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8. RECEIVING ENVIRONMENT: MARINE

This chapter characterises the existing nearshore marine environment relevant to the marine facilities proposed for the Papua LNG Project – Downstream (the Project) that are described in Chapter 2 Project Description. This chapter provides a characterisation of relevant geology and bathymetry, metocean, water and sediment quality, and ecological aspects. The spatial extents of the marine environment discussed in this chapter primarily include the foreshore, the littoral zone and benthic and pelagic habitats within and surrounding the existing Petroleum Processing Facility Licence (PPFL) and Application for Petroleum Processing Facility Licence (APPFL) boundaries, extending offshore to water depths of approximately 30 m. Figure 8.1 shows the marine study area. Some broader environmental processes occurring further offshore in the wider Gulf of Papua are also discussed due to their relevance to the local context of Caution Bay. The onshore environmental context pertinent to the LNG Plant is described in Chapter 7 Receiving Environment: Onshore.

A comprehensive desktop review of relevant literature and existing information applicable to the Project was undertaken and included data from prior studies, including those produced for the PNG LNG Project. The data from available literature was supplemented with a series of field investigations conducted in 2019 and 2022, the results of which are also summarised in this chapter.

The primary sources of information that this chapter is based on include:

- A nearshore marine habitat assessment for the ExxonMobil PNG Antelope Limited (EMPNGA) Papua LNG Project – Downstream (Appendix E Nearshore Marine Baseline)
- A fisheries and resource use characterisation study conducted by Tetra Tech Coffey in April 2019 (Appendix L Caution Bay Fisheries Resource Use Study)
- The environmental impact statement and supplementary data for the PNG LNG Project prepared by Coffey Natural Systems (Coffey Natural Systems 2009)
- Relevant published available scientific literature related to Caution Bay oceanography and ecology, including that in the Caution Bay Archaeology Project (Richards et al. 2016).

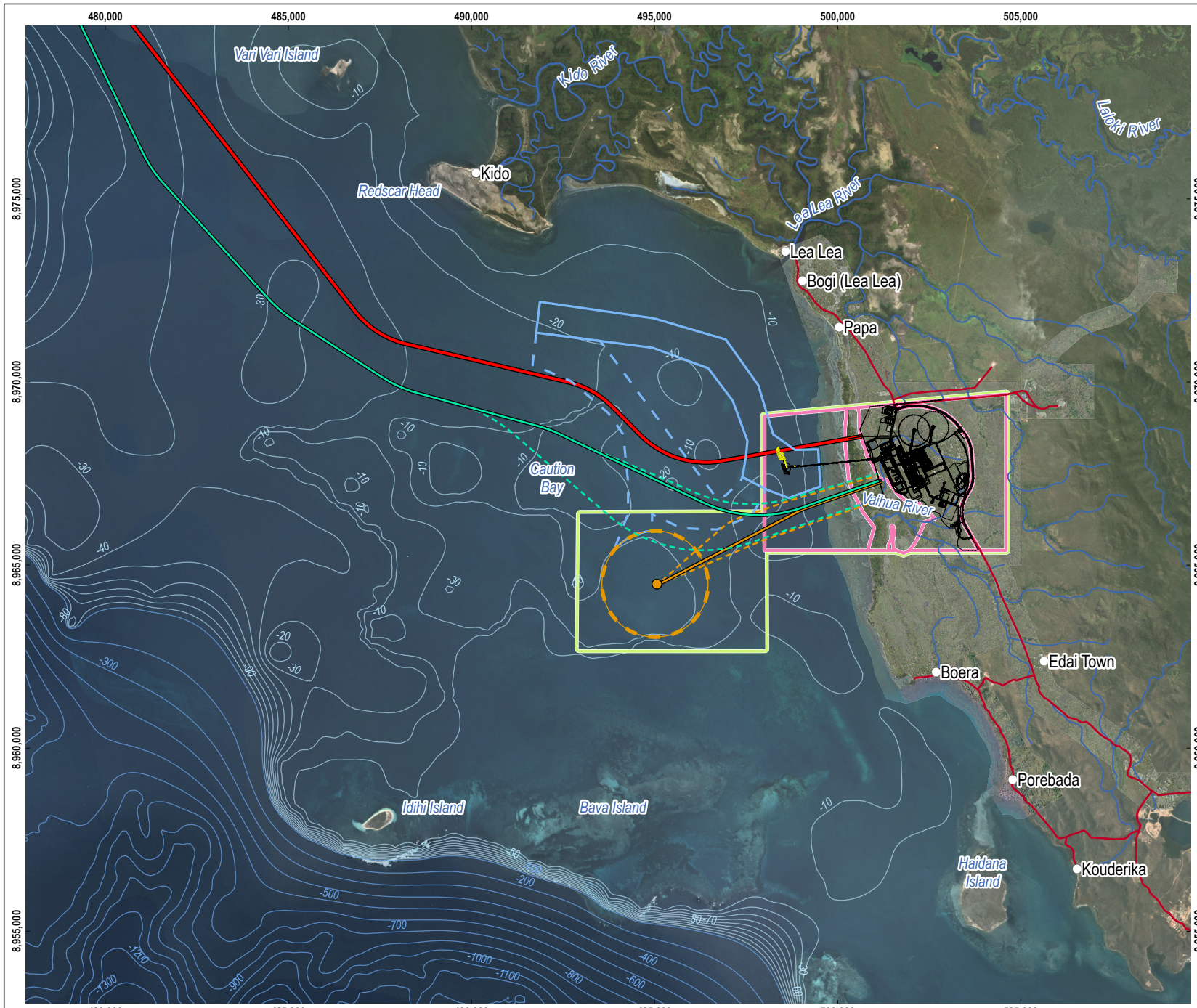
8.1 PHYSICAL ENVIRONMENT

8.1.1 Geology and physiography

Caution Bay is located between Kido and Porebada villages, approximately 20 km to the north-west of Port Moresby, within the Gulf of Papua, an area of approximately 50,000 km^2 bordering the southern mainland coast of Papua New Guinea. The entrance to Caution Bay between Redscar Head and Idihi Island is wide and south-westerly facing.

The Caution Bay geological setting is the product of regional uplift and deformation of a broad coastal plain that extends inland for 30 km to 40 km (Richards et al. 2016). The coastal plain behind Caution Bay supports a variety of different landforms and habitats, including alluvial plains and swamps, plateaus and undulating hills, and elevated ridges that rise locally to a maximum of 320 m above sea level. The coastal plain rises to meet the foothills of the Owen Stanley Range, and a massif with peaks rising to more than 3000 m above sea level is present.

As a shallow coastal basin, Caution Bay is characterised by a nearshore fringing coral reef system, seagrass and macroalgae habitats, salt plains, and mangrove communities. Narrow sandy beaches are present along much of the coastline that does not support a fringing mangrove community. A shallow lagoon exists immediately adjacent to shore on the eastern side of Caution Bay, with an intertidal zone comprising mostly mudflat and mangrove habitat.



LEGEND

- Village
- Road
- Watercourse
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Proposed Papua LNG pipelines route alternate
- Optional jetty extension
- Existing and proposed plant layout
- Bathymetry (10 m interval)
- Bathymetry (100 m interval)
- PPFL2 boundary
- APPFL boundary
- Current navigational channel
- Proposed navigational channel

Proposed CALM buoy components

- CALM buoy
- Naphtha and condensate pipelines
- Naphtha and condensate pipelines alternate
- CALM buoy navigational area

SOURCE
Infrastructure, bathymetry, roads, watercourses and lease boundary from EMPNGA.
Imagery from EMPNGA and Planet Labs.

0 1 2 3 km

SCALE **1:150,000**
PAGE SIZE: **A4**
PROJECTION: **WGS 1984 UTM Zone 55S**

EXXONMOBIL PNG ANTELOPE LIMITED

PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 8.1

Marine study area

TETRA TECH COFFEY

DATE: **04.07.23** PROJECT: **754-MELEN300733** FILE: **300733_02_F08.01_GIS**

Two major estuaries are present within Caution Bay, stemming from the Vaihua River in the south and the much broader Lea Lea River to the north (Richards et al. 2016). The main occurrences of supra-tidal mudflats are behind the protective barrier complex of dunes and sand spits, and around the Vaihua River estuary. These surfaces are flat to very gently sloping. The Vaihua River represents the major landward incursion of mudflat landforms.

8.1.2 Bathymetry

The subtidal marine environment of Caution Bay features complex bathymetry, offshore shoals, coral bommies, and Idihi Island to the southwest and Vari Vari Island to the northwest. An almost continuous nearshore fringing reef, and an outer barrier reef that is restricted to the south-west of the bay, are also present.

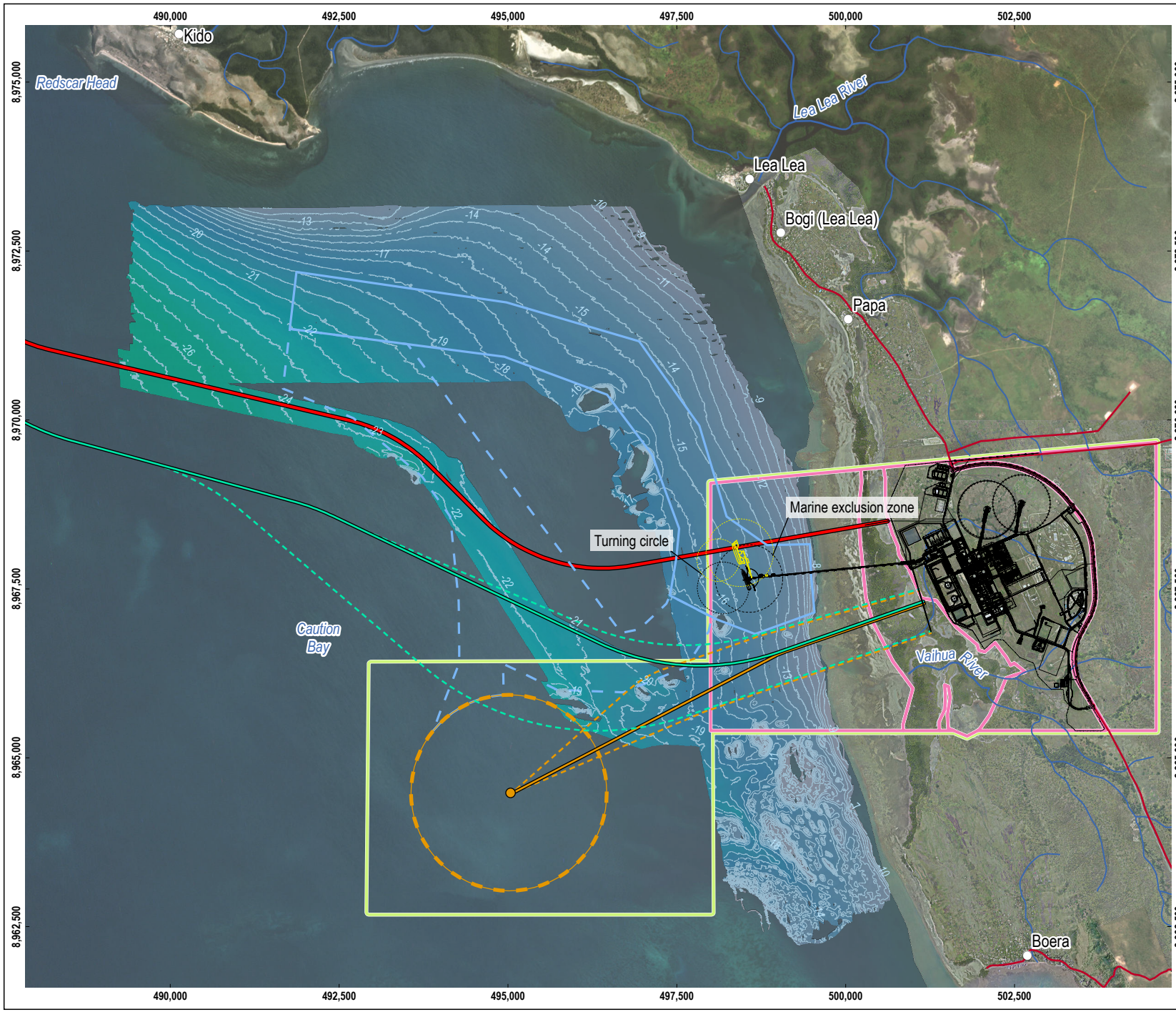
The fringing reef commences anywhere from 100 to 700 m offshore and varies in width from 150 to 400 m (Richards et al. 2016). The fringing reef is absent from the northern portion of Caution Bay in the vicinity of Papa and Lea Lea villages. This discontinuity is likely due to ongoing sediment deposition and greater turbidity resulting from freshwater outflows from the Lea Lea River. A smaller break in the fringing reef is also present in the southern extent of Caution Bay, potentially due to similar riverine influence from the Vaihua River. On the landward side of the fringing reef, a depth related stratification of habitats including sands and soft sediments, seagrass beds, macroalgae and coral rubble are present.

The outer barrier reef is restricted to the southwest of the bay and beyond it, attenuates ocean swells, and rapidly steepens to depths exceeding 1,000 m. Natural openings are present in the reef to the north of Idihi Island, where the north-western extent of the barrier reef is situated, as well as the Liljeblad Passage to the south. To the south and east of Idihi Island, the outer barrier reef forms the southern boundary of Caution Bay. The continental slope descends to depths below 1,000 m about 3 km offshore of the barrier reef. Inshore, the bathymetry gradually shelves from around 50 m to less than 5 m at the nearshore fringing reef.

Between the two reefs, the average water depth ranges between 25 m and 50 m, with isolated coral bommies and patch reefs present occasionally rising to 5 m beneath the surface at various locations, mostly in the southern extent of Caution Bay (Richards et al. 2016).

A natural channel between Redscar Head and Idihi Island of at least 14 m depth without coral bommies runs generally to the north and west and follows the alignment of the coast, until reaching the area adjacent to the LNG Plant jetty.

Geophysical and bathymetric studies were conducted in Caution Bay for the PNG LNG pipeline route (EGS 2008). This provided detailed bathymetry of Caution Bay that allowed identification of offshore coral bommies and rocky outcrops in the nearshore marine environment. Additional bathymetric surveys were undertaken in the shipping lane and at the LNG Plant jetty prior to, and following dredging, for the PNG LNG Project. A 2013 post-construction survey also showed bathymetry similar to that mapped in 2008 (EGS 2013). Available surveyed bathymetry for the relevant extent of the Project area is shown in Figure 8.2.



LEGEND

- Village
- Road
- Watercourse
- Bathymetry (1 m interval)
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Proposed Papua LNG pipelines route alternate
- Optional jetty extension
- Existing and proposed plant layout
- PPFL2 boundary
- APPFL boundary
- Current navigational channel
- Proposed navigational channel

Proposed CALM buoy components

- CALM buoy
- Naphtha and condensate pipelines
- Naphtha and condensate pipelines alternate
- CALM buoy navigational area

SOURCE
Infrastructure, bathymetry, roads, watercourses and lease boundary from EMPNGA.
Imagery from EMPNGA and Planet Labs.

N

0 1 2 km

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PROJECTION: **WGS 1984 UTM Zone 55S**

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PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 8.2

Detailed bathymetry of Caution Bay

TETRA TECH COFFEY

DATE: **04.07.23** PROJECT: **754-MELEN300733** FILE: **300733_02_F08.02_GIS**

8.2 OCEANOGRAPHY

Oceanographic conditions of the marine receiving environment are presented in this section, and are primarily derived from data including:

- A literature review of available information
- PNG LNG Project EIS oceanographic and dredging program data (detailed in Coffey Natural Systems 2009), including the modelling of coastal processes, current movements, and sediment transport in Caution Bay by Global Environmental Systems (GEMS 2008). This program included the deployment of two acoustic doppler current profiler (ADCP) instruments in Caution Bay and the western Gulf of Papua. Resultant current data were used to develop a hydrological model to assess the impacts of marine structures on coastal currents and sediment transportation processes.

8.2.1 Currents

Within the Gulf of Papua, oceanic circulation is dominated by a clockwise gyre that is generated as the Coral Sea Coastal Current enters the gulf from the south along the eastern edge of the Torres Strait and exits to the north-east (Woolfe et al. 1997). Where the East Australian Current breaks down in the northern and eastern Gulf of Papua, sediment transport flows move southward onto the continental slope from the shelf (Brunskill et al. 1995; Walsh et al. 2004; Martin et al. 2008). Sediment transport in the western gulf is primarily to the north-east, and also driven by the East Australian Current and Hiri Current (Brunskill et al 1995; Wolanski and Alongi 1995; Wolanski et al. 1995; Keen et al. 2006; Slingerland et al. 2008).

