Chapter 10

Nearshore Marine Environment Characterisation

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The EIS has been prepared by, for and on behalf of Wafi Mining Limited and Newcrest PNG 2 Limited (together the "**WGJV Participants**"), being the participants in the Wafi-Golpu Joint Venture ("**WGJV**") and the registered holders of exploration licences EL 440 and EL1105, for the sole purpose of an application (the "**Permit Application**") by them for environmental approval under the Environment Act 2000 (the "**Act**") for the proposed construction, operation and (ultimately) closure of an underground copper-gold mine and associated ore processing, concentrate transport and handling, power generation, water and tailings management, and related support facilities and services (the "**Project**") in Morobe Province, Independent State of Papua New Guinea. The EIS was prepared with input from consultants engaged by the WGJV Participants and/or their related bodies corporate ("**Consultants**").

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The EIS includes forward looking statements. Forward looking statements can generally be identified by the use of words such as "may", "will", "expect", "intend", "plan", "estimate", "anticipate", "continue", "outlook" and "guidance", or other similar words and may include, without limitation, statements regarding plans, strategies and objectives of management, anticipated production or construction commencement dates and expected costs or production outputs. The Company continues to distinguish between outlook and guidance. Guidance statements relate to the current financial year. Outlook statements relate to years subsequent to the current financial year.

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Competent Person's Statement

The information in the EIS that relates to Golpu Ore Reserves is based on information compiled by the Competent Person, Mr Pasqualino Manca, who is a member of The Australasian Institute of Mining and Metallurgy. Mr Pasqualino Manca, is a full-time employee of Newcrest Mining Limited or its relevant subsidiaries, holds options and/or shares in Newcrest Mining Limited and is entitled to participate in Newcrest's executive equity long term incentive plan, details of which are included in Newcrest's 2017 Remuneration Report. Ore Reserve growth is one of the performance measures under recent long term incentive plans. Mr Pasqualino Manca has sufficient experience which is relevant to the styles of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as a Competent Person as defined in the JORC Code 2012. Mr Pasqualino Manca consents to the inclusion of material of the matters based on his information in the form and context in which it appears.

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These materials contain forward-looking statements within the meaning of the safe harbor provided by Section 21E of the Securities Exchange Act of 1934, as amended, and Section 27A of the Securities Act of 1933, as amended, with respect to our financial condition, results of operations, business strategies, operating efficiencies, competitive positions, growth opportunities for existing services, plans and objectives of management, markets for stock and other matters. These include all statements other than statements of historical fact, including, without limitation, any statements preceded by, followed by, or that include the words "targets", "believes", "expects", "aims", "intends", "will", "may", "anticipates", "would", "should", "could", "estimates", "forecast", "predict", "continue" or similar expressions or the negative thereof.

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Competent Person's Statement

The Wafi-Golpu Joint Venture is an unincorporated joint venture between a wholly-owned subsidiary of Harmony Gold Mining Company Limited and a wholly-owned subsidiary of Newcrest Mining Limited.

The information in the EIS that relates to Golpu Ore Reserves is based on information compiled by the Competent Person, Mr Pasqualino Manca, who is a member of The Australasian Institute of Mining and Metallurgy. Mr Pasqualino Manca, is a full-time employee of Newcrest Mining Limited or its relevant subsidiaries, holds options and/ or shares in Newcrest Mining Limited and is entitled to participate in Newcrest's executive equity long term incentive plan, details of which are included in Newcrest's 2017 Remuneration Report. Ore Reserve growth is one of the performance measures under recent long term incentive plans. Mr Pasqualino Manca has sufficient experience which is relevant to the styles of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as a Competent Person as defined in the JORC Code 2012. Mr Pasqualino Manca consents to the inclusion of material of the matters based on his information in the form and context in which it appears.

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10. NEARSHORE MARINE ENVIRONMENT CHARACTERISATION

The nearshore marine environment is generally defined as the area of the sea and the seafloor adjacent to the shoreline, which is bound by and inclusive of the shoreline and beach (where one exists) on the landward side, and on the seaward side, by the inner shelf to water depths of approximately 20m. The nearshore marine environment encompasses shallow benthic and pelagic habitats, and the littoral zone and foreshore, including that part of the sea where most frequent human interaction occurs (via swimming, fishing and enjoyment of amenity); it is often the focus of human perceptions about the health of the sea (e.g., water clarity and cleanliness). Further information about the resource use of the nearshore zone is provided in Chapter 12, Socioeconomic Environment Characterisation. The nearshore zone is important ecologically, and typically comprises a range of habitat types, generally containing higher species diversity, density, and productivity compared to deep-water marine habitats.

This chapter describes the nearshore marine environment of the upper Huon Gulf. The study area extends from Salamaua (30km south of Lae) to approximately Singaua (16km east of Lae) and includes shallow benthic and pelagic habitats to a water depth of approximately 20m (corresponding to a maximum distance from shore of approximately 100m) and the littoral zone and foreshore.

This chapter provides a characterisation of the relevant geology and bathymetry, oceanography, water and sediment quality, and ecology, primarily as it pertains to the nearshore marine environment potentially affected by the Project. Various aspects of the Outfall Area (including the Outfall System) and Port Facilities Area are located within or near the nearshore marine environment, and include the mix/de-aeration tank, seawater intake pipelines and DSTP outfall pipelines, the concentrate filtration plant, materials handling, storage, and ship loading facilities and the filtrate discharge pipeline.

The offshore marine environment is discussed in Chapter 11, Offshore Marine Environment Characterisation, and generally pertains to marine environments beyond approximately 20m water depth. Due to the inherent interconnectedness of nearshore and offshore environmental settings, some description of geology, bathymetry, oceanography and biological features relating to the offshore environment, is also discussed in this chapter.

The information in this chapter is primarily based on a range of studies, including:

- A nearshore marine characterisation study of the Huon Gulf conducted by Coffey (Appendix R, Nearshore Marine Characterisation).
- An oceanography study of the Huon Gulf, and a physical, chemical and biological sedimentology study of the Huon Gulf, conducted by IHAconsult (Appendix K, Oceanographic Investigations of the Huon Gulf and Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf, respectively).
- A fisheries and marine resource use characterisation study conducted by EnviroGulf Consulting and Coffey (Appendix S, Fisheries and Marine Resource Use Characterisation).

These documents contain additional specific descriptions of the study methods, data, and further technical details concerning the information presented in this chapter.

10.1. Geology and Bathymetry

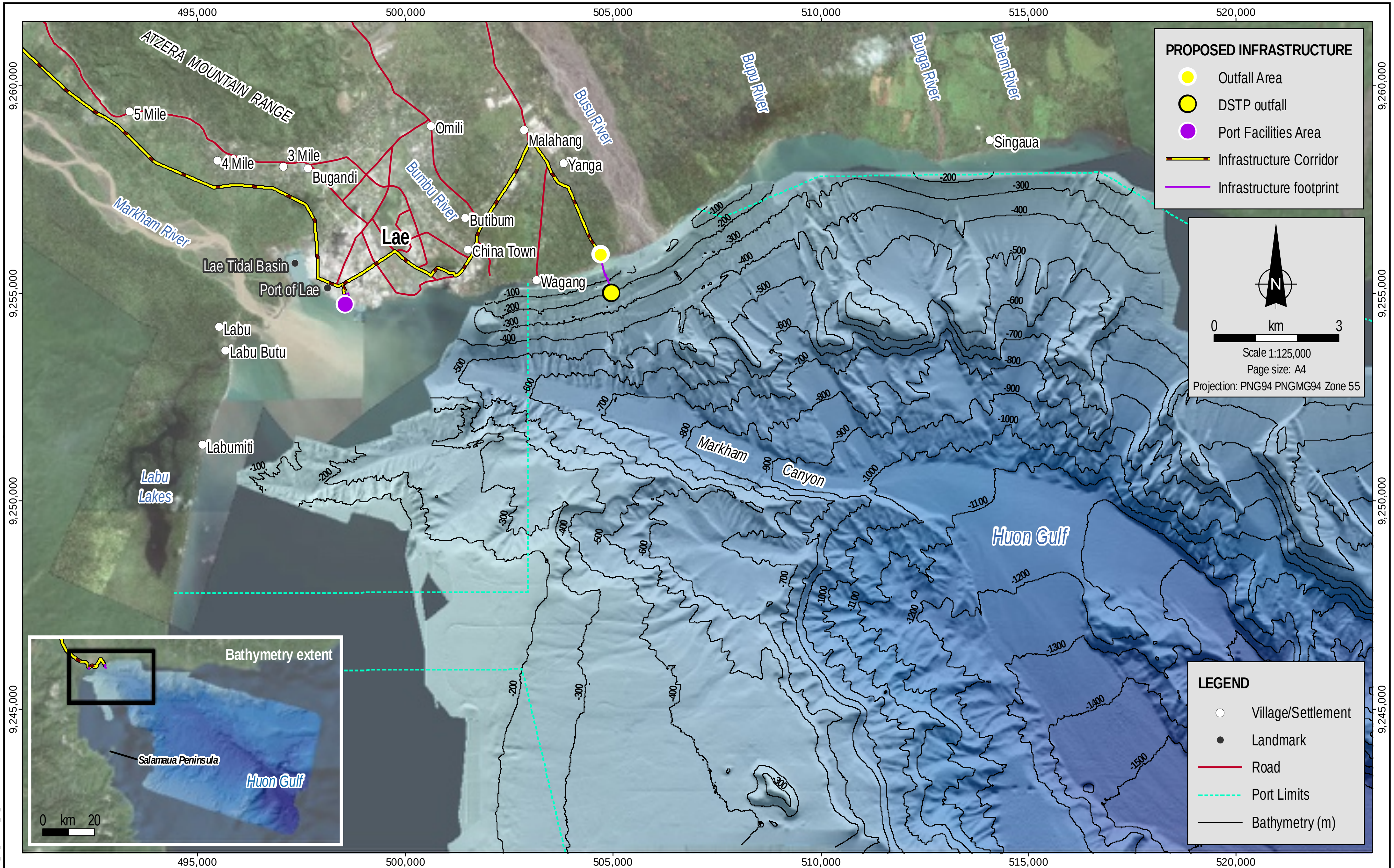
Situated between the Australian and Pacific tectonic plates, the Huon Peninsula and inner portion of the Huon Gulf are located within an active seismic zone. In this area, the South Bismarck Plate, which includes the mountainous Finisterre Range, converges with the northern margin of the Australian Plate along the Ramu-Markham Fault. Resultant tectonic activity has caused regional uplift and subsidence; the Finisterre Range is undergoing tectonic uplift at a rate of approximately 5 millimetres (mm) per year, and within the Lae area the Australian and New Guinea Plates are converging at a rate of 50mm per year (Stanaway et al., 2009; Appendix K, Oceanographic Investigations of the Huon Gulf). The Atzera Mountain Range, a spur of the Finisterre Range to the north of Lae, rises from the Leron Formation (Milsom, 1998). The Markham River discharges into the Huon Gulf directly south of the Atzera Mountain Range, and the southern slopes of the Finisterre Range meet the shoreline of the Huon Gulf to the east of Lae. Below sea level, the submarine slopes plunge steeply and directly into a feature known as the Markham Canyon. Figure 10.1 illustrates the bathymetry of the Huon Gulf near Lae.

The bathymetry of the seafloor adjacent to the mouth of the Markham River near Lae includes a steeply sloping submarine channel (15° bottom slope) that trends from northwest to southeast (PNGPCL, 2007). Some 4km from the mouth of the Markham River, the direction of the channel runs from west-northwest towards the east-southeast and forms the head of the Markham Canyon (see Figure 10.1) (Renagi et al., 2010; Appendix K, Oceanographic Investigations of the Huon Gulf). East of the Markham River along the Huon Gulf north coast, seafloor slopes are typically steep. In the vicinity of the proposed Outfall System, the average slope is around 20° until it intersects the gently sloping (3° slope) bed of the Markham Canyon (Appendix K, Oceanographic Investigations of the Huon Gulf) at a depth of around 600m. Close to shore, the sloping seafloor is characterised by subparallel channels or chutes with smooth and featureless surface texture, bounded by low relief ridges (<3m high) aligned perpendicular to the shoreline (Appendix K, Oceanographic Investigations of the Huon Gulf).

A small ridge occurs subparallel to the Outfall System at a depth of approximately 5m to 10m. Detailed characteristics of this feature have not been confirmed; it may be a section of outcropping rock or reef, or a gravel splay. The presence of this feature is consistent with bathymetric data from the area, which shows a narrow, linear ridge that extends some 750m along the coast (Appendix K, Oceanographic Investigations of the Huon Gulf).

