TOTAL
TOTAL E&P PNG LIMITED

PAPUA LNG PROJECT

UPSTREAM ENVIRONMENTAL IMPACT STATEMENT

VOLUME 1: MAIN REPORT

Chapter 12: Impacts - Marine

TOTAL E&P PNG LIMITED

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12. Impacts: Marine

12.1 Marine Physical and Sediment Processes

12.1.1 Context

The offshore elements of the Papua LNG Project extend from Orokolo Bay at the northern end of the Gulf of Papua, along the continental shelf to Caution Bay (see Figure 4.7). Metocean processes and fluvial sediment inputs to the Gulf of Papua vary between the northwest monsoon season (December to March) and the southeast trade winds season (May to October). The southeast trade winds season typically has stronger winds and higher levels of wave-driven sediment resuspension than the northwest monsoon season. Rainfall and fluvial sediment delivery to the gulf is typically higher in the northwest monsoon season.

Fluvial sediments delivered to the gulf are deposited in shallow areas immediately offshore of rivers. Waves and currents remobilize sediments leading to high turbidity in Orokolo Bay, especially during the southeast trade winds season. Sediments in Orokolo Bay comprise muds and sands, and only a single rocky-reef, located in the southeastern part of the bay, is known to occur. The shoreline of the bay experiences high rates of sediment transport driven by incident southeasterly waves. This is causing a sediment lobe, located in the eastern part of the bay, to migrate westwards towards the Purari River mouth (see Figure 8.3).

The physical and climatic settings differ between Caution Bay and Orokolo Bay. Caution Bay receives fluvial sediment loads from the Vaihua River, which has a much smaller catchment and overall sediment load compared to the Purari River. There is, therefore, lower total fluvial sediment loads to Caution Bay compared to Orokolo Bay. Caution Bay is protected from waves by a barrier reef system between Vari Vari and Idihi islands and has a fringing nearshore reef. Due to the calmer conditions and lower fluvial sediment delivery, Caution Bay has lower turbidity and total suspended solid (TSS) concentrations than Orokolo Bay.

Substrates along the offshore export pipeline route generally consist of depositional, unconsolidated sediments, predominantly comprising silts and clays, in water 35 to 60 m deep. Wave climates in these offshore waters rarely reach wavelengths sufficient to mobilize sediments at this depth. Wave-induced bottom friction velocities are very low along the offshore export pipeline route.

12.1.2 Discipline-specific Impact Assessment Method

The significance assessment approach described in Chapter 3 was primarily used to characterize impacts relevant to physical and sediment processes. The magnitude and sensitivity descriptors used to assess impacts are presented in Tables 12.1 to 12.3.[1] The assessment is a function of the magnitude[2] of impact on a resource or receptor and the sensitivity of that resource or receptor. Together, they determine the significance of the residual impact, as shown in Table 12.4.

Numerical modeling of hydrodynamics and sediment transport was also undertaken to inform the impact assessment. The assessment is therefore a combination of the qualitative significance assessment approach and quantitative modeling. Further information on the modeling activities is provided in Part 4 of Volume 3.

1 These descriptors are also relevant to marine water quality, which is assessed in Section 12.2.
2 Magnitude is assessed considering combinations of (1) geographic extent and (2) the higher of severity and duration.

This modeling was used to simulate potential impact scenarios based on the proposed marine export pipeline works and construction methods. Whilst LNG facilities inside the PNG LNG Plant lease boundary are excluded from the scope of this EIS, the modeling discussed here includes indicative information that will be refined as part of the downstream Papua LNG EIS.

Table 12.1 – Impact Magnitude Descriptors Relevant to Marine Physical and Sediment Processes, and Marine Water Quality

Geographic Extent of Impact*		Severity and Duration of Impact		
		Severity		Duration
5	Impact to any environmental feature that extends significantly beyond *subregion* (close to *regional*) scale.	5	Extreme impact such that: ♦ Intensity, frequency and duration of impact is well outside the range of natural variability; or ♦ One or more environmental values (social and biodiversity) are no longer supported.	Impact lasts >30 years
4	Impact to any environmental feature that extends beyond *subregion* (but not close to *regional*) scale.	4	Severe impact such that: ♦ Intensity, frequency and duration of impact is slightly outside the range of natural variability; or ♦ One or more environmental values (social and biodiversity) are adversely affected but supported in a highly modified condition.	Impact lasts 5 to 30 years
3	Impact to any environmental feature that extends beyond *localized* area but does not extend beyond *subregion*.	3	Moderate impact such that: ♦ Intensity, frequency and duration of impact is within the range of natural variability, similar to levels experienced during extreme events such as severe storms or tropical cyclones; or ♦ One or more environmental values (social and biodiversity) are adversely affected but still supported in a slightly to moderately modified condition.	Impact lasts <5 years
2	Impact to any environmental feature within a *localized* area.	2	Minor impact such that: ♦ Intensity, frequency and duration of impact is within the upper range of natural variability but below levels experienced during extreme events such as severe storms or tropical cyclones; and ♦ All environmental values (social and biodiversity) are maintained.	Impact lasts <1 year
1	Impact to any environmental feature within *highly localized* area.	1	Very minor to no impact such that: ♦ Intensity, frequency and duration of impact is within the average range of natural variability; and ♦ All environmental values (social and biodiversity) are maintained.	Impact lasts days to weeks

**Region* = Area greater than 20,000 km^2 (approximately 25% of the Gulf of Papua ecoregion (~75,000 km^2) and approximately 10% of the Southeast Papua New Guinea ecoregion (~225,000 km^2)).
Subregion = Area more than 2 km from the Project footprint but less than 20,000 km^2.
Localized = Area up to 2 km from the Project footprint.
Highly localized = Area up to 0.5 km from the Project footprint.

Table 12.2 – Impact Magnitude Matrix Relevant to Marine Physical and Sediment Processes, and Marine Water Quality

Severity/ Duration	Geographic Extent				
	1	2	3	4	5
1	Minimal	Low	Medium	Medium	High
2	Low	Low	Medium	High	High
3	Low	Medium	High	Very High	Very High
4	Medium	Medium	High	Very High	Very High
5	Medium	Medium	Very High	Very High	Very High

Table 12.3 – Receptor Sensitivity Descriptors Relevant to Marine Physical and Sediment Processes, and Marine Water Quality

Rating	Descriptor
Very High	♦ Environment is in a natural condition with no evidence of modification; all environmental benchmarks are met. ♦ Environment supports physical properties or processes that are considered rare or exceptional at a regional scale.
High	♦ Environment is in a near-natural condition with minimal human-induced modification; most environmental benchmarks are met. ♦ Environment supports physical properties that are considered rare or exceptional at a local scale, but well represented regionally.
Medium	♦ Environment is in a near-natural condition with some human-induced modification; most environmental benchmarks are met. ♦ Environment supports physical properties or processes that are well represented at the local scale and experience low inter-decadal variability from extreme events (e.g., cyclones, floods).
Low	♦ Environment is moderately degraded compared to equivalent areas or as measured by environmental benchmarks. ♦ Environment supports physical properties or processes that are resilient to change, experiencing extreme natural events (e.g., cyclones, floods) every few years.
Minimal	♦ Environment is highly degraded compared to equivalent areas or as measured by environmental benchmarks. ♦ Environment supports physical properties or processes that are very resilient to change, experiencing extreme natural events (e.g., cyclones, floods) every year.

Table 12.4 – Impact Significance Matrix Relevant to Marine Physical and Sediment Processes, and Marine Water Quality

Magnitude of Impact	Sensitivity of Receptor				
	Very High	High	Medium	Low	Minimal
Very High	Severe	Major	Major	Moderate	Moderate
High	Major	Major	Moderate	Moderate	Minor
Medium	Major	Moderate	Moderate	Minor	Minor
Low	Moderate	Moderate	Minor	Minor	Negligible
Minimal	Minor	Minor	Negligible	Negligible	Negligible

A final pipeline alignment has not been decided in Caution Bay. The pipeline alignment will be finalized during the Project's front-end engineering design phase. For this impact assessment, two indicative alignments were modeled in Caution Bay with one to the south of the PNG LNG Gas Pipeline (base case) and the other to the north (alternative case). LNG facilities inside the PNG LNG Plant lease boundary are excluded from the scope of this EIS, and the modeling in this EIS presents indicative information that will be refined as part of the downstream Papua LNG EIS.

The scenarios modeled for each shore crossing location and alignment were:

Orokolo Bay

- Base case alignment – northwest monsoon season.
- Base case alignment – southeast trade winds season.

Caution Bay

- Base case (southern) alignment – northwest monsoon season.
- Base case (southern) alignment – southeast trade winds season.
- Alternative case (northern) alignment – northwest monsoon season.
- Alternative case (northern) alignment – southeast trade winds season.

The Project has yet to determine the trenching method or method for dredge material management. It was assumed for the modeling and the impact assessment that a cutter suction dredge will be used. It is possible that a backhoe dredge may be used instead, but a cutter suction dredge would likely cause a higher plume release rate and therefore represents a conservative scenario.

It was estimated that trenching at both Orokolo Bay and Caution Bay would take less than five days (i.e., 4.75 days for Orokolo Bay and 1 to 2 days for Caution Bay), based on standard production rates for cutter suction dredges. When modeling, it was assumed that trenching would occur to -15 m lowest astronomical tide (LAT) and be completed in one week at each location; however, trenching is now planned to -20 m LAT. Other than the additional time required, this updated scenario does not significantly change the assessment of impacts to marine physical and sediment processes or marine biodiversity.