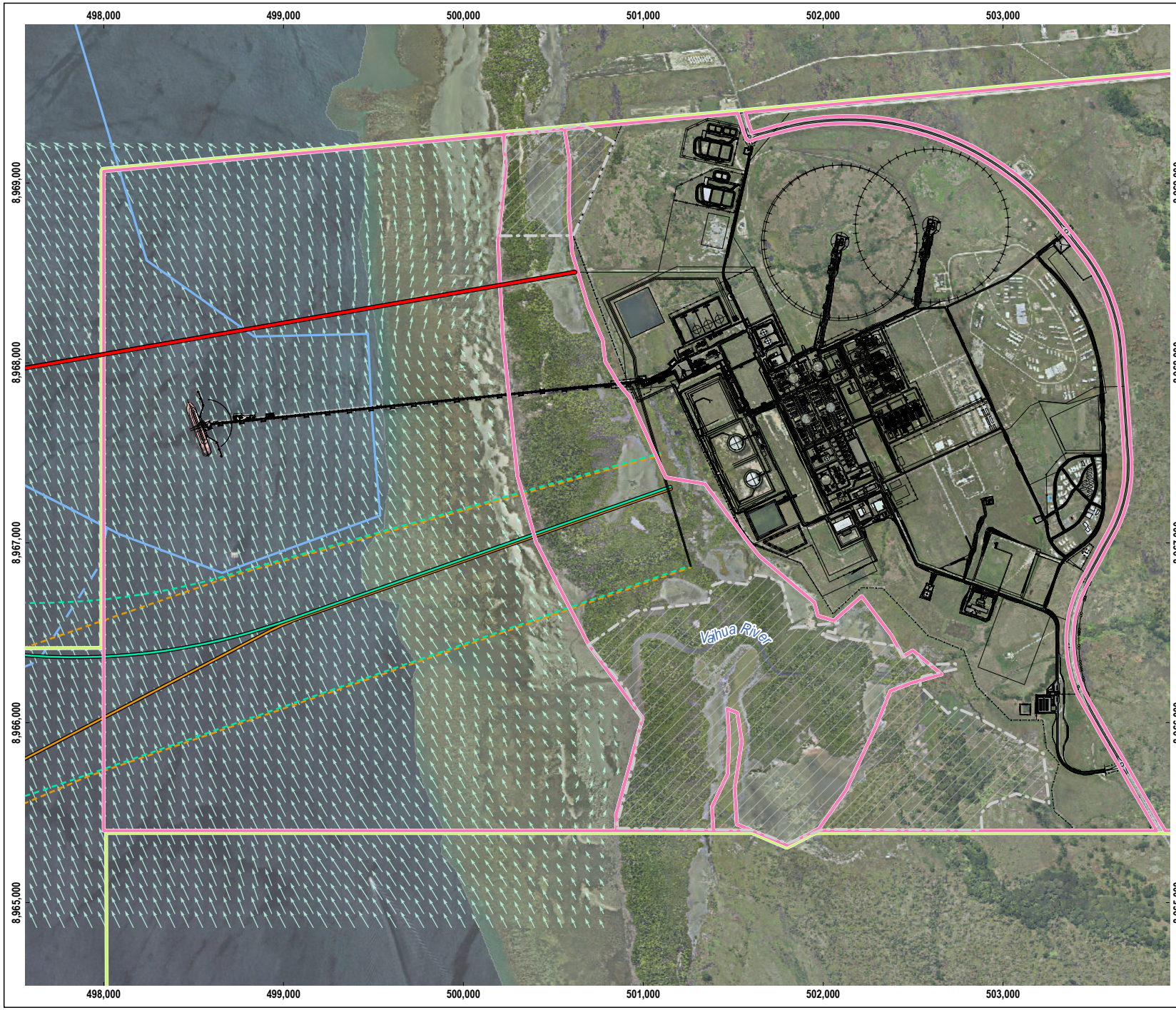
The first five months (December 2007 to May 2008) of data collected from the Caution Bay ADCPs deployed at the LNG Plant jetty site prior to construction, was used to model a 12-month period (GEMS 2008). The mean hourly current speed in Caution Bay was calculated at 0.07 m/s, with a maximum mean speed of 0.32 m/s (calculated as an average of the top 100 current speed records in Caution Bay). The dominant patterns of tidal and wind driven currents within Caution Bay over this period are shown in Figure 8.3.

Upwelling along the south coast of Papua New Guinea was assessed following an interpretation of satellite imagery of sea surface temperature by the Commonwealth Scientific and Industrial Research Organisation (Cresswell pers. com 2008, cited in Coffey Natural Systems 2009), and was signposted by the presence of cooler water, which correlated with prolonged south-east trade winds patterns (indicated by alongshore wind stress). Upwelling occurring in May 2008 was centred along the coast mainly to the south-east of Port Moresby, weakening as it moved further offshore to the west, and absent in June when the associated wind conditions had waned (Figure 8.4).

8.2.2 Tides

Tides in the Gulf of Papua are semi-diurnal to mixed. A maximum spring tidal range of 4 m and mean spring tidal range of 2.5 m to 3 m occur in the western gulf (Coffey Natural Systems 2009). Port Moresby has semi-diurnal tidal cycles, with two high and low tides per day. The mean spring tidal height in Caution Bay is less than 3 m (Coffey Natural Systems 2009).

Hydrodynamic modelling of sea surface heights was undertaken using the two ADCP instruments and included assessing data collected over a 5-month period against available global tidal data from the Australian region, including the Gulf of Papua, to compare predicted with observed sea surface heights. The results showed that longer time predictions could be made with confidence and that the overall tidal range was between 1.5 m below and 1.5 m above mean sea level (GEMS 2008).



LEGEND

- Tidal and wind driven current
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Proposed Papua LNG pipelines route alternate
- Existing and proposed plant layout
- Cultural heritage restricted area
- PPFL2 boundary
- APPFL boundary
- Current navigational channel
- Proposed navigational channel

Proposed CALM buoy components

- Naphtha and condensate pipelines
- Naphtha and condensate pipelines alternate

SOURCE
Current data, infrastructure, cultural heritage and lease boundary from EMPNGA.
Imagery from EMPNGA and Google Earth.

0 500 m

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PROJECTION: **WGS 1984 UTM Zone 55S**

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PAPUA LNG PROJECT – DOWNSTREAM

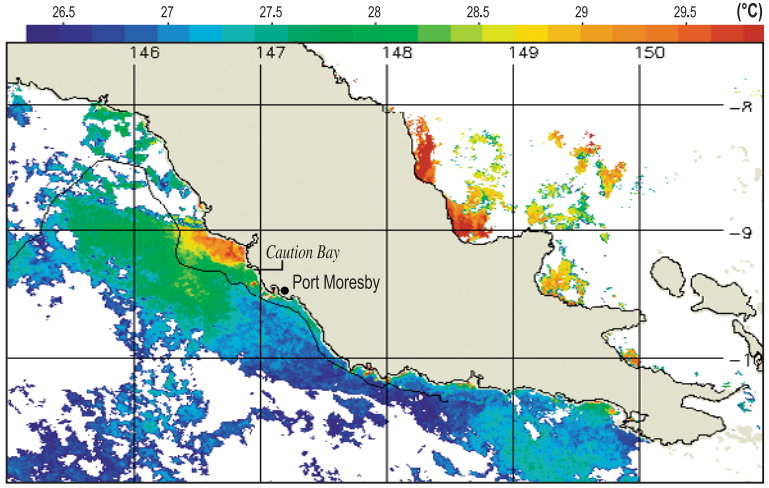
FIGURE 8.3

Tidal and wind driven current regimes in Caution Bay

TETRA TECH COFFEY

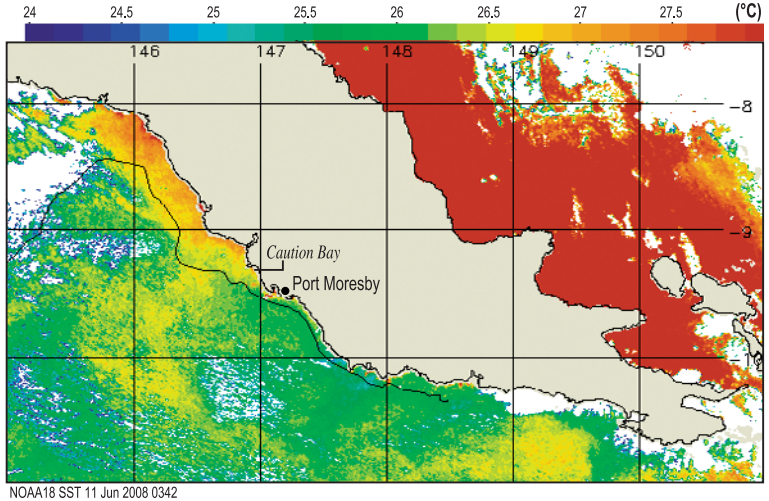
DATE: **20.07.23** PROJECT: **754-MELEN300733** FILE: **300733_02_F08.03_GIS**

Satellite image of sea surface temperature in May 2008,
indicating upwelling mainly to the east of Port Moresby (blue colour)



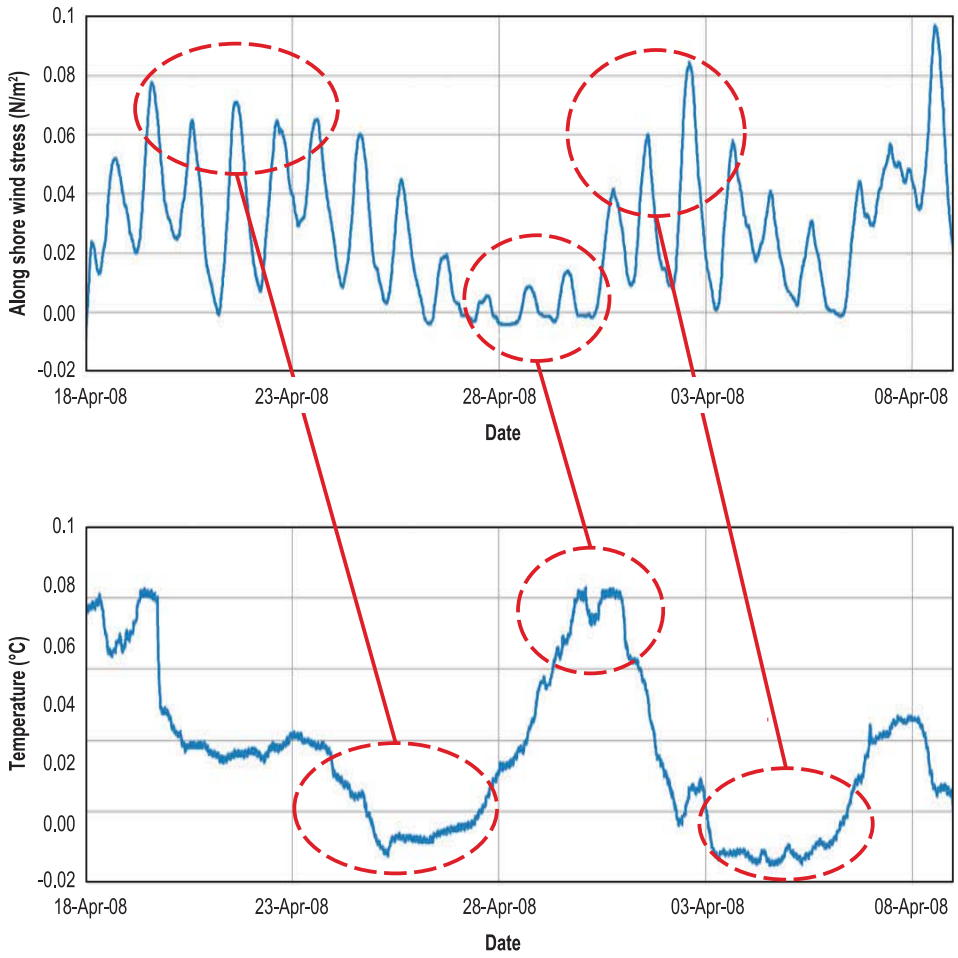
NOAA18 SST 15 May 2008 0322

Satellite image of sea surface temperature in June 2008,
showing no upwelling



NOAA18 SST 11 Jun 2008 0342

Correlation between periods of extended southeast trade winds
(high alongshore wind stress; upper graph) and
upwelling (low sea surface temperature; lower graph)
Note: Time lag of 1 to 2 days.



EXXONMOBIL PNG ANTELOPE LIMITED

PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 8.4

2008 occurrence of upwelling and correlation with south-east trade winds

SOURCE
PNG LNG EIS, 2008

TETRA TECH COFFEY

DATE: 03.07.23 PROJECT: 754-MELEN300733 FILE: 300733_02_F08.04_GRA DOC REFERENCE: \\ETSS772GISFS1\DATA$\GIS\300733_EMPNG_PAPUALNGDOWNSTREAM\2_GRAPHICS\02_EIS\300733_02_GRA031.AI_2

8.2.3 Waves

The Gulf of Papua is exposed to local surface waves generated by the prevailing south-east trade winds during the dry season (NSR 1990). These waves circulate in the general south-east direction of the winds along the coastline of the gulf but refract across shallow waters toward the shoreline. The seasonally-averaged significant wave height reaches 1.5 m relatively close to the coast during the dry season (Hemer et al. 2004). During the wet season, the offshore winds result in little or no wind-driven swell (GEMS 2008).

The wave regime in Caution Bay is strongly seasonal and tied to the regional monsoon cycle, with the transitional months of November and April characterised by variable conditions. Wave energy in Caution Bay is attenuated by the barrier reef. Martin et al. (2008) note that between December to March wind speeds tend to be mild, and wave fetch is limited, which typically results in calm seas with significant wave heights averaging 0.3 m. During the south-east trade wind season of May to October, stronger winds result in larger fetch, greater swells and an average significant wave height of 1.3 m. The results of analysis of 12 months of modelled data and observed wave data at the LNG Plant jetty site, indicated a mean wave height of 0.42 m, a maximum wave height of 1.9 m, and that wave heights exceeded 1 m for 10% of the time.

During the period of Cyclone Guba in mid-November 2007, the peak significant wave height at the LNG Plant jetty site was just over 1 m, there was only a small storm surge and peak currents reached 0.2 m/s (GEMS 2008).

Simulation of the passage of a 990 hectopascal (hPa) tropical storm travelling from the north-west to south-east past Caution Bay was used to simulate the peak wave, current, sea level and wind conditions occurring at the LNG Plant jetty due to the near-approach of cyclones (such as Tropical Cyclone Guba). This simulation represented a theoretical storm stronger than any event found in the meteorological database and therefore an extreme upper bound on sea conditions (Coffey Natural Systems 2009).

The output from the simulation reflecting the extreme theoretical conditions within Caution Bay, at a distance such that the strongest winds would impact near the coastline, and a summary of the data collected by the one of the ADCPs during Tropical Cyclone Guba, are shown in Table 8.1.

Table 8.1 Summary of the peak wave, current, sea level and wind conditions generated in Caution Bay by the passage of a theoretical 990 hPa tropical storm and Tropical Cyclone Guba

Parameter	Theoretical Tropical Storm	Tropical Cyclone Guba
Maximum significant wave height	3.2 m	1.0 m
Maximum current speed	0.40 m/s	0.21 m/s
Maximum sea level	0.25 m	0.10 m
Maximum wind speed	25 m/s (90 km/h)	12 m/s (43.2 km/h)

Source: GEMS 2008

8.3 SUSPENDED SEDIMENTS

Caution Bay is situated in the eastern portion of the Gulf of Papua. The gulf shoreline is a low-lying swamp comprising the delta complexes of large rivers including the Kikori, Omati, Fly and Purari. These rivers discharge, with little seasonal variation, fresh water at a combined rate of 15,000 m^3/s, and a combined sediment load of 350 million tonnes per annum, into the Gulf of Papua (Coffey Natural Systems 2009).

Within the Gulf of Papua, high suspended sediment concentrations are present that originate from sources including:

- Suspended sediment loads from the Vaihua River catchment, Kikori, Omati, Fly, Purari and other rivers. with the Vaihua River being the most proximal input of these to Caution Bay.

- Reworking of sediments by strong tidal currents and wave action.
- Fluid-mud bodies (which are known to occur in the Fly River delta) that flow along the deepest parts of subsea channels as dense, mobile, near-seafloor suspensions, typically around 1 m in thickness (Dalrymple et al. 2003).

Sedimentation in Caution Bay near the Project area is dependent on seasonal river inflows and rainfall events, wind direction and strength, and tidal state which may resuspend sediment (Coffey Natural Systems 2009).

Sediment tubes deployed from December 2007 to February 2008 and February to April 2008 to determine sedimentation rates during sampling undertaken for the PNG LNG Project EIS indicated little consistency across various sites during the sampling period, possibly reflective of localised conditions, given the range of values (Coffey Natural Systems 2009). Sedimentation rates in 2007 and 2008 ranged from 0.02 to 29.17 mg/cm^2/day. Samples collected close to the eastern coastline of Caution Bay comprised low proportions of calcium carbonate, indicating sedimentation of terrestrial origin. The results of calcium carbonate determination were highly variable but showed that as much as 60% to 80% of material was likely of marine origin at sites located at Idihi Island, Vari Vari Island and the shipping channel on the southern side of Haidini Island. Sampling was mostly undertaken in the wet season and lower rates would be expected in the dry season. Detailed results are available in the PNG LNG Project Nearshore Marine Baseline and Impact Assessment (Coffey Natural Systems 2009).

Some sedimentation of low-lying reef substrate and marine flora was observed from video records of nearshore habitats near the LNG Plant jetty and pipeline in 2010; however, this appeared to have cleared by 2012. The results of towed video camera deployments during 2019 and 2022 field surveys showed few obvious signs of substantial sediment accumulation close to shore or on the fringing reef, though a veneer of sediment was observed in some reef locations, and the seabed further offshore, particularly near the Vaihua River, is characterised by silty conditions. Given the time that has elapsed since the sediment tube sampling and more recent video analysis, it appears that sediment has not settled on reefs in a permanent or cumulative manner.

8.4 SEDIMENT GEOCHEMISTRY

A summary of the marine receiving environment sedimentology conditions, and methods used to conduct characterisation sampling, are presented in this section.

8.4.1 Method

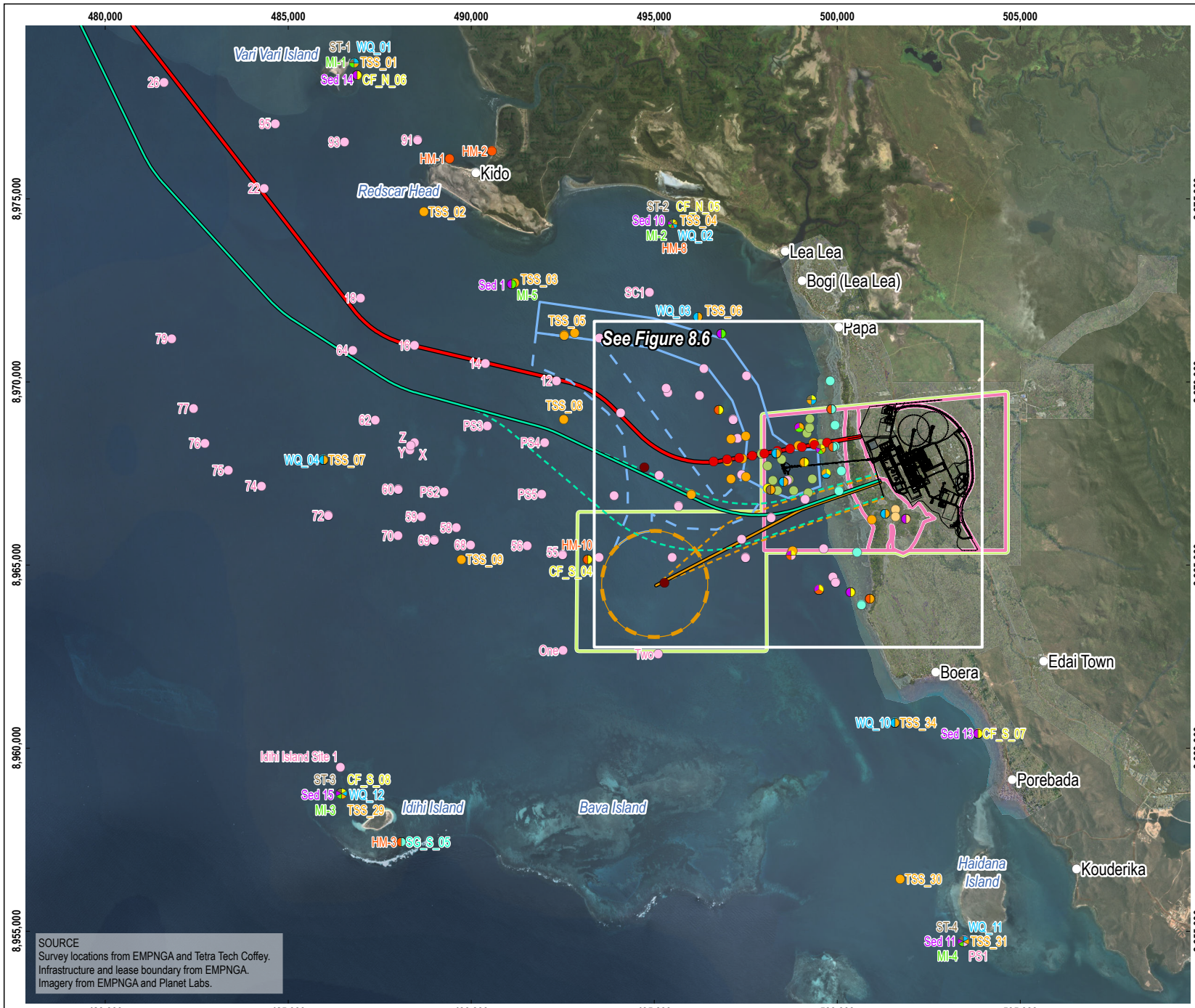
Sediment sampling was conducted in April 2019 and September and October 2022 to establish baseline conditions and provide an update to data collected in 2007/2008 and 2009 at control sites.