The western side of the Huon Gulf, to the south of Lae, is recognised as an active under-filled peripheral foreland basin (Galewsky, 1998; Webster et al., 2004), with a complex coastline punctuated by braided rivers and multiple channels, backed by steep ridges up to 2,700m high. The area is characterised by numerous seaward islands. Immediately south of the Markham River mouth, the western side of the Huon Gulf is low-lying and dominated by swamp for a distance of approximately 10km. This area includes the dense mangrove forest and tidal channels known as the Labu Lakes (Figure 10.2 and Figure 10.3). In the inshore region between the mouth of the Markham River and Salamaua Peninsula, a shelf (0m to 200m deep) extends from 5km to 10km offshore and is dissected by various subsea gullies and valleys that trend eastwards.

Further south of the Labu Lakes, the inshore region is characterised by a relatively flat area of submerged platforms and pinnacles located 100m to 2,500m below sea level, and bounded by well-developed, steep-sided and deeply incised (<1km) submarine canyons that drain toward the Markham Trench from the Morobe Shelf (Webster et al., 2004, IHAconsult, 2012). Further south still, in the vicinity of Busama and beyond, numerous islands, fringing reefs, coral atolls, shoals and pinnacles are also present along the coast, particularly around islands and promontories.



Source:
Villages/Settlements, landmarks and infrastructure from WGJV and Coffey.
Roads and Port Limits from Coffey (Port Limits indicative only).
Bathymetry from WGJV survey.
Imagery from WGJV (capture date 2016) and ArcGIS Online (capture date unknown).

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File Name: 0520DD_10_F10.01_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Huon Gulf bathymetry

Figure No: 10.1

Photo credit: Coffey

Figure 10.2
Aerial photo of Labu Lakes facing south

Photo credit: Coffey

Figure 10.3
Aerial photo of Labu Lakes, Markham River mouth and Lae

The steep and rugged Finisterre Range overlooks the northern Huon Gulf coast east of Lae, and attains altitudes of almost 4,000m. Here, 20 often heavily braided and fast flowing rivers, including the Busu River, drain a combined catchment area of about 4,000 square kilometres (km^2). Particularly during frequent flood events, large amounts of coarse-grained sediment are transported directly to the sea (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf). The nearshore marine environment in this area (until around Singaua, some 16km east of Lae) is generally characterised by frequent turbid surface plumes, contains limited estuarine and mangrove habitat, has generally narrow beaches, and, notably, seagrass and coral reefs are essentially absent.

10.2. Seismicity

The high seismicity of the Huon Peninsula region is often evidenced as frequent earthquakes. Four of the 22 magnitude 7.5 or greater earthquakes recorded in the New Guinea region between 1900 and 2010 have occurred in and around the New Britain Trench located 180km to the east of Lae. A magnitude 8 earthquake in 1906 resulted in tsunami waves along the shoreline of the Huon Gulf and nearby islands (Buleka et al., 1999). Large earthquakes can cause landslides that contribute sediment into the Huon Gulf, in addition to other sources (Royal Haskoning 2007; WorleyParsons, 2016; Appendix K, Oceanographic Investigations of the Huon Gulf).

Submarine landslides and turbidity current processes are also active in the Huon Gulf and neighbouring areas, with reports that repeated submarine slumps of mud deposits from the Markham River have been noted by residents in and near Lae (Royal Haskoning 2007). Both seismic events and slumping of built-up sediments discharged from the Markham River due to other factors influencing submarine mass movements (such as overpressuring[1]) are implicated in the occurrence of these submarine landslides (Buleka, 1999). Slumps of canyon walls and slides of the steep slopes have caused small tsunamis in the region. Submarine slope failure was considered to be the likely cause of the breakage of a communication cable some 200km to the east of Lae (Buleka et al., 1999; Appendix K, Oceanographic Investigations of the Huon Gulf).

10.3. Tides, Currents and Waves

Renagi et al. (2013) report a relatively small tidal range for the Huon Gulf coastal region from 0.4m during neap tides to 1m during spring tides. At the Port of Lae, tides are diurnal, and the mean high and low water levels have been recorded as 1.60m and 0.90m respectively (PNGPCL, 2007). Waves lower than 0.25m, with wave periods smaller than 2.5 seconds, occur approximately 50% of the time. Due to large fetch lengths (the horizontal distance over which wave-generating winds blow) in southeasterly directions, wave heights may occasionally reach 0.6m, with wave periods of about four seconds and wave lengths of 25m. Local squalls may increase wave heights to about 2m and wave periods to five to six seconds (Royal Haskoning, 2007).

Tidal currents are small in the Huon Gulf, due to minor tidal amplitudes and the presence of deep waters close to the coastline (Royal Haskoning, 2007). Wind-induced currents can occur during periods of sustained high wind velocities, with variations in water density accounting for the highly variable nature of currents in deeper offshore waters from the Port of Lae (Royal Haskoning, 2007). The wave conditions at Lae comprise swell waves generated by distant weather systems, and sea waves generated by local winds, usually

[1] The term 'overpressuring' refers to subsurface pressures that are abnormally high, exceeding hydrostatic pressure at a given depth. This can occur in areas where burial of fluid-filled sediments is so rapid that pore fluids cannot escape, so the pressure of the pore fluids increases as overburden increases.

from the east and southeast. Refraction (the bending of waves due to varying water depths underneath) of incoming waves caused by nearshore seafloor features reduces the angle at which waves break upon shore, and freshwater from the Markham River floating on top of seawater also causes wave refraction and reduces wave heights near Lae (PNGPCL, 2007). Localised sediment movements along the coastline near the Port of Lae, including but not limited to sediments suspended in brackish water surface plumes, are caused and influenced by wave action, particularly by the predominant smaller swell waves, rather than ocean and river currents (PNGPCL, 2007). Tidal current regimes also alter the direction of the brackish surface sediment plumes twice daily.

In order to inform the preparation of three dimensional plume dispersion modelling for the Project, upward and downward facing Acoustic Doppler Current Profiler (ADCP) and other moored oceanographic monitoring instruments were used to measure current velocities and direction at several locations in the Huon Gulf (Appendix K, Oceanographic Investigations of the Huon Gulf). The closest ADCP instrument to the study area was situated about 2km west of the DTSP Outfall in approximately 260m water depth. Current speeds at this location were low with maximum speeds approaching 0.20 to 0.25m/s, though most speeds were considerably lower. Currents were found to oscillate at tidal frequencies but showed variable current shearing (i.e., adjacent layers of water in the water column flowing in opposite directions) throughout the water column. Closer to the seabed, currents were turbulent and omni-directional, reflective of the frictional effects of the seabed.

For data collected at this ADCP site between October 2016 and December 2017, net current flows were mostly parallel to the shoreline and mostly to the northeast. The exception was for currents near the seabed, which exhibited weak net drift offshore to the south. Continuous vector plots showed some net drift currents, although weak (0.002 to 0.003m/s), oriented north towards the shore. Vertical flow measurements through the entire water column showed no evidence for sustained upwards flow. Chapter 11, Offshore Marine Environment Characterisation (Section 11.3) provides a comprehensive assessment of the potential for ocean upwelling at the DSTP Outfall site.

10.4. Fluvial Influences

10.4.1. Regional Sediment Regime

Large volumes of fluvial sediment are transported by the Markham River and the 20 or so other rivers that drain into the Huon Gulf to the east of Lae. Smaller quantities of sediment are discharged from rivers on the south coast of the Huon Gulf. Of the rivers discharging along the northern shoreline of the Huon Gulf coast in the Coastal Area, the Markham and Busu rivers generate the dominant turbid plumes in the region. The combined terrestrial suspended sediment load from the Markham River and catchments discharging into the northern shoreline of the Huon Gulf is presently estimated to be about 60 million tonnes per annum (Mtpa) (Renagi et al., 2010; Renagi et al., 2013; Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf). This sediment load includes an estimated 12Mtpa transported by the Markham River (Renagi et al., 2010), combined with the algorithm-based estimated proportions of sediment transported by 11 other rivers along the northern shoreline of the Huon Gulf to the head of the Markham Canyon (based on Milliman, 1995). The estimated sediment contribution from these 11 other rivers along the northern coast is 48Mtpa. It has been estimated that, of the 48Mtpa discharged by these 11 rivers draining the north coast of the Huon Gulf, about 27Mtpa of suspended sediment is delivered directly to the slopes and bed of the Markham Canyon near the shoreline with the remaining sediment being dispersed as a combination of subsurface plumes and buoyant surface plumes (Renagi et al., 2010; Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf), and indirectly delivered to the canyon.

Time-series data for total suspended solids (TSS) in 2013 (the year in which the most complete dataset was obtained) suggests strong seasonality for Markham River flows and TSS concentrations (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf). Periods of high flows and TSS concentrations occurred from November to April 2013, with lower flows and TSS concentrations during May to October 2013 (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf). Estimated daily suspended sediment loads displayed high variability, exceeding 250,000 tonnes per day (tpd) during high flow events, to less than 10,000tpd during extended periods of low flow. For all complete or near-complete months of TSS data over the period of recording in 2013, the mean daily suspended sediment load was estimated as 66,180tpd. This equates to suspended sediment load of approximately 24Mtpa, excluding the additional delivery of sediment reporting as bedload. This estimate is double the 2006 estimate of 12Mtpa by Renagi et al. (2010) and may reflect temporal climatic and sediment supply variability (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf). More work is needed to quantify the sediment bedload from the rivers draining into the Huon Gulf but according to IHAconsult (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf) bedload is likely to be at least equal to suspended load.

Stream gauging data from the Markham River and Busu River monitoring locations does not appear to indicate a direct correlation between the timing of high river flows with turbidity observations at offshore ADCP stations. Rather, it is currently postulated that the sediment delivered by high flow events settles quickly off the mouth of the rivers and is subsequently transported episodically in mass movement events (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf). Chapter 11, Offshore Marine Environment Characterisation provides further detail about these mass movement events.

Renagi et al. (2010) estimated that upon entering the Huon Gulf, approximately 55% of the total Markham River sediment flux moves directly down the steep underwater slopes as submerged density currents or as flow slides to the deep seafloor, where it is largely transported to the head of the Markham Canyon, before continuing into deeper canyon waters. Some of the suspended sediment spreads out as buoyant surface plumes of sediment-laden freshwater. These plumes range from between at least 0.4km from the Markham River mouth and as far as 12km to the south. Within 2km from the Markham River mouth, a further 30% of the fluvial sediment has settled from the surface to form subsurface plumes, and the remaining 15% of the Markham River sediment disperses as a surface plume (Renagi et al., 2010).

The Busu River has a relatively small and very steep catchment area characterised by short-duration flash flood events, with high stream power. Estimated peak TSS concentrations for flood events are greater than those occurring in the Markham River, usually exceeding 10,000 milligrams per litre (mg/L) even for small flood events (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf). During October 2016, the Busu River delivered an estimated 1.1Mt to the Huon Gulf. Figure 10.4, Figure 10.5 and Figure 10.6 show the Busu River mouth and the Busu River plume. A study is ongoing to better quantify the delivery of terrestrial sediment from the rivers draining to the Huon Gulf, and refine the transport processes of that sediment through the offshore environment.

Photo credit: Coffey

Figure 10.4
Busu River mouth, Site B1

Photo credit: Coffey

Figure 10.5
Plume from Busu River as viewed from surface of ocean

Photo credit: Coffey

Figure 10.6
Aerial photo of the Busu River mouth facing west towards Lae

10.4.2. Markham River Plume

Royal Haskoning (2007) noted the generally consistent presence of one major surface turbidity plume extending southeasterly up to 12km from the mouth of the Markham River. Further, Renagi et al. (2013) identified shore-attached plumes that move along the shoreline and do not generally form adjacent to the Markham River. Royal Haskoning (2007) documented sediment plumes extending two to three kilometers offshore that may form on both sides of the river mouth, generally close to the shore. IHAconsult (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf) also note that the sediment plumes are dynamic and highly variable, occasionally extending offshore and along the coast depending on river flows, current and winds. Occasionally, these turbid surface plumes are not visible along the nearshore waters around Lae. These coastal plumes occur due to current and wave influence, forcing the plumes in locally specific directions. The Markham River surface turbidity plume (visible in Figure 10.3) is also highly affected by strong northwesterly and southeasterly winds. During strong (15km/hr to 25km/hr) northwesterly winds, the plume is forced seaward, leaving less turbid seawater along the fringes of the northern and western coastline. During southeasterly winds, the plume is driven towards the northern coast and creates turbid waters along the fringes of the northern coast (PNGPCL, 2007).

10.4.3. Markham River Morphodynamics

According to discussions with local people, water turbidity near Labu appears to have increased in recent years due to the formation of a new distributary of the lower Markham River adjacent to Labu. This is a common process in river delta formation (Hajek and Edmonds, 2014), and the resulting turbid discharge from the new distributary of the Markham River now migrates to the mouth of the Labu Lakes. Figure 10.7 presents a sequence of aerial images from between 2002 and 2016 illustrating these changes. It is not clear how the new channel formed; however, the imagery suggests that the river broke through during high flow to follow a small track. The imagery shows that this channel joined the Huon Gulf between December 2010 and June 2013.