Modeling assumed that all the dredged material, discharged either in the water column or on the seabed, is subject to water current and wave-induced resuspension processes, which were explicitly modeled to provide conservatism to the impact assessments

The modeling outputs focused on identifying the impacts of sediment disturbed by the trenching, including sediment directly disturbed from the seafloor and sediment-laden water in the cutter suction dredge overflow. These impacts were measured as:

- Total suspended solids concentrations (mg/L) in water affected by the sediment disturbance, averaged over the depth of the water column.
- Extent of the area of TSS-affected water (the plume). The plume boundaries are based on different TSS thresholds, with the outer boundary identified to be the point at which the TSS concentration is less than 5 mg/L. As described in Section 12.3, a median TSS concentration of 5 mg/L is considered to be the threshold for moderate ecological impacts. Total suspended solids concentrations below this threshold are also considered non-discernible compared to the natural variability of background conditions.
- Extent of the area in which sediment disturbed by the trenching will deposit (i.e., the deposition extent). The deposition extent boundaries were identified to be the point at which deposition was below 200 mg/cm^2 (threshold for zone of influence described in Section 12.3) Both Orokolo Bay and Caution Bay experience frequent reworking of sediment and deposition from wave action. As such, deposition rates below 200 mg/cm^2 are considered unlikely to adversely affect sensitive receptors such as seagrass and coral, as rates below this threshold are considered to be within the range of natural variability and tolerance limits for these receptors (Erftemeijer et al., 2012).

12.1.3 Identification of Potential Impacts

Potential impacts to marine physical and sediment processes can be avoided or minimized through Project design which is based on a risk-management approach, considering geotechnical constraints (e.g., flooding, landslides risks, geohazards) and anticipating and avoiding, or where avoidance is not possible, minimizing environmental and social impacts (e.g., avoidance of sensitive features, physical and economic displacement, priority ecosystem services, and minimization of project footprint, land clearing and disturbance, emissions and discharges) [ED013]. Specific embedded design controls are identified throughout this section where they address potential impacts.

12.1.3.1 Changes to Hydrodynamic and Morphological Processes

Pipeline Installation

The offshore export pipelines are not anticipated to alter hydrodynamic and morphological processes for the following reasons:

- At the shore crossing in Orokolo Bay, if sheet piling is used, sheet piles installed during pipeline trenching will be cut off between 0.5 and 1 m below the seabed following pipeline installation, resulting in no net change to coastal land or intertidal seabed levels. The physical presence of sheet piles will alter hydrodynamic conditions, i.e., patterns of physical forcing in the water such as currents and wave action, in a limited area in the shallow waters of Orokolo Bay during pipeline installation; however, these changed conditions will be highly temporary (i.e., weeks) and are expected to have insignificant impacts on coastal processes, i.e., patterns of coastal change, including sediment transport and deposition or scouring.[3]
- The offshore pipeline will be buried with a 1 m cover depth to the top when located in water shallower than 20 m [ED041]; therefore, there will be no net change to seabed levels and hence no change to hydrodynamic and morphological processes. The burial depth is also sufficient so that scour will not expose pipelines.

On this basis, no hydrodynamic and morphological impacts are expected due to pipeline excavation and burial, and this is not assessed further.

12.1.3.2 Sediment Mobilization

Pipeline Installation

Trenching for nearshore pipeline installation will mobilize sediment through the following processes:

- Direct physical disturbance of the seabed by the dredge.
- Discharge of sediment-laden overflow from the dredge, if a cutter suction dredge is used.

Sediments disturbed by trenching and overflow will be transported by waves and currents, and will eventually settle onto the seafloor. Deposited sediment may be available for subsequent resuspension by currents and waves.

Trenching activities will be undertaken in Orokolo and Caution bays. Impacts due to sediment mobilization may differ at each site due to differences in hydrodynamic and sediment processes.

3 There is insufficient existing data to determine potential bed load transport rates from unusual events such as a significant storm. There is some uncertainty around the potential for sheetpiles to become exposed from such events in the long term (i.e., beyond the life of the Project); however, it is unlikely since this area is a prograding rather than an erosional environment, as discussed in Section 8.2.

Vessel Use

Vessels to be used by the Project include:

- Barges, which will be used to transport construction equipment, large plant and supplies to PRL-15 via the gulf, and the Purari River and its distributaries. The highest barge traffic numbers will occur during the construction phase.
- Pipelaying and support vessels, which will operate along the entire offshore export pipeline route. This vessel activity will occur during the construction phase.
- Trenching and support vessels, which will operate in waters up to -20 m LAT in Orokolo Bay and Caution Bay, and transiting to and from these areas. This will occur during the construction phase.

Propeller wash, anchoring and wake from these vessels can disturb the seabed and shoreline. Considering the environment and depths in which most work will occur, propeller wash and vessel wake are unlikely to cause any significant disturbance. The pipelaying vessel may cause some wash impacts, i.e., displacement of bed sediment, in the pipelaying footprint but these will be negligible compared to disturbance associated with the pipe trenching. Seabed disturbance from anchoring will also be minimal as the pipelaying vessel will use a dynamic positioning system (i.e., using propellers and thrusters rather than anchors) and the anchoring from other support vessels will be limited, occurring infrequently, being extremely localized and of negligible magnitude; therefore, impacts of vessel use on sedimentation and physical processes are not considered further. The potential scour impacts from vessels in the Purari River are discussed in Chapter 11.

12.1.3.3 Summary of Potential Impacts to Marine Physical and Sediment Processes

Potential impacts to marine physical and sediment processes due to the Project that have been considered in the residual impact assessment are as follows:

- Increased suspended sediment concentrations in the water column due to nearshore trenching for the pipeline.
- Increased sedimentation on the seabed due to nearshore trenching for the pipeline.

The residual risks of increases in suspended sediment and sedimentation occurring due to trenching are assessed in Section 12.1.5. The impacts on sensitive receptors, such as coral reef, seagrass and marine fauna, due to such increases in suspended sediment and sedimentation are specifically addressed in the marine biodiversity impact assessment in Section 12.3.

12.1.4 Proposed Mitigation and Management Measures

Table 12.5 describes mitigation and management measures manage to sediment mobilization during trenching. Mitigation and management in Caution Bay in the lease area for the PNG LNG project will be further aligned with the PNG LNG project and the downstream Papua LNG project.

Table 12.5 – Marine Physical and Sediment Processes Mitigation Strategies and Management Plans

Potential Impact	Mitigation Strategy	Relevant Management Plan
Sediment mobilization from trenching causing an increase in suspended sediment in the water column and sedimentation on the seabed.	♦ Where required, implement adaptive management to minimize dredging impacts on sensitive habitats and species [EM037].	Water Management Plan

12.1.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to marine physical and sediment processes subject to the embedded design controls in Section 12.1.3 and the successful implementation of the mitigation and management measures in Section 12.1.4. A summary of the residual impact assessments is provided at the end of this section, including when and where (in which Project phase and location) these impacts are expected to occur.

12.1.5.1 Sediment Mobilization

The mitigation strategies for sediment mobilization relate to adapting trenching activities to respond to excessive sediment disturbance and generation. While this adaptive management approach may reduce the total impact compared to the pre-mitigation modeled scenario, the residual impact assessment presented below assumes no change in modeled concentrations or extents of plumes and sediment deposition, and therefore represents a conservative assessment.

Impacts are discussed for Orokolo Bay and Caution Bay based on: (i) plume impacts (combining plume concentration and plume extent results); and (ii) deposition impacts (focusing on the extent of deposition).

Orokolo Bay

Numerical modeling was undertaken to predict changes to: (i) TSS concentrations; and (ii) final net sediment deposition depth, from the proposed trenching works in Orokolo Bay (and Caution Bay). Refer to Part 4 of Volume 3 for details on the modeling.

Increase in Suspended Sediment in the Water Column

Plots of the predicted increase in 50th and 95th percentile TSS concentrations due to trenching during the northwest monsoon season and southeast trade winds season are shown in Figures 12.1 and 12.2, respectively. These concentrations are depth-averaged, i.e., average over the full depth of the water column, increments in concentration over background levels. The 50th percentile (i.e., median) concentration occurs 50% of the time and is therefore considered to represent typical conditions. The 95th percentile concentration, which is exceeded only 5% of the time, is considered to represent a short-term peak concentration.

During the northwest monsoon season, the plume from trenching generally extends in a southeasterly direction, with the typical 50th percentile concentration up to about 5 mg/L. The short-term peak increment in TSS (95th percentile) is up to approximately 100 mg/L within 500 m of trenching, but decreases to less than approximately 25 mg/L within 2 km. These peak concentrations are predicted to occur over a total period of five to six hours during a 4.75-day dredge campaign.

Similar impacts are predicted during the southeast trade winds season, except that the plume extends in a westerly direction.