Sampling locations are shown on Figure 8.5. The sample locations in 2019 were generally within 2 km of the LNG Plant jetty and the discharge point of treated wastewater from the LNG Plant retention pond. Additional locations were also included to provide adequate coverage of proposed piling or trenching for the LNG Plant jetty expansion, and reference sites outside of the areas of potential impact.

The sample locations in 2022 were from representative locations inside the proposed Project infrastructure footprints, including the CALM buoy locations and jetty extension location option. There were also sampling locations set in proximity to the proposed naphtha and condensate pipeline alignment and Papua LNG pipeline alignment being assessed as part of the Papua LNG Project - Upstream.

One control site sample was also collected.

At each sampling location, three sub-samples of sediment were collected from the surface of the seabed using a Petite Ponar sediment grab sampler.



LEGEND

- Village
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Proposed Papua LNG pipelines route alternate
- Existing and proposed plant layout
- PPFL2 boundary
- APPFL boundary
- Current navigational channel
- Proposed navigational channel

Proposed CALM buoy components

- Naphtha and condensate pipelines
- Naphtha and condensate pipelines alternate
- CALM buoy navigational area

Marine survey location

- Coral and fish video transect site
- Dredge spoil video transect site
- Pipeline video transect site
- Seagrass video transect site
- Water quality sampling site
- TSS and CTD sampling site
- Drop camera site
- Habitat map site
- Macrobenthic infauna sampling site
- Mangrove transect site
- Sediment sample site (pre-dredging)
- Sediment quality site
- Sediment trap site

0 1 2 3 km

SCALE **1:150,000**
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PROJECTION: **WGS 1984 UTM Zone 55S**

EXXONMOBIL PNG ANTELOPE LIMITED

PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 8.5

Marine survey locations

TETRA TECH COFFEY

DATE: **04.07.23** PROJECT: **754-MELEN300733** FILE: **300733_02_F08.05_GIS**

A composite of the three samples was prepared in a clean stainless-steel mixing bowl to obtain consistency throughout the whole sample. A sub-sample was taken for laboratory analysis which included some or all the following physicochemical parameters:

- pH
- Particle size distribution
- Carbon content (organic, inorganic and total)
- Total metals in the <2,000 µm fractions: Arsenic, barium, boron, cadmium, chromium, cobalt, copper, iron, mercury, manganese, nickel, lead, selenium, silver, tin, vanadium and zinc
- Nutrients: Including total nitrogen and total phosphorus
- Total polychlorinated biphenyls (PCBs)
- Organochlorine pesticides
- Total petroleum hydrocarbons (with silica gel cleanup)
- Polynuclear aromatic hydrocarbons (PAHs)
- Radionuclides
- Tributyltin.

As sediment quality guidelines have not been established by regulatory authorities in Papua New Guinea, the Revision of the ANZECC/ARMCANZ Sediment Quality Guidelines (Simpson et al. 2013) has been used to compare the sediment sampling results. There are two sediment quality guideline (SQG) values, a default guideline value (herein referred to as DGV) and an upper guideline value GV-high. The sediment DGVs indicate the concentrations below which there is a low risk of unacceptable effects occurring, and should be used, with other lines of evidence, to protect aquatic ecosystems. In contrast, the 'upper' guideline values (GV-high), provide an indication of concentrations at which you might already expect to observe toxicity-related adverse effects. As such, the GV-high value should only be used as an indicator of potential high-level toxicity problems, not as a guideline value to ensure protection of ecosystems.[1]

8.4.2 Results

Results from sediment sampling undertaken in 2019 and 2022 are discussed in this section, and are compared where applicable against:

- Relevant sediment quality criteria where available
- Sediment sampling results from 2007/2008
- Sediment sampling results collected ahead of the PNG LNG Project 2009 dredging programme.

Appendix E Nearshore Marine Baseline documents all 2019 and 2022 sediment analysis results in detail.

8.4.2.1 Particle size distribution

Most sediment samples collected within Caution Bay in 2007/2008 were represented by sediments between 63 µm and 2,000 µm and varied with the type of seafloor habitat sampled. Approximately one-third of sediment particle size distributions of samples obtained from areas dominated by coral reefs (where sediment is dominated by coral rubble and shell debris) were in the greater than 2,000 µm fraction (Sed 9, 10, 12, 13 and 16). Sediment samples collected from the shipping channel in Caution Bay (Sed 1, 2 and 3), at Idihi Island and in the Vaihua River mangrove communities were dominated by particle sizes below the 63 µm fraction, and between the 63 µm and 2,000 µm sediment fraction.

[1] Additional information regarding the derivation and application of toxicant default guideline values for sediment quality is available at: https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants

Analysis of sediment samples collected in 2009 near the LNG Plant jetty and PNG LNG pipeline landfall (prior to trenching) showed sediments mainly comprised of silt (2.0 µm to 60 µm) and sand (0.06 mm to 2.0 mm), with these fractions making up between 71% and 87% (by weight) of the total particle composition in each sample. Clay was also a major component comprising between 11% and 25% of the total particle composition in each sample. Sites further offshore generally had a slightly higher proportion of clay (approximately 20%), when compared with nearshore sites (less than 20%). Nearshore sites had greater proportions of silt/sand (approximately 80% or higher) when compared to sites further offshore (less than 80%) (Coffey Natural Systems 2009).

In 2019, most of the sediment samples were represented by sediments between 63 µm and 2,000 µm. The proportion of coarser fractions in some of the sites differed to that observed in 2007/2008, particularly at sites Sed 9, Sed 10, and Sed 11. This may have been due to small adjustments to the sample sites which were required, particularly in locations near the LNG Plant when the sampler was unable to pick up material at the exact point sampled previously.

In 2022, the size composition in sediment samples varied, and obvious spatial trends were not clear, suggesting local scale heterogeneity. The most common sizing was 125 µm to 250 µm, including in samples collected furthest from the shoreline, aside from at Sed 35 and Sed T3, where the >2,000 µm was predominant. The highest proportion of fines (<63 µm) was taken from the most seaward sample collected approximately 15 km from shore. The lowest proportion of fines was observed in samples collected 1 km from shore and 8.5 km from shore. The coarser fractions of materials were mainly observed at sites near coral reefs, where substrates consist mainly of sands, and coral rubble and debris. Sand/silt constituted a smaller proportion of the samples, particularly at sites closest to the shoreline.

Due to a difference in laboratory analytical sieving techniques between 2019 and 2022, direct comparisons of particle size could not be made between sampling periods.

8.4.2.2 Metal concentrations

Metal concentrations from the sub 2,000 µm fraction have been analysed for sediment samples across various years. A summary of the findings is provided below.

Sampling conducted in 2009 prior to the construction of the LNG Plant jetty and the PNG LNG pipeline trenching programme, showed no exceedances of relevant sediment metals concentrations criteria, although nickel concentrations (21 mg/kg) equalled the screening level at one site. Metal concentrations were generally similar across sites and different depth intervals (Coffey Natural Systems 2009).

Total sediment metals analysis data from sampling in 2019 and 2022 are provided in Appendix E Nearshore Marine Baseline. Results from 2019 and 2022 are summarised as follows, with comparisons made to results from 2007/2008 in instances where the site had been sampled previously:

- Nickel concentrations in sediment sample Sed 20 in 2019 (23 mg/kg) were reported above the DGV guideline of 21 mg/kg but remained below the GV-high value (52 mg/kg). This site was not sampled in 2007/2008; however, other sites displayed similar concentrations, up to 11 mg/kg at Sed 9. Nickel concentrations in 2022 varied across samples; two sites (Sed 35 and Sed T5) had concentrations below the laboratory detection limit (<5 mg/kg), seven sites had concentrations below the DGV (21 mg/kg), and six sites had concentrations above the DGV (21 mg/kg) but below the GV-high (52 mg/kg). It is not uncommon for nickel concentrations in nearshore marine sediment to be above guideline values (Forstner and Salomons 1984).
- Arsenic, copper, chromium, lead, and zinc concentrations were typically above the detection limits in 2007/2008, 2019 and 2022, but all results were below the applicable ANZG (2018) DGV.
- Cadmium and silver concentrations were below detection limits in 2019. The achievable laboratory detection limit for silver (<2 mg/kg for most samples) was higher than the DGV (1 mg/kg), therefore

comparison of silver concentrations to the DGV was not possible. Silver concentrations in 2019 were below the GV-high value of 4 mg/kg. In 2022, all samples of silver and cadmium were below the laboratory detection limit of 1 mg/kg, and therefore also below the ANZG (2018) DGV.

- Cobalt concentrations ranged from <2 mg/kg (Sed 15) to 12 mg/kg (Sed 20) in 2019, and from <5 mg/kg (Sed T5 and Sed 35) to 16 mg/kg (Sed T1) in 2022. There are no ANGZ (2018) DGVs for cobalt.
- Iron and manganese levels were variable, being higher at some sites in 2007/2008, while higher at other sites in 2019 and 2022, with no clear spatial pattern observed. In 2019 iron levels ranged from 300 mg/kg (Sed 15) to 34,400 mg/kg (Sed 20). In 2022, iron levels ranged from 7,000 mg/kg (Sed T5) to 50,000 mg/kg (Sed T1). In 2019, manganese levels ranged from 49 mg/kg at Sed 15 to 529 mg/kg at Sed 21, while in 2022 manganese levels ranged from 120 mg/kg at Sed T5 to 780 mg/kg at Sed T1. Differences may be due to natural variation over time or slight variations in sampling locations between the surveys. There are no ANGZ (2018) DGVs for iron or manganese.
- The highest and second highest concentrations of barium, chromium, cobalt, iron, lead, manganese, nickel, zinc, and vanadium from both the 2019 and 2022 surveys were all recorded in 2022 at Sed T1 and Sed T2 respectively.

Results from sediment analysis over the various sampling periods generally do not exceed applicable regulations and criteria or indicate signals of contamination. Where observed, elevated concentrations, of any specific metals or metalloids are most likely due to the natural variability that occurs in sediments found in coastal and estuarine environments.

8.4.2.3 Carbon content

Proportions of total organic carbon in sediment samples collected in 2007/2008 ranged from 2.2% to 10.8%. Total inorganic carbon ranged from 1.17% to 10.7%. There was no clear pattern in terms of carbon content and site location.

Total organic carbon in samples collected in 2009 prior to the pipeline trenching program near the PNG LNG pipeline landfall and prior to construction of the jetty ranged from 0.12% to 0.68%. Levels of organic carbon were found to generally decrease with increasing sediment depth interval (Coffey Natural Systems 2009).

In 2019, the proportions of total organic carbon content in samples ranged from <0.02% at Sed 27 and Sed 28 near the previously proposed jetty extension location option, to 9.91% at Sed 11 at the southern extent of the Caution Bay study area. Total inorganic carbon content ranged from 1.09% at Sed 10 inland of Kido Peninsula, to 11.6% at Sed 15 at Idihi Island.

In 2022, the proportion of total organic carbon content in samples ranged from 0.8% at Sed 38 (near the LNG Plant jetty) and Sed T5 (13 km offshore near the alternate CALM buoy location), to 9.1% at Sed T4 along the proposed naphtha and condensate pipeline route at a depth of approximately 10 m. Total inorganic carbon ranged from <1% at Sed T5, Sed T4, Sed 31 and Sed T1 to 4.1% at Sed 34.

No clear spatial patterns have been observed regarding carbon content and site location in either 2019 or 2022, and no trends have been observed in terms of changes to carbon content over time.

8.4.2.4 pH

Sediment pH in samples collected in 2009 was similar across all sediment samples, ranging from 8.9 to 9.5. The relatively high pH, indicative of basic sediment conditions, is reflective of the high levels of natural calcium carbonates present in the sediment. There were no apparent trends between pH and sample site location or sample depth interval (Coffey Natural Systems 2009).

In 2019 pH values ranged from 8.4 to 9.0, and in 2022 the range of pH values was between 7.1 (Sed T5) and 8.5 (Sed 33). There were no apparent trends between pH and sample site location or sample depth interval in

2009 (Coffey Natural Systems 2009), and this was also the case for the 2019 and 2022 sampling. A possible exception to this was the lowest pH value of 7.1 at Sed T5 in 2022. As this was the sample taken closest to shore and near the Vaihua River mouth, the relatively low pH is likely due to the presence of relatively anoxic conditions, muds, and the aeration of soil sulphates (as also found in the nearby mangroves). This sample also had the lowest phosphorus content recorded of all samples in 2022 (180 mg/kg).

8.4.2.5 Total polychlorinated biphenyls

Total polychlorinated biphenyl (PCB) concentrations in sediment samples collected in 2009 were below laboratory detection limits (Coffey Natural Systems 2009).

Concentrations of PCBs were also below detection limits (and below SQG criteria) at all sediment sample sites collected in 2019 and 2022 (ANZG, 2018).

8.4.2.6 Organochlorine pesticides

Testing for organochlorine pesticides in 2009 recorded concentrations of DDD, DDE, total DDT, dieldrin, chlordane, lindane and endrin, all below the respective limits of laboratory analytical detection for all samples (Coffey Natural Systems 2009).

Organochlorine pesticide concentrations were below detection limits (and below SQG criteria) in all samples collected during sediment sampling in 2019 and 2022.

8.4.2.7 Hydrocarbons

Total petroleum hydrocarbons (TPH) for sediment samples collected in 2009 near the LNG Plant jetty showed concentrations below laboratory detection limits of <10 mg/kg (for C6-14 fractions) and <50 mg/kg (for C15-C36 fractions) (Coffey Natural Systems 2009).

Total recoverable hydrocarbon (TRH) and TPH concentrations in sediment samples collected in 2019 at Sed 3, Sed 16, Sed 18, Sed 19, Sed 21, Sed 22, Sed 27, Sed 28, and Sed 29 in the nearshore environment along the proposed pipelines route options and near the LNG Plant jetty also remained below detection limits. Benzene, toluene, ethylbenzene and xylenes (BTEX) were below detection limits at all sites.

Sediment sampling in 2022 showed that total recoverable hydrocarbons (TRH) and BTEX values in sediment samples collected across all sites in the nearshore marine environment and along the proposed and alternate pipeline route options remained below their respective detection limits.

8.4.2.8 Radionuclides

Radionuclide analysis was undertaken of sediment samples taken in 2009 from sites near the LNG Plant jetty and PNG LNG pipeline landfall and showed the concentration of radionuclides in all samples was below the Papua New Guinean screening level. The maximum radiation concentration of 330 Bq kg-1 (0.33 Bq g-1) was well below the National Assessment Guidelines for Dredging (NAGD) screening level of 35 Bq g-1. Interpretation of the results by Queensland Health Scientific Services indicated that concentrations were typical of naturally occurring radioactive material in marine sediments (Coffey Natural Systems 2009).

In 2019, radionuclide analysis was undertaken for selected sediment samples collected nearshore near the LNG Plant at Sed 3, Sed 16, Sed 18, Sed 19, Sed 21, Sed 22, Sed 27 and Sed 28. Radionuclides were below the detection limit of <500 Bq/kg dry weight (DW) at all sites except for a duplicate sample collected at Sed 28 (Sed 29) near the jetty extension option location which displayed gross beta radionuclides of 540 Bq/kg DW.

Further radionuclide testing was not undertaken in 2022.

8.4.2.9 Tributyltin

Tributyltin analysis of sediment samples was undertaken taken in 2009 from sites near the LNG Plant jetty and PNG LNG pipeline landfall. Concentrations of tributyltin and the metabolite by-products DBT and MBT were below the respective detection limits (and SQG guidelines) at all sites (Coffey Natural Systems 2009).

In 2019, tributyltin analysis was undertaken for selected sediment samples collected along the proposed pipelines route options and near the LNG Plant jetty at Sed 3, Sed 16, Sed 18, Sed 19, Sed 21, Sed 22, Sed 27, Sed 28 and Sed 29. Concentrations of tributyltin were below detection limits and below SQG criteria (being 9 µg/kg for the default guideline value and 70µg/kg for the guideline value high) at all sites.

Analysis of tributyltin was not performed on samples in 2022.