This recently formed outflow indicates that the marine waters around Labu are likely to display higher turbidity more frequently, compared to about five years ago. Aerial imagery from 2017 (Figure 10.8) shows the turbid plume of the Markham River entering the mouth of the Labu Lakes. During the November 2016 field survey, the water inside the mouth of the Labu Lakes was reasonably turbid with a turbidity of 45.1 nephelometric turbidity unit (NTU) and TSS concentration of 36mg/L. In contrast, turbidity of 3.5NTU and TSS of 4mg/L was recorded within the deeper reaches of the Labu Lakes. Further detail regarding physicochemical aspects and water quality within the study area is provided in Section 10.7 and Appendix R, Nearshore Marine Characterisation.

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Date: 06.12.2017
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F10.07_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Imagery showing the formation of a distributary of the lower Markham River

Figure No: 10.7

INDD Reference:0520DD_10_GRA046.indd_4

Photo credit: WGJV

Figure 10.8
Aerial imagery of Markham River plume entering the mouth of the Labu Lakes

10.5. Nearshore Marine Environment Sediment Geochemistry

10.5.1. Method

Targeted sampling to characterise sediment quality was conducted in the study area within and adjacent to the Coastal Area, and at reference locations near Labu Tale, Salamaua and east of the Busu River. The locations of sampled sites are shown in Figure 10.9. A total of 16 sites were sampled across two surveys; comprising 12 sites in November 2016 and 11 sites in February 2017. In February 2017, seven of the sites were in the same locations as sites sampled in November 2016, and four new sites were sampled in the vicinity of the Port of Lae. Images of the sediment samples retrieved are provided in Figure 10.10 to Figure 10.27.

Samples were analysed for the following:

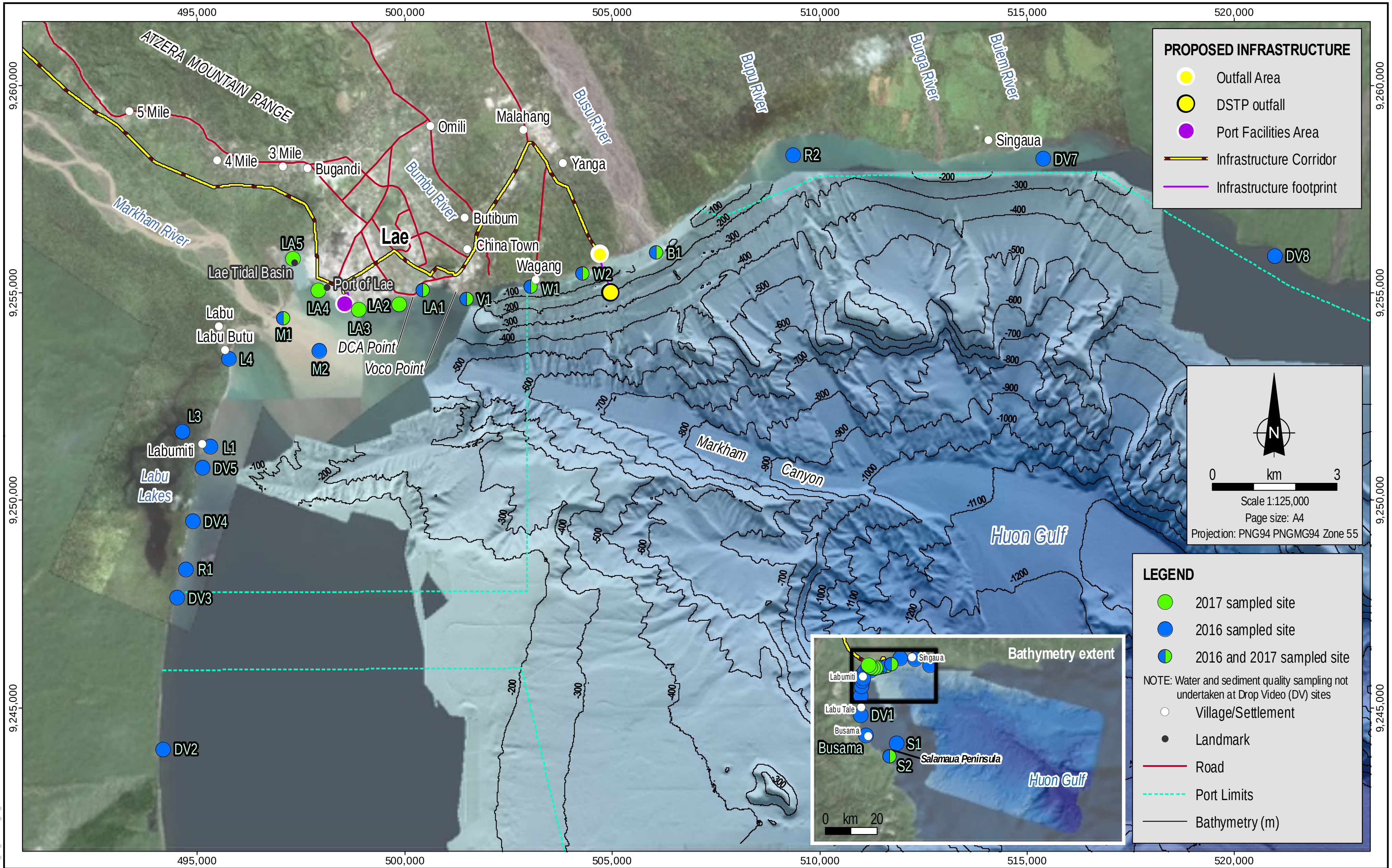
- Particle size distribution
- Total and bioavailable metals (for <63 microns (µm) and <2,000µm particle size fractions)
- Nutrients (including total nitrogen and total phosphorus)
- Carbon content (organic, inorganic and total)

Sediment metals concentrations were compared to sediment quality guidelines to understand whether any existing concentrations are likely to be adversely affecting benthic biota. International sediment quality guidelines (The Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand ANZECC/ARMCANZ (2000)) were adopted for comparison as per Long et al. (1995), as there are no Independent State of Papua New Guinea (PNG) sediment quality guidelines. There are also currently no sediment quality guidelines in PNG for phosphorus and nitrogen concentrations.

The Long et al. (1995) guidelines were developed from a North American biological effects database for sediments and are frequently used in the United States of America, Australia, PNG and elsewhere. These guidelines are also those adopted by ANZECC/ARMCANZ (2000), which are the 'interim sediment quality guidelines' for sediment assessment in Australia and New Zealand. The guidelines used in this characterisation also incorporate the more recent revision to the guideline for silver (Simpson et al., 2013). The sediment quality guidelines in Simpson et al. (2013) are presented as two guideline values:

- Guideline Value: threshold concentration level below which there is a low probability that biological effects could occur.
- Guideline Value-High: threshold concentration level above which there is a high probability that biological effects could occur.

These guidelines were developed for assessing potential risks to organisms in contact with benthic sediment rather than suspended solids. The guidelines (a summary of which is provided in Table 10.1) were used in the analysis of the existing benthic sediment quality. Further detail regarding the guidelines is provided in Appendix R, Nearshore Marine Characterisation.



Source:
Villages/Settlements, landmarks and infrastructure from WGJV and Coffey.
Nearshore sites, roads and Port Limits from Coffey (Port Limits indicative only).
Bathymetry from WGJV survey.
Imagery from WGJV (capture date 2016) and ArcGIS Online (capture date unknown).

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Date: 06.12.2017
Project: 754-ENAUABTF100520DD
File Name: 0520CC_10_F10.09_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

2016 – 2017 nearshore marine survey sampling sites

Figure No: **10.9**

MXD Reference: 0520DD_10_GIS022_v0_4

Figure 10.10
Sediment collected from S2

Figure 10.11
Sediment collected from S2

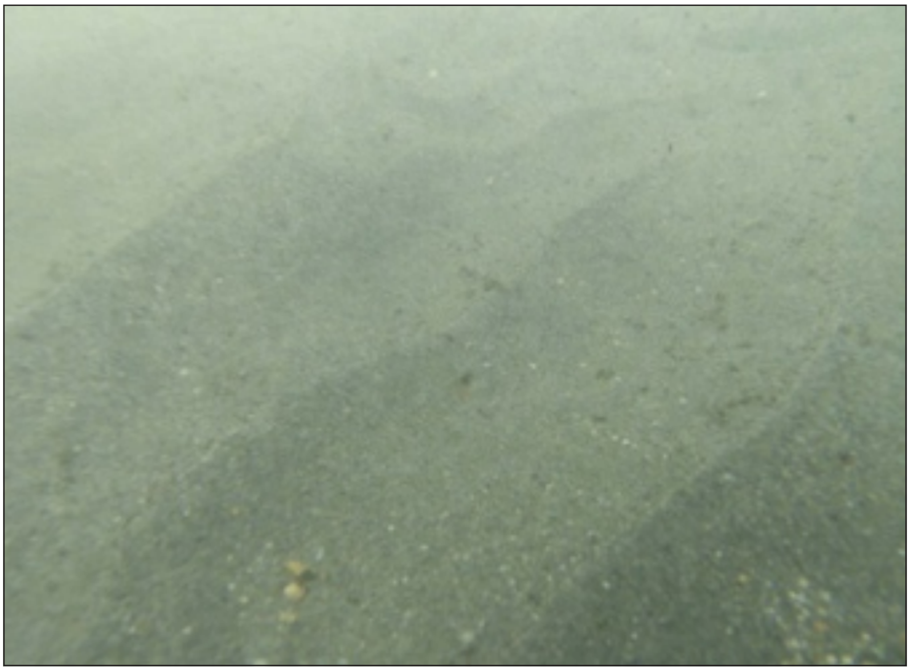

Figure 10.12
Sands at site DV3

Photo credit: Coffey

Figure 10.13
Sediment collected from R1

Photo credit: Coffey

Figure 10.14
Sediment collected from L1

Photo credit: Coffey

Figure 10.15
Sediment collected from L3


Photo credit: Coffey

Figure 10.16
Sediment collected from L4


Photo credit: Coffey

Figure 10.17
Sediment collected from M1


Photo credit: Coffey

Figure 10.18
Sediment collected from LA5

Photo credit: Coffey

Figure 10.19
Sediment collected from LA4

Photo credit: Coffey

Figure 10.20
Sediment collected from LA3

Photo credit: Coffey

Figure 10.21
Sediment collected from LA2

Photo credit: Coffey

Figure 10.22
Sediment collected from LA1

Photo credit: Coffey

Figure 10.23
Sediment collected from V1

Photo credit: Coffey

Figure 10.24
Sediment collected from W1

Photo credit: Coffey

Figure 10.25
Sediment collected from W2

Photo credit: Coffey

Figure 10.26
Sediment collected from B1

Photo credit: Coffey

Figure 10.27
Sediment collected from R2

Table 10.1: Sediment quality guidelines

Parameter	Units	Sediment Quality Guidelines (ANZECC and Simpson et al., 2013)	
		Guideline Value	Guideline Value-High
Silver (Ag)	mg/kg	1.0	4.0
Arsenic (As)	mg/kg	20	70
Cadmium (Cd)	mg/kg	1.5	10
Chromium (Cr)	mg/kg	80	370
Copper (Cu)	mg/kg	65	270
Mercury (Hg)	mg/kg	0.15	1.0
Nickel (Ni)	mg/kg	21	52
Lead (Pb)	mg/kg	50	220
Antimony (Sb)	mg/kg	2.0	25
Zinc (Zn)	mg/kg	200	410

10.5.2. Particle Size Distribution

Most sediments were predominantly comprised of dark coloured sand and silt-sized particles. However, site L3 in the Labu Lakes, sites LA2, LA3, LA4 and LA5 near the Lae Tidal Basin, and site M1 adjacent to the Markham River mouth, were dominated by silts and clays with little sand present. Sites L4 (Labu Lakes mouth) and R2 (reference location at Singaua) comprised mostly coarser sediment (gravels and sands). Sediment particle size distribution results were generally similar between sites in both 2016 and 2017.

Royal Haskoning (2007) has previously described sediments at the mouth of the Markham River as mainly composed of sandy gravel, gravely sand and boulders up to 50 centimeters (cm) in diameter, and sediments of the Busu River sub aerial fan, covering about 60km^2, as silts and coarse gravels and boulders up to 30cm diameter. WorleyParsons (2016) also reported sediments near the Lae Port and Lae Tidal Basin to be soft, sandy silts. Due to the dynamic nature of the hydrological and sediment transportation regimes in the Huon Gulf nearshore marine environment, it is likely that temporarily deposited fine material, as well as coarser river bed material, is present at various times around the mouths of the Markham and Busu rivers.

The sediment at site S2 near Salamaua was noticeably lighter in colour than the other sediments within the Huon Gulf. This is likely due to the different mineralogy between the riverine silts and sands deposited closer to Lae and the sandy material present in coastal locations of the southern Huon Gulf, distant from riverine influence.

