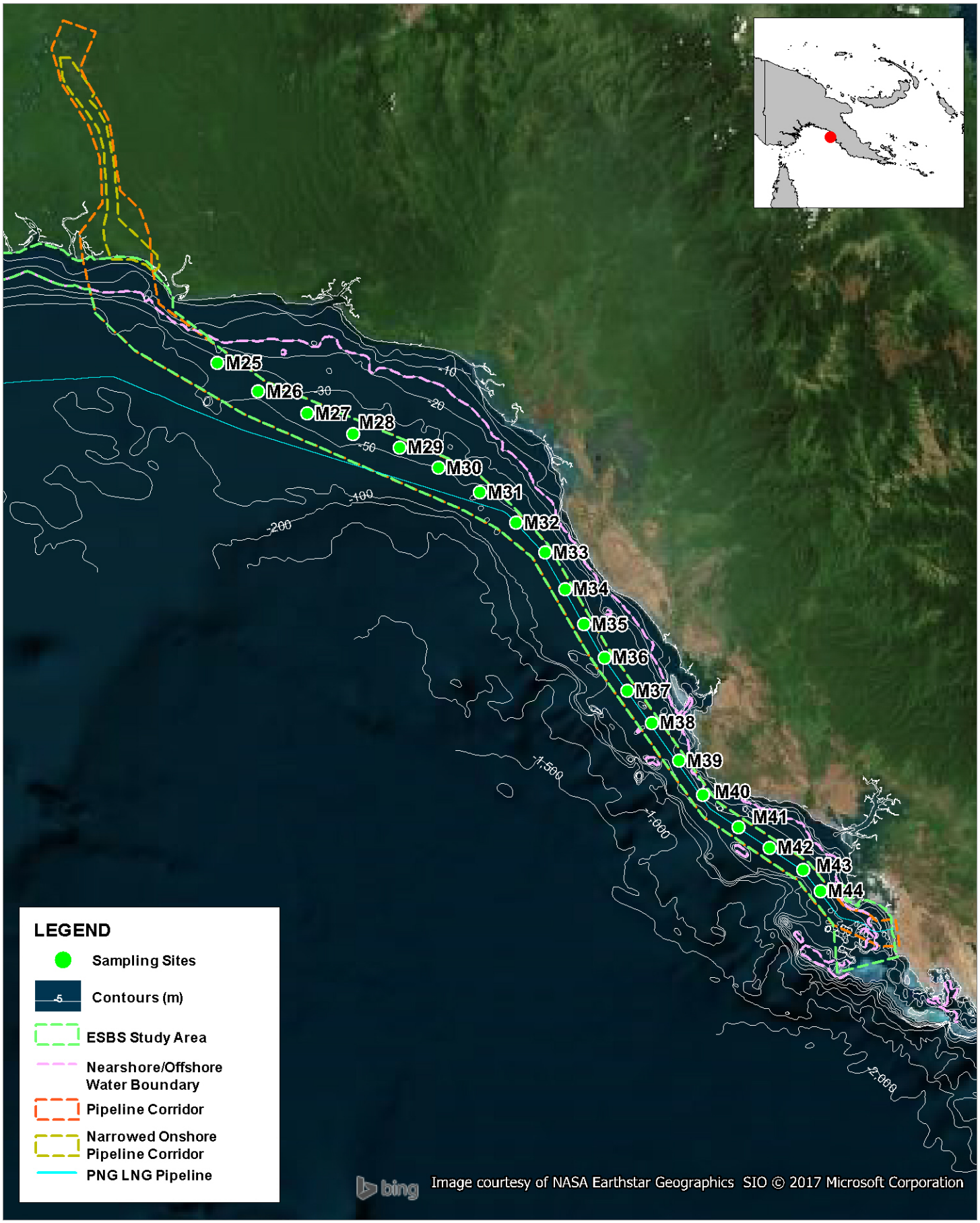
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Title:

Survey Sites – Offshore Pipeline Corridor

Figure: 5-2

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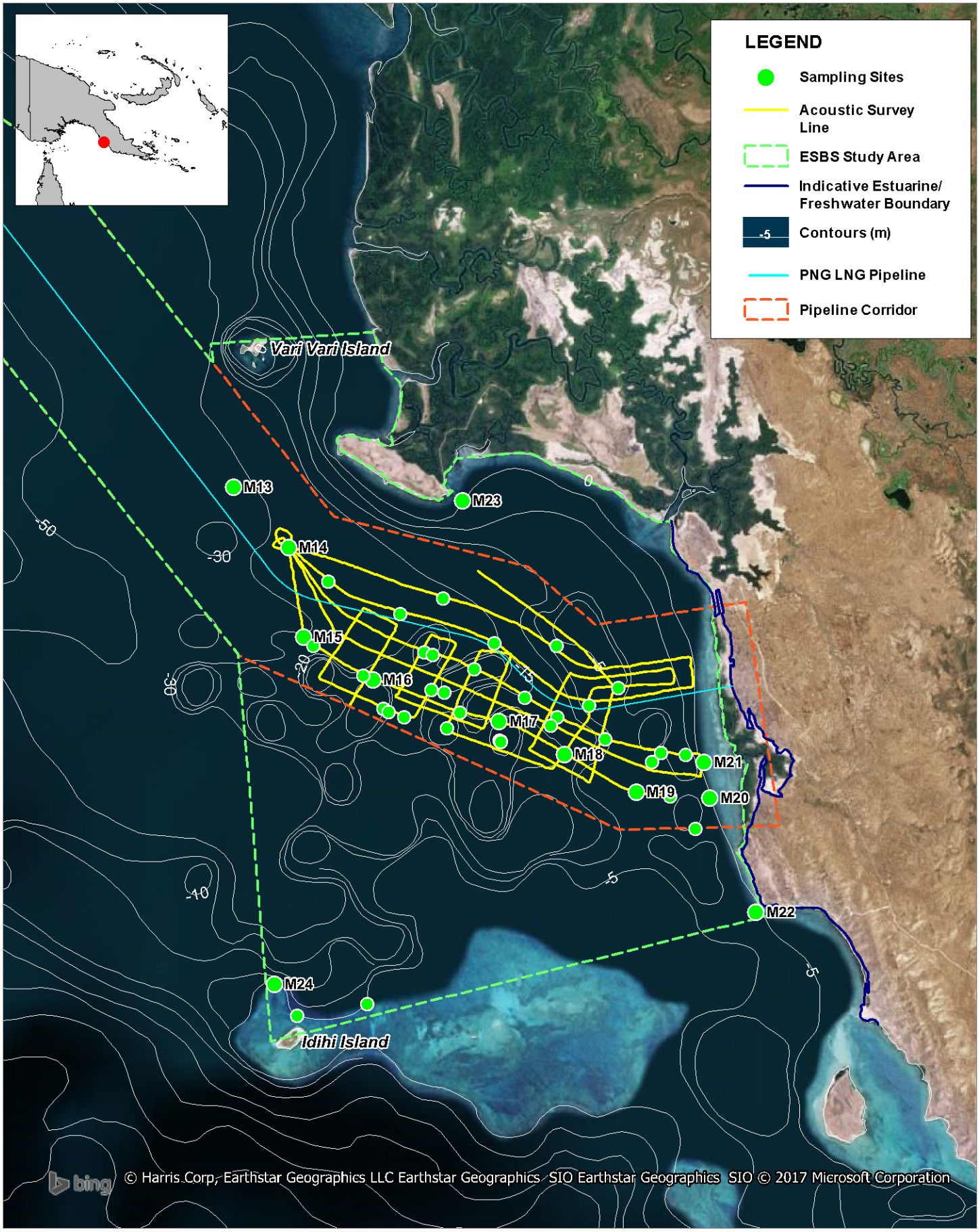
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Title:

Location of Study Sites at Caution Bay

Figure: 5-3

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5.5 Limitations

The following limitations in study approach are noted:

- In-field assessments, especially acoustic mapping, were not intended to provide 100% coverage of the study area, with interpretation and extrapolation of benthic habitat mapping undertaken to describe broader areas. As a result, some geomorphological features may not have been captured while others may be subject to some exaggeration. In addition, acoustic mapping results may also be subject to some error as a result of sea surface anomalies, modeled in the Gulf of Papua by Saint-Cast and Condie (2006), and survey conditions (e.g. wave height, pitch and yaw of survey vessel) as no height datum was available. Effort has been made to account for these errors in post-processing of data.
- Due to the risk of unexploded ordnances (UXOs) at Caution Bay, sediment sampling was not possible at this location. While this limited the ability to undertake analysis of sediment to identify physical features (i.e. grain size) it is not considered to be a significant limitation due to the presence of existing data for this area collected for the PNG LNG Project EIS.
- No long-term (i.e. multi-month) deployment of instruments to measure coastal and seabed processes (e.g. sedimentation, sediment transport) was undertaken at any sites. This was considered unnecessary for the Project as the proposed infrastructure and activities are not expected to cause significant changes to sedimentation and sediment transport in the gulf. As a result, however, a conservative approach will be adopted for the assessment of changes to coastal and seabed processes caused by the Project. This is considered suitable for environmental impact assessment.

These limitations are not anticipated to impact on the ability to characterize the baseline seabed and coastal geomorphology environment suitable for preparation of an EIS/ESHIA.

6 Baseline Characterization

This section provides a description of the seabed and coastal geomorphology baseline for the study area, including regional context. It provides a focus on the following areas:

- Geomorphology and processes in the Gulf of Papua.
- Local geomorphology and processes of:
  - Purari River delta and Orokolo Bay.
  - Offshore export pipeline corridor.
  - Caution Bay.

This baseline characterization considers the results of oceanographic modeling activities. A full description of modeling activities and all results are provided in the Physical Oceanography Baseline Report (BMT WBM, 2017b). In addition, more detail on acoustic habitat mapping techniques and results are provided in the Marine Biodiversity Baseline Report (BMT WBM, 2017d) and sediment sampling and analysis results are presented in the Marine Water and Sediment Quality Baseline Report (BMT WBM, 2017c; Part 11 of ESBS Dossier).