8.4.2.10 Acid sulphate soils

The most recent acid sulphate soil (ASS) testing data relevant to the Project is summarised below and derived from sampling undertaken in 2009 for the PNG LNG Project, that involved the collection of 22 sediment samples from shallow soil profiles within the foreshore environment at the LNG Plant site. Sample locations included soils from nearshore beach ridges, back swamps, mangrove swamps and mudflats as well as the intertidal seaward reef (Coffey Natural Systems 2009). The results of the study showed that:

- Nearshore land, beach ridges and shallow soils within the mudflats (0 m and 0.5 m) were non-ASS and non-potential acid sulphate soils (non-PASS).
- Deeper soil profiles between 0.75 m and 2.5 m within the mudflats and back swamp soils were PASS containing oxidizable sulphur which could potentially release acid if disturbed in aerobic conditions. The natural acid neutralising capacities of these soils, measured as $CaCO_3$ in the form of shell and/or coral fragments, were around 10 times and 50 times the average acid generating capacity respectively, meaning the soils would not create any acid if disturbed. It was determined that no treatment would be required.
- Soil profiles within the mangrove swamp were PASS. It was recommended that any disturbance be undertaken in accordance with an ASS management plan for any excavations greater than 100 m^3 or fill placement greater than 500 m^3 within the mangrove swamp area.
- Soils of the seaward reef were PASS. The natural neutralising capacity of the reef soil was around 150 times greater than the acid generating capacity meaning that soils would not be acid-forming if disturbed.

Further ASS testing was not undertaken in 2019 or 2022 for the Project but it is being conducted in the mangrove communities adjacent the LNG Plant as part of the Upstream component of the Papua LNG Project and findings will be included in the forthcoming addendum to the 2019 Papua LNG Project – Upstream EIS.

8.5 WATER QUALITY

This section summarises relevant historical and current water quality data for the Caution Bay marine receiving environment.

8.5.1 Method

A literature review of existing studies was undertaken, and water quality samples were collected in Caution Bay during April and August 2019. The water quality sampling regime undertaken in 2007 and 2008 for the PNG LNG Project EIS, and in 2011, 2012, 2013 and 2014 for ongoing PNG LNG Project monitoring, was repeated in 2019 to provide a 5-year update of the nearshore marine baseline and a basis for impact assessment for the Papua LNG Project – Downstream. Additional sampling sites were added for coverage of the two previously proposed options for the Papua LNG pipeline alignment.

A total of 16 sites were sampled across two surveys in 2019. Photographs of selected sites are provided in Appendix E Nearshore Marine Baseline and sampling locations are shown in in Figure 8.5.

All water quality samples were analysed for the following parameters:

- Total suspended solids
- Total and dissolved (field-filtered) metals: Arsenic, barium, boron, cadmium, chromium (as hexavalent), cobalt, copper, iron, mercury, manganese, nickel, lead, selenium, silver, tin, vanadium and zinc
- Nutrients: Total nitrogen, total kjeldahl nitrogen, nitrite, nitrate, ammonia, total phosphorus, reactive phosphorus
- Potassium
- Cyanide
- Fluoride
- BTEX, total petroleum hydrocarbons, speciated phenols and oil and grease
- Chemical and biological oxygen demand
- Sulphate and sulphide.

Samples collected at water quality (WQ) sites near the discharge point of the LNG Plant retention pond (WQ_06, WQ_07, WQ_08 and WQ14) (see Figure 8.6) were also analysed for faecal coliforms, enterococci, *Escherichia coli* and amines (EA, DEA and MDEA).

In-situ measurements of physicochemical parameters were collected concurrently with water sampling using a YSI ProDSS (digital sampling system) handheld multiparameter meter. Measurements are discussed for in situ parameter sampling taken at approximately 1 to 1.5 m water depth.

The following in-situ parameter measurements were recorded in April 2019:

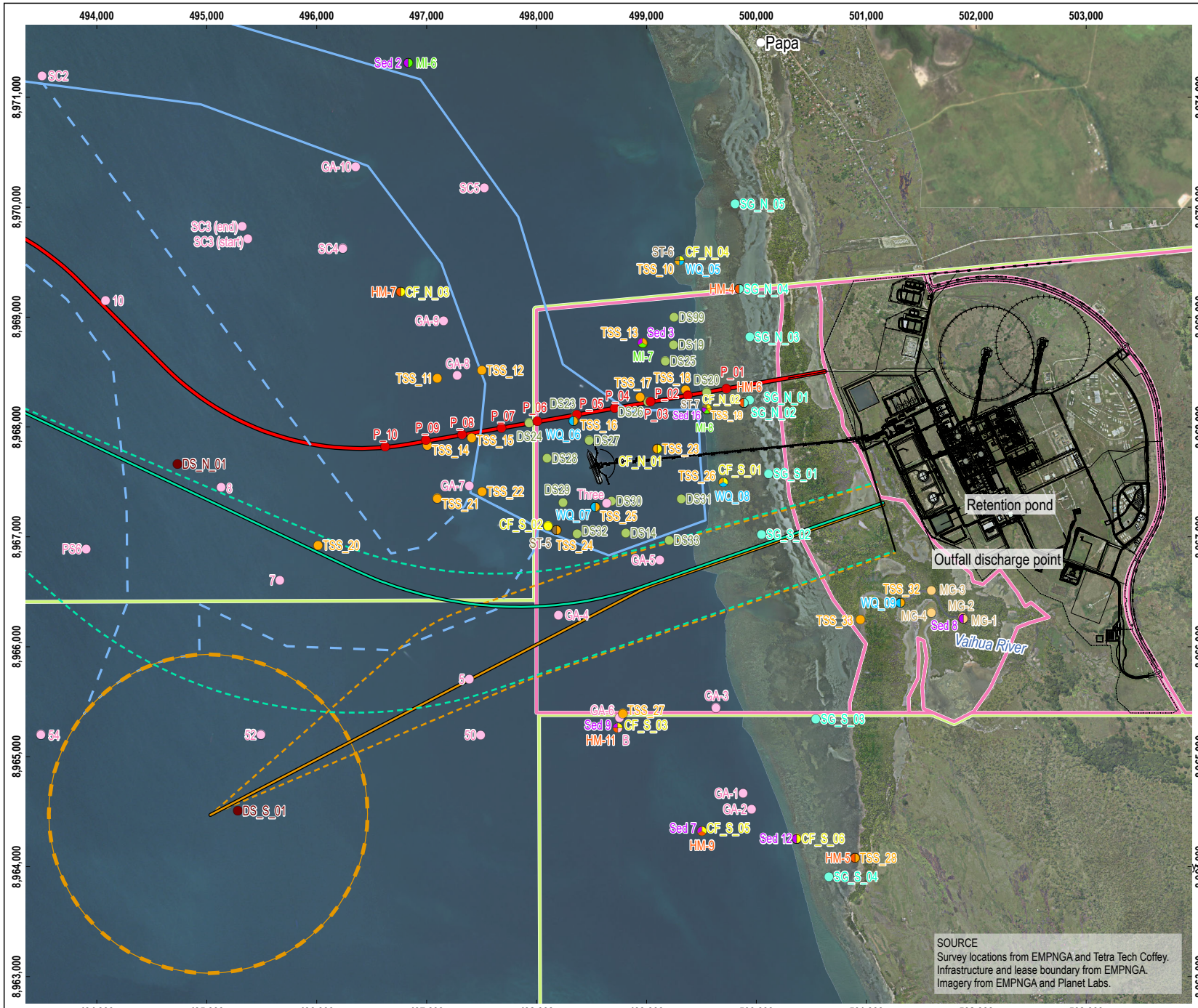
- Temperature (ºC)
- pH
- Conductivity (milli-Siemens per centimetre (mS/cm))
- Salinity (parts per thousand (ppt))
- Dissolved oxygen (mg/L and % saturation)
- Turbidity (NTU).

8.5.1.1 Water quality criteria

Water quality guidelines for the protection of marine aquatic life are provided in Papua New Guinea Environment (Water Quality Criteria) Regulation 2002 – Schedule 1 – Water Quality Criteria for Aquatic Life Protection (Seawater) (PNG ER).

As the Papua New Guinean legislation does not include criteria for some parameters, water quality guidelines published by the Australian and New Zealand Governments and Australian state and territory governments (ANZG 2018) have also been adopted as an additional assessment framework for the Papua LNG Project - Downstream.

Water quality results are also compared to the prescribed environmental limits in Annex 2 of the Environment Permit for the PNG LNG Project. These limits are based on the PNG ER water quality guidelines and the pre-construction baseline data collected in 2009 and 2010 for the PNG LNG Project.



LEGEND

- Village
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Proposed Papua LNG pipelines route alternate
- Existing and proposed plant layout
- PPFL2 boundary
- APPFL boundary
- Current navigational channel
- Proposed navigational channel

Proposed CALM buoy components

- Naphtha and condensate pipelines
- Naphtha and condensate pipelines alternate
- CALM buoy navigational area

Marine survey location

- Coral and fish video transect site
- Dredge spoil video transect site
- Pipeline video transect site
- Seagrass video transect site
- Water quality sampling site
- TSS and CTD sampling site
- Drop camera site
- Habitat map site
- Macrobenthic infauna sampling site
- Mangrove transect site
- Sediment sample site (pre-dredging)
- Sediment quality site
- Sediment trap site

0 0.5 1 km

SCALE **1:50,000**
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EXXONMOBIL PNG ANTELOPE LIMITED

PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 8.6

Marine survey locations - local context

TETRA TECH COFFEY

DATE: 04.07.23 PROJECT: 754-MELEN300733 FILE: 300733_02_F08.06_GIS

Discharges associated with the Project will be managed under the Project environment permit and relevant requirements of the Project ESMPs, that will be developed for the respective construction and operations phases of the Project (see Chapter 18 Environmental Management, Monitoring and Reporting).

The adopted assessment criteria are presented in Table 8.2.

Table 8.2 Water quality guideline values

Parameter	Units	Guideline Values		
		PNG ER Schedule 1	ANZG 2018[†]	EMP (Table 4) Sea Water Quality Criteria
pH	-	No alteration to natural pH	-	No alteration to natural pH[‡]
Dissolved Oxygen (DO)	mg/L	>6 mg/L	85 - 120	Not less than 5 mg/L
Total suspended solids (TSS)		50 mg/L or <10% change from background	-	50 mg/L or <10% change from background[ǁ]
Turbidity	NTU[#]	No alteration >25	-	No alteration greater than 25 NTU or <10% change from background**
Temperature	°C	No alteration >2°C	-	No alteration greater than 2°C[§§]
Electrical Conductivity (EC)	µs/cm	-	-	-
Salinity	PSU/ppt	-	-	-
COD	mg/L	-	-	125
BOD	mg/L	-	-	25
Ammonia[ǁǁ]	mg/L	3.6	-	-
Nitrate (as NO3- + NO2-)	mg/L	45	-	-
Nitrite	mg/L	-	-	45
Sulfide[§]	mg/L	0.002	-	0.002
Sulphate as $SO4^2$	mg/L	-	-	-
Potassium	mg/L	450	-	600
Cyanide	mg/L	0.01	-	-
Fluoride	mg/L	1.5	-	-
Oil and Grease	mg/L	None	-	10
Phenols	mg/L	0.002	-	0.002
Faecal coliforms	CFU/100ml	200	-	200
Antimony (Sb)	mg/L	-	ID	-
Arsenic (As)	mg/L	.005	ID	-
Boron (B)	mg/L	1	ID	10
Barium (Ba)	mg/L	1	ID	1.0
Beryllium (Be)	mg/L	-	ID	-
Cadmium (Cd)	mg/L	0.001	0.0055[A, B]	0.001

Parameter	Units	Guideline Values		
		PNG ER Schedule 1	ANZG 2018†	EMP (Table 4) Sea Water Quality Criteria
Chromium (Cr)##	mg/L	0.01	0.0044	0.001
Cobalt (Co)	mg/L	DL*	0.001	DL*
Copper (Cu)	mg/L	0.03	0.0013	0.03
Iron (Fe)	mg/L	1	ID	1.0
Lead (Pb)	mg/L	0.004	0.0044	0.004
Manganese (Mn)	mg/L	2.0	ID	2.0
Mercury (Hg)	mg/L	0.0002	0.0004B	0.0002
Molybdenum (Mo)	mg/L	-	ID	-
Nickel (Ni)	mg/L	1.0	0.07B	1.0
Selenium (Se)	mg/L	0.01	ID	0.01
Silver (Ag)	mg/L	0.05	0.0014	0.05
Tin (Sn)	mg/L	0.5	ID	0.5
Vanadium (V)	mg/L	-	0.1	-
Zinc (Zn)	mg/L	5	0.015B	5.0

Note: Trace metal data are for dissolved concentrations.
* Detection limit.
† (ANZG (2018). Trigger values for marine water (ug/L) level of protection 95% (% species). Appendix 2, Table 1A trigger value.
‡ The EMP Table 4 Criteria requiring pH 'not to vary from natural pH' was determined by calculating using the average preconstruction monitoring pH result obtained in 2009/2010 on a site-by-site basis and noting any variations greater than 0.5.
§ Environmental Monitoring Plan criterion is less than limit of detection.
‖ The EMP Table 4 Criteria for change of less than 10% from background was calculated using the average preconstruction monitoring result obtained in 2009/2010 on a site-by-site basis.
Nephelometric Turbidity Units.
** The EMP Table 4 Criteria for turbidity of no alteration greater than 25 NTU was calculated using the average preconstruction monitoring result obtained in 2009/2010 on a site-by-site basis and adding 25 NTU.
§§ The EMP Table 4 Criteria for temperature of no alteration greater than 2°C was determined using the average preconstruction monitoring temperature result obtained in 2009/2010 on a site-by-site basis and adding 2°C.
‖‖ Ammonia guideline values are dependent on temperature and pH – guideline value listed is based on freshwater temperature of 25°C and pH of 7.
Chromium as IV.
ID Insufficient data to derive a reliable trigger value.
A Chemicals for which possible bioaccumulation and secondary poisoning effects should be considered.
B Figure may not protect key species from chronic toxicity (this refers to experimental chronic figures or geometric mean for species).
- No result.

8.5.2 Results

The results of monitoring from the 2019 sampling campaign are presented in Table 8.3 and summarised and compared against earlier data, where relevant, in this section. Detailed results and discussion, including complete laboratory analysis reports are provided in Appendix E Nearshore Marine Baseline.

Table 8.3 2019 physical parameters and TSS data

Site ID	Parameter				
	pH*	DO (mg/L)	TSS (mg/L)†	Turbidity (NTU)‡	Temperature (°C)§
Environment Permit Criteria (Seawater)	**No alteration to natural pH**	**Not less than 5 mg/L**	**50 mg/L or <10% change from background**	**No alteration greater than 25 NTU or <10% change from background**	**No alteration greater than 2°C**
TSS01/WQ_01	8.39	7.20	<5	1.82	30.3
TSS02	8.24	6.53	<1	2.05	28.4
TSS02 Deep	-	-	<5	-	-
TSS03	8.20	5.61	1	1.02‖	29.5
TSS04/WQ_02	8.18	5.57	<1	1.76	30.5
TSS05	8.48	6.70	<5	0.85	30.1
TSS05 Deep	-	-	<5	-	-
TSS06/WQ_03	8.19	5.44	<1	1.80	28.8
TSS06 Deep	-	-	1	-	-
TSS07‖/WQ_04	8.10	6.96	1	1.17	30.7
TSS08	8.47	6.71	<5	0.89	30.0
TSS08 Deep	-	-	<5	-	-
TSS09	8.65	7.01	<5	0.34	29.8
TSS09 Deep	-	-	<5	-	-
TSS10/WQ_05	8.17	6.93	<1	1.21	29.2
TSS11	8.19	-#	1	1.59‖	29.4
TSS11 Deep	-	-	<1	-	-
TSS13	8.17	5.17	1	1.23‖	29.2
TSS15	8.19	-#	<1	1.67‖	29.4
TSS15 Deep	-	-	2	-	-
TSS16/WQ_06	8.54	6.83	<5	0.46	29.6
TSS16 Deep	-	-	<1	-	-
TSS17	8.18	-#	<1	0.93‖	29.2
TSS17 Deep	-	-	2	-	-
TSS18	8.18	-#	<5	1.09‖	29.7
TSS19	8.18	-#	<1	0.80‖	29.6
TSS20	8.18	-#	<1	1.05‖	29.5
TSS21	8.17	-#	1	1.19‖	29.5
TSS23	8.11	-#	1	0.71‖	30.4
TSS23 Deep	-	-	2	-	-
TSS24	8.19	-#	<1	0.61‖	28.6

Site ID	Parameter				
	pH*	DO (mg/L)	TSS (mg/L)†	Turbidity (NTU)‡	Temperature (°C)§
Environment Permit Criteria (Seawater)	**No alteration to natural pH**	**Not less than 5 mg/L**	**50 mg/L or <10% change from background**	**No alteration greater than 25 NTU or <10% change from background**	**No alteration greater than 2°C**
TSS25/WQ_07	8.72	6.88	<1	0.35	30.1
TSS25 Deep	-	-	1	-	-
TSS26/WQ_08	8.21	6.79	3	0.07	30.2
TSS27	-	-#	<5	-#	-
TSS27 Deep	-	-	<5	-	-
TSS28	8.22	7.09	<5	0.28	25.3
TSS29/WQ_12	8.55	6.87	<5	0.23	29.3
TSS31/WQ_11	8.10	7.2	<5	1.15	32.3
TSS32/WQ_09	8.11	-#	6	24.41‖	31.3
TSS33	8.26	-#	4	24.41‖	31.9
TSS34/WQ_10	8.23	7.89	1	0.69	29.4
TSS35	8.20	5.19	<1	1.14‖	29.6
TSS35 Deep	-	-	<1	-	-
TSS36	8.21	-#	<1	0.95‖	29.1
TSS36 Deep	-	-	2	-	-
TSS38	8.28	-#	2	0.89‖	31.9
TSS39	8.18	-#	2	1.22*	29.8
TSS40	8.31	-#	2	-#	32.6
TSS41/WQ_15	8.11	7.04	<1	0.21	31.3
TSS42/WQ_16	8.18	5.24	<1	1.32	30.2
TSS43	8.56	5.25	<5	0.27	29.9
TSS43 Deep	-	-	<5	-	-
TSS44	8.79	5.20	<1	0.64#	29.6
TSS 44 Deep	-	-	<5	-	-
WQ_13	8.25	6.95	<5	1.52	29.6
WQ_14	8.19	6.68	<5	1.39	30.3

* The criterion requiring pH 'not to vary from natural pH' was determined by calculating the average pre-construction monitoring pH result obtained in 2009/2010 on a site-by-site basis and noting any variations greater than 0.5 pH units.
† The criterion for change of less than 10% from background TSS mg/L was calculated using the highest pre-construction monitoring result obtained in 2009/2010 on a site-by-site basis and adding 10%.
‡ The criterion for turbidity of no alteration greater than 25 NTU was calculated using the highest pre-construction monitoring result obtained in 2009/2010 on a site-by-site basis and adding 25 NTU.
§ The criterion for temperature of no alteration greater than 2°C was determined using the average pre-construction monitoring temperature result obtained in 2009/2010 on a site-by-site basis and adding/subtracting 2°C.
‖ Reading sourced from the average value of conductivity, temperature and density (CTD) data obtained at each site, due to hand-held water quality meter malfunction.
Reading not obtained due to water quality meter malfunction.