Table 10.2 presents the November 2016 particle size distribution results.

Table 10.3 shows the February 2017 particle size distribution results.

Table 10.2: Sediment classification based on particle size (data in % of total) (November 2016)

Sediment classification	Site											
	R1	R2	L1	L3	L4	M1	V1	LA1	W1	W2	B1	S2
Clay (<2µm)	<1	2	<1	29	<1	23	10	1	2	18	4	1
Silt (2–60µm)	1	3	1	64	<1	76	28	<1	3	42	5	<1
Sand (0.06-2.00mm)	99	42	98	7	29	1	36	99	77	40	45	79

Sediment classification	Site											
	R1	R2	L1	L3	L4	M1	V1	LA1	W1	W2	B1	S2
Gravel (>2mm)	<1	53	1	<1	71	<1	26	<1	18	<1	46	20
Cobbles (>6cm)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Table 10.3: Sediment classification based on particle size (data in % of total) (February 2017)

Sediment classification	Site										
	LA1	LA2	LA3	LA4	LA5	M1	V1	W1	W2	B1	S2
Clay (<2µm)	4	30	28	31	36	19	13	4	9	1	<1
Silt (2–60µm)	3	57	70	67	50	51	35	3	17	3	2
Sand (0.06-2.00mm)	93	13	2	2	14	30	28	92	69	43	79
Gravel (>2mm)	<1	<1	<1	<1	<1	<1	24	1	5	53	19
Cobbles (>6cm)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

10.5.3. Metals

Most samples had at least one metal (typically nickel or copper) that exceeded either the Guideline Values or Guideline Values - High in the less than 2,000µm particle size fraction. These elevated concentrations are likely to originate from terrestrial sources. Further, and although beyond the nearshore marine study area, IHAconsult (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf) also note that crustal concentrations of nickel derived from all of the 13 box core samples collected from the deep seafloor of the Huon Gulf exceeded the lower Guideline Values, and four of those samples exceeded the Guideline Values - High. This suggests that elevated nickel concentrations may typically occur in the Huon Gulf and may be considered to be a naturally occurring geochemical feature of the Huon Gulf. Ultimately, it is the bioavailable concentration that has greater relevance to sediment quality guidelines when considering the effects on marine biota. Measurement of metal bioavailability (measured via the 1M HCl weak acid digest method for extractable trace metal analysis) showed that the bioavailable portions were generally low. Results show that apart from site W2, where the Guideline Value was exceeded due to the recorded nickel concentration of 24.5mg/kg in 2016, all other sites had bioavailable metal concentrations below sediment quality guidelines. This, along with the fact that nickel concentrations in sediment are naturally high in the Huon Gulf, indicates that any adverse biological effects due to sediment metals concentrations are unlikely. Site W2 is located adjacent to the Outfall System, west of the Busu River, and is in the depositional path of sediments from the Busu River, transported westward by littoral drift.

In 2016 and 2017, the measured concentrations of chromium, copper and nickel in Huon Gulf nearshore sediments (<63µm size fraction) were similar to those in nearshore sediments in previous sediment baseline investigations in the Vitiaz Basin and near Basamuk on the north coast of the Finisterre Range in waters 70m to 200m deep (NSR, 1998). This suggests that outcropping rocks in the Finisterre Range may have elevated levels of chromium, copper and nickel in the catchments draining into both the Huon Gulf and into the Vitiaz Basin. Previous sediment sampling also reported that nickel and copper concentrations in sediments taken from the Lae Tidal Basin, Markham River mouth, and near Labu, commonly exceed the 'effects range low' guidelines

(WorleyParsons, 2016). However, it was not reported whether those results pertain to the total metals or bioavailable metals concentrations, or which size fractions were analysed.

Detailed laboratory analytical data of metals in sediment samples collected in 2016 and 2017 is presented in Appendix R, Nearshore Marine Characterisation.

10.5.4. Nutrients and Carbon

Sampling by Coffey in 2016 and 2017 (Appendix R, Nearshore Marine Characterisation) indicated that total nitrogen and total phosphorus concentrations were highly variable across all sites and there were no spatial trends.

Organic carbon is derived from sources such as decayed plant matter, while inorganic carbon consists of carbonates and bicarbonates and other ionic forms of carbon. Total organic carbon content of more than 1% can provide additional adsorptive surfaces for metals to bind to, thereby decreasing metal bioavailability in the sediment (ANZECC/ARMCANZ, 2000). No evident trend in total organic and inorganic carbon concentrations was apparent between sites. The highest organic carbon concentration was recorded within the Labu Lakes (site L3) and is not unexpected, given that organic material is more likely to accumulate on substrates beneath relatively quiescent waters, than in the more dynamic environment of the Huon Gulf. Only two sites, L3 (2.16% total organic carbon in 2016) and LA5 (1.02% total organic carbon in 2017), had total organic carbon of greater than 1%.

There are no sediment quality guidelines for nutrients and carbon.

10.6. Nearshore Marine Environment Water Quality

10.6.1. Method

Water quality samples were collected in the study area, with targeted sampling taking place within and adjacent to the Coastal Area and at reference locations near Labu Tale, Salamaua and east of the Busu River. A total of 19 sites were sampled across two surveys; comprising 14 sites in November 2016 and 11 sites in February 2017. In February 2017, six of the sampling sites from the 2016 investigation were sampled, and a further five sites located around the Port of Lae were sampled. The locations of sampling sites are shown in Figure 10.9.

Samples were analysed for the following:

- Total and dissolved metals (ultra-trace level)
- Major ions
- Faecal coliforms (most probable number/100mL and colony forming units/100mL)
- Total suspended solids (TSS)
- Nutrients (including ammonia, nitrate, nitrite, phosphorus and nitrogen)
- Oil and grease

Faecal coliform sampling results were provided by the laboratory as either ‘most probable number’ or ‘colony forming units’. The former measure is the number of organisms that are most likely to have produced laboratory results in a particular test. It is not a count of the actual number of indicator bacteria present in the sample. This method is used to quantify the concentration of the viable microorganisms in a sample and involves inoculating decimal dilutions into tubes of a broth medium, observing results and using a standard index. The latter measure involves counting the colonies (groups of cells growing together) of faecal coliform bacteria. A colony-forming unit is a unit used to estimate the number of viable bacteria or fungal cells in a sample. Viable is defined as the ability to multiply via binary fission under the controlled conditions. Expressing results as colony-forming units reflects this uncertainty.

In-situ measurements of physicochemical parameters were collected concurrently with water sampling using a YSI ProDSS (digital sampling system) handheld multiparameter meter. The following in-situ measurements were taken at 1.5m water depth in November 2016 and at 1.5m and 10m water depth in February 2017:

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

Water quality results were compared to the PNG Environment (Water Quality Criteria) Regulation 2002 – Schedule 1 – Water Quality Criteria for Aquatic Life Protection (Seawater) (PNG ER). Water quality results were also assessed against the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000) guidelines to facilitate further understanding of the existing water quality of the study area. The ANZECC/ARMCANZ (2000), guidelines are the trigger values outlined for marine ecosystem protection (95% protection of species). The use of these trigger values is to initiate (or 'trigger') investigations into ecosystem health if they are exceeded for one or more parameters. There are no PNG criteria or ANZECC/ARMCANZ guidelines for faecal coliforms in marine waters. Table 10.4 provides a summary of the various water quality guideline values discussed above and includes those of the PNG Environmental Code of Practice for the Mining Industry for additional comparison (ECoP) (Office of Environment and Conservation, 2000). The guideline values for metals and metalloids are for dissolved metals and metalloids.

Table 10.4: Water quality guideline values

Parameter	Units	Guideline Values		
		PNG ER	PNG ECoP	ANZECC[1]
Temperature	°C	No alteration >2°C	No alteration >2°C	-
Dissolved Oxygen (DO)	% sat	-	>80-90	-
	mg/L	>6	> 6	85 - 120
Turbidity	NTU[2]	No alteration >25	<10% change from background seasonal mean	-
Electrical Conductivity (EC)	µs/cm	-	<1,500	-
pH	-	No alteration to natural pH	6.5 – 9.0	-
Total suspended solids (TSS)	mg/L	-	<10% change from background seasonal mean	6.0 – 8.0
Potassium (K)	mg/L	5	-	-
Sulphate (SO_4^{2-})	mg/L	400	-	-
Silver (Ag)	mg/L	0.05	0.0001	-
Arsenic (As)	mg/L	0.05	0.05	0.00005

Parameter	Units	Guideline Values		
		PNG ER	PNG ECoP	ANZECC[1]
Boron (B)	mg/L	1	0.5	0.024
Beryllium (Be)	mg/L	-	0.004	0.37
Cadmium (Cd)	mg/L	0.01	0.0007 *	-
Chromium (Cr)	mg/L	0.05	0.01	0.0002 *
Cobalt (Co)	mg/L	Limit of detection	0.00024	0.001
Copper (Cu)	mg/L	1	0.007 *	-
Iron (Fe)	mg/L	1	1	0.0014 *
Mercury (Hg)	mg/L	0.0002	0.0001	-
Manganese (Mn)	mg/L	0.5	-	0.00006^
Zinc (Zn)	mg/L	5	0.18 *	1.9
Selenium (Se)	mg/L	0.01	0.005	0.008 *
Lead (Pb)	mg/L	0.005	0.0013 *	0.005^
Nickel (Ni)	mg/L	1	0.056 *	0.0034 *
Aluminium (Al)	mg/L	-	0.1 (if pH >6.5) 0.005 (if pH <6.5)	-
Antimony (Sb)	mg/L	-	0.03	-
Tin (Sn)	mg/L	0.5	-	-
Ammonia**	mg/L	3.6	1.04	-
Nitrate	mg/L	-	-	-

Note: Guideline values for metals/metalloids are for dissolved metals/metalloids.
[1] ANZECC values are not hardness-modified and are based on a 95% level of species protection for metals/metalloids in typical slightly–moderately disturbed systems, and slightly disturbed lowland river in tropical Australia for other parameters except: mercury and selenium values are for protection of 99% of species in typical slightly–moderately disturbed systems.
[2] Nephelometric Turbidity Units.
* Guideline values for Cd, Cu, Pb, Ni, Zn are dependent on water hardness in PNG ECoP and ANZECC – PNG ECoP values presented are based on a hardness of <50mg/L of $CaCO_3$ while ANZECC values are based on a hardness mid-range value of 30mg/L $CaCO_3$.
** Ammonia guideline values are dependent on temperature and pH – guideline value listed is based on temperature of 25°C and pH of 7.

10.6.2. Physicochemical Parameters

The ANZECC/ARMCANZ (2000) guidelines indicate that seawater typically has a pH of around 8.1 to 8.3, conductivity of about 50mS/cm and salinity between 30ppt to 40ppt. November 2016 sampling results indicated a riverine influence at most sites within the Markham River plume and around Lae (i.e., elevated turbidity, and lower pH, conductivity and salinity than typical of seawater). For most sites in the study area (see Figure 10.9), samples typically had a pH of 7.9 to 8.1, conductivity generally ranged between about 30 and 48mS/cm and salinity was between 20ppt to 30ppt. The waters south of the Markham River plume at sampling sites R1, S1 and Busama had a lower freshwater influence; however, conductivity and salinity data were still lower than for typical seawater. These results are consistent with measurements taken for another study at Busama and Salamaua in 2007 (PNGPCL, 2007). Site L3 within the Labu Lakes had obvious freshwater influence and waters were brackish, as evidenced by salinity of 6.7ppt, pH of 7.4 and conductivity of 13.2mS/cm.

In February 2017, in-situ measurements of physicochemical parameters indicated that samples were more characteristic of typical seawater. Compared with 2016 in-situ data, samples at both 1.5m and 10m water depth in 2017 typically had higher pH (ranging from 8.3 to 8.5), higher conductivity (ranging from 39.9 to 54.4mS/cm) and higher salinity (ranging from 25.4 to 31.9ppt). Turbidity and TSS were lower except for site M1, where turbidity of 420NTU and TSS of 2,620mg/L was recorded. Site M1 in the Markham River plume (see Figure 10.9), was the only site with obvious freshwater influence during the 2017 sampling, with very low salinity of 6.0ppt at 1.5m water depth, and 29.5ppt salinity at 10m water depth, indicating the presence of a layer of predominantly freshwater floating on top of the underlying seawater. February 2017 results indicated little variability between sampling depths, except for salinity at most sites, where evidence of freshwater influence in the upper 1.5m of the water column was observed and salinity values were generally around 28ppt to 29ppt. This is slightly below the range expected for typical seawater.

The variation in physicochemical results between the two surveys suggests that the surface freshwater plumes fluctuate in thickness and degree of influence over time. It was noted during the February 2017 sampling that rainfall had been relatively low in the weeks prior to the survey. The Markham and Busu rivers were also observed to have lower flow than in November 2016. Reduced riverine input in February 2017 could explain the chemistry of the upper water column being more typical of seawater than it was in November 2016.