These increases in median TSS concentrations represent a minimal increase above background levels in this area of Orokolo Bay (measured in the area to be 1 to 2 mg/L during the northwest monsoon season, and between 2 and 9 mg/L during the southeast trade wind season; as represented by results for sites M4, M8 and M12 described in Part 11 of Volume 2) and will be limited in duration and extent. The short-term peak increment in TSS also represents a localized impact of two to three hours. The magnitude of impact is therefore categorized to be ***Low***. Orokolo Bay in the area to be trenched has a ***Low*** sensitivity of sediment processes, as this area is relatively undisturbed but regularly receives high fluvial suspended sediment loads from the Purari and Vailala rivers. Combining these, the residual impact significance is ***Minor***.

DEPTH-AVERAGED TSS INCREASE IN OROKOLO BAY DURING NORTHWEST MONSOON SEASON

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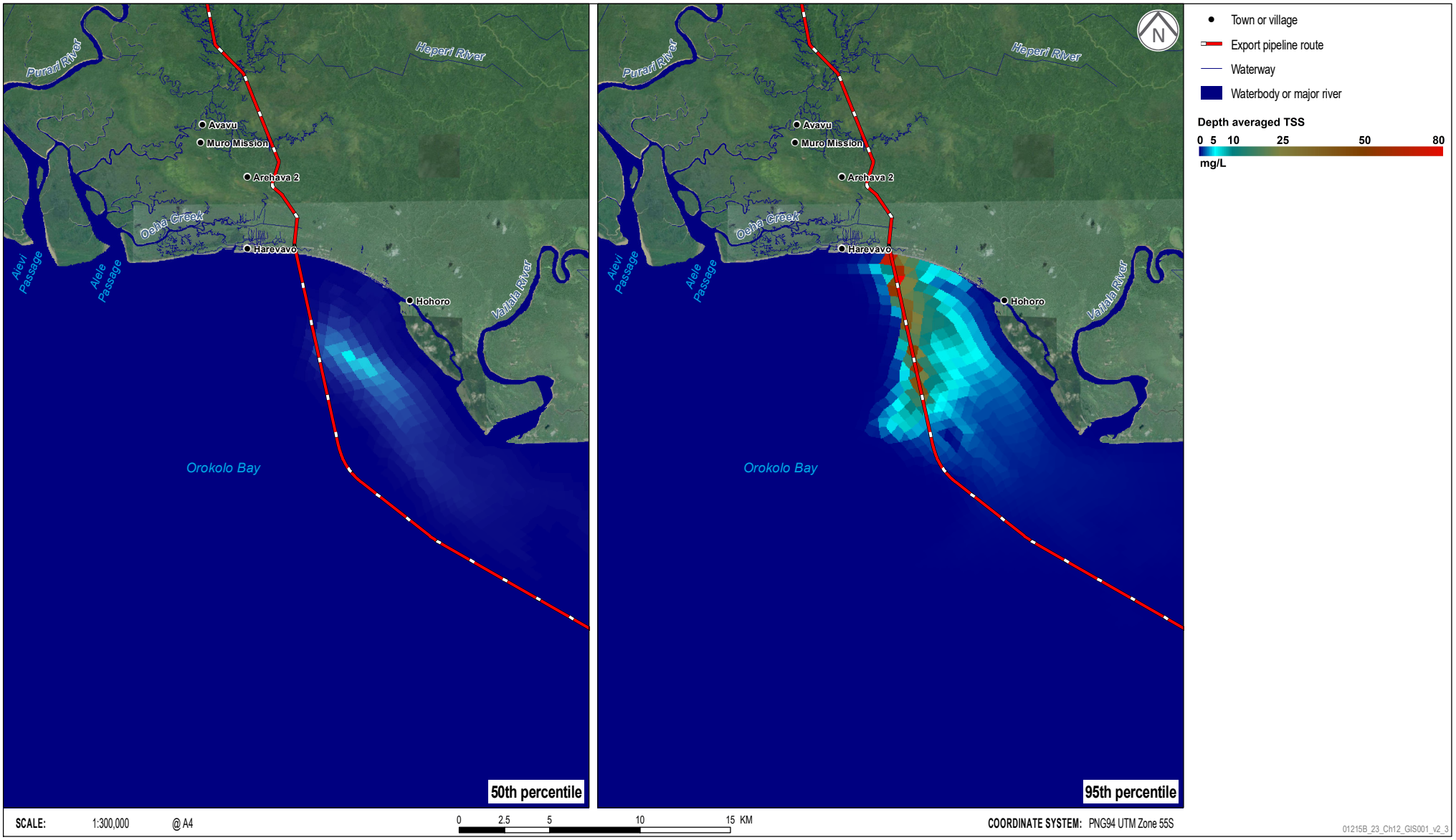
FIGURE 12.1



Source: Figure theme data from Part 4 of Volume 3.

DEPTH-AVERAGED TSS INCREASE IN OROKOLO BAY DURING SOUTHEAST TRADE WINDS SEASON

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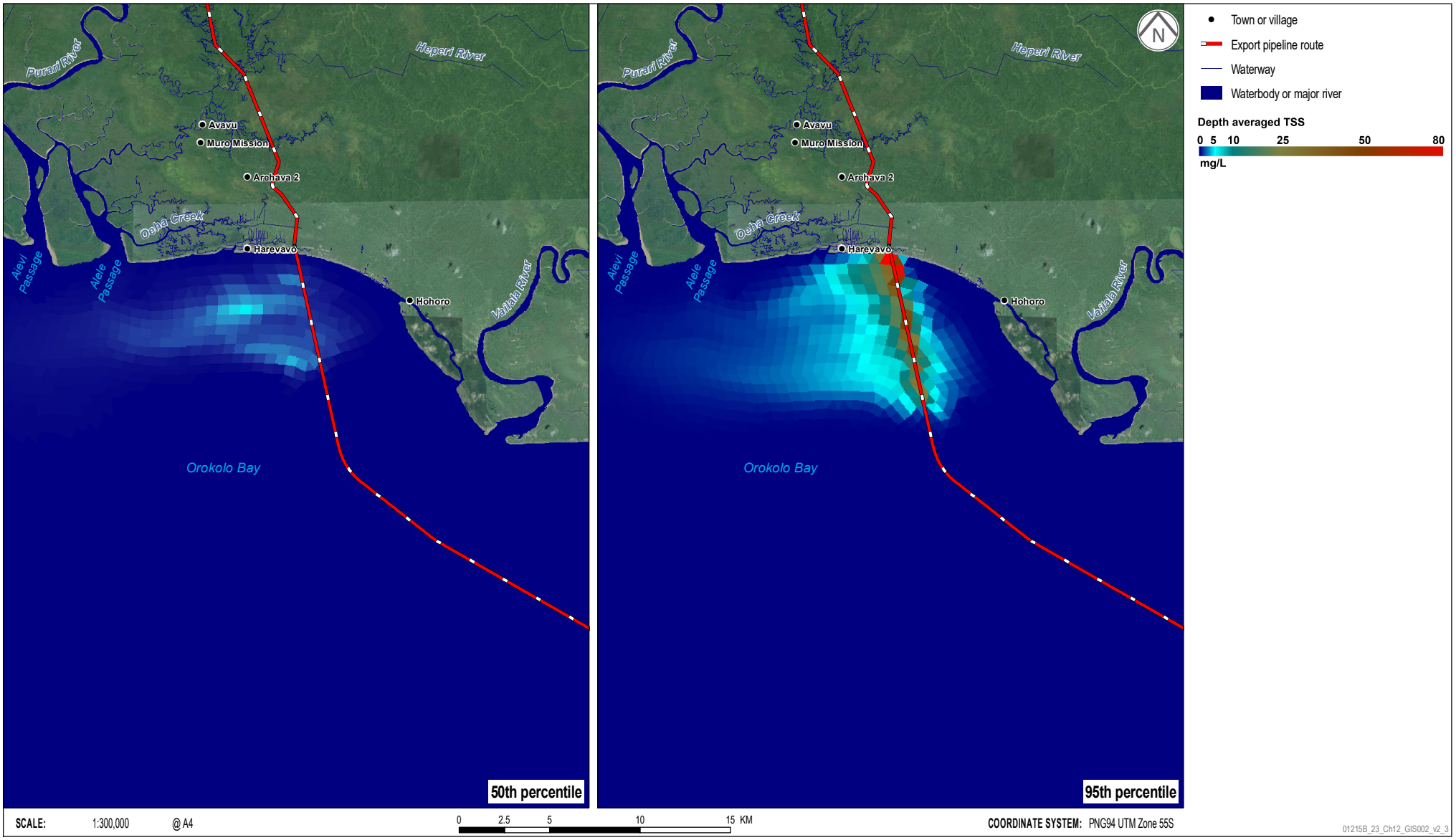
FIGURE 12.2



Source: Figure theme data from Part 4 of Volume 3.

Increased Sedimentation on the Seabed

Final net sediment deposition depths for trenching occurring during the northwest monsoon season and southeast trade winds season are shown in Figure 12.3.

The modeled deposition extent above 200 mg/cm^2 is limited to within 500 m of the trenching during both the northwest monsoon and the southeast trade winds seasons. The model resolution for this deposition assessment uses a 500 m cell (i.e., all deposition occurs in the first cell of the model); hence the extent of deposition may be less. Maximum final sediment deposition rates for both seasons are 2,000 to 4,000 mg/cm^2 (Figure 12.3) in the deposition area. Sedimentation rates are negligible further than 500 m from the pipeline alignment.