Appendix A provides photographs showing some of the principal geomorphological and/or coastal features of the study area.

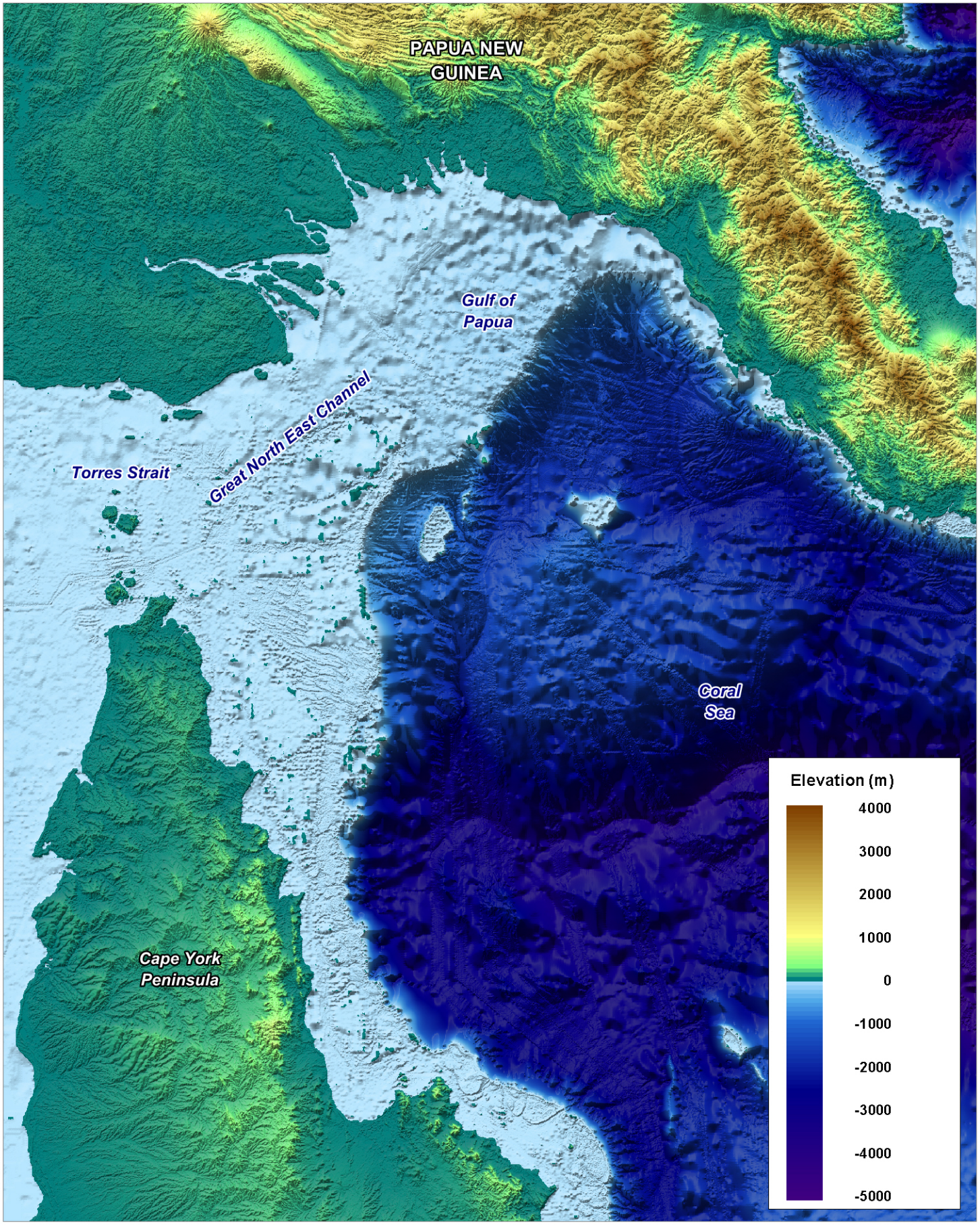
6.1 Gulf of Papua

The Gulf of Papua borders the southern coast of Papua New Guinea, covering an area of 50,000 km^2. The Fly, Kikori and Purari rivers discharge into the Gulf, draining the highlands or central Papua New Guinea.

Much of the seafloor within the gulf is located at depths less than 100 m. In particular, a large section of the western gulf, up to 200 km from land, has a depth no greater than 100 m. Beyond this, the depth increases to 200 m over a distance of 30 to 50 km before reaching the edge of the continental shelf where the seafloor descends to a depth of 2,000 m over a distance of about 100 km. By contrast, on the eastern side of the gulf the edge of the continental shelf is within 30 to 50 km of the mainland and the seafloor rapidly falls to 2,000 m deep within 50 km of the continental shelf. This is shown in Figure 6-1.

The sediment dynamics in the Gulf of Papua is driven primarily by waves which mobilize about 10 times more sediment than currents alone (Saint-Cast and Condie, 2006). Therefore, wind and wave driven resuspension is likely to be highest during the southeast trade winds season, when winds are strongest. In addition, Wolanski *et al.* (1995) indicate that fluvial inflows (based on modeling of the Fly River) also have a significant influence on sediment dynamics, with freshwater sediment plumes capable of reaching the boundary of the gulf[1] within two months (a distance of ~50 to 100 km).

[1] As modeled by Wolanski *et al.* 1995; the boundary of the gulf roughly corresponds to the model mesh adopted for modeling described in the Physical Oceanography Baseline Report (BMT WBM, 2017b)



Title:

Regional Bathymetry

Figure: 6-1

Rev: A

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Sediment characteristics on the shelf within the Gulf of Papua transition from deltaic terrigenous muds in shallow waters to reefal and non-reefal shelf carbonates in deeper areas (Harris *et al.* 1996). In the past there has likely been significant off-shelf removal of terrigenous sediment by the Coral Sea Coastal Current, which transport sediment northeastwards towards a narrow section of the shelf where it is removed by gravity currents (Harris *et al.* 1996).

Modeling of the dispersal of sediments discharged by the Fly River indicates that sediment is mobilized over a larger portion of the shelf during the southeast trade winds season with lesser mobilization during the northwest monsoon season (Hemer *et al.* 2004). The model results indicated that approximately 30% of the Fly River plume sediment is transported to the northeast along the south coast of Papua New Guinea (Hemer *et al.* 2004).

A study of the prograding clinoform (seaward moving depositional slope at the edge of a coastline) within the Gulf of Papua found that muddy terrigenous sediment discharged by the rivers is initially deposited in shallower areas (less than 15 m depth) but may be remobilized and transported down-slope during periods of large wave-current bed shear stress (more probable to occur during the southeast trade winds season) (Walsh *et al*. 2004).

A conceptual model of sediment transport processes for the Gulf of Papua is presented in Figure 6-2. This has been developed based on review of the literature (including Thom and Wright, 1983) and TUFLOW FV model results described in the Physical Oceanography Baseline Report (BMT WBM, 2017b). Significant terrigenous sediment is contributed to the northern and western parts of the gulf throughout the year, driven by flows from several large rivers (including the Purari, Fly, Kikori, Bamu and Turama rivers). During the southeast trade winds season (see Section 3) the combined wave and current bed shear stress acts to maintain sediment in suspension and the clockwise current circulation pattern in the gulf transports sediment to the southeast, towards Caution Bay. At the same time, the waves coming predominantly from the southeast generate shoreline wave-driven sediment transport in a north-westerly direction. During the northwest monsoon season there is an anticlockwise circulation pattern on the continental shelf within the gulf, and the lower energy wave conditions causes more of the sediment delivered by the rivers to be deposited locally and there is a much lower rate of shoreline sediment transport.

The currents which are responsible for the advection and dispersion of sediments are discussed further in the Physical Oceanography Baseline Report (BMT WBM, 2017b).