Comparison against ANZECC/ARMCANZ (2000) salinity criteria also indicates the sampled waters were typical of estuarine water, primarily in November 2016. The observed surface-water salinity range at several sites was also consistent with that of 20ppt to 22ppt reported by a previous sampling program near the mouth of the Markham River (WorleyParsons, 2016). The physicochemical results of the water sampling program demonstrate the variable influence of freshwater from rivers including the Markham, Busu and Bumbu rivers, as well as outflows from the Labu Lakes, on the receiving waters of the nearshore marine environment.

10.6.3. Nutrients, Faecal Coliforms and Oil and Grease

Nutrient concentrations were typically close to or below laboratory detection limits at all sites sampled in November 2016 and at most sites in February 2017. Concentrations of nitrate and nitrite were below the PNG criterion of 45mg/L at all sites. Concentrations of ammonia were below the ANZECC/ARMCANZ (2000) guideline of 0.91mg/L at all sites. As concentrations of nutrients were low at sites located both away from and in proximity to towns or villages, the low levels of nutrients are expected to be naturally occurring.

Faecal coliform concentrations in November 2016 were below detection limits at reference sites remote from urban or village areas (i.e., at sites R1, R2 and S1, see Figure 10.9). However, faecal coliforms were detected at sites near Labu (L1, L3 and L4), within the Markham River plume near Lae (M1 and M2), adjacent to Lae (V1, LA1), at Wagang and the Outfall System (W1 and W2) and within the Busu River plume (B1). Site LA1 is in the vicinity of the main Lae sewage outfall. At this site, a concentration of 540 most probable number/100 millilitres (mL) of faecal coliform bacteria was detected. A most probable number of 920/100mL was detected further afield at sites M1 (in the Markham River plume) and V1 (at Voco Point), suggesting that the presence of faecal coliform bacteria in the nearshore waters around Lae is widespread and likely to be influenced by river and terrestrial runoff.

Faecal coliform results in 2017 were highly variable both between sites and between depths, with no obvious trend apparent except that faecal coliforms were detected at all sites around Lae and Wagang. The only sample with no faecal coliforms detected was taken from a reference location near Salamaua, more than 20km south of Lae.

The PNG marine water quality criteria for aquatic ecosystem protection stipulates that there is to be no detectable oil and grease in marine waters. Low concentrations of oil and grease were detected at sites L1, L3, L4 and B1 in 2016 (ranging between 6mg/L to 8 mg/L) in 2016. Oil and grease were absent from all samples in 2017. The source of the oil and grease is not clear and no oil or grease residue was observed at the sites at the time of sampling. Surface oil sheens were visible within the Lae Yacht Club marina and within the small boat harbour at Voco Point; these are locations with ongoing, observable boat traffic, and vessel refueling takes place in these areas. Oil and grease concentrations of up to 96mg/L have been previously reported during studies for the Lae Port Tidal Basin Project. However, this concentration was detected south of the Labu Lakes and well away from development activities near Lae, and considered to be due to passing marine traffic (CHEC, 2015).

10.6.4. Dissolved Metals

Concentrations of dissolved metals were typically low, and generally below PNG water quality criteria and ANZECC/ARMCANZ guidelines. One exception was boron which exceeded the PNG criteria of 2,000µg/L at all sites except sites L3 and L4 in 2016.

The concentrations of dissolved boron were lower for samples taken at 1.5m in 2016 (between 1,310µg/L and 3,850µg/L) than 2017 (where all sites aside from the 276µg/L recorded at M1, were between 3,730µg/L and 4,150µg/L). Both sampling campaigns yielded results at 1.5m below the background range typical of seawater described in literature, of between 4,500µg/L to 5,100µg/L (ANZECC/ARMCANZ, 2000). In 2017, dissolved boron concentrations were notably greater at 10m depth at all sites (between 4,090 and 4,410µg/L), though still somewhat lower than the concentrations typically reported for seawater by ANZECC/ARMCANZ (2000) and Emsley (1991).

The majority of other dissolved metals concentrations were similar between samples collected from 1.5m and 10m water depths.

While not exceeding the PNG water quality criterion for copper, dissolved copper concentrations at two sites were in excess of the ANZECC/ARMCANZ 2000 guideline: Site V1 (2µg/L in 2016) and at M1 (1.9µg/L in 2017).

The source of copper concentrations at M1 and V1 is unknown; however, these sites are located adjacent to the Lae urban area and Lae Port Facilities. Here, boat traffic and numerous shipwrecks and debris are present in the water and along the shoreline, and possible waste water discharges (sewage) and industrial waste discharges and runoff from urban and industrial areas have been identified, therefore the concentrations are not unexpected.

10.7. Nearshore Marine Ecology

The nearshore marine ecology study methods and results are presented in the sections below.

10.7.1. Method

A comprehensive desktop review of relevant literature and existing information pertinent to the Project was undertaken including studies such as those produced for the Lae Port Development Project (PNGPCL, 2007) and for the Wafi-Golpu Project by CSIRO (Haywood et al., 2012) and WorleyParsons (2016).

To complement the analysis of pre-existing data a visual assessment of benthic features and foreshore and shallow pelagic environments was undertaken during field surveys conducted in November 2016 and February 2017. This assessment incorporated photography and videography of environmental features in proximity to the Outfall System, Port Facilities Area and reference locations, to determine the types and condition of habitats, species of conservation significance and anthropogenic influences.

The State of PNG does not have a system in place for the categorisation of threatened marine ecological communities. As such, this assessment was conducted with consideration of features of high biodiversity significance, including habitat types, defined under International Finance Corporation (IFC) Performance Standard 6 (IFC, 2012).

The IFC Performance Standard 6 distinguishes between natural and modified habitats, as well as a subset of these habitats, known as critical habitats. The criteria for distinguishing these habitat types are set out in IFC Performance Standard 6 and its associated guidance notes. Habitat types are distinguished based on their condition and biodiversity values, and each are subject to differing management requirements.

Performance Standard 6 recognises three different types of biodiversity habitat, each of which is associated with IFC operational standards that differ in level of stringency:

- Modified habitat – Areas that may contain a large proportion of plant and/or animal species of non-native origin, and/or where human activity has substantially modified an area's primary ecological functions and species composition.
- Natural habitat – Areas composed of viable assemblages of plant and/or animal species of largely native origin, and/or where human activity has not essentially modified an area's primary ecological functions and species composition.
- Critical habitat – Areas with high biodiversity value that satisfy one or more of the following criteria:
  - Criterion 1 – Habitat of significant importance to species listed as Critically Endangered or Endangered on the IUCN Red List of threatened species.
  - Criterion 2 – Habitat of significant importance to endemic and/or restricted-range species.
  - Criterion 3 – Habitat supporting globally significant concentrations of migratory species and/or congregatory species.
  - Criterion 4 – Highly threatened and/or unique ecosystems.
  - Criterion 5 – Areas associated with key evolutionary processes.

International Finance Corporation Guidance Note 6 (IFC, 2012) further defines a highly threatened or unique ecosystem as one that:

- Is at risk of significantly decreasing in area or quality e.g., is losing a high percentage of its area each year.
- Has a small spatial extent and/or contains unique assemblages of species including assemblages or concentrations of biome-restricted species.

The outcomes of these investigations as they pertain to the ecological characteristics of the study area of the Huon Gulf, are presented below. Additional details regarding the methodology and results of the 2016 and 2017 field studies are available in Appendix R, Nearshore Marine Characterisation.

10.7.2. Foreshore and Shallow Pelagic Environment

This section describes the habitat types and condition of the foreshore and shallow pelagic environments present within the study area.

The study area around Lae, and much of the north coast of the Huon Gulf (including the Outfall System), is primarily influenced by: steep seafloor bathymetry directly offshore; very high sediment loads in freshwater riverine outflows from the Markham, Busu and other rivers located along the coast; and the persistence of turbid nearshore waters for most of the time.

The northern shoreline of the Huon Gulf is relatively straight with only a few embayments and small estuary systems (Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf). The intertidal zone is generally narrow due to the steeply sloping shoreline and relatively small tidal amplitude. Where present, typically away from human activity, beaches are generally unmodified though are usually narrow, and are comprised of poorly-sorted medium to coarse grey facetted pebbles and river sands of sedimentary or metamorphic origin (Royal Haskoning, 2007).

Around Lae, substantial portions of the coastline have been modified by dumping rock to prevent coastal erosion. Extensive plastic litter pollution and other rubbish (mostly plastic bags and bottles), deliberately dumped or washed up has accumulated on beaches near and east of Lae, and floating rubbish was frequently observed in the nearshore zone during field surveys. Rubbish was observed along the coastline further east toward the Busu River although in lower amounts. Plastics, both floating and suspended within the water column, are a known source of harm leading to mortality in sea turtles and other fauna due to ingestion or entanglement (Nelms et al., 2015), and by physically preventing turtles accessing nesting beaches. The highest concentration of rubbish on the shoreline was observed between Voco Point and Wagang village. Additional influences include waste water discharges and run-off from residential, commercial and industrial areas in and around Lae. Driftwood naturally transported by the rivers is also abundant on the beaches and although used for firewood or building by local people, also traps much of the other floating debris.

Several large shipwrecks (approximately 20m in length or greater) in varying states of degradation were observed near Lae, together with others anchored nearshore that appeared (due to extensive corrosion and biofouling) to have been unused for an extended period of time. Approximately 10 such vessels were seen along the coast between the Markham River mouth and Wagang, mainly near the Port of Lae, DCA Point and east of Voco Point. Shipwrecks were also present near Labu Tale and in the Labu Lakes. Shipwrecks can provide varying degrees of artificial habitat for fauna and a viable structure for invertebrates to colonise, in the absence of suitable natural hard substrate. When situated above the seafloor, shipwrecks also reduce the likelihood of benthic smothering. This was observed near the Port of Lae, where a shipwreck resting between 5 to 40m depth was observed to have undergone heavy siltation, with some colonisation by invertebrate fauna (small alcyonarians, hydroids, sponges, ascidians and molluscs) (WorleyParsons, 2016). None of the shipwrecks are of cultural or archaeological significance.

Figure 10.28 to Figure 10.30 illustrate driftwood accumulated between Lae and Wagang. Figure 10.31 and Figure 10.32 illustrate rubbish near the Port of Lae and Voco Point. Figure 10.33 to Figure 10.35 show shipwrecks observed in various locations.

Along the southwest and northern coast of the Huon Gulf, beaches and shallow nearshore habitats (i.e., the intertidal zone) are largely natural and exhibit fewer signs of human influence compared with those near Lae, and visible signs of habitat disturbance are few except in proximity to coastal villages. Little rubbish was observed on the southwestern coast around Labu, Labu Miti and further south. Seasonal erosion and accretion occurs along the beaches in these areas, and can be substantial (Pilcher, 2015).

Photo credit: Coffey

Figure 10.28
Floating wood and other mobilised terrestrial vegetation agglomerating near Voco Point

Photo credit: Coffey

Figure 10.29
Shoreline at the Outfall Area. Note the woody debris and plastic litter along the shoreline

Photo credit: Coffey

Figure 10.30
Tree limbs and other driftwood or debris deposited on the beach at Wagang and collected by villagers


Photo credit: Coffey

Figure 10.31
Various debris and concrete either placed or accumulated on the beach near LA1


Photo credit: Coffey

Figure 10.32
Plastic and other anthropogenic debris accumulated on the beach near Voco Point


Photo credit: Coffey

Figure 10.33
Recreational swimming and shipwreck near Voco Point


Photo credit: Coffey

Figure 10.34
Shipwreck along coast near LA1


Photo credit: Coffey

Figure 10.35
Shipwreck on beach near Labu Tale

No mangrove habitat was observed between the Markham River mouth and east of the Busu River during field surveys conducted in November 2016 and February 2017. However, two small areas of mangrove vegetation located 2km west of the Outfall Area, near Wagang within the un-named tributaries of the Nungwa River were identified in separate studies (refer to Appendix R, Nearshore Marine Characterisation). These are referred to by local people as the Butudendeng and Nungawahac mangrove areas. Figure 10.36, Figure 10.37 and Figure 10.38 illustrate these Nungwa River tributaries and mangroves.

The Labu Lakes is a freshwater and estuarine lake system located about 2km southwest of Lae and 1km to the south of the Markham River. The Labu Lakes support an extensive area of intact and largely undisturbed mangrove-dominated ecosystem that appears to sustain many of the well-recognised functions of productive mangrove nursery habitats. The Labu Lakes are shallow, with typical water depths of approximately 2m, and subject to variable amounts of freshwater and marine influence i.e., upstream regions have higher freshwater inflows compared to downstream regions near the interface with the sea. The Labu Lakes meet the Huon Gulf via an opening approximately 50m wide, near the village of Labu. Figure 10.39 and Figure 10.40 illustrate representative mangrove habitat present within the Labu Lakes.