Inshore sediments of Orokolo Bay are frequently re-worked by waves generated from the southeast trade winds, and deposits or high points of sediment will be rapidly remobilized and distributed over the sea floor. The geographic extent of impact will therefore be localized. The severity of impact will be within natural variability, considering the high fluvial inputs of sediment from the Purari and Vailala rivers, providing an overall impact magnitude rating of ***Low***. As described above, Orokolo Bay, in the area to be trenched, has a ***Low*** sensitivity with regard to sediment processes; therefore, the residual impact significance is assessed as ***Minor***.

Caution Bay

As indicated earlier, LNG facilities inside the PNG LNG Plant lease boundary are excluded from the scope of this EIS, the related indicative information presented here will be refined as part of the downstream Papua LNG EIS.

Increase in Suspended Sediment in the Water Column

Plots of the predicted increase in 50th and 95th percentile TSS concentrations due to trenching during the northwest monsoon season and southeast trade winds season for the southern alignment scenario are shown in Figures 12.4 and 12.5, respectively. Plots for the alternative northern alignment scenario are shown in Figure 12.6 (northwest monsoon season) and Figure 12.7 (southeast trade winds season).

During the northwest monsoon season, the increases in median TSS concentrations in Caution Bay due to trenching are predicted to be 0.3 mg/L along the southern alignment and 0.6 mg/L along the northern alignment. During the southeast trade winds season, the increases in median TSS concentrations are slightly higher, with 1.7 and 4.5 mg/L expected for the southern and northern alignments, respectively. This relatively low level of suspended sediment is due to the high amount of sand expected in the material to be trenched. In the northwest monsoon season, this low-concentration plume extends south to Haidana Island due to the prevailing wind direction and resuspension associated with the wave climate. Within the southeast trade winds season, it remains contained in Caution Bay.

In comparison to these predicted increases, median TSS concentrations measured during baseline studies were less than 1 mg/L during the northwest monsoon season, and between 4 and 5 mg/L during the southeast trade winds season (see Part 11 of Volume 2). The predicted increase in the median TSS concentration from trenching represents a minimal increase in absolute TSS concentrations that will be short-term and of limited extent. A short-term peak increment in TSS concentration (i.e., 95th percentile concentration) of up to approximately 80 mg/L occurs; however, this is localized within 500 m of both pipeline alignments during both seasons. The magnitude of impact is therefore categorized to be ***Low.*** The Caution Bay marine environment is considered to have ***Medium*** sensitivity. The residual impact significance is therefore assessed to be ***Minor***.

FINAL NET DEPOSITION OF SEDIMENT MOBILIZED FROM TRENCHING IN OROKOLO BAY

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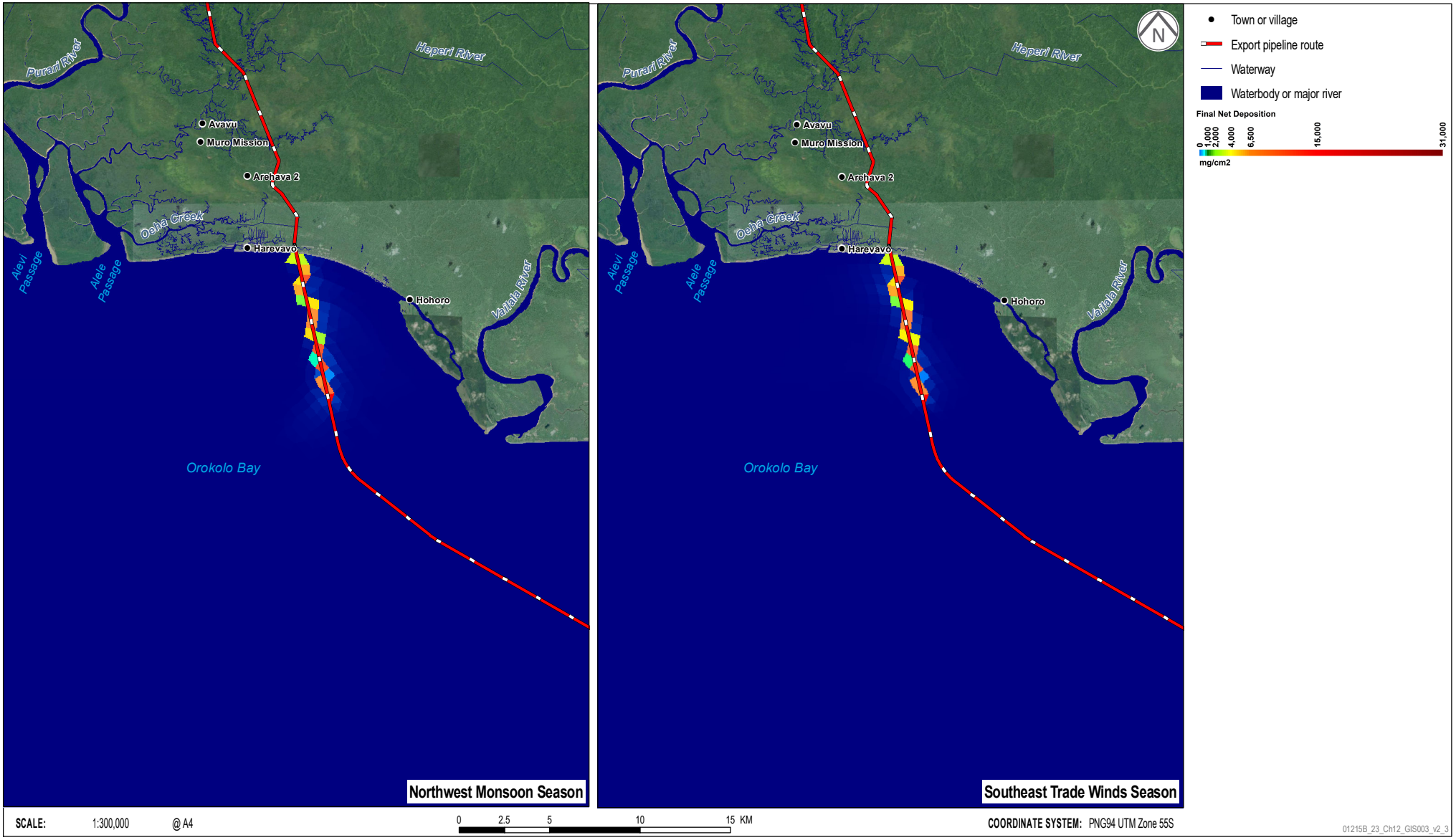
FIGURE 12.3



Source: Figure theme data from Part 4 of Volume 3.

INDICATIVE DEPTH-AVERAGED TSS INCREASE IN CAUTION BAY DURING NORTHWEST MONSOON SEASON - SOUTHERN ALIGNMENT

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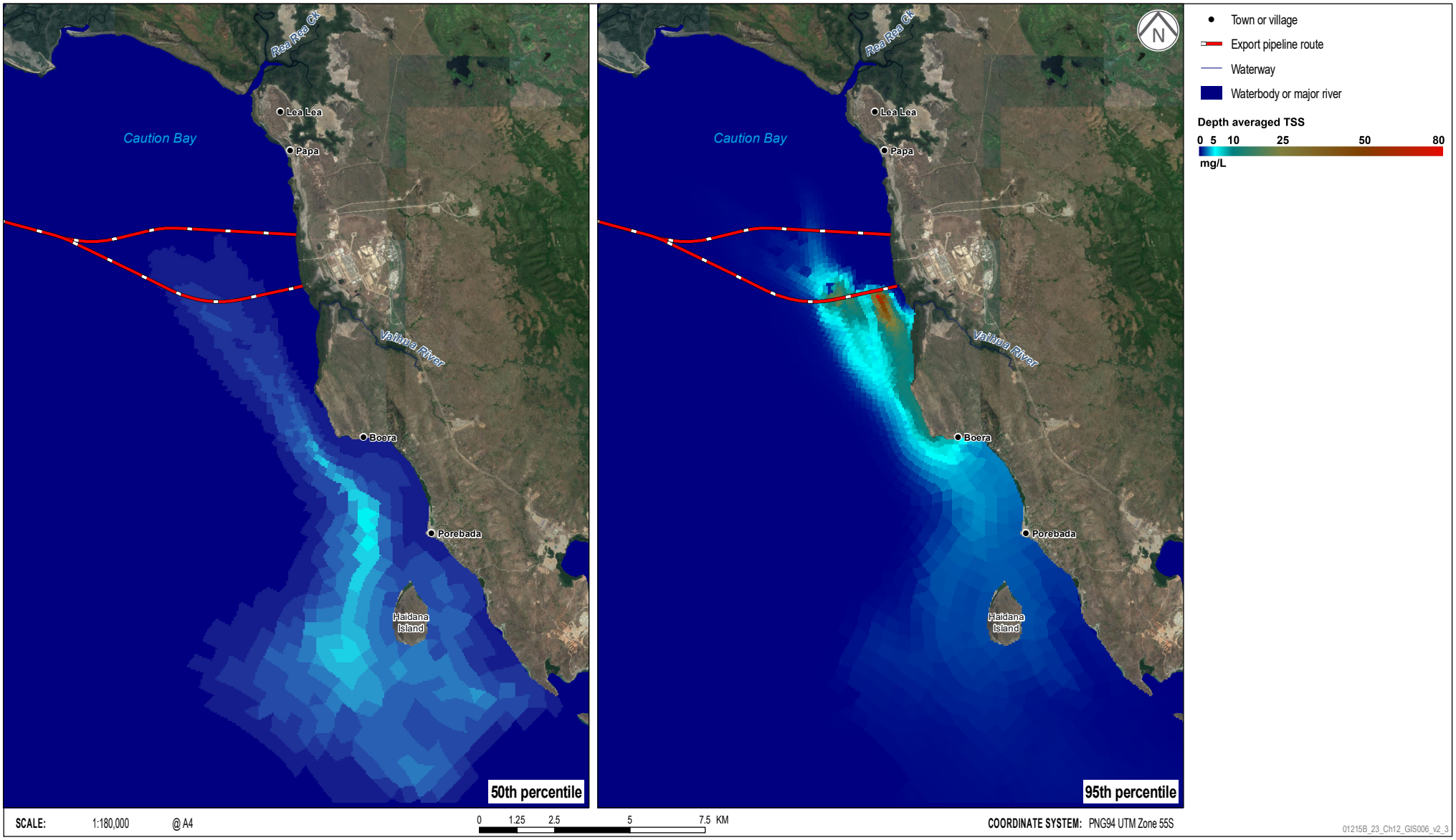
FIGURE 12.4



Source: Figure theme data from Part 4 of Volume 3.