Results from 2019 are discussed below including a comparison against the various criteria presented in Table 8.3, and to historical data presented in the following:

- Baseline water quality data collected for the PNG LNG EIS in 2007/2008 (Coffey Natural Systems 2009)
- Water quality data collected as part of pre-, during- and post-construction monitoring in fulfilment of conditions 92 to 94 of the PNG LNG Project Environment Permit (EP-L3(210)), and including data from 2009, 2010, 2011, 2012, 2013 and 2014 (Coffey Environments 2015).

8.7.2.1 Physiochemical parameters

Temperature

Baseline water temperatures measured in 2007/2008 ranged from 28.1°C to 30.9°C (Coffey Natural Systems 2009). Temperatures monitored during PNG LNG Project construction activities ranged from 25.2°C to 32.8°C and the final round of monitoring for that project undertaken in 2014 showed a range of 28.2°C to 33.3°C (Coffey Environments 2015).

Temperatures recorded in 2019 ranged from 28.6°C to 32.6°C with an average of 30.0°C, similar to observations from previous years.

Water temperature has been higher than a 2°C change from background temperatures in some instances, with variations between 2.1°C and 3.6°C above background levels observed. These likely arose due to a combination of factors including natural fluctuations, freshwater-influences, time and season of sampling event, tidal state, variability of measurement depth and calibration of the temperature probe.

pH

pH values recorded in 2007/2008 generally ranged from 7.9 to 8.2. A slightly lower pH value of 7.66 was recorded within the estuarine mangrove community environment of the Vaihua River (Coffey Natural Systems 2009).

During the PNG LNG Project construction phase, pH values in Caution Bay ranged from 7.5 to 8.3. Post-construction pH monitoring values ranged from 7.2 to 8.7, with a mean of pH 8.2. This value was the same as the average pH recorded across all sites during monitoring in 2010.

In September 2013 and April/May 2014 most pH values varied from background by less than 1 pH unit. Lower pH values (7.2 to 7.9) more indicative of estuarine water and freshwater influence were recorded at some sites, primarily those located within 1 km of the shore (Coffey Environments 2015).

In 2019, pH readings ranged from 8.1 to 8.8. The average value of 8.3 was within the range expected for sea water of 7.5 to 8.5. Values typically differed by less than 1 pH unit from those recorded prior to PNG LNG Project construction activities.

The similar range in pH values recorded over the various sampling campaigns reflects the relatively constant pH of seawater within a recognised band of values, and the unlikelihood of anthropogenic activities affecting this parameter.

Dissolved oxygen

No pre-construction data was available for dissolved oxygen for the PNG LNG Project.

Levels below the Environment Permit criterion of 5 mg/L were recorded at some sites during each of the construction and post-construction monitoring events, except during monitoring undertaken in February 2012. Some sites (TSS28, TSS32 and TSS33) in shallow, estuarine locations close to shore or near the mouth of the Vaihua River (see Figure 8.6) displayed levels below 5 mg/L, with a lowest recorded concentration of

3.4 mg/L. The recorded results at sites prone to lower dissolved oxygen levels due to reduced flow and mixing rates associated with the meeting of sea and freshwater, as well as elevated levels of nutrient input and organic matter from the river, are expected and likely to exhibit variability depending on weather and other environmental conditions.

Concentrations of dissolved oxygen recorded in 2019 ranged from 5.17 mg/L at TSS13 to 7.89 mg/L at WQ_10, above the Environment Permit criterion at all sites.

Total suspended solids

Suspended solids concentrations in 2007/2008 ranged from 2 mg/L at WQ_5 to 68 mg/L at WQ_7 (Coffey Natural Systems 2008).

TSS concentrations in 2019 ranged from below detection limits at around half of the sites, to 6 mg/L at WQ_09. At most sites concentrations were below or similar to background levels. Where concentrations were above background levels, the increase was minor and within the range of values observed in previous monitoring years.

Results from all sampling campaigns in Caution Bay have recorded TSS concentrations below the PNG LNG Project Environment Permit (EP-L3(210)) criterion of 50 mg/L.

Turbidity

Turbidity measurements in 2007/2008 and those obtained during construction from 2011 to 2013 showed similar values, ranging from 0 to 8.5 NTU. The consistency in results indicated that construction contributed negligible levels of sediment to the sampling sites (Coffey Natural Systems 2008, Coffey Environments 2014b). Turbidity measurements post construction in 2014 remained below 4.96 NTU at all sites (Coffey Environments 2014b).

In 2019, field measurements of turbidity ranged from 0.21 NTU to 24.41 NTU. Values of up to 24.21 NTU were observed in the Vaihua River and river mouth, a mangrove environment with fine sediment and murky water. Excluding the Vaihua river environment, the highest levels of turbidity elsewhere in the Project area were 2.05 NTU at TSS2.

No results above the Environment Permit (EP-L3(210) criterion of more than 25 NTU change from baseline levels (defined as 25 NTU above the highest historical value recorded at the site in 2009 and 2010) have been recorded in any of the years of monitoring. On occasion, values have been slightly above a 10% change from background conditions/pre-construction levels (defined as 10% above the highest historical value recorded at the site in 2009 and 2010). Such changes are also typically within the instrument error margin between measurements (Coffey Environments 2014b). Background levels were determined from a data set of only two to three recordings for each site in 2009 and/or 2010 and is unlikely to capture fluctuations in turbidity associated with a range of weather conditions.

Conductivity

There are no Environment Permit or other relevant adopted criteria for conductivity. However, the ANZECC/ARMCANZ (2000) guidelines indicate that seawater typically has a conductivity of about 50 mS/cm.

Baseline conductivity measurements recorded in 2011 ranged from 43.4 to 57.8 mS/cm, with an average across all sites of 51 mS/cm. Post-construction activities, conductivity readings were generally comparable to the 2011 baseline data (Coffey Environments 2015).

In 2019, conductivity readings were similar to baseline data ranging from 24.6 mS/cm at WQ_15 to 58.6 mS/cm at TSS33, with an average of 55.7 mS/cm across all sites.

Salinity

There are no EMP or other relevant adopted criteria for salinity. However, ANZECC/ARMCANZ (2000) guidelines indicate that seawater salinity typically ranges between 30 to 40 ppt.

Salinity measurements taken for the PNG LNG Project EIS in 2007/2008 ranged from 27.8 to 34.5 ppt in marine areas.

During PNG LNG Project construction activities, most salinity values were between 20 to 30 ppt. In 2011, relatively low salinity (the minimum value was 14.8 ppt) was recorded at some sites closer to the coast, that was expected to be indicative of the influence of freshwater mixing in the upper layers of the water column.

During post-construction monitoring, average salinity results derived from CTD profiles ranged from 17.4 to 34.0 practical salinity units (PSU) (approximately equivalent to ppt). In 2019, salinity ranged from 13.1 PSU at WQ_09 to 34.4 PSU at WQ_15, with an average across all sites of 33.7 PSU.

Natural and spatial variability in salinity levels across sampling events and the effect of depth-related salinity stratification is likely to explain much of the observed variation in salinity measurements.

Nutrients

Total Kjeldahl nitrogen and total nitrogen have been below analytical detection limits at all sites during baseline monitoring undertaken for the PNG LNG Project EIS and on all further monitoring occasions including in 2019.

Ammonia concentrations in 2007/2008 ranged from below laboratory detection limits to 0.055 mg/L (Coffey Natural Systems 2009). The concentration of ammonia in natural waters varies widely, with typical concentrations in seawater ranging from 0 to 0.17 mg/L (Johansson and Wedbourg 1980).

In 2010 and 2011, ammonia concentrations were below the analytical detection limits at most sites, with one higher reading of 1.1 mg/L at site WQ_06 in 2011 (Coffey Environments 2015).

Concentrations of potassium have remained below the Environment Permit (EP-L3(210)) (600 mg/L) criterion on all monitoring rounds other than in 2014, when sampling for this parameter was not undertaken.

Fluoride

There are no Environment Permit (EP-L3(210) criteria for fluoride. Seawater fluoride concentrations of around 1.2 to 1.4 mg/litre are typical (Smith and Ekstrand 1996).

Fluoride levels in 2019 were similar to or higher than previously recorded levels. The lowest levels of fluoride generally occurred in 2010, with the highest levels in 2019 generally less than 0.2 mg/L above the pre-construction levels measured.

Oil and grease and hydrocarbons

Oil and grease concentrations in Caution Bay samples have remained below the limits of laboratory detection at all sites during baseline, construction and operations monitoring undertaken for the PNG LNG Project. No observations have been made of visible sheens on the water surface.

The presence of TPH, PAH and BTEX were tested for in samples collected in 2019, and results were below the limits of laboratory detection at all sites.

Phenols

Phenol concentrations have remained below detection limits in all samples collected in Caution Bay during baseline, construction and operations monitoring undertaken for the PNG LNG Project. Phenol and pentachlorophenol remained below detection limits (<0.002 mg/L) in all samples tested in 2019.

Faecal coliforms

Faecal coliform samples were below detection limits at all sites in monitoring undertaken in 2010 and 2011 and were not analysed in 2013 or 2014 as holding times were exceeded prior to analysis (Coffey Environments 2014a).

Faecal coliforms were tested at five sites in August 2019: WQ-05 to WQ-08, and WQ-14. Total coliforms ranged from 870.4 to greater than 2,419.6 most probable number (MPN)/100 mL. *Escherchia coli* ranged from 116.9 to 186 MPN/100 mL and Enterococci ranged from 549.3 to greater than 2,419.6 MPN/100 mL. The highest levels of total coliforms and *Escherchia coli* were present at WQ-05, WQ-06 and WQ-26, although the highest levels of Enterococci were observed at WQ-08, with all results greater than 2,419.6 MPN/100 mL.

The source of the elevated levels of coliforms in 2019 results is not known but may be associated with various sources of discharge into the Vaihua River, potentially including a package sewage treatment plant servicing housing estates in Edai Town that discharges into a creek flowing into the Vaihua River, adjacent to the LNG Plant. Construction of Edai Town started in 2010 with ongoing expansion resulting in hundreds of houses on site. The sewage treatment plant is privately operated under approval from Water PNG. The sewage treatment plant also operates under a permit from CEPA for the discharge of sewage. The LNG Plant sewage treatment plant toray system that was commissioned in 2017 discharges to the ground within the LNG Plant near Camp A and, depending on factors such as fluid percolation and rainfall characteristics, this may also influence coliform concentrations.

Sulphide

Sulphide concentrations in all samples have been below the relevant laboratory limits of detection (<0.1 mg/L in 2019) during all monitoring events. The limit of detection for all monitoring rounds has been above the EMP criterion of 0.002 mg/L; consequently, any determination of compliance is not possible.

Chemical and biological oxygen demand

Due to short holdings times, chemical and biological oxygen demand (COD and BOD) were not measured in water quality samples collected for the PNG LNG Project EIS. In 2010 and 2011 levels were generally at or below laboratory detection limits (<100 mg/L for COD and <2 mg/L for BOD).

In 2014, concentrations of both parameters at most sites were higher than levels recorded pre-construction. The elevated levels in 2014 were considered likely due to the analytical methods used rather than increased presence of bacterial and organic material (and subsequent increased oxygen demand) in the samples. Analyses on seawater samples are less common than for freshwater samples and require many dilutions. This increases the limits of detection, along with the likelihood for error and anomalous results. Dissolved oxygen concentrations at the sites were not substantially reduced as would be expected with elevated COD and BOD concentrations. Levels of nutrients and faecal coliforms, which can be conducive to elevated oxygen demand, were also low (Coffey Environments 2014b).

In 2019, COD levels were below detection limits at some sites but were above Environment Permit (EP-L3(210)) criteria at other sites (WQ_03, WQ05, WQ_08, WQ_11 and WQ_14). However, levels remained below those observed in 2014. Levels of BOD were below detection limits at all sites in 2019.

8.5.2.1 Metals

In 2007/2008, most water samples had concentrations of cobalt, chromium, copper, nickel, lead, selenium, and zinc below the analytical detection limits of <0.001 mg/L. Concentrations of aluminium, iron, arsenic, cadmium, manganese and silver were above the detection limits at some sampling locations, however results remained below the (applicable at the time) ANZECC/ARMCANZ (2000) criteria (Coffey Natural Systems 2009).

In 2010/2011 and 2014, barium, boron and tin were added to the list of metals to be analysed. Most metals concentrations were at or below analytical detection limits, and/or below the applicable Environment Permit EP-L3(210) criteria. An exception was levels of cobalt in 2011, which was above the Environment Permit criterion but remained below the ANZG 95% guideline. Another exception was one lead concentration of 0.0046 mg/L at WQ1 in 2014, which was marginally above the Environment Permit criterion of 0.004 mg/L (Coffey Environments 2014b). Zinc was also above the ANZG 95% guideline (0.015 mg/L) at some sites in 2010 and 2011 but remained below the Environment Permit and Schedule 1 criteria.

In 2019, the sampling results displayed a similar pattern with most parameters either below the applicable detection limit for each parameter, or above the detection limit but below the Environment Permit EP-L3(210) criteria, ANZG (2018) 95% and Schedule 1 guideline values. An exception was chromium at WQ_03 which displayed a concentration of 0.078 mg/L. This level is above the Environment Permit criteria of 0.01 mg/L and was a significant outlier, possibly due to cross contamination of the sample or laboratory error. No obvious source of contamination has been identified near this site and all other water quality sites showed levels close to or below the detection limit, across all sampling years. Levels of silver at this site were above the ANZG (2018) 95% guideline of 0.0014 mg/L (but below the Environment Permit criterion of 0.5 mg/L), while results at other sites were below the detection limit (<0.0001 mg/L).

8.6 ECOLOGY

8.6.1 Method

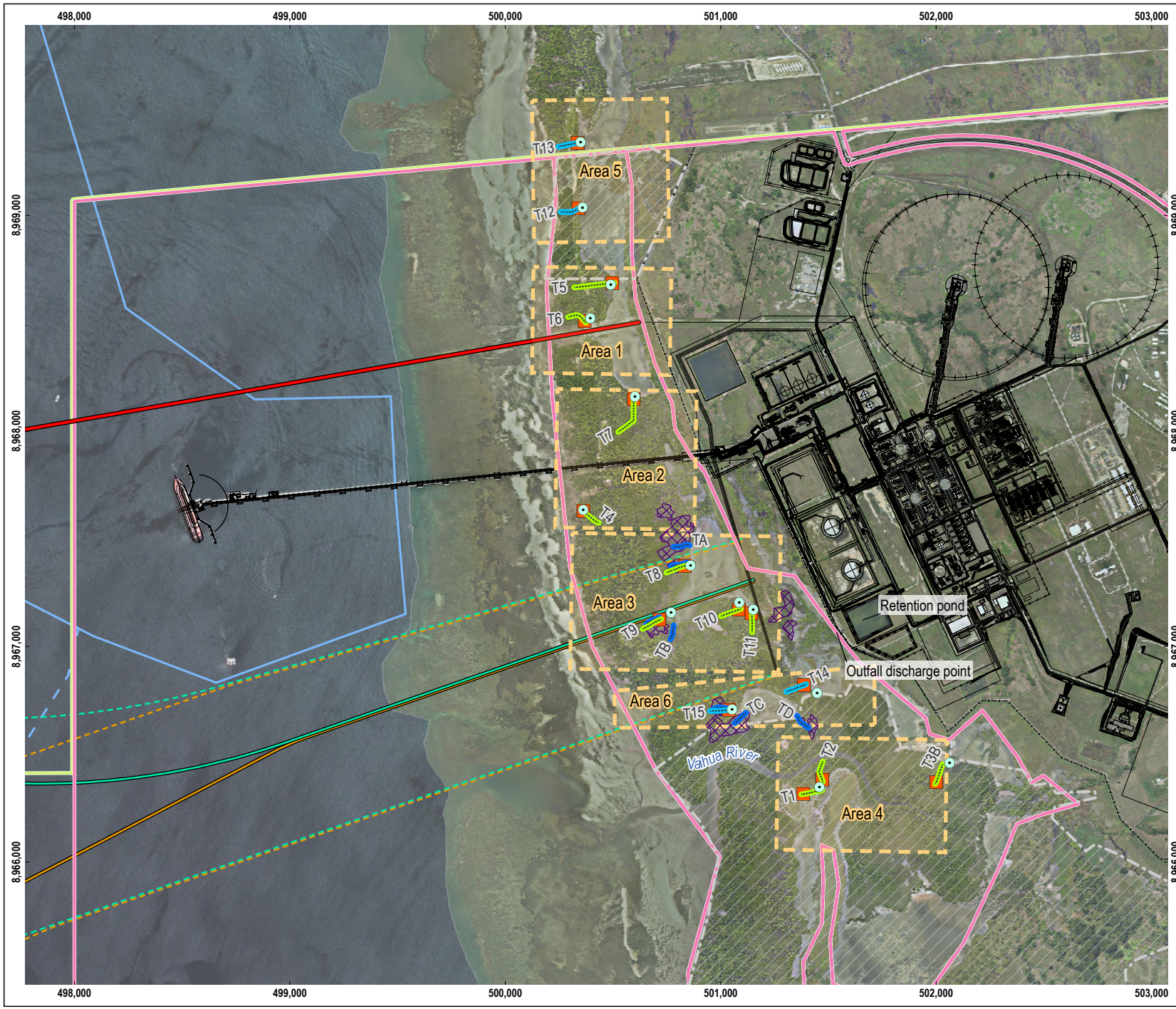
The marine ecology study methods used to inform the characterisation studies are outlined in this section. The primary methods undertaken included a desktop review of relevant literature and existing information pertinent to the Project (including studies for the PNG LNG Project), and field surveys conducted in 2019 and 2022.

8.6.1.1 Mangroves

A review of historical data was undertaken to characterise the mangrove environment, and field studies across in May 2019, August 2022 and February 2023 were also conducted.

The 2019 field study involved surveying previous mangrove transects and new transects near the LNG Plant, including proposed pipeline landfall sites. The 2022 survey comprised an in-depth field investigation of the areas of potential mangrove dieback, to determine the extent and possible causes. Remote sensing and spatial analysis was also conducted in 2022 to assess land erosion and accretion. The sampling locations are shown in Figure 8.7.