10.7.3. Benthic Environment

10.7.3.1. Habitat Type and Condition

High terrestrial sediment input, low light penetration and high freshwater inflow - combined with a steeply sloping seafloor - largely preclude the development of complex benthic communities and present unfavourable conditions for the establishment and growth of invertebrates, including reef-building corals (Gilmour, 1999; Nugues and Roberts, 2003; Anthony and Connolly, 2004; Weber et al., 2012; Storlazzi et al., 2015). For similar reasons, seagrass growth is also absent in areas under the influence of high turbidity, elevated concentrations of suspended solids and subsequently reduced light transmissivity (Broderson et al., 2017).

The above set of environmental conditions generally characterises much of the Huon Gulf north coast between the Markham and Busu rivers. These factors have resulted in nearshore benthic habitats largely characterised by low structural and faunal diversity and limited benthic marine resources, relative to tropical nearshore environments. No live coral reefs or seagrass beds were observed in the study area aside from at Busama and Salamaua.

While most benthic habitats near Lae in particular are characterised as impoverished (PNGPCL, 2007; WorleyParsons 2016), benthos (including coralline algae, macroalgae, porifera (sponges) and invertebrates (shrimp)) were identified in sediment samples near Voco Point during field surveys in 2016 and 2017 (Figure 10.41 to Figure 10.44). This indicates that benthic communities that have adapted to or are tolerant of these conditions are established, and that there are localised areas able to support a greater diversity of algae and invertebrates.

Photo credit: Coffey

Figure 10.36
Aerial photo of Butudendeng and Nungawahac mangroves near Wagang village, with Lae visible in background

Photo credit: Coffey

Figure 10.37
Butudendeng and Nungawahac mangroves to the north-east of Wagang village

Photo credit: Coffey

Figure 10.38
Butudendeng and Nungawahac mangroves to the north-west of Wagang village

Photo credit: Coffey

Figure 10.39
Mangroves of Labu Lakes, including unsubmerged portion of shipwreck

Photo credit: Coffey

Figure 10.40
Fisherman in Labu Lakes. Extensive mangrove forest present in background

Photo credit: Coffey

Figure 10.41
Shrimp (species unknown) collected during sediment sampling at V1

Photo credit: Coffey

Figure 10.42
Green marine algae (*Halimeda* sp.) collected during sediment sampling at V1

Photo credit: Coffey

Figure 10.43
Plating coralline algae (*Padina* sp.), branch algae and sponge growth retrieved from site LA1

Photo credit: Coffey

Figure 10.44
Green macroalgae retrieved with sediment sampler at site LA1

High turbidity from suspended sediments discharged from the Busu River precluded a visual assessment of the seafloor in the vicinity of the Outfall System, Wagang and the Busu River. A low diversity of benthos was observed in seafloor sediment samples in these areas. Local people from Wagang have anecdotally reported the presence of a small 'rocky reef' in the immediate vicinity of the Outfall System in approximately 5m to 10m of water. The feature is apparently discernible from canoes when the overlying waters are sufficiently clear and calm. These descriptions are consistent with bathymetric data indicating the presence a linear ridge that extends some 750m along the coast (see Section 10.3). Local people from Wagang reported using the 'rocky reef' as a fishing resource, suggesting presence of a habitat different from the surrounding sediments that may attract fish or other species from the surrounding area.

10.7.4. Coral Reefs and Seagrass

The nearest known coral reefs and seagrasses to the east of Lae occur approximately 18km away near Singaua, and the nearest known coral reefs and seagrasses to the south of Lae occur approximately 25km away at Busama. The Huon Gulf south coast has a relatively broad shelf with clear water, and a wider spectrum of marine habitats, including offshore islands and reefs (Webster et al., 2004). Fringing and aggregate patch reefs are described in earlier studies at southern locations including Busama and the Salamaua Peninsula (Haywood et al., 2012; WorleyParsons, 2016), and these southern locations represent the only places during the 2016 and 2017 field surveys where underwater visibility was consistently and sufficiently high to obtain clear imagery of the seafloor. Opportunistic video camera deployments during the field surveys recorded intact reefs in these locations, with live corals present to within a few metres of the shoreline in some areas, in approximately 0.5m to 20m water depth.

Coral reefs observed near Salamaua were generally contiguous, appeared to be of variable structural complexity, moderate to high coral cover and diversity (based on a qualitative review of video footage), and in generally healthy condition. No obvious coral bleaching or disease, or widespread reef degradation was observed; however, occasional patches of fragmented reef and coral rubble were evident. Haywood et al. (2012) report that the corals at Salamaua extend to 40m water depth.

The aggregate and patch reefs observed near Busama during surveys in 2016 and 2017 appeared to be restricted to shallower depths of around 10m (as was also reported in Haywood et al., 2012). The condition of these reefs was generally good, though variable, as some evidence of coral damage and sedimentation was observed during the 2016 field surveys. Compared to Salamaua, less cohesive coral growth and more reef fragmentation and sedimentation was generally present at Busama, and soft sediments present in the absence of reefs exhibited prolific bioturbation. Closer proximity to both the shoreline (and therefore to sediment resuspension resulting from wave action) and riverine sediments being transported south via longshore drift, are likely responsible for the higher sedimentation and lower visibility observed near Busama, compared with Salamaua.

In 2017, opportunistic observations of benthic habitats closer to shore near site S2 revealed the presence of dense, contiguous meadows of seagrass. These were located approximately 5m to 10m from the shoreline, in shallow, clear water on flat seafloor.

Figure 10.45 to Figure 10.47 illustrate the coral reefs observed at Busama and coral reefs and seagrass observed at Salamaua.

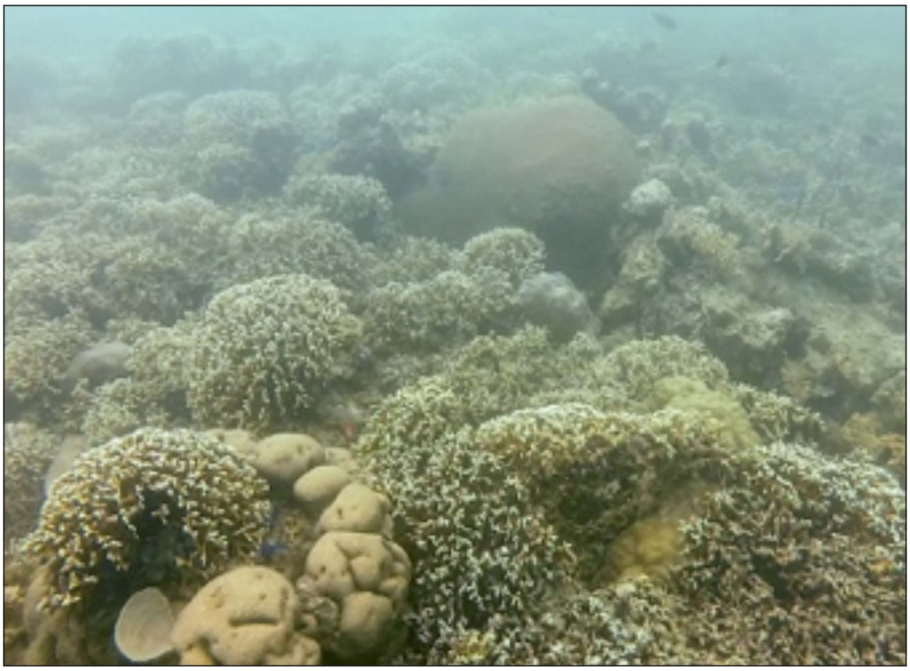

Photo credit: Coffey

Figure 10.45
Coral reef at S1

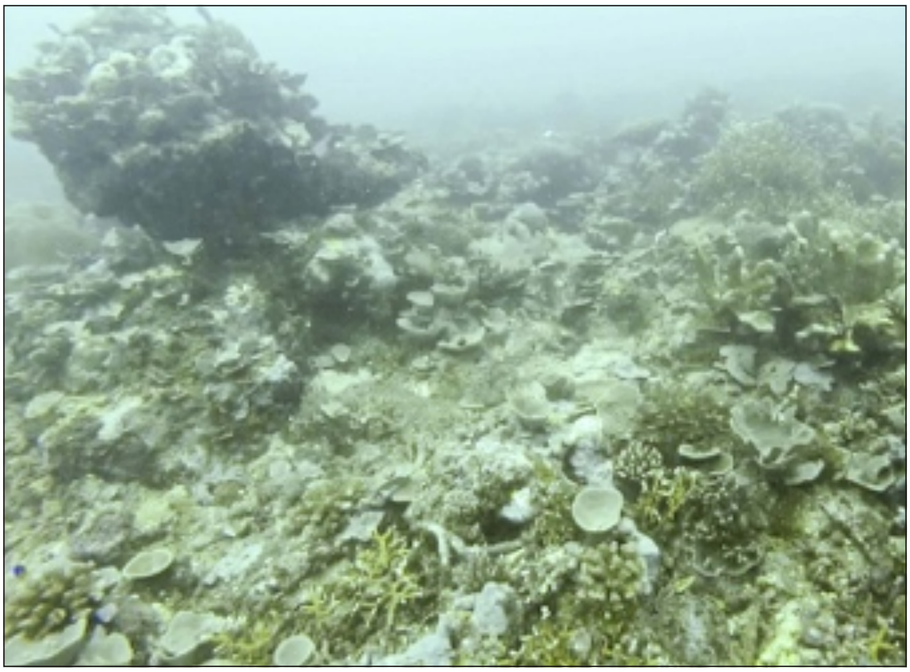

Photo credit: Coffey

Figure 10.46
Coral reef at Busama

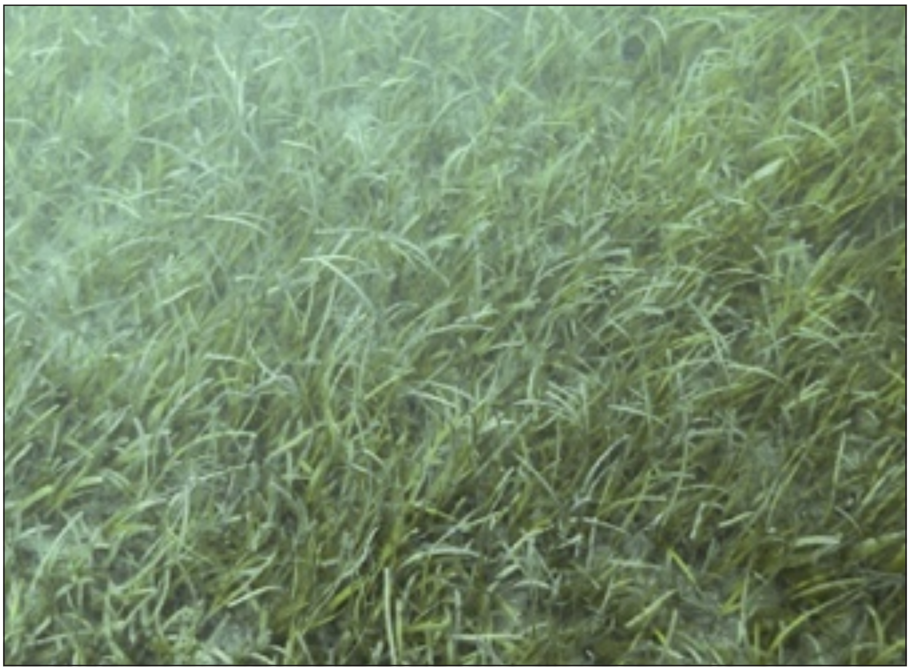

Photo credit: Coffey

Figure 10.47
Seagrass at S2 (*Thalassia* sp.)

While somewhat closer than the reefs at Busama, satellite imagery (Haywood et al., 2012) and reports from local people indicate the presence of reefs to the east of Lae at Singaua. However, these were not identified during the field survey conducted in 2016 in the time afforded and due to low water clarity in the surrounding waters preventing direct observation. Beyond Singaua, the next closest reefs identified from satellite imagery are situated a further 50km east at Butala. An extensive set of reefs is present 12km from this location, fringing the coastline towards Finschhafen and the Tami Islands.

Overall, there are substantial differences between the benthic habitats of the north and western Huon Gulf around Lae compared with the coral reef and seagrass habitats present around 25km to the south of the Labu Lakes. The Huon Gulf north coast around Lae (including offshore Labu Lakes), and east beyond the Busu River are largely characterised by high-turbidity waters, and a predominantly muddy seafloor of lesser structural and faunal diversity. These differences illustrate how the underlying geological setting of the region, combined with terrigenous sediment inputs, have influenced the characteristics of the nearshore benthic marine environment in the Huon Gulf.