INDICATIVE DEPTH-AVERAGED TSS INCREASE IN CAUTION BAY DURING SOUTHEAST TRADE WINDS SEASON - SOUTHERN ALIGNMENT

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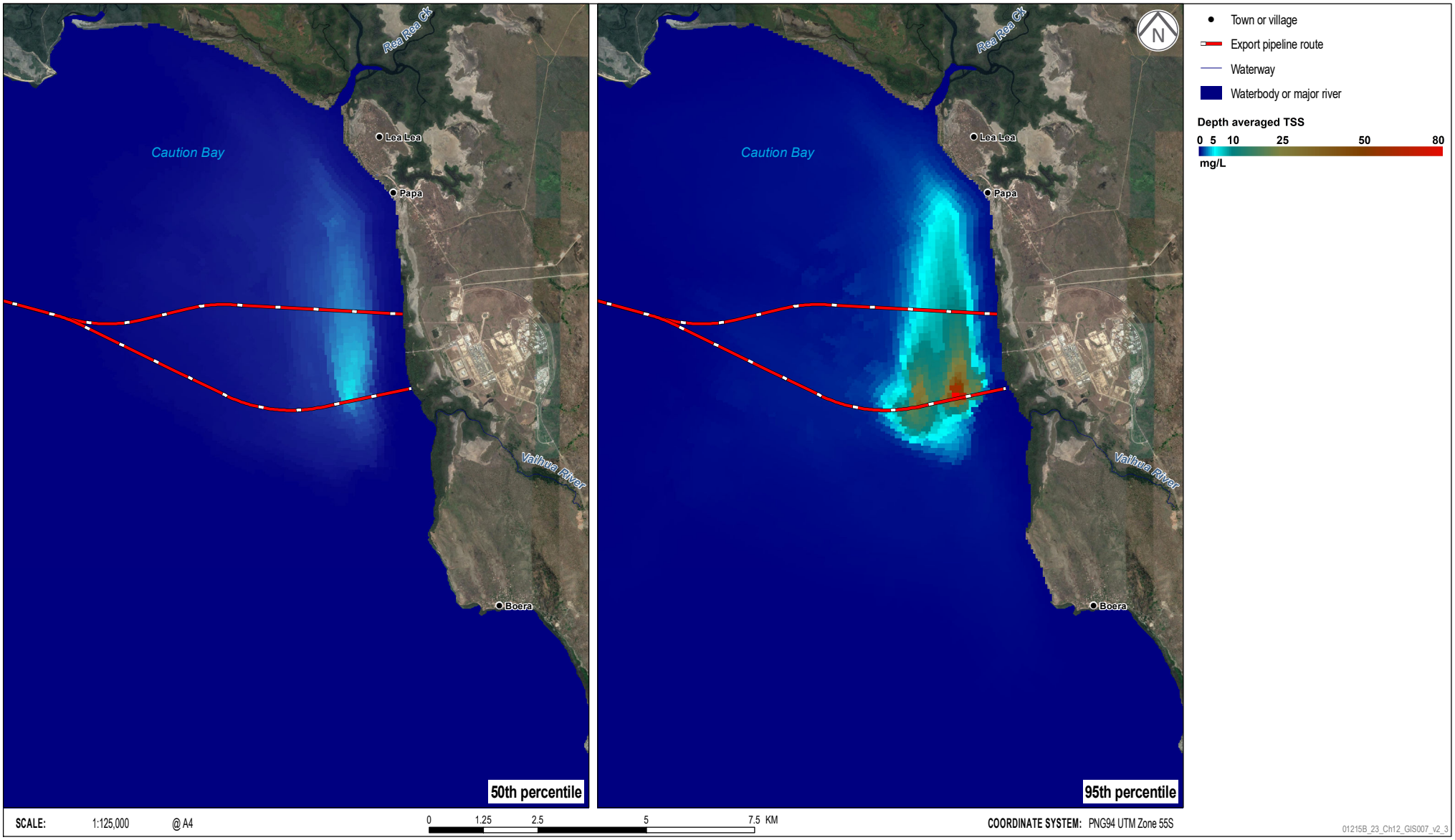
FIGURE 12.5



Source: Figure theme data from Part 4 of Volume 3.

INDICATIVE DEPTH-AVERAGED TSS INCREASE IN CAUTION BAY DURING NORTHWEST MONSOON SEASON - NORTHERN ALIGNMENT

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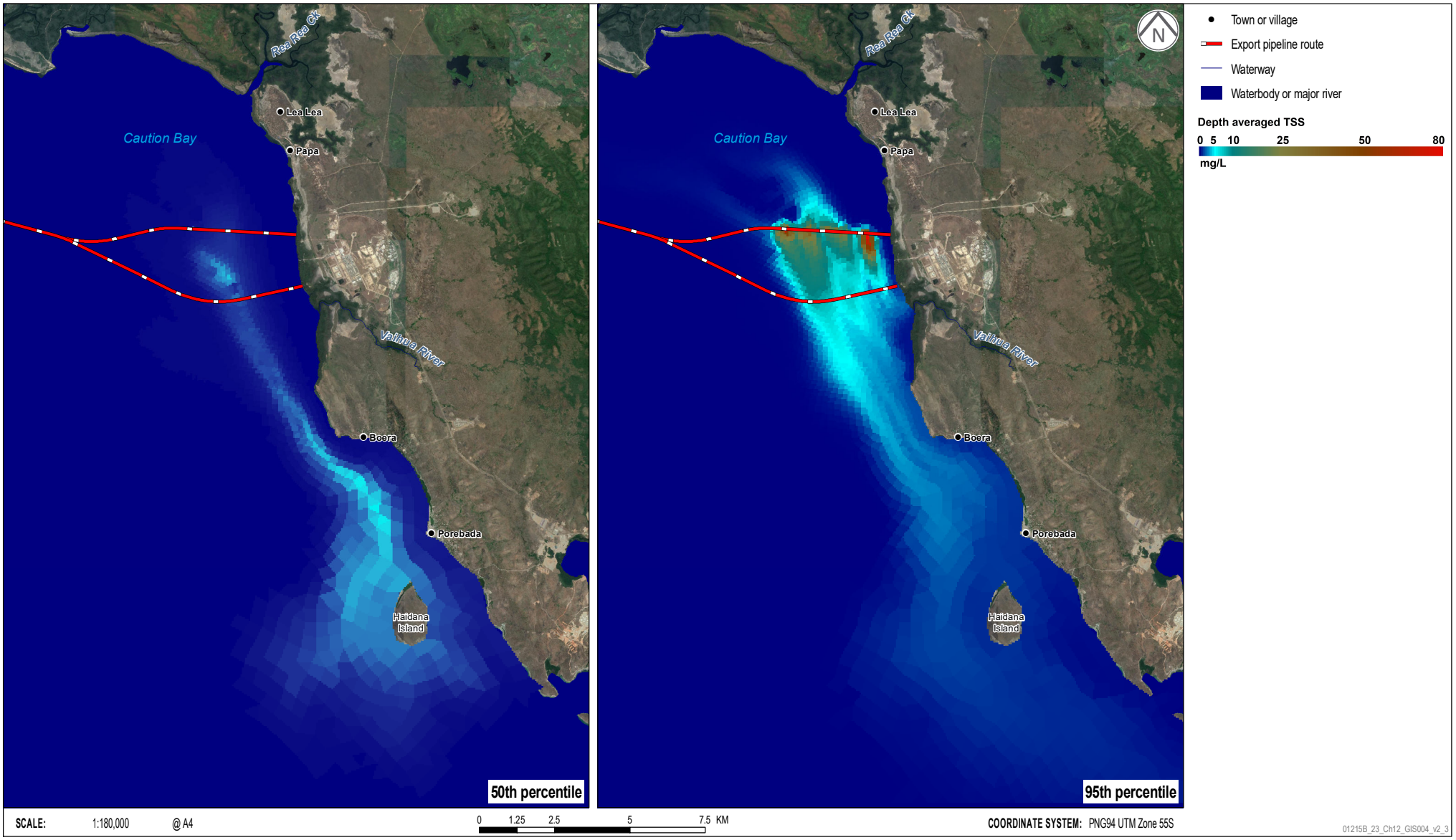
FIGURE 12.6



Source: Figure theme data from Part 4 of Volume 3.