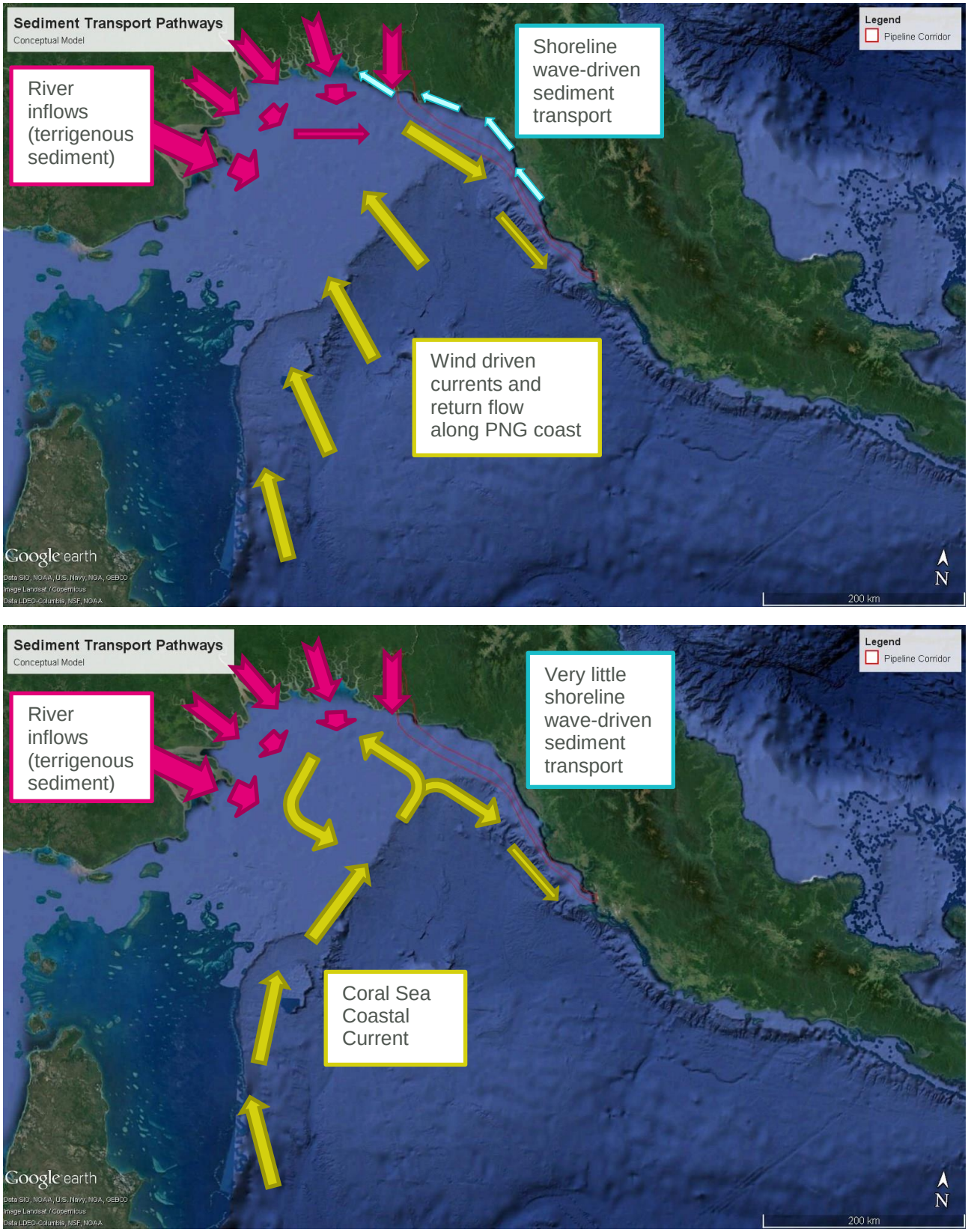


Figure 6-2 Conceptual Diagram of Sediment Transport Patterns along the Offshore Export Pipeline Corridor During Southeast Trade Winds Season (Top) and Monsoon Season (Bottom)

6.2 Purari River Delta and Orokolo Bay

Geomorphological maps developed as part of the CSIRO's Land Research Series (Ruxton *et al.* 1969) have mapped two primary landforms for the Purari River delta and Orokolo Bay:

(1) Beach ridges and beach plains, between Alele Passage and the Vailala River (i.e. Orokolo Bay coastline)

(2) Brackish and saltwater tidal flats across the Purari River delta.

These landforms are both part of the 'littoral plains' geomorphological environment. Figure 6-3 shows a composite figure based on these landform types, utilizing the Land Research Series and Papua New Guinea National Resource Information System data.

6.2.1 Purari River Delta

The Purari River delta is a large deltaic complex draining the Purari River catchment into the Gulf of Papua. The delta is composed of the three main channels of the Purari River (Purari channel – via Aievi and Alele passages, Wame-Varoi channel and Urika-Ivo channel) combined with a complex network of smaller, interconnecting distributaries. The main channels dominate in the upper deltaic plain, with additional influences of distributaries within the lower plain (Thom and Wright, 1983).

Approximately 88.6 Mm^3/yr of sediment is discharged from the Purari catchment, dispersed across the delta (Pickup, 1983; Thom and Wright, 1983). The majority of the total load of sediment is discharged through the three main river channels, with the remainder distributed throughout the delta by smaller channels (Thom and Wright, 1983). Suspended sediment in the delta is predominantly silt (48%) and clay (46%), with a small proportion of sand (6%) (Thom and Wright, 1983; Ruxton *et al.* 1969).

Based on sediment sampling by Thom and Wright (1983) and BMT WBM in January 2017, bed sediment is also predominantly silts and clays across the delta, except in Aievi Passage. Samples from Site 45 in Aievi Passage (east of Apiope) collected by BMT WBM were predominantly sand, indicating a high velocity environment preventing deposition of fine material at this location. Results of particle size analyses are shown in Table 6-1. See Figure 4-3 for location of sites sampled by Thom and Wright (1983).

Both the Urika-Ivo and Purari channels discharge directly into the Gulf of Papua. As a result, these channels are subject to significant wave action, causing the formation of longshore bars and shoals. The Purari channel in particular is noted to typify a wave-dominated river mouth, featuring broad underwater levees topped with sandy swash bars (Thom and Wright, 1983). The Urika-Ivo channel, the most important of the three channels in terms of sediment discharge, conforms to the 'friction dominated model' of river mouths, characterized by shallow bifurcating channels and an extensive 'middle ground' of bar deposits. Both of these channels are subject to significant ongoing change in morphology. An example of this is illustrated in Figure 6-4, which shows sketch maps published by Thom and Wright (1983) comparing the morphology of the Urika-Ivo river mouth between 1956 and 1973/74.

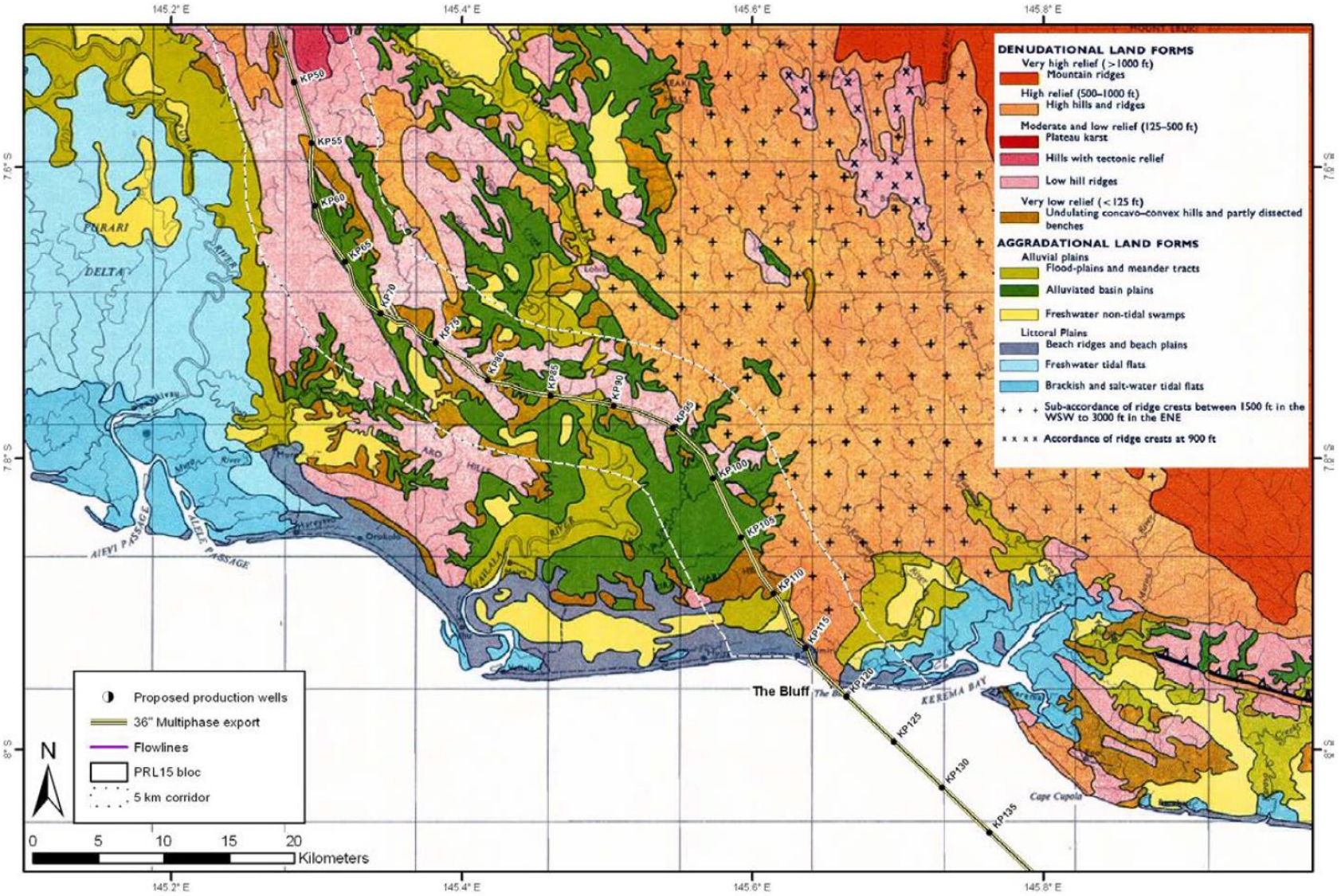


Figure 6-3 Detailed Geomorphological Features of the Kerema-Vailala Area

Table 6-1 Surface Sediment Particle Size Results for Purari River Delta

Site	Clay (<2 µm)	Silt (2-60 µm)	Sand (0.06-2 mm)	Gravel (>2 mm)	Cobbles (>6 cm)	Heavy mineral	Organic matter
	%	%	%	%	%	%	%
BMT WBM Survey (January 2017)							
M45	6	3	91	<1	<1	Not measured	
M46	23	74	3	<1	<1		
Thom and Wright Survey (July 1979)							
2 (Urika-Ivo River at Mapaio)	3	14	83	Not measured		1	7
3 (Pie River near Baimuru)	44	31	25			16	9
4 (Tributary to Pie River estuary)	44	42	14			-	13
5 (Tributary to Pie River estuary)	51	33	16			-	15
6 (Varoi estuary)	38	24	38			-	31
7 (Tributary to Wame River)	10	54	36			-	11
8 (Varoi estuary)	42	41	17			-	18
9 (Varoi estuary)	20	32	48			-	13
10 (Pie River near Baimuru)	60	28	12			-	12
11 (Pie River estuary)	41	26	33			2	11
12 (Kaimari Channel)	8	34	58			-	12
13 (Urika-Ivo River mouth)	1	2	97			9	-
14 (Urika-Ivo River mouth)	1	1	98			7	3
15 (Aievi Passage)	1	-	99			30	3
16 (Alele Passage)	1	-	99			22	1
17 (Alele Passage)	1	-	99			10	2
18 (Panaroa River)	-	-	100			21	2
19 (Varoi estuary mouth)	7	17	76			4	11