The surveys were undertaken in a similar manner to the mangrove surveys completed in 2011 (CQU 2011). and 2014 (Vision Environment 2014). New transect sites were selected at locations that were representative of habitat in the area and were easily accessible for habitat characterisation. In 2022, three previously established transects were surveyed and four new transects were established based on possible dieback areas identified via satellite imagery.



LEGEND

- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Proposed Papua LNG pipelines route alternate
- Existing and proposed plant layout
- Cultural heritage restricted area
- PPFL2 boundary
- APPFL boundary
- Current navigational channel
- Proposed navigational channel

Proposed CALM buoy components

- Naphtha and condensate pipelines
- Naphtha and condensate pipelines alternate

Mangrove survey location

- Pore water sampling
- Macroinvertebrate sampling
- Mangrove transect (PNG LNG Project EIS/ monitoring)
- Mangrove transect (2019)
- Mangrove transect (2022)
- Dieback area
- Mangrove transect area

SOURCE
Mangrove survey locations from Vision Environment and Tetra Tech Coffey
Infrastructure, cultural heritage and lease boundary from EMPNGA.
Imagery from EMPNGA and Google Earth.

0 500 m

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PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 8.7

Mangrove survey locations

TETRA TECH COFFEY

DATE: **20.07.23** PROJECT: **754-MELEN300733** FILE: **300733_02_F08.07_GIS**

Mapping of habitat areas and the dominant species composition of Caution Bay mangroves was undertaken using satellite imagery to assist in analysing the spatial extent of the mangrove area, identify community composition classes and density, and identify any changes to the area since previous surveys.

The 2019 survey and sampling included:

- Determining mangrove composition and relative canopy cover at 10 m intervals along each transect
- Establishing replicate 25 m^2 plots at 50 m intervals on each transect, and recording the following data:
  - Tree and seedling density
  - Diameter at breast height (DBH) and sum of Live Basal Area (LBA) per transect.
  - Projective Foliage Cover (PFC) expressed as percentage covered by foliage (canopy density).
  - Crab hole densities.
- Observing the extent and nature of mangrove timber harvesting as relative frequency of new versus regenerating areas
- Collecting one pore water sample from sediment in the intertidal area at each mangrove survey transect.

The 2022 survey and sampling included:

- Determining mangrove composition and relative canopy cover at 10 m intervals along each transect
- Establishing three replicate 25 m^2 quadrats at the start, end and midway point on each transect, and recording the following data:
  - Tree and seedling species richness, density and diversity indices (number per 25 m^2 replicate plot)
  - Projective foliage cover with four cover classifications: open (0 to 5%), sparse (6 to 25%), moderate (26 to 50%) and dense (>50%)
  - Live basal area
  - Recording of crab hole densities.
- A total of 25 water quality samples were taken from locations where localised pooling and ponding of water was observed within the observed dieback areas and adjacent discharge points.

The 2023 survey and sampling included:

- Habitat mapping and a water tracer study, based on the 2022 field survey results, to determine if water discharged from the LNG Plant retention pond mixing pit was reaching dieback areas of interest, specifically those downstream of and in proximity to the LNG Plant discharge location. For this study:
  - Water tracer was released at two locations and as it moved downstream water quality parameters, including rhodamine concentrations, were used to track the tracer along its pathway.
  - Aerial drones were used to capture images at 60 m altitude during water tracer movement.
  - The water tracer layers were visually assessed to determine the final route and destination of the discharge water from the mixing ponds and reproduced as high-quality maps.

8.6.1.2 Macroinvertebrates and infauna

Macrobenthic infauna has been sampled at various times from Caution Bay for the PNG LNG Project, and for the Project, to characterise the infauna community. Infauna sampling locations are shown on Figure 8.5.

Sediment infauna abundance and diversity analysis was conducted by Dr John Moverley for the 2019 survey and by Benthic Australia Pty Limited for the 2022 survey, details of which are provided in Appendix E Nearshore Marine Baseline.

One macroinvertebrate sample was also collected at each mangrove sampling transect during the 2019 survey (see Figure 8.7).

Macroinvertebrate grab samples were collected from near the sediment surface using a Petit Ponar grab sampler. Samples were bagged and preserved in ethanol for sorting. Field observations were recorded including sediment surface type and evidence of fauna (burrows, mounds, tracks etc.). Sample material and any obvious fauna were photographed.

Samples were analysed by a benthic taxonomic specialist for the following:

- Identification to lowest known taxonomic level
- Abundance counts of the number of individuals of each taxonomic group.

8.6.1.3 Nearshore habitats and fauna

The habitat composition and faunal communities relevant to the Project in Caution Bay were assessed to characterise ecological value and establish a set of baseline conditions. Pre-existing data generated for the PNG LNG Project and published literature were used to characterise the habitat and faunal communities, in conjunction with an assessment of benthic features and foreshore and shallow pelagic environments undertaken during field surveys conducted for the Project in April and July 2019, and in September and October 2022. This assessment incorporated photography and videography of environmental features in proximity to existing infrastructure, the proposed Project facilities, and reference locations, to determine the types and condition of habitats, species of conservation significance, and anthropogenic influences. A summary of the studies conducted to characterise the nearshore ecological setting is provided below.

During the PNG LNG Project EIS studies in 2007 and 2008, a variety of diver-based and remote camera techniques were used to characterise the reef, seagrass and benthic habitat communities. Fixed transects were typically 20 to 25 m long, with line-intercept method used to assess the extent of different habitat types. From 2010 to 2014, and then again in 2019, data were recorded at reef/coral fish and seagrass monitoring sites that were derived from towed video survey and post-survey visual analysis, using the point-intercept method. This method involved habitat imagery being overlain by five randomly located points on 50 frames (approximately one frame every 2 m), identified along 100 m video transects. The towed video survey covered reef, seagrass, macroalgal bed and soft sediment habitats.

The frequencies of observations of each habitat type were then summed and represented as a percentage frequency (out of 250 points) for each of the community indices (including live coral, rubble, dead coral, sediment, macro algae, rock) at each site.

Where relevant, these categories were further divided into sub-categories of coral growth forms, seagrass and algal species, and base substrate type (52 sub-categories in total) for comparison in graphical and multivariate analyses.

The characteristics of the biological communities for all surveys (2010, 2011, 2012, 2014 and 2019) were compared using multivariate analysis techniques. This provided a dissimilarity matrix for each site and showed, in this application, whether or not sites had become progressively different in the community indices over time, or between sites within and outside 2 km proximity of construction activities.

While the diver-based survey undertaken for the PNG LNG Project EIS had greater fixed site precision, it was more restricted in the total area that could be covered when compared with the towed video transect methods.

8.6.2 Nearshore marine habitats

The nearshore marine environment of Caution Bay within and adjacent to the proposed Project and its likely areas of influence comprises various habitat components including salt plains, mudflats, mangroves, seagrass and macroalgae zones, coral reefs and a soft sediment seafloor. The shallowest nearshore and intertidal areas, particularly in the vicinity of the Vaihua River estuary, are predominantly supratidal saltflats that receive tidal inundation during extreme spring high tides and also occur to the landward side of the mangroves. These

are predominantly dry during the dry season and typically bare of vegetation (Coffey Natural Systems 2009). A marine habitat map is provided in Figure 8.8. Each of the main marine habitat components are summarised below, with additional detail provided in Appendix E Nearshore Marine Baseline.

8.6.2.1 Littoral zone and beaches

Coastal features within the Caution Bay littoral plains zone include plains, spits and barrier-beaches, as well as tidal flats that are differentiated by the frequency and depth of inundation. Sandy beaches occur in small patches along the southern coast of Caution Bay in regions not supporting mangroves. Wide sandy beaches are present in northern Caution Bay and north of the Kido River.

The sediment composition in these areas transitions from medium to fine sands mixed in variable proportion with fine powdered coral and shell sandy deposits along beaches and at the outer shore where wave and current action removes very fine materials, through a range of intermediate textures to peaty-clays in the highest areas of shallow inundation and above (Rowe et al. 2013). Small creeks in the area are often transient, shallow and irregular, and their drainage to the coast, along with the large volumes of river discharge, facilitates the development of tidally influenced estuarine areas. The outer tidal flats occur on an accreting coast, with the inner tidal flats situated slightly below to slightly above the mean high-water mark (Rowe et al. 2013).

8.6.2.2 Mangroves

Mangrove communities provide nursery habitat for many juvenile fish, bird and invertebrate species. Mangroves also facilitate other important ecological functions including acting as buffers against erosion during severe weather, binding sediments transported in terrestrial runoff, and acting as a natural nutrient filtration and conversion system.

Global mangrove diversity is at its highest across the Indo-Pacific region, and the ecosystems of the Gulf of Papua in southern Papua New Guinea are some of the largest and most undisturbed (Ellison, 2005; Shearman, 2010). Across the Gulf of Papua, mangrove communities occupy several different environmental settings, with two mangrove communities predominating at Caution Bay (Rowe et al. 2013):

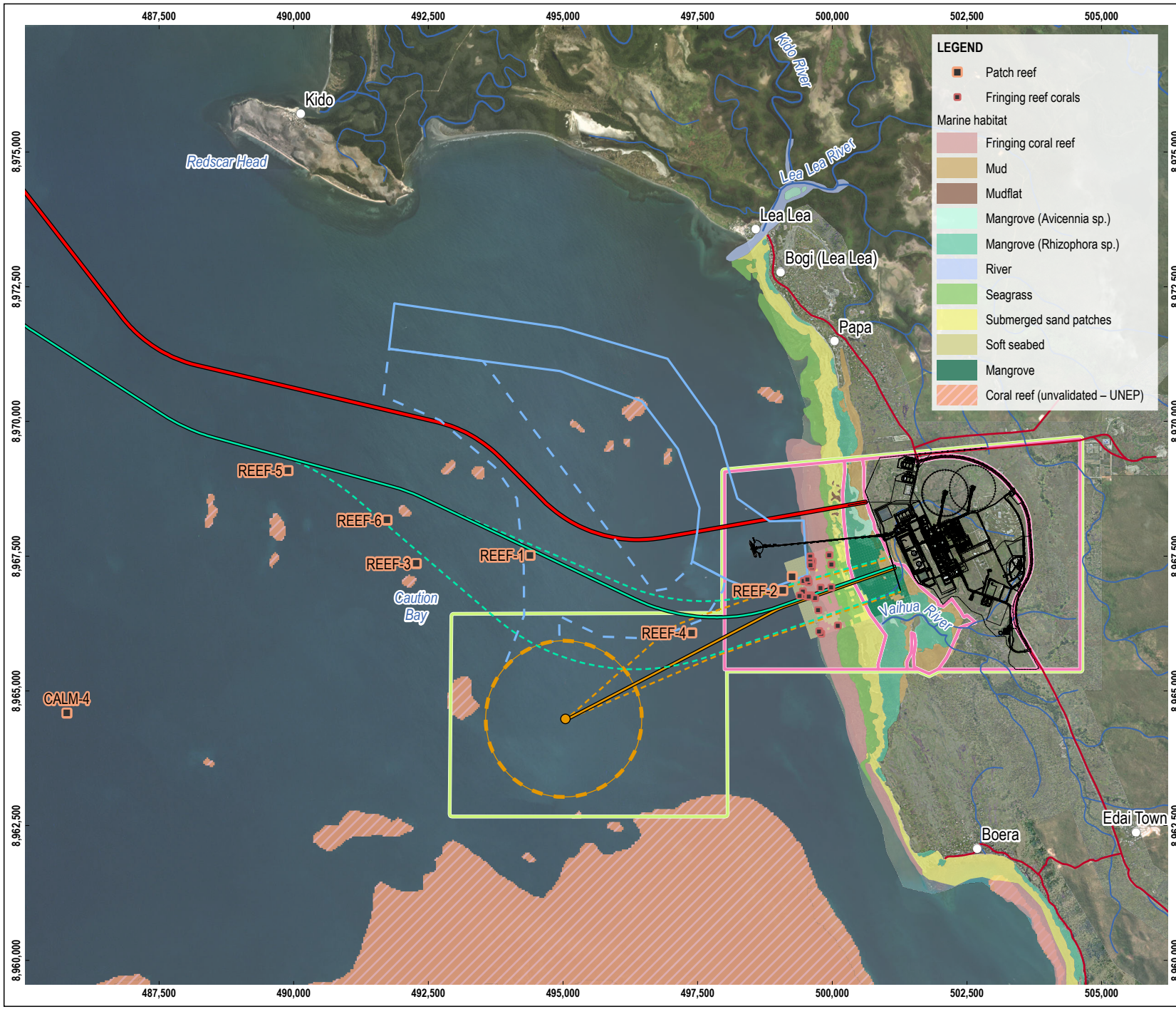
- A tall, dense canopied, one-layered forest of almost pure even-aged *Rhizophora* occurring seaward and at lower elevations that is subject to frequent tidal inundation. *Bruguiera* occurs secondary to *Rhizophora*.
- An irregular to low-height *Avicennia* dominated open canopy woodland that occurs inland of the *Rhizophora* and occupies a higher tidal position. *Ceriops* and *Bruguiera* are sparsely observed and tentative identifications of *Aegiceras* and *Lumnitzera* have been made. The woodland is without groundcover aside from numerous *Avicennia* pneumatophores and wooden debris. The transition between the *Avicennia* woodland to open mudflat is abrupt.

For the PNG LNG Project a total of 1,647 ha was mapped comprising:

- 70% classified as mangrove forest (530 ha dense *Rhizophora* and *Rhizophora/Bruguiera*, 147 ha dense *Ceriops*, and 88 ha emergent *Avicennia*)
- 30% (492 ha) saltpan.

Targeted mangrove surveys in 2014 for the PNG LNG Project indicated that:

- Dense *Rhizophora* forests and mixed *Rhizophora/Bruguiera* forests were present at the seaward side of the mangroves
- *Ceriops* and *Osbornia* were present toward the landward side
- Emergent *Avicennia* were present throughout the mangrove area.



LEGEND

- Village
- Road
- Watercourse
- PNG LNG pipeline
- Proposed Papua LNG pipelines route
- Proposed Papua LNG pipelines route alternate
- Existing and proposed plant layout
- PPFL2 boundary
- APPFL boundary
- Current navigational channel
- Proposed navigational channel

Proposed CALM buoy components

- CALM buoy
- Naphtha and condensate pipelines
- Naphtha and condensate pipelines alternate
- CALM buoy navigational area

SOURCE
Marine habitat from Tetra Tech Coffey (CNS, 2008 & 2023).
Unvalidated coral reef locations from UNEP-WCMC.
Infrastructure, roads, watercourses and lease boundary from EMPNGA.
Imagery from EMPNGA and Planet Labs.

0 1 2 km

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PROJECTION: **WGS 1984 UTM Zone 55S**

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PAPUA LNG PROJECT – DOWNSTREAM

FIGURE 8.8

Caution Bay marine habitat map

TETRA TECH COFFEY

DATE: **04.07.23** PROJECT: **754-MELEN300733** FILE: **300733_02_F08.08_GIS**

The composition of mangrove communities identified during the 2019 mangrove survey was similar to that recorded in surveys undertaken in 2011 and 2014. The mangrove species observed during field surveys adjacent the LNG Plant are commonly recorded elsewhere in Papua New Guinea and neighbouring countries.

Mangrove communities observed adjacent to the LNG Plant in 2019 were dominated by *Rhizophora/Brugeria* forest, with a smaller proportion of grey mangrove (*Avicennia marina*) dominated forest and yellow mangrove (*Ceriops tagal*) shrubland. A total of 817 mangrove plants were recorded (74% live and dead adults, 26% seedlings) within the seven transects (see Appendix E Nearshore Marine Baseline for location details and characteristics). The mangrove communities were stable with no significant temporal variation in mangrove parameters observed.

The four main mangrove vegetation types consisted of:

- *Rhizophora/Bruguiera* forest communities (seaward extent)
- Grey mangrove dominated communities and growing among other species
- Yellow mangrove dominated shrub communities (landward extent)
- Mangrove dieback areas.

The effects of the direct removal of mangroves for the construction of the pipeline right of way and jetty for the PNG LNG Project facilities are evident; however, the construction of the LNG facility has not had a substantial impact on the neighbouring mangrove community. No noticeable effects to the health indices of mangrove communities adjacent to the cleared areas have been observed (Coffey Environments 2015). Local people have also previously been recorded as harvesting mangroves for firewood, building material and tools, food, and fishing activities (Liebezeit and Rau 2006; Shearman 2010).

Several localised mangrove dieback areas were identified adjacent to the LNG Plant during the 2019 and 2022 mangrove surveys. Mangrove dieback areas were identified adjacent to the LNG Plant mixing pit and retention pond, as well as to the south of the LNG Plant jetty and LNG Plant pipeline disturbance areas. The mangrove species observed to be the most affected are the yellow mangrove and Indian mangrove (*Ceriops spp.*), which inhabit the landward edge of the mangrove habitat.

Change analysis conducted in 2019 along three transects showed areas of mangrove dieback or loss and mangrove forest gain. Change analysis in 2022 also indicated that mangrove coverage areas increased within the pond discharge areas from 2010 to 2022, primarily attributable to an increase in *A. marina* density. *Avicennia* is a genus demonstrating wide physiological tolerance to higher salinity, intertidal position and temperature and will outcompete other mangroves when conditions shift inland beyond the lower-tidal window (Rowe et al. 2013). This was most likely due to the construction of the retention and mixing ponds and resultant increase in water discharge, indicating that changes in hydrodynamic flows can have both positive and negative impacts.

The findings of a tracer dye investigation in 2023 further indicated that the pooling of discharge waters from the LNG Plant mixing pond that flow into low lying areas and influence hydrodynamic flows, may be resulting in plant stress and mortality in *Ceriops spp*, while supporting conditions that have resulted in growth of other mangroves including *A. marina*, a species suited to frequent tidal inundation. The associated mangrove faunal communities (see Section 8.6.3.1) are not expected to be affected by the change in mangrove species, due to the generalist nature of most fauna, meaning they utilise mangrove vegetation interchangeably. The causes of mangrove dieback are multifactorial, and in other locations away from the potential influence of the existing PNG LNG Project operation, causation has not been assessed and is largely unknown. Ongoing investigations are being undertaken regarding this matter.