INDICATIVE DEPTH-AVERAGED TSS INCREASE IN CAUTION BAY DURING SOUTHEAST TRADE WINDS SEASON - NORTHERN ALIGNMENT

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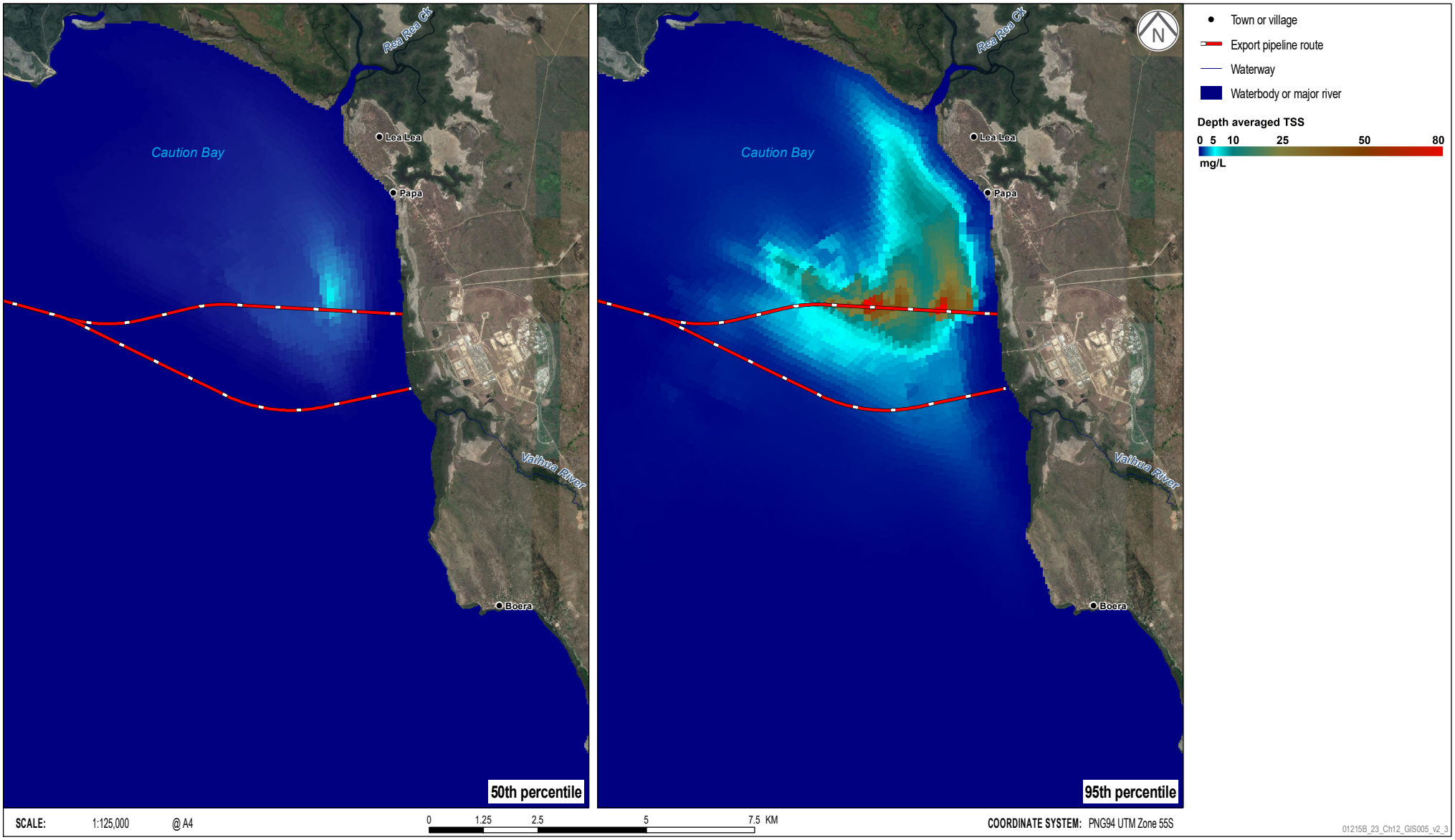
FIGURE 12.7



Source: Figure theme data from Part 4 of Volume 3.

Increased Sedimentation on the Seabed

The extent of sediment deposition above 200 mg/cm^2 is predicted to be limited to within 500 m of the trenching for both pipeline alignments, as shown in Figures 12.8 (southern alignment) and 12.9 (northern alignment). Within 500 m of trenching activities, sedimentation rates are predicted to reach a peak of over 15,000 mg/cm^2 for both alignments in both seasons. As wave action naturally and rapidly reworks sediment, these modeled peak deposition rates are considered conservative, with the associated volume of sediment spread across a wider area, within the deposition extent. Outside of this higher impact area, the sediment rates rapidly attenuate to below 200 mg/cm^2.

Impacts to benthic communities in the localized area of sediment deposition may occur for up to five years, during which period wave action will rework and redistribute the deposited sediment. Environmental values would be supported in a slightly to moderately modified condition. The magnitude of impact is therefore categorized to be ***Low.***

The Caution Bay benthic environment is considered to have ***Medium*** sensitivity, based on existing levels of disturbance, with some fringing and nearshore reefs observed to be in poor condition due to fishing practices and suspension of sediment from strong winds and waves (see Section 8.5.2). The residual impact significance is therefore assessed to be ***Minor***.

12.1.6 Summary of Residual Impacts to Marine Physical and Sediment Processes

A summary of the residual impact assessment of marine physical and sediment processes is provided in Table 12.6, including in which Project phase and location these impacts are expected to occur. The table should be read in conjunction with the mitigation measures provided in Table 12.5.

Residual impacts are assessed to be ***Minor***.

INDICATIVE FINAL NET DEPOSITION OF SEDIMENT MOBILIZED FROM TRENCHING OF CAUTION BAY - SOUTHERN ALIGNMENT

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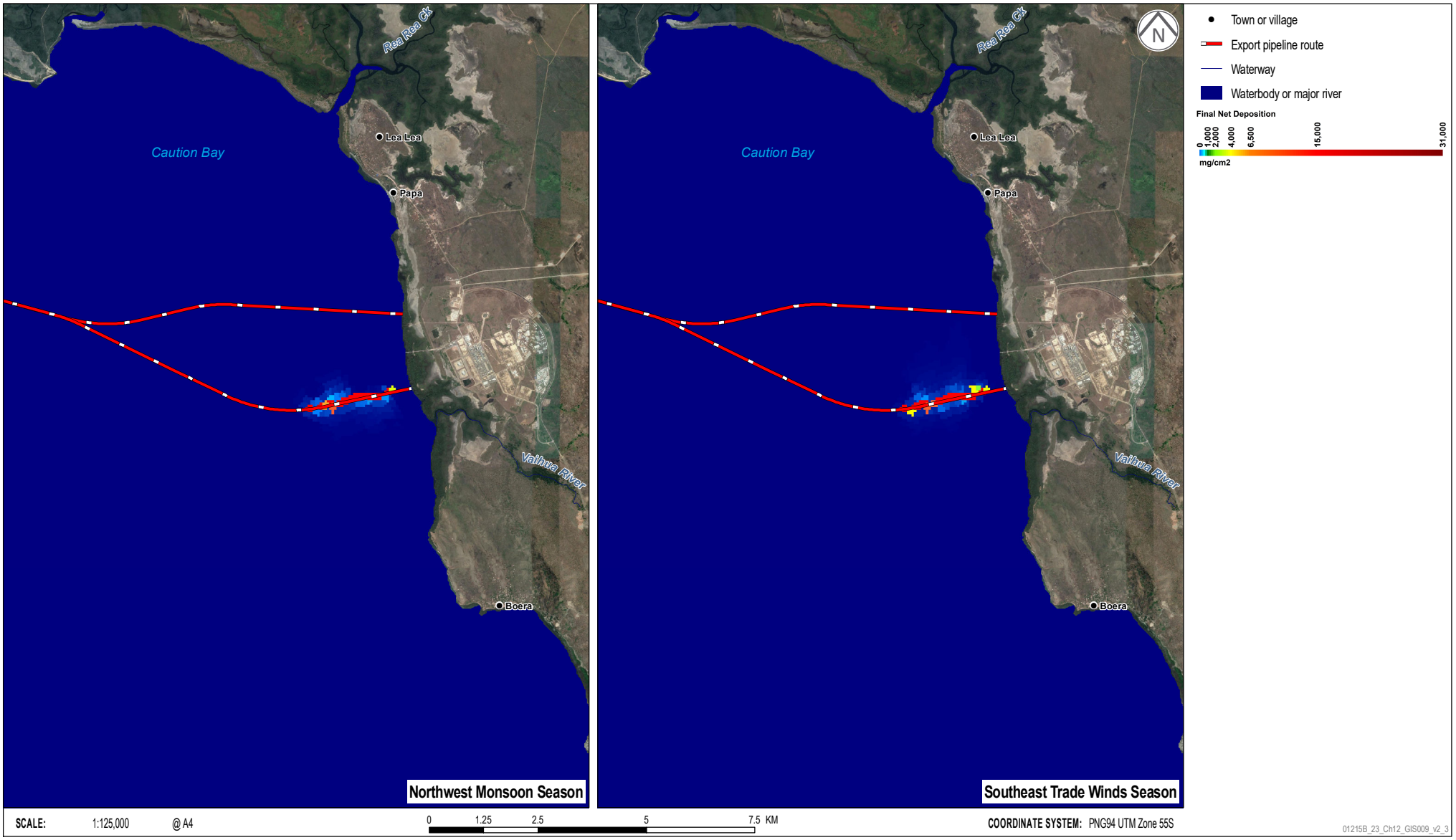
FIGURE 12.8



Source: Figure theme data from Part 4 of Volume 3.