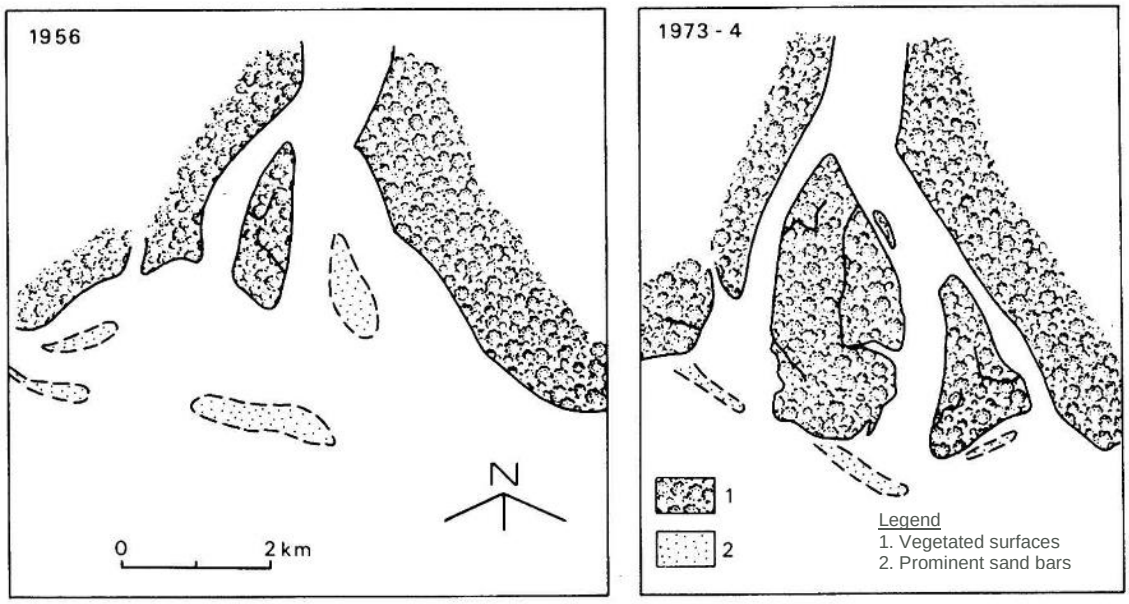


Figure 6-4 Sketch Map of Morphological Changes in Urika-Ivo River Mouth (Thom and Wright, 1983)

By contrast to the Purari main channel, the Wame-Varoi discharges into the sheltered environment of the Pie River estuary. As a result, wave effects in this estuary are negligible, although tidal flows are expected to be important (Thom and Wright, 1983). This channel delivers only a small fraction of the total sediment discharge from the Purari River catchment.

Other estuaries and distributaries in the Purari River delta are maintained by tidal flows. Thom and Wright (1983) note the following in regard to these estuaries, in comparison to the main channels:

- Bed load transport is small, with channel beds composed largely of mud.
- Flow velocities are weaker, with flow direction following the tide.
- Greater deepening of channels as a result of tidal scour and the absence of continued fluvial input.

Figure 6-5 compares the channel depths and cross-sections of the Urika-Ivo channel with three tidal estuaries: Pie River, Kaimari channel, and Varoi estuary. This shows the significantly deeper channel in tidally-dominated estuaries.

Mangrove wetlands dominate much of the coastline of the Purari River delta. However, sandy beaches intermittently occur between tidal inlets and river mouths. This is partly the result of strong erosion pressures on vegetated areas caused by the shifting of river mouths (Thom and Wright, 1983; Ruxton *et al.* 1969).

Due to continual sediment discharge from the Purari and Vailala rivers, the coastline is slowly prograding, leading to infilling of Orokolo Bay and the landward progression of coastal dunes (see below). This has also caused the generation of sandy spits and bars across the delta. Prevailing sediment transport is westerly, caused by southeast trade winds, as shown in Figure 6-6 and further discussed in Section 6.2.2.

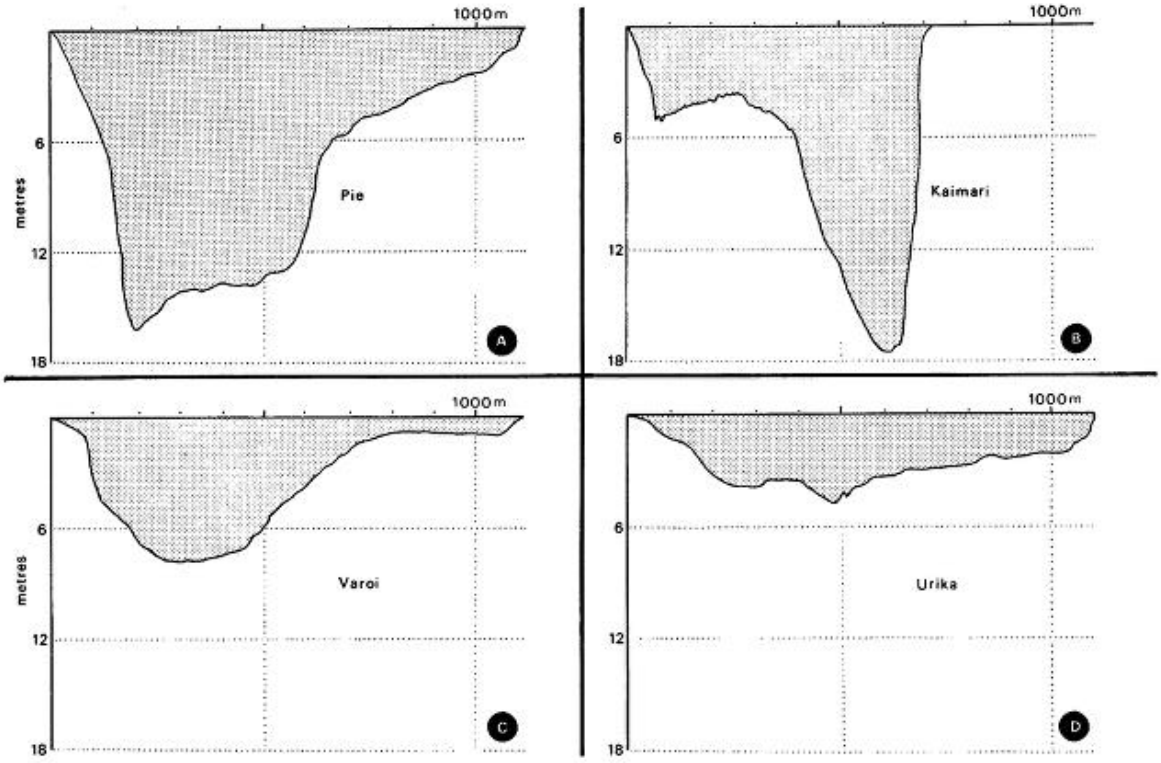


Figure 6-5 Comparison of Cross-sections of Major Channels and Estuaries in Purari River Delta (Thom and Wright, 1983)

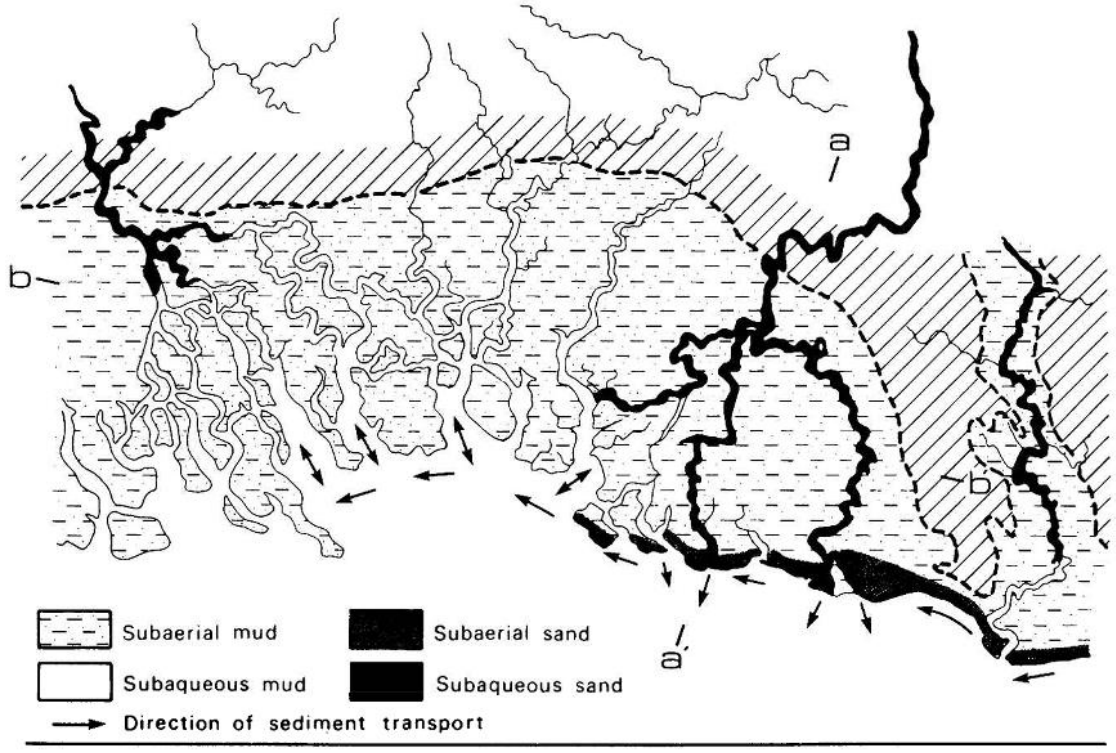


Figure 6-6 Thom and Wright (1983) Sediment Transport Model for Purari River Delta and Orokolo Bay