8.6.2.3 Seagrass and macroalgae

Seagrass beds occur in Caution Bay on the generally flat, sandy seafloor between the shore line and the fringing reef in water depths up to approximately two metres. They range from dense, to sparse and patchy,

typically multispecific communities of *Enhalus acoroides, Syringodium isoetifolium* and *Cymodocea* sp. Other seagrass species such as *Halophila* spp. have also been observed. Seagrasses do not extend deeper into the lagoon beyond a transitional and occasionally mixed zone where they co-occur with occasional sponges, scattered corals, rubble and macroalgae (*Sargassum, Padina, Halimeda, Caulerpa* and *Turbinaria* spp.), before.

Seagrass communities are of ecological significance as nursery and feeding habitats and are utilised by multiple species including those of conservation significance such as marine turtles and dugong. Juvenile fish in mangrove forests or salt marshes often feed in seagrass, and juvenile reef fish reside in seagrass meadows before inhabiting reefs upon maturity. Other species move between seagrass habitats from mangroves into offshore environments, thereby forming a connection between terrestrial, mangrove/salt marsh, seagrass, reef and beyond into the pelagic zone. Seagrass habitats are highly productive and also stabilise substrates, regulate nutrients, sequester carbon and filter and bind suspended sediment.

Sargassum is the most prolific macrophyte observed beyond the seagrass zone and this macroalga is present across much of the shallow-water reef system where corals are absent (in waters between approximately 2 to 5 metre depth). The 2019 and 2022 survey findings indicated that these conditions remained similar to those documented for Caution Bay in the PNG LNG Project EIS. This may largely be an ongoing consequence of dynamite fishing activity that is known to have occurred in prior years, other anthropogenic factors (such as pollution, overfishing, and runoff), natural factors and other oceanographic influences, or a combination of these aspects. Riverine inputs from the Vaihua River also appear to influence the dynamics of reef development in the south of Caution Bay near the LNG Plant jetty, and to some extent this may regulate coral recruitment and the presence of macroalgae. *Sargassum* has a high resilience to disturbance.

No substantial seagrass or macroalgal growth has been observed beyond the fringing reef.

8.6.2.4 Coral reefs

Multi-year assessments from 2008 to 2014 and 2019 and 2022 has enabled characterisation of coral communities at various locations in Caution Bay. Most recently, surveys in 2022 focused on the locations of the proposed marine facilities (see Chapter 2 Project Description). No earlier comparative data was available in these areas.

The general presence of corals and associated benthic habitat types observed during surveys broadly relate to depth-facilitated zones including:

- Sand and seagrass with small individual corals (0 to 1 m water depth)
- Scattered small coral bommies, macroalgae and coral rubble (1 to 3 m water depth)
- Largely contiguous fringing reef habitat (4 to 8 m water depth)
- Isolated corals amidst rubble and sand transitioning to low complexity soft seabed (8 m and beyond).
- Sporadic occurrences of patch reefs and substantial outcrops of rock and corals in waters beyond the fringing reef (from approximately 8 m to 25 m depth).

The shallow waters in the vicinity of the existing LNG Plant jetty that are traversed by the proposed export pipelines, and the Papua LNG Pipelines Option 15A alignment (as well as the alternative Option 15F pipeline route and prior 2019 pipeline options 1 and 2), consist of the same depth-related habitat type zonation listed above, and as previously identified in Caution Bay (Coffey Natural Systems 2009; Richards et al. 2016).

Around the Caution Bay coastline, a patchy though generally intact fringing reef is situated in water depths of between four to eight metres, forming a belt of habitat of varying structural complexity. The majority of the shallow water and nearshore fringing reefs appear degraded to varying extents, with generally low coral species diversity, and low coverage of live coral cover. Substantial coverage of *Sargassum* macroalgae occurs in several areas of low relief fringing reef, in conjunction with high proportions of rubble or hardstand substrate where live coral is absent. However, some areas of greater three-dimensional reef habitat, intact

hardstand structure and live coral are present which support a greater diversity of associated fish and invertebrate species. The intact tracts of healthy reef are usually characterised by occasionally large tabular *Acropora* corals, though these are less common than the generally low complexity or degraded reefs observed more widely.

Across survey sites, where present, the most readily recognisable hard corals identifiable from video records have been various reef-building corals belonging to common genera including *Acropora*, *Faviid*, *Porites*, *Pocillopora* and *Seriatopora*. Some smaller colonies belonging to other genera are present that are not readily identified from video records, and others are also more conspicuous at deeper sites and locations where the reef is of greater structural complexity.

High coral cover and diversity is present at Idihi Island (CF-17), and at site CF-14 (located approximately 2 km south of the existing LNG Plant jetty) where an extremely large *Pavona clavus* colony exists that has been documented since first observed during studies for the PNG LNG Project EIS (Coffey Natural Systems 2008), and during subsequent monitoring studies. This species can form large mono-specific stands; however, specimens of the size of the colony present in Caution Bay are uncommon (Coffey Natural Systems 2008). It was noted that this colony could be 150 to more than 300 years old (Cronin, 1999, cited in Coffey Natural Systems 2009). The colony was again observed in 2019 and appeared to still support a locally diverse and abundant community of fish.

Beyond the coastal fringing reef, at depths greater than 8 m to 10 m, coarse sand substrate transitions into largely homogeneous fine sand and softer silty substrate sediments with some organic detritus and shell fragments, with generally sparse visible epibiota (primarily gorgonians, soft corals and barrel sponges are present on silty seabed). There is substantial bioturbation (burrows, mounds, and pits) from biological activity of benthic infauna present in these sediments.

The 2022 surveys in proposed Project infrastructure locations identified that large or contiguous tracts of hardstand seabed and rocky outcrops or reefs were uncommon beyond approximately 8 m depth; though areas were observed where outcropping rock and patch reefs supported relatively diverse coral assemblages (see Figure 8.8). Two main habitat types were observed during targeted towed camera surveys in 2019 and 2022:

- Discrete areas of seabed characterised occasionally dense stands of corals; the main corals in these areas were octocorals and gorgonians (various soft corals, whip corals and sea fans, as well as some sponges (Porifera). Some reef-building hard corals are also present, along with ascidians and echinoderms.
- Generally homogeneous and flat seabed characterised by fine silts and low benthic structural complexity.

The locations of the proposed CALM buoy and the associated export pipelines are characterised by silty substrates and low three-dimensional complexity. Given the sporadic occurrence of patch reefs elsewhere in Caution Bay, some of these may also be present in proximity to the export pipelines. These patch reefs do not appear to be readily connected to the more contiguous fringing reef present in shallower waters in Caution Bay.

The general predominance of soft corals, sea fans and gorgonian corals in the deeper waters offshore the fringing reef amidst silty sediments (as opposed to rock and calcium carbonate substrates) suggests that these communities are adapted to higher suspended sediment and turbidity levels and potentially lower levels of light than reefs close to shore or observed in other tropical coastal locations. Nearby riverine influences may play a role in their development and the prevailing ecological characteristics.

Coral health

No substantial changes in the ecological structure or functionality of the reef ecosystem and habitats observed and subsequently monitored for the PNG LNG Project between 2008 and 2014, have been observed during subsequent surveys for the Project in 2019 and 2022.

From a qualitative and observational perspective, the 2019 and 2022 surveys showed no clear increases in the abundance of dead or diseased coral compared to surveys conducted between 2010 and 2014, or signs of the recent occurrence of these aspects. No changes to species abundance or diversity or large-scale or ecologically significant changes were evident from video footage or remote imagery in 2019 or 2022. Some signs of coral recovery and recruitment of small colonies is apparent closer to shore.

The general pattern in abundance and distribution of living coral colonies in 2019 was relatively consistent and comparable with observations made during surveys conducted in 2011, 2012 and 2014, notwithstanding the slight differences in transect alignments, and consideration of natural coral growth and attrition rates.

The results of multivariate analyses of benthic habitat types have shown clear clustering separation of seagrass and coral/fish over the monitoring period (Appendix F of Appendix E Nearshore Marine Baseline includes figures presenting the abundance of each category at the 'coral and fish' sites assessed in 2019 compared with those observed in sampling years 2010, 2011, 2012 and 2014). Sites CF-09, CF-10 and CF-16 showed an increase in macroalgae cover in 2019 compared to prior years. These sites are largely characterised by areas of base rock, coral rubble and shallow-water fringing reef with varying, though generally low, rates of live coral cover.

While some sedimentation has previously been observed on occasion, including following PNG LNG Project construction activities, little evidence of coral bleaching, anchor scars or anthropogenic debris has been apparent at any the coral reef survey sites. Coral disease has been observed, though this has been very limited in extent.

Discussions with local fishers have indicated that the practice of dynamite fishing has previously occurred in Caution Bay in recent times, likely exacerbating the degradation of reefs (Coffey Natural Systems 2009). However, no fresh evidence of dynamite fishing has been apparent during surveys for the PNG LNG Project conducted between 2009 and 2014, or during the 2019 and 2022 surveys for the Project. At a reference site near Idihi Island, there are no signs of anthropogenic disturbance of this kind, which would suggest that dynamite has not been used for fishing in this offshore location. Other obvious mechanical damage or substantial impacts have also not been observed at this location.

8.6.2.5 Soft sediment habitats

Soft, generally homogeneous sediments cover most of the deeper seafloor of Caution Bay. These habitats are primarily distributed seaward of the fringing reef, at depths ranging from approximately 8 m to 30 m (tidally dependent) and predominate aside from where shoals or patch reefs are present. Some coarse coral sand, organic matter (vegetative debris) and shell grit are typically also present on the seabed closer to shore, while fine silt, muddy terrigenous silts and clays are abundant in deeper water. The finer sediments are easily re-suspended by wave action or currents. There are no seagrasses or macroalgae, and few hard stand structures for encrusting organisms to colonise. Epifauna is typically sparse, though not absent, and in these areas various sea fans and other octocorals are present. The sediment surface is often covered by thin films of algae and microphytobenthos and there is often evidence of benthic faunal activity in the form of burrows, mounds and casts. These seabed conditions have been observed throughout all surveys from 2008 to 2022.

8.6.3 Marine and mangrove fauna

The marine fauna occurring in Caution Bay and the wider Gulf of Papua is discussed in this section. Studies in Caution Bay have been conducted for the PNG LNG Project marine facilities from 2008 to 2014, and during the 2019 and 2022 marine surveys for the Project. BMT WBM (2017) also conducted faunal surveys in June/July 2016 and January 2017 (to inform the 2019 Papua LNG Project – Upstream EIS). The findings of the various investigations are summarised below.

8.6.3.1 Mangrove fauna

Estuaries along the southern mainland coast of Papua New Guinea support a distinctive fish community that includes families not well represented in reef or sandy inshore habitats; however, many of these species do occur in mangroves. These include the mullets (family: Mugilidae), hardyheads (family: Atherinidae), garfish (family: Hemirrhamphidae) and trevally or jacks (family: Carangidae) (Richards et al. 2016).

At least one marsupial, two or more rodents, six or more bats, three semi-aquatic snakes, two monitors as well as various small lizards, the saltwater crocodile and around 60 birds are known to occur within the mangrove forest habitats at Caution Bay, at least on a seasonal basis (Woxvold 2008). This fauna includes the little file snake (*Acrochordus granulatus*), the crab-eating water snake (*Fordonia leucobalia*), Richardson's mangrove snake (*Myron richardsoni)* and the mangrove monitor (*Varanus indicus)*, which is the largest of the mangrove forest species. Although the mangrove monitor also occurs in fully terrestrial habitats, in mangroves it feeds principally on crustaceans (Richards et al. 2016). All the above-named species are classified as Least Concern on the IUCN Red List.

Five freshwater turtle species are known to occur in the southern lowlands of PNG (Georges and Thomson, 2010). Although not observed, all but one of these may occur in the Caution Bay catchment (Woxvold, 2008). The potentially extant species include all members of the family Chelidae, which includes the long-necked turtles (*Chelodina* spp.) and several genera of short-necked turtles including Emydura and Myuchelys. The species of *Chelodina* and *Emydura* are essentially semi-aquatic animals that can cross large areas of forest or grassland to find suitable new aquatic habitats. Species in both genera are recorded in the Laloki River and it is possible that they either reside in the coastal catchments of Caution Bay or else disperse on occasion into this area (Richards et al. 2016). Pritchard's snake-necked turtle (*Chelodina pritchardi*) is associated with freshwater habitats, is endemic to a restricted area of Central Province that overlaps the Project area and is listed as VU on the IUCN Red List.

Mangrove macroinvertebrate fauna

Macroinvertebrates found in the intertidal muds were sampled during mangrove habitat sampling in the intertidal zone in the LNG Plant in 2019.

A total of 22 macroinvertebrates were identified from nine taxa including crustaceans, molluscs, chordates, and annelids. The fiddler crab (*Uca* sp.) was the most common taxa across all transects, followed by the gastropods *Alvania* sp. and *Cerithidae*.

Of the 15 samples, seven samples held no organisms, a common occurrence in mangrove habitats, particularly when compared to adjacent intertidal areas. Macroinvertebrate abundance, species richness and diversity varied across the mangrove habitat. The low number of organisms per sample indicates that a more intensive sampling effort would be required to characterise the relevant macroinvertebrate communities and enable statistical analysis.

No further investigation for macroinvertebrates was undertaken in 2022 monitoring.

8.6.3.2 Fish fauna

Marine fauna in the wider Gulf of Papua area has been characterised from observations of catches made from the commercial prawn trawl fishery that has operated in the area since the 1970s. Surveys of the prawn trawl grounds were carried out by the Papua New Guinea National Fisheries Authority to investigate the status of prawn stocks (NFA, pers com. 2005; Koren 2004a, 2005, 2006, cited in Coffey Natural Systems 2009). These surveys included sample locations that corresponded with the PNG LNG Project offshore pipeline route. Typical species observed included prawns (mainly banana prawns (*Penaeus merguiensis*) and black tiger prawns (*Penaeus monodon*)) and bycatch of small fish, crustaceans, and occasionally large rays or sharks.

Fish species mainly comprised pony fish, hairtails, anchovies, clupeids, jewfish, goatfish and Bombay duck (lizardfish), while invertebrate species included squid, crabs and mantis shrimps.

The fish community observed from the nearshore reefs of Caution Bay comprises a range of generally small sized (less than 20 cm length and typically smaller), mostly reef-attached and reef-associated, generalist Indo-Pacific species that are typically present as small schools or individuals.

Damselfish (family Pomacentridae) were the most abundant group across all sites in December 2007 and April 2008, and were conspicuous in all following surveys including 2019 and 2022. Various members of the damselfish genus *Abudefduf*, *Chromis*, *Chrysiptera*, and *Dascyllus* were frequently observed, often in groups, in direct proximity to hard corals, primarily branching growth form *Acropora* spp. Butterflyfish (Chaetodontidae) were usually observed in pairs or as individuals, and surgeonfish (Acanthuridae) were frequently observed in small schools. These fish are typically opportunistic algal grazers and occasionally feed on corals and other invertebrates and were observed at most sites in Caution Bay.

Wrasse (Labridae) have also been observed at most survey locations in Caution Bay. The most common species observed are the checkerboard wrasse (*Halichoeres hortulanus*), moon wrasse (*Thalassoma lunare*) and cleaner wrasse (*Labroides dimidiatus*). Small bream (Nemipteridae) Goatfish (Mullidae) and dwarf angel fish (Pomacanthidae) were also amongst the more commonly observed fish. Representatives from several other families were also identified including squirrelfish (Holocentridae), goatfish, monocle bream, triggerfish (Balistidae) and pufferfish (Tetraodontidae).

While damselfish, butterflyfish, surgeonfish, and wrasse are all common fish families that are resident on fringing reefs globally, and expected to be present as observed, larger predator groups such as the snappers (Lutjanidae), groupers (Serranidae), and jacks (Carangidae) have consistently been observed in low abundance across all sampling sites. However, the catch data from the 2019 Caution Bay Fisheries Study (Appendix L) indicates that many of those fish are present within Caution Bay or nearby. The reefs within and adjacent to the Caution Bay project facilities therefore appear to function as nursery habitat and have been referred to as such by local people from communities inhabiting the coastal regions of Caution Bay (Coffey Natural Systems 2009).

BMT WBM (2017) deployed baited remote underwater video stations (BRUVS) to conduct fish surveys during the January 2017 at Caution Bay. A total of 42 fish species were identified across BRUVS installed on three reef sites. Reef fish assemblages were dominated by damselfish and wrasses, with butterflyfish also well represented. Other observed fish taxa were similar to those recorded previously during studies conducted for the PNG LNG Project.

Fish abundance and diversity observed in 2019 was variable between monitoring sites, though fish were present at all locations, and species composition was very similar to that observed during monitoring surveys conducted between 2009 and 2014. No endemic, range-restricted or high-conservation priority reef fish species have been observed in Caution Bay.

Fish observations were largely not observed in video imagery collected in 2019 and 2022 for most of the proposed Project marine facility locations. This was likely due to the absence of well-developed habitat features in these locations, particularly in water beyond 10 m depths. Fish were present in association with patch reefs.

8.6.3.3 Cetaceans and marine mammals

During the 2019 and 2022 Caution Bay surveys, as with the March and April 2008 surveys for the PNG LNG Project, opportunistic observations of dolphins (species undetermined) were made. Dolphins are also regularly observed in inshore waters of the Gulf of Papua near prawn trawlers and are associated with discarded fish bycatch (Coffey Natural Systems 2009). Several species of dolphin are known to be present in the wider Gulf of Papua, including the Indo-Pacific humpback dolphin (*Sousa chinensis*), common dolphin

(*Delphinus delphis*), bottlenose dolphin (*Tursiops truncatus*), and the Australian snubfin dolphin (*Orcaella heinsohni*). The Australian humpback dolphin (*Sousa sahulensis*) is also found in the southern parts of Papua New Guinea and the Kikori Delta (Beasley et al. 2005; Parra and Cagnazzi 2017).

Published data specific to cetaceans in Caution Bay is limited, as is knowledge on marine mammals in Papua New Guinea more generally. Haywood et al. (2012) noted 20 species of cetacean recorded from Papua New Guinea more broadly; all are widely distributed in tropical seas. It is possible that some of these species utilise or transition through Caution Bay.

Dugong (*Dugong dugong*) have a distribution that overlaps the study area, are protected under the Papua New Guinea *Fauna (Protection and Control) Act 1976* and are listed as Vulnerable (VU) on the IUCN Red List (Marsh et al. 2019). While possible dugong feeding areas are present due to the seagrass that exists in Caution Bay, there is no available evidence to suggest resident populations are present in the study area and no indication of site-dependence or other established resident populations have been observed. No dugong feeding trails have been observed in areas of seagrass growth during field surveys between 2008 to 2022, and this finding remains consistent with statements from local people indicating that dugongs do not occur in Caution Bay (Coffey Natural Systems 2009). During PNG LNG Project EIS surveys it was noted from discussions with local people that dugong do not occur in Caution Bay and are ‘rarely caught’.