INDICATIVE FINAL NET DEPOSITION OF SEDIMENT MOBILIZED FROM TRENCHING OF CAUTION BAY - NORTHERN ALIGNMENT

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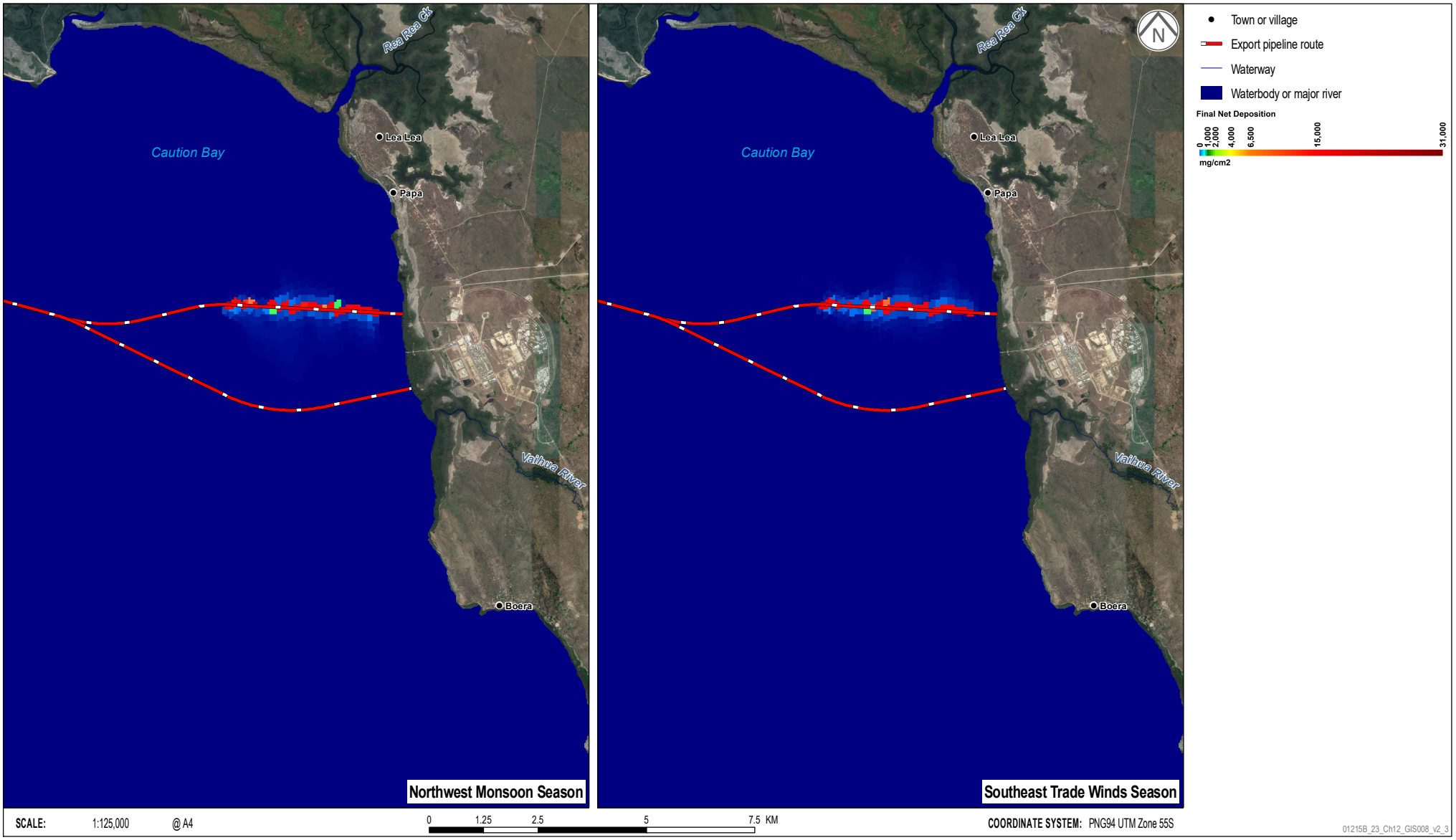
FIGURE 12.9



Source: Figure theme data from Part 4 of Volume 3.

Table 12.6 – Summary of Assessment of Residual Impact Significance – Marine Physical and Sediment Processes

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/Magnitude	Significance
Mobilization of sediments	Offshore pipeline construction – trenching for the pipeline in Orokolo and Caution bays	Increased suspended sediment concentrations in the water column.	Orokolo Bay	C	♦ EM037	Low/Low	Minor
			Caution Bay	C		Medium/Low	Minor
		Increased sedimentation on the seabed.	Orokolo Bay	C		Low/Low	Minor
			Caution Bay	C		Medium/Low	Minor

C = Construction, O = Operations, D = Decommissioning and closure.

12.2 Marine Water Quality

This section considers potential contamination of marine water quality resulting from planned discharges and accidental releases of hydrocarbons or chemicals. Impacts on marine water quality due to increased levels of suspended sediment due to Project activities are described in Section 12.1. Associated impacts on sensitive receptors, i.e., marine fauna, due to deterioration of water quality are specifically addressed in the marine biodiversity impact assessment In Section 12.3.

12.2.1 Context

The marine waters of the PAOI are in a largely undisturbed condition; however, there are several existing sources of potential water quality contamination, including:

- Commercial shipping activities, which are potential sources of sewage and hydrocarbons. The PNG LNG Facilities in Caution Bay are the main shipping area in the marine PAOI. Major shipping lanes exist through the marine PAOI.
- Small craft (potential source of sewage and hydrocarbons), especially fishing vessels.
- Stormwater runoff and point source discharges, as occur in Caution Bay.
- Inputs from rivers and streams.

Despite these existing potential sources of contamination in the PAOI, ambient nutrient, metal, metalloid and hydrocarbon concentrations all meet water quality guidelines for the protection of aquatic ecosystems (see Section 8.4).

12.2.2 Discipline-specific Impact Assessment Method

The significance assessment approach described in Chapter 3 was used to characterize impacts to marine water quality. The magnitude and sensitivity descriptors used to assess impacts to marine water quality are the same as used for the assessment of impacts to marine physical and sediment processes (see Section 12.1.2).

Consideration was also given to the following standards and guidelines, as relevant to water quality:

- *Papua New Guinea Environment (Water Quality Criteria) Regulation 2002 (Water Quality Regulation),* applicable to ambient waters for the protection of aquatic ecosystems.
- Emission limit values for discharge water quality provided by:
  - TOTAL General Specifications, Environmental Requirements for Projects Design and E&P Activities (GS EP ENV 001).
  - International Finance Corporation Environmental, Health and Safety guidelines (IFC, 2007, 2015).
  - International Convention for the Prevention of Pollution from Ships 1973, as amended by the Protocol of 1978 (MARPOL 73/78).

12.2.3 Identification of Potential Impacts

Potential impacts to marine water quality processes can be avoided or minimized through Project design which is based on a risk-management approach, considering geotechnical constraints (e.g., flooding, landslides risks, geohazards) and anticipating and avoiding, or where avoidance is not possible, minimizing environmental and social impacts (e.g., avoidance of sensitive features, physical and economic displacement, priority ecosystem services, and minimization of project

footprint, land clearing and disturbance, emissions and discharges) [ED013]. Specific embedded design controls are identified throughout this section where they address potential impacts.

12.2.3.1 Planned Wastewater Discharges

Planned discharges to the marine waters of the PAOI have the potential to contaminate marine waters. Controlled Project-related discharges to the marine environment may include:

- Hydrotest waters.
- Sewage, grey water, ballast and bilge discharges from Project vessels.

As described in Section 4.10.6, pipeline hydrotesting will be undertaken to confirm the weld integrity following pipeline installation. Hydrotest water will contain a small amount of an oxygen scavenger, such as sodium bisulfite, to inhibit corrosion, and a biocide to prevent bacteria developing.

The hydrotest water discharge location will be defined during FEED and options may include the Purari River, Orokolo Bay or Caution Bay. The total volume of the offshore export pipelines is 220,000 m^3 and the hydrotest water volume will be similar to the pipeline volume. The hydrotest water discharge rate will depend on the dewatering train capacity but would typically be 15 to 23 m^3/minute. Consequently, discharge could take six to ten days from one or more discharge lines. Discharge will be undertaken according to applicable requirements.