6.2.2 Orokolo Bay

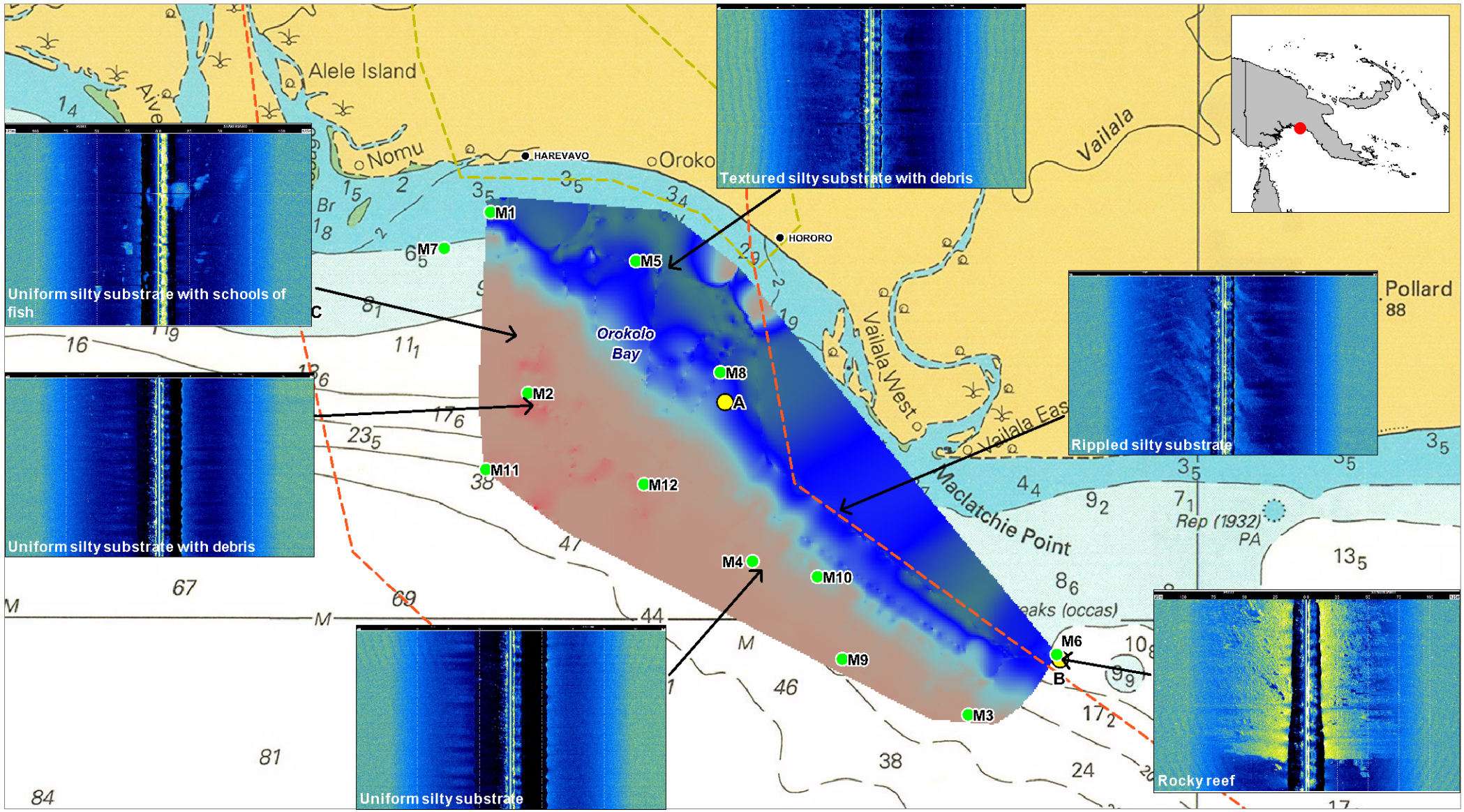
Ruxton *et al.* (1969) describe the beach ridges of Orokolo Bay as part of the Arimiri land system, marked by strongly gleyed undifferentiated sandy soils. The soils contain heavy mineral sands which give sediment a dark color (i.e. black sand beaches). Inland of the beach ridges are the degraded remnants of historical ridges and beach plains, backing on low-relief hills. This series of ridges has been developed as a result of sandy bed loads discharged from the Purari River and forming a chain of beach ridge barriers cut at intervals by tidal channels (Ruxton *et al.* 1969; Thom and Wright, 1983). This coastal complex is known as a chenier plain.

Bedrock at Orokolo Bay comes closer to the coast than areas further to the west (Thom and Wright, 1983). This was observed during the field surveys undertaken by BMT WBM in 2016 and 2017, with a rocky reef identified at Site M6, immediately offshore of the Vailala River. Bedrock is more dominant east of the study area, including a well-developed rock platform, The Bluff, formed from an outcrop of bedrock part way between the Vailala River and Kerema (Thom and Wright, 1983).

Particle size data for surface sediment collected by BMT WBM in Orokolo Bay is provided in Table 6-2. This sampling, together with acoustic mapping, identified the dominant benthic substrate in the area as clay and silt (Figure 6-7). This can be attributed to the influence of the Purari and Vailala rivers that deliver large volumes of fine sediment to the nearshore waters of the gulf. Silts and clays were found to make up more than 90% of surface sediment samples at all sites in Orokolo Bay, except Site M7 (closest to Purari River mouth) which had a much higher proportion of sands (55%).

Table 6-2 Surface Sediment Particle Size Results for Orokolo Bay

Site	Clay (<2 µm)	Silt (2-60 µm)	Sand (0.06-2 mm)	Gravel (>2 mm)	Cobbles (>6 cm)
	%	%	%	%	%
M1	28	66	6	<1	<1
M2	45	52	3	<1	<1
M3	39	56	5	<1	<1
M4	45	52	3	<1	<1
M5	21	73	6	<1	<1
M6	27	71	2	<1	<1
M7	20	25	55	<1	<1
M8	27	64	9	<1	<1
M9	42	53	5	<1	<1
M10	33	61	6	<1	<1
M11	39	58	3	<1	<1
M12	49	49	2	<1	<1



LEGEND

- Town/Village
- Sampling and validation sites
- Instrument deployment site
- Pipeline Corridor
- Narrowed Onshore Pipeline Corridor

Benthic Habitat Classes

1. Silty substrate with debris
2. Textured silty mud with 25-30% clay
3. Uniform silty mud
4. Uniform silty clay
5. Higher relief bed structures

Title:

Acoustic Habitat Mapping Results and Validation Sites

Figure: 6-7

Rev: A

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Sediment supply to Orokolo Bay is predominantly from the Purari and Vailala rivers, though Thom and Wright (1983) note sands on Ihu Spit (eastern part of Orokolo Bay) are likely reworked from the continental shelf. Ruxton *et al.* (1969) describe the infilling of embayments in the Kerema-Vailala area (i.e. between Purari River and Kerema) as a result of the outgrowth of the Purari and Vailala deltas. This is causing the movement of beach ridge barriers seaward, causing the degradation of inland margins by tidal scour, leading to the development of swamps within the swales of older dune systems (Ruxton *et al.* 1969). Wind-generated littoral currents at Orokolo Bay move material westward along the coast, as a result of stronger winds during the southeast trade winds season. This has led to the westward growth of trains of sandy spits and a pattern of broad composite beach ridges separated by tidal creeks, i.e. chenier plains (Ruxton *et al.* 1969; Thom and Wright, 1983).

There is no available measured data to characterize sediment transport patterns within Orokolo Bay. A review of the literature (including Thom and Wright 1983, Harris *et al.* 1996, Hemer *et al.* 2004, and Walsh *et al*. 2004) and a qualitative assessment of the TUFLOW FV model results described in the Physical Oceanography Baseline Report (BMT WBM, 2017b) has informed development of the conceptual diagram of sediment transport processes presented in Figure 6-8. This conceptual diagram shows significant sediment inflows to the Orokolo Bay area from the Purari and Vailala rivers across the year. Due to the weaker effect of currents during the northwest monsoon season, deposition of this material occurs in Orokolo Bay at this time of year. During the southeast trade wind season, however, there is a clockwise circulation pattern in the Gulf of Papua due to wind-driven currents entering the gulf from the southeast and generating a return flow towards the southeast along the southern coast of Papua New Guinea. Therefore, wave-related resuspension together with the southeasterly-directed current causes net transport in a southeast direction offshore while wave-driven transport moves sediment northwest along the coastline.

This conceptual model is consistent with comparisons made of Landsat imagery for Orokolo Bay for the period 1984 to 2015. A review of imagery indicates that although the alignment of the majority of the shoreline of the bay has remained unchanged, there have been changes in the alignment of the shoreline in the south-eastern part of the bay over the last 30 years. Figure 6-9 and Figure 6-10 show Landsat satellite images from the years 1984, 1995, 2005 and 2015. In the 1984 image, there is a lobe of sediment forming an island in the eastern section of the bay, separated from the mainland by a narrow waterway. In the 1995 image, the lobe of sediment has extended in length (to the north) and contracted in width, the waterway separating the island from the mainland has narrowed, and the lobe appears to have increased in overall size. This trend is seen to continue in the 2005 and 2015 images, with the waterway narrowing (particularly at its northern end) to the point where the lobe is no longer an island and can be considered an extension of the mainland. The shoreline protrusion into the bay can be expected to continue to extend in length (to the north) and reduce in width over the coming years. The driver for this process is likely to be net north-westerly longshore sediment transport driven by the waves that are generated during the southeast trade winds season. The growth in the lobe is most likely fed by sediment delivered to the coastal system by the Vailala River which has its mouth at the southeast corner of the bay. The Landsat imagery also reveals the extent of turbid river plumes from the Purari and Vailala rivers. These are clearly visible in the satellite photography as far as 5 km to 10 km offshore, and disperse in all directions. Advection of the offshore parts of the plume to the southeast or northwest (depending on the seasonal conditions) is observed in some of the photos.