10.7.5. Nearshore Marine Environment Fauna and Flora

Observations of fauna and flora within the study area, and that potentially present within the upper Huon Gulf more broadly, are discussed in this section.

10.7.5.1. Method

The information in this section includes that derived from existing reports and publications obtained during a desktop review, and data obtained during field surveys conducted in November 2016 and February 2017. These surveys incorporated capturing photography and videography records, and both direct (first hand sightings of fauna) and indirect (scats, tracks, nests, reports from local interview respondents, and historical records) observations.

Targeted sampling of infauna (benthic fauna living in the substrate or sediment, especially in a soft seafloor) was also conducted at eight sites in February 2017, including meiofauna and macrofauna. Meiofauna are multicellular animals that include those retained on 63µm mesh and pass through 500µm mesh. While occasionally larger than 500µm, all nematodes and harpacticoid copepods present in meiofauna samples were counted as meiofauna. Macrofauna are multicellular animals that are retained on a 500µm sieve. Sediment infauna abundance and diversity analysis was conducted by Dr. John Moverley, details of which are provided in Appendix R, Nearshore Marine Characterisation.

International Finance Corporation (2012) notes the prioritisation of highly threatened or unique ecosystems should employ similar factors to those used for the IUCN Red List of Threatened Species, including long-term trend, rarity, ecological condition, and threat.

Accordingly, for the purposes of this characterisation, species of conservation significance include:

- Species of international conservation priority, listed as threatened (Critically Endangered, Endangered or Vulnerable) or near threatened on the IUCN Red List.
- Species of national conservation priority, listed as protected or restricted under the Papua New Guinea (PNG) *Fauna (Protection and Control) Act 1966*.
- Species endemic to the Huon Gulf.

10.7.5.2. Cetaceans and Marine Mammals

There are 20 species of cetacean recorded from PNG; all are widely distributed in tropical seas. It is possible that some of these species utilise the waters in the study area, however published data specific to cetaceans in the Huon Gulf near Lae is extremely limited, as is knowledge on marine mammals in PNG more generally (Haywood et al., 2012). Surveys conducted in 2002 and 2003 in Kimbe Bay (West New Britain) indicated the presence of 11 species of cetacean; none of these are considered as being threatened with extinction by the IUCN, however several are classified as Data Deficient (Haywood et al., 2012; IUCN, 2017).

During the 2016 and 2017 field surveys, dolphins were observed on several occasions at different locations within the Huon Gulf near Lae and Salamaua, in pods of approximately three to eight individuals. Figure 10.48 illustrates dolphins observed near site S1 in November 2016. The dolphins could not be identified to species level due to their distance from the observers. The presence of dolphins supersedes earlier reports that marine mammals were not known to occur within the vicinity of the Port of Lae (WorleyParsons, 2016).

Interview respondents from the Lae Game Fishing Club stated that pilot whales and blue whales were occasionally seen in the Huon Gulf near Lababia some 60km southeast of Lae.

Local residents stated that dugong are occasionally hunted near Salamaua and Lababia, which is likely to be one of the only viable dugong habitat areas in the region. Dugong habitat is not expected near Lae and along the Huon Gulf north coast portion of the study area due to the absence of seagrass.

10.7.5.3. Sea Turtles

Five sea turtle species, none of which are endemic to the study area, are known to have distributions that include the Huon Gulf. All five are of conservation significance and comprise the:

- West Pacific leatherback turtle (*Dermochelys coriacea*), listed as Critically Endangered on the IUCN Red List.
- Hawksbill turtle (*Eretmochelys imbricata*), listed as Critically Endangered on the IUCN Red List.
- Green turtle (*Chelonia mydas*), listed as Endangered on the IUCN Red List.
- Olive ridley turtle (*Lepidochelys olivacea*), listed as Vulnerable on the IUCN Red List.
- South Pacific subpopulation of the loggerhead turtle (*Caretta caretta*), listed as Critically Endangered on the IUCN Red List.

Predation of nests by humans and dogs, hunting of nesting females, erosion and degradation of beach nesting habitats, fisheries bycatch, pollution (e.g., plastic bags), and climate change (e.g., elevated sand temperatures on nesting beaches) are among the known major threats to sea turtles in the Huon Gulf (Kinch, 2006; Tiwari et al., 2013). Additional information regarding turtle egg harvesting and community conservation and management activities is provided in Appendix S, Fisheries and Marine Resource Use Characterisation. The targeting of turtles and eggs for consumption was also reported in NFA (2007).

While none of these species are endemic to the study area, the west side of the Huon Gulf coast to the south of the Labu Lakes represents one of the few remaining known major nesting grounds for the west Pacific leatherback (Kinch, 2006; Haywood et al., 2012; Tiwari et al., 2013). In November 2016, sea turtle nests (species unconfirmed, though likely to be those of the west Pacific leatherback due to the size of the nesting pits and reports from local people) were observed from boats along the shore near Labu Miti and Labu Tale (Figure 10.49).

Photo credit: Coffey

Figure 10.48
Dolphins near site S1

Photo credit: Coffey

Figure 10.49
Sea turtle nesting pit observed near Labu Tale

Photo credit: Coffey

Figure 10.50
Gastropod molluscs (Family: Thiaridae) collected from the Labu Lakes by local villagers

10.7.5.3.1. West Pacific Leatherback

The west Pacific leatherback is a subpopulation of the global leatherback sea turtle population that belongs to a single regional genetic stock. The west Pacific leatherback subpopulation has experienced a long-term population decline, and recent population estimates are in the order of 1,500 mature individuals (Tiwari et al., 2013). The marine habitat for this subpopulation extends north into the Sea of Japan, northeast and east into the North Pacific to the west coast of North America, west to the South China Sea and Indonesian Seas, and south into the high latitude waters of the western South Pacific Ocean and Tasman Sea (Tiwari et al., 2013). The west Pacific leatherback is a congregatory species whose individuals gather in large groups on a cyclical or otherwise regular and/or predictable basis to nest. Approximately 75% of the nesting activity of the total west Pacific leatherback subpopulation is concentrated at four sites along the northwest coast (Bird's Head Peninsula) of West Papua (Dutton et al., 2007), over 1,500km to the west of the Huon Gulf.

The majority of west Pacific leatherback nesting within PNG occurs on the west side of the Huon Gulf along approximately 120km of beach habitat between Labu Tale and Paiawa (Rei, 2005; Kinch, 2006; Tiwari et al., 2013). Nesting primarily occurs during the austral summer from October/November to February/March each year, with peak nesting occurring during December and January (Benson et al., 2007). The nearest nesting to Lae takes place some 7km south of the Labu Lakes at Labu Tale, with nesting activity progressing south along the west coast and including beaches at Busama (25km from Lae), within the Kamiali Wildlife Management Area, the Buang-Buasi region, and at Paiawa, some 100km south of Lae (Kisokao, 2005; Kinch, 2006; Benson et al., 2007; Pilcher, 2012 and Tiwari et al., 2013).

The beaches in these areas to the south of Lae are generally unmodified, aside from where human settlement occurs, though subject to seasonal erosion and accretion. Telemetry data indicate that after nesting, turtles in PNG generally migrate in January and February through deep waters to the east and southeast toward the high latitude waters of the South Pacific (Benson et al., 2007). Data from the 2012 to 2013 nesting season indicate that 35 and 68 clutches were laid on the beaches at Labu Tale and Busama respectively (Pilcher, 2013; Pilcher, 2015). Conservation activities at the Labu Tale Turtle Reserve are not currently taking place (Pilcher, 2015).

Interviews with people from Wagang Village indicated that the west Pacific leatherback also nests between Wagang and the Busu River with about three turtles nesting per year (see Appendix S, Fisheries and Marine Resource Use Characterisation for further data pertaining to these reports from local people). Some aerial survey records (Dutton et al., 2007) support this assertion, however specific nesting data for the Wagang area are not available (Kinan, 2005; Benson et al., 2007). People from Wagang indicated that sea turtle nesting in the area between Wagang and the Busu River is presently less common than it was historically (i.e., in the 1970s), and did not indicate that any other species of sea turtle other than west Pacific leatherbacks are observed nesting in this area. No evidence of sea turtles or sea turtle nests was observed at Wagang during field surveys in November 2016, a period that coincided with the early stages of the west Pacific leatherback nesting season in the Huon Gulf.

The lack of data, compared with the known documented nesting and research focus along the western coast of the Huon Gulf suggests that the Wagang area is not a preferred nesting area, and that nesting activity is low (Kinch, 2006; Benson et al., 2007; Dutton et al., 2007; Tiwari et al., 2013; Pilcher, 2015). A possible explanation is that the north coast of the Huon Gulf is cut by numerous rivers and there are also widespread and extensive accumulations of rubbish and driftwood on the beaches between Lae and the Busu River which make the beaches less attractive and less viable for nest building.

While more recent data suggests that west Pacific leatherback turtle nesting activity in the Huon Gulf is somewhat stable (Pilcher, 2012), the reduction in nesting observations by local people is potentially related to the wider population of west Pacific leatherback turtles declining between 83% and 95% during the past three generations, in addition to variable coverage by rangers and the nature of historical anecdotal data (Spotila et al., 2000; Eckert et al., 2012; Pilcher, 2012; Tiwari, et al., 2013; Pilcher, 2015).

10.7.5.3.2. Other Sea Turtle Species

People from Wagang Village stated that hawksbill and green sea turtles were observed occasionally in the waters along the coast between Wagang and the Busu River. Similar accounts were given by people from Labu Tale, regarding these sea turtle species along the coast around Labu Tale and Busama. However, no turtles, turtle nests or prior nesting pits were observed during the November 2016 or February 2017 field surveys, or during a follow up visit to Wagang in May 2017 (observations were not expected in May however, due to May being outside of the recognised nesting season).

In comparison with the well-documented nesting activities of the west Pacific leatherback turtle, little published literature specific to the other sea turtle species with distributions including the Huon Gulf is available. The Huon Gulf region more broadly, is not specifically recognised as an important habitat area, or a major nesting ground for these other species of sea turtle. However, IUCN database records of threatened species within the estuarine, nearshore and offshore marine environment adjacent to the PNG mainland does indicate that the hawksbill and green turtle are known from nearshore marine environments near Lae (WorleyParsons, 2016).

10.7.5.4. Coral Reef Flora and Fauna

Historical studies, conducted in 1983 and 1984 and summarised by WorleyParsons (2016), indicated that 95 coral species from 48 genera and 13 families have been identified growing in fringing reefs from Busama to Salamaua. A survey of coral reefs by Kojis et al. (1985) indicated that 55 coral genera where present in the Huon Gulf. Data from these studies indicated that live coral cover was greatest at depths shallower than 5m, declining rapidly to less than 10% at depths of 15 to 20m. No coral was found beyond a depth of 20m at Busama. At Salamaua, live coral cover was highest (43% to 58%) between depths of 0m and 20m, moderate between 20m to 35m, and at 45m water depth 5% coral cover was recorded.

While the characteristics of the coral assemblages at these historical survey locations may have since changed (given the age of this data), *Acropora palifera* (now classified as *Isopora palifera*) was the predominant coral species. This species was the most common in shallow waters, and not recorded in depths beyond 5m near Busama and 15m at Salamaua. Differences in the fecundity of *Acropora palifera* at Busama and Salamaua were examined in relation to differences in the sedimentation rate; the associated concomitant light attenuation at Busama was found to limit the depth at which *Acropora palifera* grew and reduced its fecundity (Quinn and Kojis, 1983). The research by Quinn and Kojis (1983) which indicated that higher turbidity occurs in waters at Busama than Salamaua, was corroborated by the field surveys conducted in 2016.

A high-level qualitative review of video footage from 2016 and 2017 also revealed the conspicuous presence of *Isopora palifera* (primarily at Salamaua), as well as various growth forms (mainly tabular and branching) of hard coral genera including *Porites*, *Favia*, *Favites*, *Acropora*, *Seriatopora*, *Montipora*, *Pocillopora*, *Fungia*, *Platygyra*, *Plerogyra*, *Pachyseris*, *Diploastrea*, *Herpolitha* and *Echinophyllia*. Soft corals (*Sinularia and Lobophyllia*) were more apparent at Busama than at Salamaua. Of the non-scleractinian corals with carbonate skeletons, *Distichopora*, *Heliopora*, *Stylaster* and *Millepora* were observed. Dense stands of *Millepora* were present at Busama, as they were also reported to be by Quinn and Kojis (1983). Whip coral was present at Busama in areas where intact reef was absent, and usually near regions where the soft seafloor was observed to have abundant bioturbation (burrows) and corals were sparse or damaged, and sedimentation was visible. Crinoids were often observed on coral heads, while the blue sea star (*Linckia laevigata*) was readily visible around live corals at Busama. No evidence of crown of thorns starfish was observed.