8.6.3.4 Sharks and rays (Chondrichtyes)

No shark or ray species of conservation significance (that is, species listed on Papua New Guinean legislation or classified by the IUCN as CR, EN or VU) were observed directly during the 2019, 2022 or previous field surveys in Caution Bay, apart from the Papuan epaulette shark (*Hemiscyllium hallstromi*) and the giant guitarfish (*Glaucostegus typus*). Both species occur within inshore coastal habitats, embayments and around coral reefs.

The giant guitarfish is listed as CR on the IUCN Red List (Kyne et al. 2019) and was observed in 2019 at the seagrass reference site near Idihi Island (site SG-13), approximately 15 km southwest of the LNG Plant jetty. The Papuan epaulette shark is listed as VU on the IUCN Red List and has a restricted coastal distribution along the southern edge of Papua New Guinea extending from the western extent of the Gulf of Papua to the eastern edge of the Papua New Guinea mainland in Milne Bay (Dudgeon et al., 2016). The species was observed among catch during the Caution Bay fisheries study (Appendix L).

No other large sharks or ray species have been directly observed during nearshore marine video monitoring surveys; small blacktip reef sharks have been encountered. The New Guinea river shark (*Glyphis garricki*) and speartooth shark (*Glyphis glyphis*) are both listed by the IUCN as CR and known to inhabit turbid estuarine and inshore marine areas but data regarding their presence in Caution Bay is not available. The scalloped hammerhead (*Sphyrna lewini*) and the great hammerhead (*Sphyrna mokarran*) are both coastal species with wide distributions although no specific information related to Caution Bay is published in the scientific literature. These species are both listed as EN on the IUCN Red List. The wide-ranging coastal, epipelagic, and oceanic shortfin mako shark (*Isurus oxyrinchus*), listed as EN on the IUCN Red List, is also likely to be present along the coast of Caution Bay at various times. Various other wide-ranging species of elasmobranch have distributions that overlap Caution Bay, several of which are listed on the IUCN Red List as either CR, EN or VU (see Appendix E Nearshore Marine Baseline). None of these species have a recognised affinity to Caution Bay.

Previous reports by local fishermen (Coffey Natural Systems 2009) have noted that whale sharks (*Rhincodon typus*) are occasionally observed beyond the fringing reef in Caution Bay, and that other shark species are targeted by fishing activities near Idihi Island. Whale sharks have a pan-tropical distribution and are listed on the IUCN Red List as EN (Pierce and Norman 2016). Data regarding fisheries has been collected during Caution Bay fisheries studies for the PNG LNG Project, and the catch data related to Chondrichthyes includes records of shark fins, small reef sharks, and mako shark.

Sawfish (Pristidae)

A review by White et al. (2017) of locations where sawfish (family Pristidae) have been recorded in Papua New Guinea was assessed and yielded no records specific to Caution Bay. Some species have been previously recorded from Yule Island, 60 km north of Caution Bay. This review showed that due to the paucity of detailed catch and observational records available, both historic and contemporary, the status of most sawfishes, sharks, and rays in Papua New Guinea is largely unknown. Some sawfish species of known conservation significance that have distributions overlapping Caution Bay include:

- With distribution ranges including and beyond Papua New Guinea, the dwarf sawfish (*Pristis clavata*), largetooth sawfish (*Pristis pristis*), and green sawfish (*Pristis zijsron*, also known as the narrow snout sawfish) may occur in Caution Bay. Although the presence of these species near the LNG Plant jetty has not been recorded, they may occur and the largetooth and green sawfish have previously been recorded from Yule Island, 60 km north of Caution Bay (White et al. 2017). These species are restricted to coastal, estuarine and freshwaters, are generally associated with muddy seafloors. All are classified on the IUCN Red List as CR.
- Similarly, the narrow sawfish/knifetooth sawfish (*Anoxypristis cuspidata*, listed as EN on the IUCN Red List) is also reported from the Gulf of Papua and most commonly occurs in shallow water coastal and estuarine areas, however no specific information for Caution Bay is available.

8.6.3.5 Marine reptiles

No marine reptiles have been observed during previous or current field surveys in Caution Bay. Several species are expected to occur in the vicinity of the Project marine facilities, at least sporadically, particularly due to the presence of mangrove, seagrass and coral reef habitats that provide food and habitat resources.

Sea turtles

Several marine turtle species are known to inhabit the coastal and offshore waters of Papua New Guinea, with the most relevant of these to the Project including the:

- Hawksbill turtle (*Eretmochelys imbricata*), listed as CR on the IUCN Red List
- West Pacific leatherback turtle (*Dermochelys coriacea*), listed as CR on the IUCN Red List and protected under the *Fauna (Protection and Control) Act 1976*
- South Pacific subpopulation of the loggerhead turtle (*Caretta caretta*), listed as CR on the IUCN Red List
- Green turtle (*Chelonia mydas*), listed as EN on the IUCN Red List
- Olive ridley turtle (*Lepidochelys olivacea*), listed as VU on the IUCN Red List.

No marine turtles, turtle tracks or nests have been observed in Caution Bay during field surveys between 2007 and 2022.

No sandy beaches exist in the immediate vicinity of the existing LNG Plant jetty or Project marine facilities locations, due to the presence of mangroves, though beaches are present along the coast to the north near the settlements of Papa and Lea Lea (the closest beach being approximately one kilometre away). Sandy beach habitats in Caution Bay may serve as rookery sites for one or more species of turtle; however, there are no recorded observations of large nesting events.

In Caution Bay, the only record of turtle breeding obtained during field surveys comes from local people who claim to have harvested turtle eggs occasionally from Idihi Island, situated 15 km southwest of the mouth of the Vaihua River, with nesting activity by green turtle and West Pacific leatherback turtles also said to occur in December (Coffey Natural Systems 2009). No suitable beaches exist in the immediate vicinity of the existing LNG Plant jetty or proposed Project facilities; sandy beach habitats elsewhere in Caution Bay may serve as

rookery sites for one or more species of turtle. The green turtle and olive ridley turtle are known to be caught in prawn trawl nets in the Gulf of Papua (Coffey Natural Systems 2009).

Anecdotal and uncorroborated discussions with local people have also indicated that the beaches around Kido Village and Redscar Head (in the north of Caution Bay, more than 20 km away from the LNG Plant), may be used by turtles (species not determined) for nesting. Two possible nesting areas were identified during ad hoc discussions with local people conducted during field surveys. One of these nesting areas is Lagava Beach, part of the Caution Bay coastline but not adjacent to the immediate Project area of influence. The second nesting area is along the northern Lagava Island coast from Kido Village towards Gorohu (in Redscar Bay, also north of the Project area).

Additional information pertaining to individual turtle species is provided in Appendix E Nearshore Marine Baseline.

Sea snakes

Several species of sea snake (including Hydrophiidae spp.) and sea krait (Laticauda spp.), have geographic distributions across the coastal zones of the tropical Indo-Pacific, north-eastern Australia and Papua New Guinea. Several of these species have been caught in prawn trawl nets in the Gulf of Papua (Coffey Natural Systems, 2009) and can be expected to occur in the Caution Bay nearshore zone at various times.

Crocodiles

Two species of crocodile, the estuarine or saltwater crocodile (*Crocodilus porosus*) and the southern variant (Hall's New Guinea Crocodile; *Crocodylus halli*) of the New Guinea crocodile (*Crocodilus novaeguineae*), occur in the estuaries of PNG (Coffey Natural Systems, 2009), and can be found within a few kilometres of the shore. Both species are listed as LC on the IUCN Red List (Solmu and Manolis, 2019; Webb et al. 2021). The New Guinea crocodile is known to enter brackish waters such as those of the Fly River estuary but is rare in coastal areas and is not found in the presence of the saltwater crocodile (Britton 2009). These species have not been observed during field surveys but given the prevailing mangrove habitat and proximity of the Vaihua River, are expected to be present at various times.

8.6.3.6 Other marine invertebrates

The ornate rock lobster (*Panulirus ornatus*) migrates from Torres Strait through the Gulf of Papua to breeding grounds at Yule Island, located approximately 75 km northwest of Caution Bay. The species is part of the tropical rock lobster fishery and a known migratory species. There are no marine benthic macroinvertebrates in Papua New Guinea listed as threatened or trade-restricted.

Other important invertebrate fishery species include prawns which are commercially harvested by the Gulf of Papua Prawn Fishery. Prawn species include tiger, banana, and endeavor prawns, which occur throughout the water column from nearshore to the edge of the continental shelf. These species are reliant on mangroves as nursery habitat.

Four species of Holothuroidea (sea cucumbers) most relevant to the Project (based on known distributions and conservation status) are listed on the IUCN Red List as EN, as follows:

- *Holothuria whitmaei*
- *Holothuria lesson*
- *Holothuria scabra*
- *Thelenota ananas.*

Additional Holothurians, listed as VU and with distributions that overlap Caution Bay, include:

- *Actinopyga mauritania*
- *Actinopyga echinites*
- *Actinopyga miliaris*
- *Holothuria fuscogilva*
- *Stichopus herrmanni.*

In the absence of contemporary population studies for Caution Bay, population estimates for Holothurians relative to the broader populations of various species are not possible. Several commercial varieties, that are widely distributed in the Indo-Pacific, have experienced large-scale population declines and decreasing population trends are evident. Harvesting bans have occurred at various stages, including in 2009 when the National Fisheries Authority, responsible for the conservation and management of Papua New Guinea's sea cucumber fishery and gazetting the National Bêche-de-mer Management Plan in 2001, enforced a national closure of the bêche-de-mer fishery for three years (Skewes et al. 2011).

There is insufficient information on the taxonomy and ecology of more cryptic marine macroinvertebrates more broadly, to determine whether locally endemic or restricted-range species occur in Caution Bay, or Papua New Guinea.

8.6.3.7 Macrobenthic infauna

Macrobenthic infauna has been sampled from Caution Bay at various times for the PNG LNG Project and for the Project, to characterise the infauna community. Findings from these investigations are discussed in this section.

During sampling undertaken for the PNG LNG Project EIS in 2007/2008, a total of 725 individuals from 68 different macrobenthic taxa were collected. This was also indicative of a high diversity of fauna. The number of taxa varied between sampling locations, with polychaete worms and crustaceans comprising the dominant taxa, typical of shallow water sediments. Statistical data analysis indicated a distinct depth-related gradient grouping macrobenthic infauna into inshore shallow water fauna, nearshore deep-water fauna (located in the shipping channel), and three individual sites of fauna from regions of carbonate sand (Coffey Natural Systems 2009).

During sampling undertaken in 2019, a total of 971 individuals from 74 different macrobenthic taxa were collected. This indicated a high diversity of fauna, and all taxa present were those expected to be found in shallow tropical environments with mud, sand and silty sediments, with the exception of site MI-16 where oligochaetes, which are not typical in high numbers in marine samples, comprised approximately 30% of the sample. It was also noted that some common taxa were absent or occurred in low abundance, that a low percentage (3%) of snails and bivalves was present, and a high proportion of small or immature specimens was collected, indicating that the macrofauna community may have been in a developmental stage at the time of sampling.

During sampling undertaken in 2022, a total of 104 individuals from 33 different macrobenthic taxa were collected from six sites. This indicated a high diversity of fauna. The three most abundant species across all sample sites were the sea flea (Melitidae; 13 in total), the tanaid (Apseudidae; 13 in total) and the peanut worm (Sipuncula; 10 in total). Macrobenthic fauna observed in the sediment samples included a mixture of smaller individuals and larger, mature individuals. This diversity indicates that the community is an established population that has not experienced any recent environmental disturbances (for example, cyclones, freshwater inundation). Individual counts were distributed evenly among the different species and dominance was low across all sites suggesting that no individual species population dominated the study area. Detailed results from the macrobenthic infauna sampling undertaken in 2019 and 2022 are provided in Appendix E Nearshore Marine Baseline.

8.6.3.8 Birds

Surveys to characterise the LNG Plant site conducted for the PNG LNG Project (Woxvold 2008) recorded 70 bird species from 30 families, including four species protected under the PNG Fauna Act (osprey, little egret, intermediate egret, and great egret). Other species present in Caution Bay near the LNG Plant include the eastern curlew, sharp-tailed sandpiper, Pacific golden plover, lesser sand plover, grey plover, grey-tailed tattler, bar-tailed godwit and terek. No IUCN-listed bird species were recorded. The LNG Plant and adjacent coastal area is situated in the southern half of the East Asian-Australasian Flyway, which holds the highest number of shorebird populations of any of the world's flyways. More than 35 species of Arctic-breeding migratory shorebirds use this area to reach regular non-breeding grounds in Australia and New Zealand. Of 16 wholly migratory species recorded, three are marine coastal seabirds (common tern, little tern, and lesser frigatebird.

Additional detail on bird fauna is provided in Chapter 7 Receiving Environment: Onshore, and also the PNG LNG Project EIS.

8.6.4 Summary of species, habitats and ecosystems in the Caution Bay area

Marine habitat within Caution Bay that has been directly studied during field surveys has been observed to exist on a continuum of ecological value, with some areas exhibiting no signs of degradation or disturbance that have locally-high ecological value, to highly degraded areas of low ecological value, largely due to historical and present-day impacts such as dynamite fishing, construction of the existing LNG Plant jetty, and where benthic (including coral reefs) and mangrove habitat was disturbed for the PNG LNG pipeline installation and subsequent operation. Degraded habitats show varying signs of recovery.

Nearshore marine environmental conditions in Caution Bay in the vicinity of the proposed Project marine infrastructure appear to be similar to those observed during previous studies conducted for the PNG LNG Project.

Sediment and water quality analysis indicates that contamination has largely not been detected from 2009 to 2022, and most results do not exceed applicable regulations and criteria. Where exceedances have occurred, these are primarily due to the natural variation and occurrence of various metals and metalloids in the environment.

The general composition of subtidal habitats observed in 2019 and 2022 shows discernible zonation related to depth and distance from shore. Where present, seagrass communities are typically well established, while fringing reef habitat has generally been observed in a variable, but typically degraded state. Given the substantial amount of *Sargassum* and turf algal cover observed to be present on much of the rocky and rubble substrates proximal to the fringing reef, it appears that the effects of habitat disturbance have contributed to a low abundance and diversity of fish and live corals. Beyond the fringing reef crest, substrates are largely homogeneous and of low complexity and habitat value, comprising soft sediments and silt, aside from at patch reef locations that are punctuated with occasionally well-established coral communities, where relatively isolated bommies support various hard and soft corals (particularly various sea fans and gorgonians in deeper waters), and reef fish fauna that is present across the Indo-Pacific.

The mangrove species present adjacent the LNG Plant are commonly recorded elsewhere in Papua New Guinea and neighbouring countries, with most survey transects hosting healthy mangrove communities typical of the Australasian/south east Asian bioregion. Localised mangrove dieback has been observed in various areas, including adjacent to the LNG Plant mixing pond and retention pond, as well as to the south of the LNG Plant jetty and LNG Plant pipeline disturbance areas. The mangrove species observed to be the most affected by dieback are the yellow mangrove and Indian mangrove (*Ceriops* spp.), which inhabit the landward edge of the mangrove habitat.

No areas within Caution Bay are designated as Key Biodiversity Areas or listed specifically on the IUCN Red List of Ecosystems in the local context. At present, there is no quantitative or qualitative evidence to suggest that any particular marine ecosystem type in Caution Bay that presently qualifies as highly threatened and/or unique or represents ≥5% of the global extent of an ecosystem meeting the criteria for IUCN status of CR or EN, or any area determined to be of high priority for conservation by regional or national systematic conservation planning that have not yet been assessed by the IUCN.

Various species of conservation significance that are listed as Critically Endangered, Endangered and Vulnerable on the IUCN Red List of Threatened Species have been recorded or may occur (based on known distribution ranges) within Caution Bay. These include dugong, several species of marine turtle, sharks, rays, and invertebrates. However, no habitat within Caution Bay has been observed to support regular occurrences of any of these species. Various migratory species are also known to be, or potentially could be, present within the study area, including the saltwater crocodile, cetaceans, sharks and several species of marine turtle.

The absence of documented concentrations of dugong, turtle or marine mammal feeding or breeding activity, or other clear evidence that Caution Bay is a location of importance for migratory or congregatory species indicates that the location is not a known agglomeration location for megafaunal species. While absence of evidence may not constitute evidence of absence, Caution Bay is a relatively well studied location, i.e., several field studies have occurred in the area for over 15 years and a human presence is well established This does suggest that such significant aggregations are not present in this location. Conversely, substantial aggregations of various species of conservation significance are documented elsewhere, including in Indonesia and elsewhere in Papua New Guinea (such as leatherback turtles in the Huon Gulf; which are discussed in the Wafi-Golpu Project EIS).[2] These locations have received corresponding levels of attention and associated conservation and management actions.

The faunal connectivity within and between Caution Bay, in the context of its location at the intersection of the Gulf of Papua and Milne Bay coral ecoregions, as well as the broader linkages between the south-east coast Papua New Guinea bioregion and larger Northern Coral Sea and Solomon Sea marine ecoregions more broadly (Green et al. 2014) suggests that isolation and reduced gene flow are not dominant factors affecting most species assemblages in this area. Reproductive isolation is a key mechanism driving speciation (and an important evolutionary process) and the presence of large, isolated coral bommies in Caution Bay, including the *Pavona clavus* coral colony at site CF-14, facilitate local genetic connectivity via provision of habitat for recruitment and spawning. While established coral, seagrass and mangrove habitat is present, various assemblages of more extensive communities exist elsewhere in Papua New Guinea and neighbouring Indonesia.

The Caution Bay marine environment experiences a high degree of oceanographic interconnectivity between the Arafura Sea and Coral Sea, and the Project is situated within a dynamic interface between terrestrial and marine habitats and associated ecological processes.

Caution Bay is also situated within a large and expanding port area servicing the requirements of Port Moresby, and substantial urban and industrial change to marine environmental values has occurred because of associated disturbances. Studies to date (including those detailed within the supplementary data used to inform this EIS) show the PNG LNG Project to have contributed relatively little to this change, as evidenced by the observations of marine habitat and ecological processes in 2022 and 2019 being similar to those made in 2014 and previous years.

[2] https://www.wafigolpujv.com/eis987654321