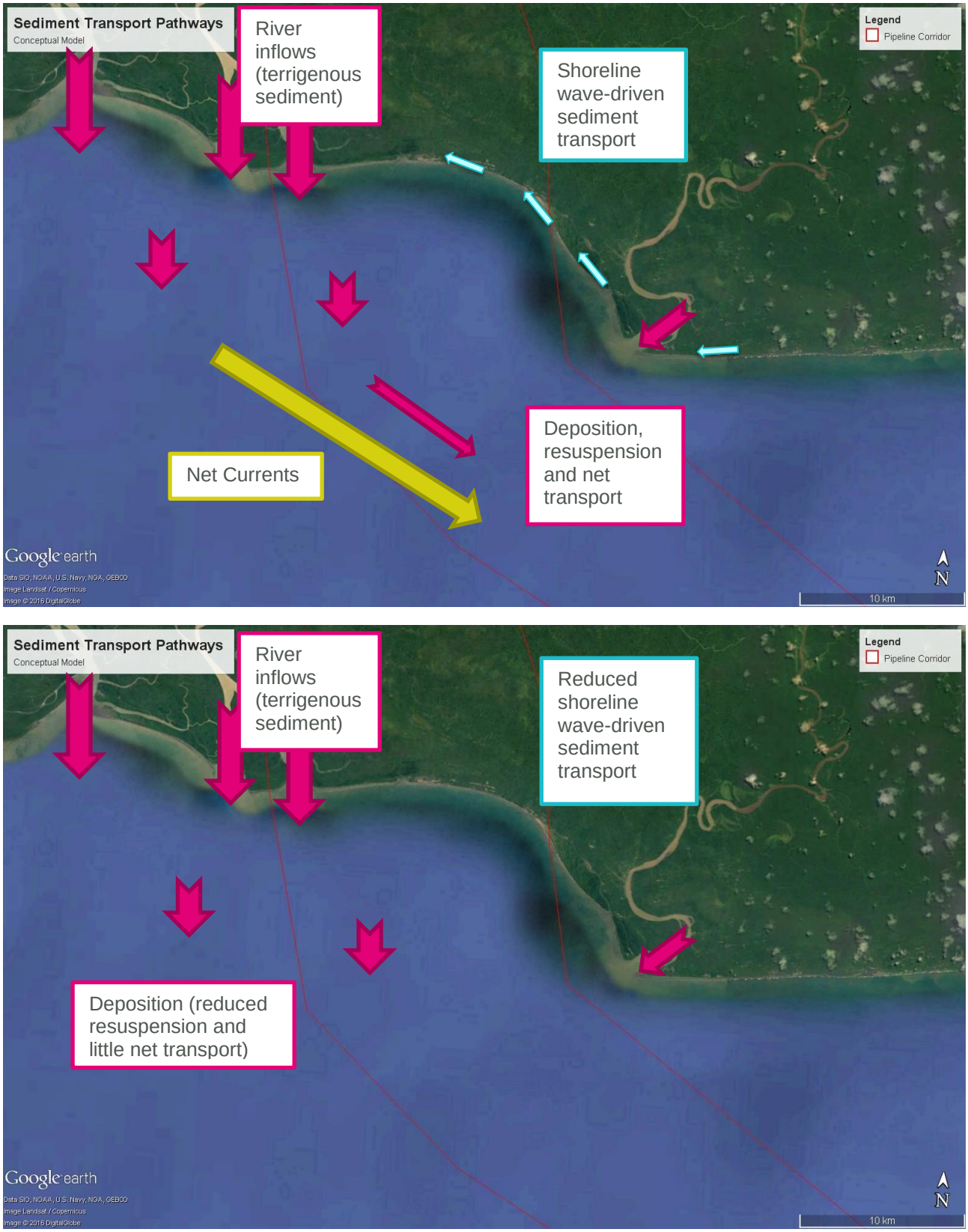


Figure 6-8 Conceptual Diagram of Sediment Transport Patterns in Orokolo Bay During Southeast Trade Winds Season (Top) and Monsoon Season (Bottom)



Figure 6-9 Landsat Satellite Photos of Orokolo Bay – 1984 (Top) and 1995 (Bottom)



Figure 6-10 Landsat Satellite Photos of Orokolo Bay – 2005 (Top) and 2015 (Bottom)

6.3 Offshore Export Pipeline Corridor

The seabed sediment of the offshore export pipeline corridor primarily consists of soft, slightly silty clay, interspersed with areas of rocky outcrop surrounds by sandy gravel. This was observed by Coffey Natural Systems (2009) and other unpublished studies, and as part of the June-July 2016 and January 2017 surveys conducted by BMT WBM.

The majority of the offshore export pipeline corridor between Orokolo Bay and Yule Island is between the 50 and 100 m depth contours, sitting along the edge of the continental shelf for much of its length. The seafloor gradient corridor is typically smooth, without any significant trenches or canyons. Acoustic habitat mapping previously undertaken of part of this area identified most of the eastern offshore export pipeline corridor to be featureless, with the exception of some reef platforms and shoals on the outer part of Caution Bay and near Yule Island.

Particle size analyses of sediment collected along the offshore export pipeline corridor indicate material in this area was greater than 90% clays and silts. The exception is Site M37, due west of Yule Island, where there was a high concentration of sandy sediment (66%). This is consistent with the findings of previous studies and is likely due to the presence of sandy shoals at Yule Island. Previous studies also found higher concentrations of gravels at the eastern extent of the offshore export pipeline corridor and surrounding area, especially at the Yule Island shoal and outer parts of Caution Bay.

Table 6-3 summarizes the particle size analysis results from both the BMT WBM and previous surveys.

Table 6-3 Surface Sediment Particle Size Results for Offshore Export Pipeline Corridor

Site	Clay (<2 µm)	Silt (2-60 µm)	Sand (0.06-2 mm)	Gravel (>2 mm)	Cobbles (>6 cm)
	%	%	%	%	%
BMT WBM Survey (June-July 2016)					
M25	40	56	4	<1	<1
M31	52	43	5	<1	<1
M37	22	12	66	<1	<1
M43	41	55	4	<1	<1
Previous Unpublished Survey					
3. Port Moresby Channel 3	2-10		40-86	4-58	Not measured
4. Yule Shoal 1	62-72		4-15	13-34	
5. Yule Shoal 2	41-64		35-57	1-2	
6. The Bluff (east)	68-82		18-32	<1	
7. The Bluff (west)	95-98		2-5	<1	
8. Pike Shoal	98-99		1-2	<1	

The coastal and seabed processes operating in the offshore export pipeline corridor are the same as those operating in the Gulf of Papua at a regional scale and are described in Section 6.1.

6.4 Caution Bay

The coastline at Caution Bay consists of a wide strip of coastal mangrove flats, interspersed with areas of beach/dune (CNS, 2009; Mabbutt *et al.* 1965). This backs an area of mudflats and backwater. Sediment through this area consists of grey clayey or sand peats to brown sticky clays (CNS, 2009).

Acoustic habitat mapping undertaken during the BMT WBM January 2017 surveys (Figure 6-11) identifies the seabed in deeper parts of the bay (30 m to 50 m water depth) as predominately silty mud. The seabed in shallow areas (less than 30 m water depth) closer to the coast is characterized by coarser coral sands and coral rubble (CNS, 2009).

Particle size analysis of samples collected during the PNG LNG Project EIS (CNS, 2009) also indicate that deeper samples were composed of more than 50% silts and clays, while shallow samples were composed of predominantly sands and rubble, except in mangrove areas. These results are presented in Table 6-4, with sample sites locations shown in Figure 4-2.

Table 6-4 Sediment Particle Size Results for Caution Bay (CNS, 2009)