The fish fauna associated with coral reefs in PNG is known to be of extremely high biodiversity, with at least 1,500 species described (Burke, 2012). Reef-associated fish including fusiliers (*Caesionidae*), damselfish (*Pomacentridae*), surgeonfish (*Acanthuridae*), filefish (*Monacanthidae*), *Pseudanthias*, moorish idol (*Zanclus cornutus*), foxface rabbitfish (*Siganus vulpinus*), wrasse including the bluestreak cleaner wrasse (*Labroides dimidiatus*) and checkerboard wrasse (*Halichoeres hortulanus*), and others were observed at the Busama and Salamaua coral reefs in 2016 and 2017. Over 200 fish species have been identified somewhat further south, within the Kamialai Wildlife Management Area (Longnecker et al., 2008).

Adverse changes or death to coral reefs from causes such as coral collection (for lime), poisoning, dynamite fishing and diving was reported in many responses (including from Salamaua) during a socioeconomic survey by the NFA (2007). However, other respondents reported reef growth, thought to be shallowing of reef areas.

Due to the absence of coral reefs along the north coast of the Huon Gulf between Lae and the Busu River, there is no data regarding reef-associated flora and fauna to be collected in those areas. The nearest reefs to the east of Lae (located at Singaua approximately 18km away) could not be identified during the field survey in 2016 in the time afforded and due to low water clarity in the surrounding waters. No published data exists for this area aside from satellite imagery of the reef locations (Haywood et al., 2012). Beyond Singaua, the closest reefs identified from satellite imagery are situated a further 50km east at Butala. An extensive set of reefs is present 12km from this location, fringing the coastline towards Finschhafen and the Tami Islands.

10.7.5.5. Nearshore Infauna Assemblage

Subtidal infauna sampling in the study area indicate that the meiofauna and macrofauna communities observed around Lae and the Huon Gulf north coast are generally representative of stressed environmental conditions brought about by the dynamic sedimentation regime. While most macrofauna taxa had fewer than five representatives, a limited number of taxa had high relative abundance. Groups such as Sedentaria, amphipods and tanaids were under-represented and overall diversity was low, when compared to typical tropical subtidal infauna communities. Near the Outfall System (site W2) and near the mouths of the Busu and Markham rivers macrofauna abundance was very low. These findings differ from the assemblages observed on the southwest coast of the Huon Gulf at Salamaua (site S2), a location well removed from the influence of riverine sediment.

Meiofaunal communities typically displayed high variability in abundance and diversity between sites. Sites with greater proportions of gravel content in sediments and less apparent riverine influence had higher meiobenthic community complexity (i.e., diversity), while sites characterised by substantial riverine influence with large quantities of terrestrial organic material had low meiofauna community complexity and typically low abundance.

Harpacticoid abundance is known to be inversely correlated with current velocity and suspended solids (Casanova and Henry, 2004), and this may explain the very low abundance of this group at sites near the Markham and Busu rivers. The stressed environmental conditions associated with these locations (i.e., high concentrations of suspended solids, mobile seafloor and high current flow) is likely to be the main cause of impoverished infaunal communities.

Given the variable proximity of the sampling sites to the high sedimentation load discharged from the Markham and Busu rivers, and varying exposure to industrial influences such as those associated with the Port of Lae and coastal infrastructure development, the observed localised differences in infauna communities are not unexpected.

10.7.5.6. Other Fauna and Flora

Except for dolphins and turtle nesting pits, no other marine mammals or mega fauna such as whales, sharks, whale sharks, dugong, manta rays, sportfish (e.g., marlin or sailfish), sea turtles or crocodiles were directly observed during the four survey days completed in November 2016, and the three survey days completed in February 2017.

No endemic species, meaning those that have greater than 95% of their global range inside the island of New Guinea (i.e., West Papua and PNG), were observed during the field surveys.

Records of threatened estuarine, nearshore and offshore species were obtained via an IUCN database search, a revision of the IUCN database search conducted by WorleyParsons (2016), and other sources (Haywood et al., 2012). These records included various fauna including bony fish, sharks, rays, sea turtles and holothurians (beche-de-mer). Most the species identified by the literature search were listed as Vulnerable and are pelagic species with wide distributions. Data pertaining to these species that is specific to the Huon Gulf is unavailable.

10.7.5.6.1. Sharks and Rays (*Chondrichthyes*)

The status of sawfishes (family *Pristidae*), and indeed most sharks and rays in PNG is largely unknown due to the paucity of detailed catch and observational records available, both historic and contemporary (White et al., 2017). With distribution ranges beyond PNG, the Critically Endangered large tooth sawfish (*Pristis pristis*) and green sawfish (*Pristis zijsron*, also known as the narrow snout sawfish) are known to be present within PNG waters. These species are restricted to coastal, estuarine and freshwaters and are generally associated with muddy seafloors; although the presence of these species in the study area has not been recorded, they may occur. Similarly, the Critically Endangered knifetooth sawfish (*Anoxypristis cuspidata*) is reported from Morobe Province, however no specific information for the Huon Gulf is available (Haywood et al., 2012). A recent review by White et al. (2017) of locations where sawfish have been recorded in PNG yielded no records for the Huon Gulf.

The New Guinea river shark (*Glyphis garricki*) and speartooth shark (*Glyphis glyphis*) are also both listed by the IUCN as Critically Endangered, and known to inhabit turbid estuarine and inshore marine areas, however data regarding their presence in the Huon Gulf is not available.

The scalloped hammerhead (*Sphyrna lewini*) and the great hammerhead (*Sphyrna mokarran*) are both coastal species with wide distributions, and also reported as possibly inhabiting the Huon Gulf (Haywood et al., 2012), although no specific information is published in the scientific literature. These species are both listed as Endangered on the IUCN Red List. Further, the wide-ranging coastal, epipelagic and oceanic shortfin mako shark (*Isurus oxyrinchus*, listed as Endangered on the IUCN Red List) is known to be present in the Huon Gulf from information provided by the Lae Gamefishing Club (Haywood et al., 2012).

While minimal data is available for the species, the hooded carpet shark (*Hemiscyllium strahani*) is known to be restricted to a small region off the northern and southern coasts along the eastern extent of PNG. Due to this species being associated with coral reefs where it is typically observed in 3m to 18m water depth, it is unlikely to occur in the study area, with the potential exception of the coral reef habitat near Busama and Salamaua. This species is listed as Vulnerable on the IUCN Red List (Heupel and Kyne, 2003).

10.7.5.6.2. Crocodiles

Along the Huon Gulf north coast, wild crocodiles are generally absent and not usually expected (EnviroGulf, 2017). No crocodiles were observed during the field surveys and local people at Wagang indicated that crocodiles were rarely seen, though were aware of their occasional presence. However, WorleyParsons (2016) previously reported that the saltwater crocodile, *Crocodylus porosus*, is found in all rivers of the Huon coast. Further, a crocodile was caught at Lae Yacht Club in June 2017 and six other recent sightings have occurred within the vicinity of the Lae Tidal Basin area. A commercial crocodile farm is operating near ‘9 Mile’ in Lae and escapes from this facility have occurred, particularly during Markham River flood events, and these factors may influence the presence of crocodiles in the area (Wissink, 2017 pers. com.). BAAM (Appendix C, Terrestrial Ecology Characterisation – Mine Area to Markham River) also recorded the presence of a saltwater crocodile skull in the coastal village of Chiatz. This suggests that crocodiles can be expected to occur in the study area at some times. The IUCN status of the saltwater crocodile is Least Concern (Crocodile Specialist Group, 1996).

10.7.5.6.3. Avifauna

WorleyParsons (2016) reported that the estuarine mud flats of the Markham River provide habitat for a wide variety of shorebirds, including the far eastern curlew (*Numenius madagascariensis*) listed as Endangered on the IUCN Red List, however this finding was not observed during the 2016 and 2017 field surveys. The highly migratory far eastern curlew has a broad range, however the global population is declining. The population decline is primarily due to habitat loss as indicated by reduced population numbers at several migratory stopover points and a rapid decline in the number of non-breeding individuals wintering in Australia and New Zealand (Birdlife International, 2016). The Huon Gulf north coast is not a known area of significant habitat importance for this species. The majority of the other bird species identified by WorleyParsons (2016) as being present in the area are listed as Least Concern, with the black-tailed godwit (*Limosa limosa*) and grey-tailed tattler (*Heteroscelus brevipes*or) listed as Near Threatened.

10.7.5.6.4. Labu Lakes Flora and Fauna

Within the brackish waters and mangroves of the Labu Lakes, WorleyParsons (2016) note the presence at least 39 species of fish belonging to 26 families including mangrove jack, mullet, croaker, ponyfish, trevally, sardine, snapper and catfish. Crustacea including mud crabs (*Scylla serrata*), burrowing mud lobsters (*Thalassina* spp.) and penaeid and stomatopod shrimp are known from the area, as well as molluscs (see Figure 10.50) including mangrove horn snails (*Telescopium telescopium*), mud clams (*Polymesoda erosa*), air-breathing sea slugs (Onchidium spp.) and various mangrove gastropod snails (Cerithidae and Neritidae).

Data collected some 33 years earlier by Womersley (1984), notes that the vegetation assemblage of the Labu Lakes primarily comprises *Rhizophora apiculata* and Bruguiera spp., with *Aegiceras corniculatum*, *Avicennia marina*, *Heritiera littoralis*, *Sonneratia caseolaris* and *Xylocarpus granatum* also present.

10.7.5.6.5. Invasive and Alien Species

The presence of any alien or non-native species of flora and fauna that had become invasive, spread rapidly, or obviously out-competed native species, was not observed in the study area.

10.7.6. Summary of Species, Habitats and Ecosystems of Biodiversity and Conservation Significance in the Study Area

All habitat within the study area is considered to be natural habitat as defined by IFC PS6 (see Section 10.7.1), with the exception of the modified habitat present along the portion of the coastline in the immediate vicinity of Lae. Namely, modified habitat includes that around the Lae Tidal Basin, the Port of Lae and other nearby coastal areas such as DCA Point, Voco Point and locations obviously affected by dumping of refuse and development activities. While the degree of modification of nearshore habitats in the study area and the effects this will have on individual species varies, the primary ecological functions and species composition of these locations has been substantially modified. Areas of natural habitat include around the proposed Outfall Area and further east (while observations of refuse pollution at this location were made, they were much less prevalent than observations made closer to Lae), and all nearshore marine habitat south of the Markham River. None of the modified habitats around Lae, or the nearshore portion of the Outfall Area (i.e., the Outfall System) are considered to be 'critical habitat' in accordance with PS 6 criteria.

The species listed as Critically Endangered and Endangered that have been recorded or may occur within the habitats of the study area include the west pacific Leatherback turtle, the hawksbill turtle and the green turtle, the green sawfish, large tooth sawfish, knifetooth sawfish, New Guinea river shark, speartooth shark, scalloped hammerhead, great hammerhead and the shortfin mako shark. However, except for the documented habitat supporting the nesting activities of the west Pacific leatherback turtle (i.e., habitat along the western coast of the Huon Gulf from around Labu Tale and further south), no other habitat within the study area can be considered as supporting regular occurrences of any of these species. Therefore, IFC critical habitat is present on the basis of Criterion 1, however it does not apply to the entire study area.

No species that occur within the study area, or the Huon Gulf more broadly, are known to be endemic. The hooded carpet shark is known to be restricted to a small region off the northern and southern coasts along the eastern extent of PNG and found on coral reefs. However, given the relative absence of coral reefs in the study area (aside from at Busama and Salamaua), the study area is unlikely to contain habitat supporting greater than 1% of a global population. Therefore, there is no IFC critical habitat in the study area on the basis of Criterion 2.

A number of migratory species are known to be, or potentially could be, present within the study area, including the saltwater crocodile and west Pacific leatherback turtle. The west Pacific Leatherback turtle is a migratory and congregatory species and greater than 1% of the population is known to occur in the study area along the western coast of the Huon Gulf from Labu Tale to Paiawa. However, within the Coastal Area and along the Huon Gulf north coast, no habitat is known or expected to sustain greater than 1% of the population of any migratory species, or any congregatory species. Therefore, IFC critical habitat is restricted to the portion of the study area between Labu Tale and Salamaua, on the Huon Gulf coast to the south of Lae, on the basis of Criterion 3.

At present, there is no quantitative or qualitative evidence to suggest any particular marine ecosystem type in the study area presently qualifies as highly threatened and/or unique. Therefore, there is no IFC critical habitat in the study area on the basis of Criterion 4.

No previous studies have been conducted of the study area or of the Huon Gulf more broadly, in relation to the identification of unique evolutionary processes. Reproductive isolation is a key mechanism driving speciation, a key evolutionary process, however the Huon Gulf experiences a high degree of oceanographic interconnectivity and the study area represents a dynamic interface between terrestrial and marine habitats and ecological processes. There is, therefore, little evidence available to suggest any of the habitats of the area represent critical habitat on the grounds of key evolutionary processes. Therefore, there is no IFC critical habitat in the study area on the basis of Criterion 5.

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