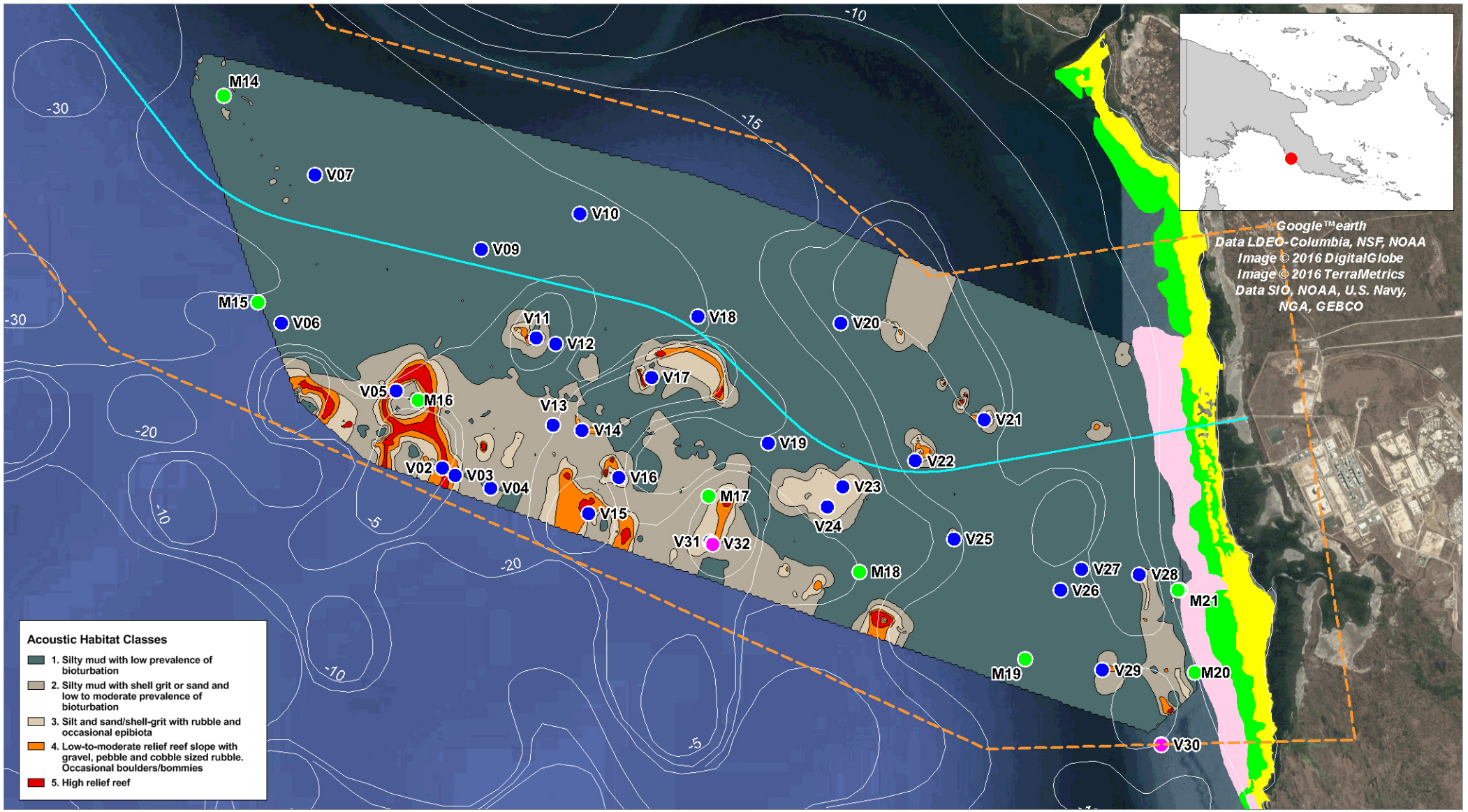
Site	Silts/Clay (<63 µm)	Sand (0.063-2 mm)	Gravel (>2 mm)
	%	%	%
Sed 1 (south of Redscar Head)	70.4	29.5	0.1
Sed 1A (south of Redscar Head)	63.3	33.6	3.1
Sed 2 (northeast Caution Bay)	80.2	19.3	0.6
Sed 3 (east Caution Bay – north of Vaihua River))	72.9	26.6	0.5
Sed 4 (east Caution Bay – north of Vaihua River)	41.4	56.6	2.0
Sed 5 (east Caution Bay – north of Vaihua River)	0.6	88.4	11.0
Sed 6 (east Caution Bay – north of Vaihua River)	52.2	43.3	4.5
Sed 7 (east Caution Bay – south of Vaihua River)	0.4	89.3	10.3
Sed 8 (Vaihua River estuary)	63.3	34.7	2.0
Sed 9 (east Caution Bay – south of Vaihua River)	0.5	63.4	36.1
Sed 10 (northern Caution Bay)	1.8	73.2	25.0
Sed 11 (south of Porebada)	2.1	87.5	10.4
Sed 12 (east Caution Bay – south of Vaihua River)	0.7	72.0	27.3
Sed 13 (south of Boera)	1.5	78.6	19.9
Sed 14 (east Caution Bay – north of Vaihua River)	0.6	87.2	12.2
Sed 15 (Idihi Island)	0.1	98.4	1.5
Sed 16 (east Caution Bay – north of Vaihua River)	3.2	75.9	20.9

Mapping undertaken for the PNG LNG Project EIS (CNS, 2009; Figure 6-11) outlines fringing and nearshore reef habitat present on the eastern shore of Caution Bay. Coral reef systems in Caution Bay are comprised of the following:

- An extensive nearshore fringing reef, located approximately 200 to 500 m offshore, parallel to the eastern shoreline in Caution Bay (CNS, 2009; see Figure 6-11).
- An outer barrier reef located along the south-west offshore boundary of Caution Bay, which provides protection from ocean swells.
- Offshore reef environments at Vari Vari Island (situated to the north) and Idihi Island (near the outer barrier reef) (see Figure 5-3 for locations). Idihi Island is a coral cay, located on the northwest limit of the barrier reef.
- A large number of coral outcrops and reefs extending from the seafloor up to 5 m below the water surface; these are found mostly in the southern and central regions of Caution Bay (Figure 6-11) including several throughout the survey area.

Due to the protection provided by the southern fringing reefs, lack of significant riverine input and the relatively benign wave and current climate within Caution Bay, sediment transport rates are expected to be small in magnitude and any associated morphology changes would be very gradual. The incidence of extreme wave and current conditions is very infrequent, since tropical cyclones rarely occur in the vicinity of Caution Bay.

The shoreline at the pipeline corridor landfall location in Caution Bay is fringed by a small area of saltflat, mangroves, sandy seafloor and reef (refer to Figure 6-11 and Figure 6-12). There is little evidence that the shoreline is undergoing active change. This is supported by comparison of Landsat satellite imagery from the 1980s and 2015, which shows very little change in the extent of mangrove forests and no change in shoreline position (refer to Figure 6-13). This is consistent with Mabbutt *et al.* (1965) who indicate that aggradation processes in tidal flats are discontinuous without a clear trend towards growth or loss of intertidal and supratidal areas.



LEGEND

- Water Sampling Site
- Acoustic Validation Site
- BRUV Site
- Pipeline Corridor
- PNG LNG Pipeline

CNS (2009) Marine Habitat

- Coral Reef (Fringing Reef)
- Seagrass
- Submerged sand patches

Title:

Sediment classes in the Caution Bay acoustic study area

Figure: 6-11

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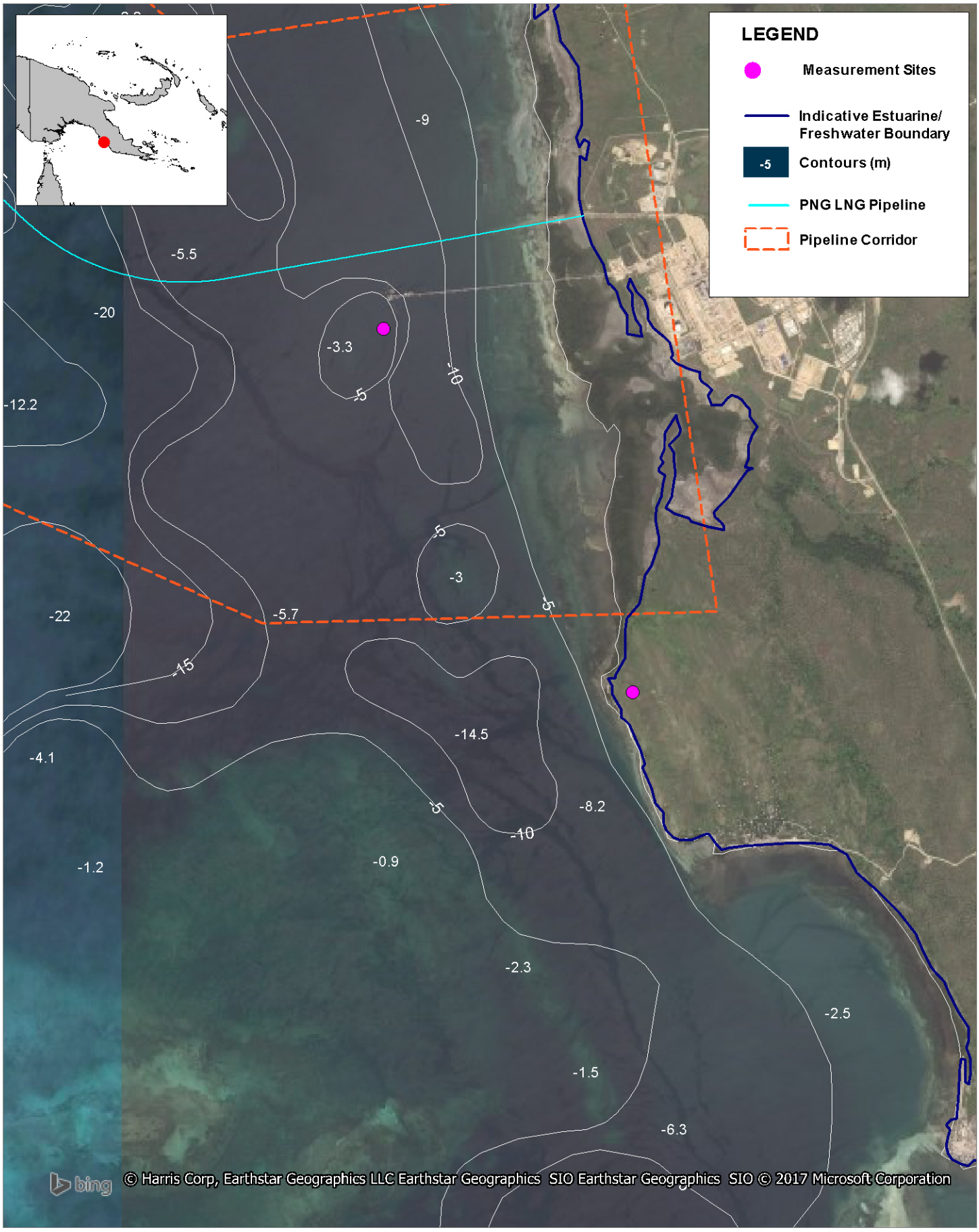
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Title:

Coastline in the Vicinity of the Pipeline Crossing at Caution Bay

Figure: 6-12

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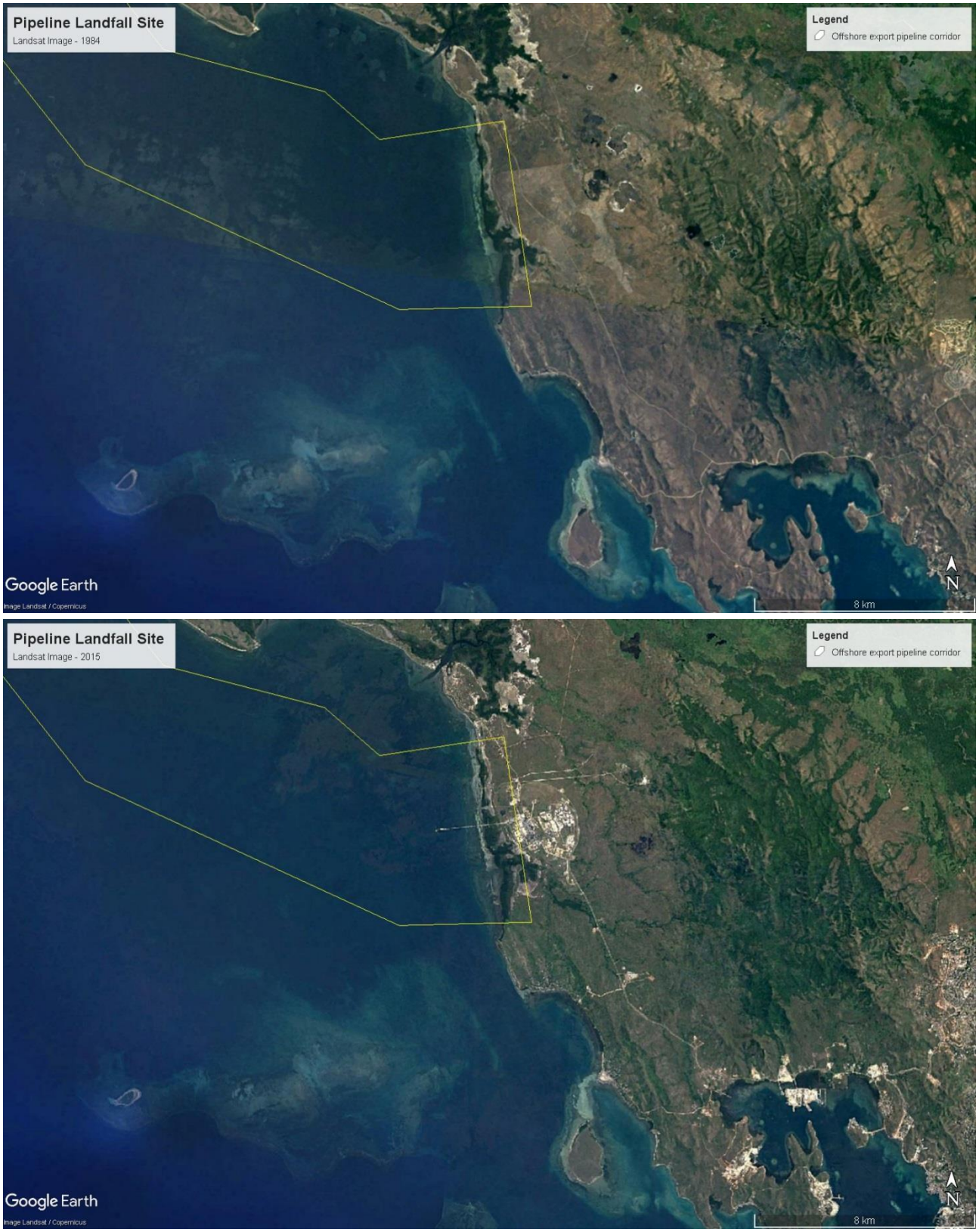


Figure 6-13 Aerial Imagery of Caution Bay from Landsat 1984 (Top) and 2015 (Bottom)

6.5 Summary

The seabed sediment sampling campaign and the acoustic mapping indicate that the seabed along most of the offshore export pipeline corridor is predominantly composed of silts and clays. Shoreline sediment transport in Orokolo Bay is likely to be significant, from the southeast to the west, driven by incident waves from the southeast during the trade winds season. A shoreline protrusion formed by a lobe of sediment has been progressively migrating towards the northwest and elongating in shape based on analysis of satellite imagery over the past 30 years.

Shoreline sediment transport in Caution Bay is not likely to be significant, and the shoreline alignment is stable. The shoreline in the vicinity of the offshore export pipeline corridor is fringed by mangrove forests and coral reefs.

7 Conclusions

This report characterizes the seabed and coastal geomorphological processes within the Gulf of Papua, between Orokolo Bay and Caution Bay. While some previous studies have been conducted in these areas, further studies have been carried out in order to characterize the baseline environment for a future EIS/ESHIA.

The key findings of the seabed and coastal geomorphology baseline characterization are as follows:

- The coastal environment of the Purari/Orokolo consists of two main geomorphological units: brackish and saltwater tidal flats, associated with the Purari River delta, and beach ridges and beach plains between Alele Passage and Vailala River.
- Visual observations and analysis of sediment samples at the Purari River delta and Orokolo Bay show a seabed composed predominantly of silts and clays.
- The sediment composition along the offshore export pipeline corridor was more than 90% silts and clays.
- Acoustic mapping indicates that the seabed in Orokolo Bay is relatively smooth with the only significant geomorphological feature being a rocky reef in the south-eastern part of the bay.
- Large volumes of terrigenous sediment are delivered to the coastline near Orokolo Bay by the Purari and Vailala rivers. Most of this sediment is deposited in shallow areas directly offshore but is remobilized by wave-current bed shear stress, particularly during the southeast trade winds season.
- Net sediment transport offshore is likely to be directed towards the southeast along the export pipeline corridor due to the prevailing currents, particularly during the southeast trade winds season.
- Shoreline sediment transport rates within Orokolo Bay are likely to be significant (driven by incident south-easterly waves) and a lobe of sediment forms a shoreline protrusion in the eastern part of the bay that is progressively migrating from the southeast to the west and elongating in shape.
- The shoreline alignment in Caution Bay is stable and is fringed by mangroves and coral reefs.

8 Study Team

The study team responsible for the preparation of the Seabed and Coastal Geomorphology Baseline Report are listed in Table 8-1 below.

Table 8-1 Seabed and Coastal Geomorphology Study Team

Personnel	Role	Qualifications
Dr Ian Teakle	Technical Lead for Seabed and Coastal Geomorphology Modeling Peer Review	Bachelor of Civil Engineering Doctor of Philosophy
Dr Paul Guard	Hydrodynamic and Sediment Transport Modeling	Bachelor of Civil Engineering Doctor of Philosophy
Steven Ettema	Hydrodynamic and Sediment Transport Modeling	Bachelor of Civil Engineering
Toby Devlin	Hydrodynamic and Sediment Transport Modeling	Bachelor of Civil Engineering
Jeremy Visser	Study Coordinator	Bachelor of Laws, Bachelor of Environmental Management
Lyn Leger	Study Manager	Bachelor of Laws, Bachelor of Science (Honors) Master of Laws

9 Glossary and Abbreviations

ALS	Australian Laboratory Services
ANZECC	Used as a short-form abbreviation to reference ANZECC/ARMCANZ (2000) water quality guidelines
ANZECC/ARMCANZ	Australian and New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand
Bioturbation	Reworking of sediment by living organisms
Caution Bay	Subset of the study area, including all the waters of Caution Bay, as far seaward as the offshore export pipeline corridor
CEPA	Conservation and Environment Protection Authority of Papua New Guinea
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
Clinoform	Sloping depositional surface of a major morphological feature
CNS	Coffey Natural Systems
CPF	Central Processing Facility
EHS Guideline	Environment, Health and Safety Guidelines, developed by the IFC as representation of good international industry practice
EIS	Environmental Impact Statement
Elk/Antelope Gasfield Project	Gas extraction, transport and processing project proposed by InterOil. Involves operation of Elk-Antelope gasfields in Gulf Province and transport to a LNG Plant on Purari River, Gulf Province.
ESBS	Environmental and Social Baseline Study
ESHIA	Environment, Social and Health Impact Assessment
GIIP	Good International Industry Practice
GL-ENV/02/2004	*Guideline for Conduct of Environmental Impact Assessment & Preparation of Environmental Impact Statement*, prepared by (former) Department of Environment and Conservation (2004)
GS EP ENV 120	*Environmental impact assessment of E&P activities*, General Specification prepared by TOTAL (2007)
GS EP ENV 111	*Environmental Baseline and Monitoring Studies: Onshore Sites*, General Specification prepared by TOTAL (2012)
GS EP ENV 112	*Environmental Baseline and Monitoring Studies: Offshore and Nearshore Sites*, General Specification prepared by TOTAL (2012)
IFC	International Finance Corporation
IUCN	International Union for the Conservation of Nature
IPIECA	International Petroleum Industry Environmental Conservation Association
LNG	Liquid natural gas
Nearshore	The zone extending from the shoreline to the 15 meter depth contour
NMSA	National Maritime Safety Authority
OECD	Organization for Economic Cooperation and Development
Offshore	The zone where the water depth is greater than 15 meters
Offshore export pipeline corridor	Subset of the study area based on the offshore export pipeline corridor defined for the Project

Papua LNG	Gas extraction, transport and processing project proposed by TEP PNG. Involves operation of Elk-Antelope gas fields in Gulf Province, and onshore and subsea pipeline via Orokolo Bay to LNG Plant at Caution Bay, Central Province
PDL	Petroleum Development License
PL	Pipeline License
PNG LNG	Gas extraction, transport and processing project operated by ExxonMobil. Involves operation of gas fields in Hela and Western Provinces, and onshore and subsea pipeline to LNG Plant at Caution Bay, Central Province
Project	The Papua LNG Project
PSD	Particle size distribution - the relative amount of particles present according to size
Purari/Orokolo	Subset of the study area, including the waters immediately adjacent to the Purari River delta through to Orokolo Bay, as far seaward as the offshore export pipeline corridor
Study area	The area which is the focus of this ESBS report, consisting of the following three subsets: (i) Purari/Orokolo (ii) Offshore export pipeline corridor (iii) Caution Bay
TEP PNG	Total E&P Papua New Guinea
Terrigenous	Derived from erosion of rocks on land
UXO	Unexploded ordnance

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Appendix A Photos of Study Area Geomorphology

A.1 Orokolo Bay



Plate 1: Orokolo Bay Black Sand Beaches



Plate 2: Orokolo Bay Beach Dunes



Plate 3: Tidal Wetlands Behind Orokolo Bay Foredune



Plate 4: Example of Depositional Lobe at Orokolo Bay

A.2 Purari River Delta



Plate 5: Intertidal Communities of Purari River Delta



Plate 6: Mangroves of Purari River Delta



Plate 7: Purari River Mouth



Plate 8: Unvegetated Intertidal Areas



Plate 9: Estuary of Purari River Delta

A.3 Caution Bay and Vaihua River



Plate 10: Caution Bay Coastline



Plate 11: Headland near Boera



Plate 12: Vaihua River Estuary



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