Project vessels will discharge ballast waters, domestic wastewaters (i.e., sewage and grey water) and bilge waters. These wastewater discharges may contain elevated nutrient levels, which can degrade the water quality of receiving waters. Sewage discharges may also contain pathogens including *Escherichia coli* (*E. coli*), Salmonella and fecal coliforms. Bilge waters can be expected to contain high hydrocarbon concentrations.

The following embedded design controls address these potential impacts:

- Chemical use will be minimized, and selection of chemicals will be made considering lowest toxicity, lowest bioaccumulation potential, highest biodegradation and bans or phase-outs [ED006].
- Ballast waters, liquid effluents and waste from vessels will be managed according to MARPOL 73/78 requirements [ED022].

12.2.3.2 Accidental Contaminant Releases

The assessment relates only to spills or leaks that are typically incidental (but controllable) as part of construction and operation of large projects. Major accidental spills from unplanned events (e.g., bunker rupture from vessel collisions or groundings, or pipeline rupture) are considered in Chapter 18.

Hydraulic fluids, lubricants, oil, petrol, diesel and miscellaneous chemicals will be used in the Project construction and operation phases and could be accidentally spilt or leaked into the marine environment from Project vessels, e.g., during vessel refueling. The volumes of such spills are typically small, particularly in the context of the large dilution factor of the marine environment.

Condensate or gas leaks may also potentially occur if there are faulty joins in the offshore export pipeline. The potential for such leaks to occur will be avoided by the hydrotesting that will be undertaken prior to commissioning the pipeline.

Contaminants released from accidental releases have the potential to degrade water quality, with the potential for environmental harm dependent on various factors including:

- Contaminant type and volume.
- Sensitivities of the receiving environment, with nearshore environments containing coral, mangroves, seagrass and other high value habitats being more sensitive than open waters remote from sensitive receptors.
- The dispersal characteristics of the receiving waters.

Aside from accidental leaks from the offshore export pipeline, spills and leaks are more likely to occur during the construction phase rather than the operations phase, as larger volumes of equipment and materials will be used and more activities will occur in the marine environment during this phase.

The following embedded design controls address these impacts:

- Minimization of chemical use and selection of chemicals considering lowest toxicity, lowest bioaccumulation potential, highest biodegradation and bans or phase-outs [ED006].
- Adopt standard industry practices to prevent and protect against soil/water contamination, due to Project activities, such as:
  - Preparing hydrocarbon and chemical management procedures, as part of the Hazardous Materials Management Plan.
  - Building infrastructure on impervious surfaces where required
  - Providing permanent fuel and chemical stores, and maintenance and refueling areas with secondary containment of an appropriate volume to prevent loss to the environment or mixing with incompatible materials.
  - Installing interceptor pits or similar to collect contaminated surface water runoff and treat where required.
  - Installing tanks above ground with impermeable liners and bunds around tanks.
  - Regularly inspect and maintain the containers, storage and transfer infrastructure to prevent/control spills or leaks.
  - Installing readily accessible spill kits and training staff in their use.
  - Appropriately treating and disposing of any accidentally contaminated soils. [ED003].
- Management of ballast waters, liquid effluents and waste from vessels according to MARPOL 73/78 requirements [ED022].
- The gathering and reinjection system, wells and export pipeline system will be routinely inspected, monitored and maintained, as part of operational controls (including pipeline instrumented pigging, well wellbore and reservoir pressure monitoring) [ED011].
- Hydrotesting will be undertaken to confirm weld integrity [ED012].

12.2.3.3 Summary of Potential Impacts to Marine Water Quality

Potential impacts on marine water quality due to Project activities that have been considered in the residual impact assessment are as follows:

- Deterioration in marine water quality due to planned wastewater discharges, including hydrotest water, domestic wastewater and bilge water.
- Deterioration in marine water quality due to accidental releases of hydrocarbons and chemicals.

12.2.4 Proposed Mitigation and Management Measures

Table 12.7 describes mitigation and management measures to further reduce impacts marine water quality from planned wastewater discharges and accidental contaminant releases. Mitigation and management in Caution Bay in the lease area for the PNG LNG Project will be further aligned with the PNG LNG Project and the downstream Papua LNG Project.

Table 12.7 – Marine Water Quality Mitigation Strategies and Management Plans

Potential Impact	Mitigation Strategy	Relevant Management Plan
Deterioration in marine water quality due to planned wastewater discharges	♦ Sewage effluents from Project facilities will be treated to meet the environment (waste discharge) permit before discharge, in accordance with applicable standards. [EM008]. ♦ Hydrotest water management will consider: – The definition of volume and discharge rates and discharge locations. – Chemical additive selection, according to requirements defined in embedded design controls. – Reusing hydrotest water to minimize the discharge volume. – Reducing the need for chemicals by minimizing the time hydrotest water remains in the pipeline. – Monitoring hydrotest water discharges to the environment against applicable limits. [EM015]	Water Management Plan
Deterioration in marine water quality due to accidental releases of hydrocarbons and chemicals	♦ An Emergency Response Plan will be developed to effectively manage the preparedness and response to emergency events. It will contain: – Site Contingency Plans, that will consider fire management measures – An Oil Spill Contingency Plan, that will consider spill risks for construction, operation and decommissioning of facilities and associated infrastructure, and supply services on land and in aquatic and marine environments. – A Blow Out Contingency Plan including well blowout control and contingency measures [EM018]. ♦ Vessels will be required to have shipboard Oil Pollution Emergency Plans/Oil Spill Contingency Plans as per TOTAL requirements and *Marine Pollution (Ships and Installations) Act 2013* [EM019].	Emergency Response Plan

12.2.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to marine water quality subject to the embedded design controls in Section 12.2.3 and the successful implementation of the mitigation and management measures in Section 12.2.4. A summary of the residual impact assessments is provided at the end of this section, including when and where (in which Project phase and location) these impacts are expected to occur.

12.2.5.1 Planned Discharges of Wastewaters

Hydrotest waters discharges will be monitored and managed according to applicable limits. Rapid dispersion of discharges would occur given the large assimilative capacity of the open waters of the gulf. The magnitude of any impact to water quality is therefore expected to be ***Minimal***, with minor impacts occurring over a localized area (i.e., up to 500 m) for a short duration and the aquatic ecosystem health is maintained.

The marine waters of the PAOI are considered to have a ***Medium*** sensitivity since; although, they are in a near-natural condition with environmental benchmarks met (e.g., complying with water quality criteria in *Papua New Guinea Environment (Water Quality Criteria) Regulation 2002 (Water Quality Regulation),* it is an environment that is well represented in the broader gulf and there is large assimilative capacity with regard to water quality. The residual impact significance is therefore ***Negligible.***

12.2.5.2 Accidental Releases

In the unlikely event that accidental spills do occur, impacts are likely to be localized due to low contaminant volumes typically released by incidental spills and leaks. Impacts to water quality are expected to be short-term (i.e., days to weeks) after applying appropriate spill prevention, containment and cleanup measures; however, the severity of the impacts to water quality may be moderate depending on the nature of the contaminant, having slight to moderate impacts on the environmental values of the impacted area. The magnitude of impact is therefore considered to be ***Low.***

Hydrotesting, monitoring and maintaining the offshore export pipelines will limit the occurrence and extent of any condensate or gas leaks. The condensate is hydrophobic, lighter than water and has high volatility, and therefore can be expected to diffuse and disperse up through the water column to evaporate into the atmosphere. Any gas leaks would also evolve to the atmosphere. Impacts to water quality are expected to be minor if a leak from a pipeline join was to occur, extending over a highly localized area and for a short period (much less than a year). The magnitude of impact from such leaks is therefore also considered to be ***Low.***

As described in Section 12.2.5.1, the marine waters of the PAOI are considered to have a ***Medium*** sensitivity; hence the residual impact significance for impacts on marine water quality due to accidental releases of contaminants is ***Minor.***

12.2.6 Summary of Residual Impacts to Marine Water Quality

A summary of the assessment of residual impacts related to marine water quality is provided in Table 12.8, including in which Project phase and location these impacts are expected to occur. The table should be read with the mitigation measures provided in Table 12.7.

Residual impacts to marine water quality due to planned wastewater discharges and accidental contaminant releases from Project activities are assessed to be ***Negligible*** or ***Minor.***

Table 12.8 – Summary of Assessment of Residual Impact Significance for Marine Water Quality

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Planned wastewater discharges	Controlled discharges of hydrotest water, vessel domestic wastewater and bilge water.	Deterioration in marine water quality	Orokolo Bay, offshore export pipeline route and Caution Bay	C, O	♦ EM008 ♦ EM015	Medium/Minimal	Negligible
Accidental releases of hydrocarbons and chemicals	Spill or leak of hydrocarbons and chemicals from vessels.	Deterioration in marine water quality	Orokolo Bay, offshore export pipeline route and Caution Bay	C, O, D	♦ EM018 ♦ EM019	Medium/Low	Minor
	Leaks of condensate or gas from pipeline joins.	Deterioration in marine water quality	Orokolo Bay, offshore export pipeline route and Caution Bay	O	None	Medium/Low	Minor

C = Construction, O = Operations, D = Decommissioning and closure.

12.3 Marine Biodiversity

12.3.1 Context

The marine PAOI includes several marine ecosystem types and habitats. In order of largest to smallest spatial extent, these are:

- Pelagic (open water) environments.
- Unconsolidated sediment habitat (i.e., beach, nearshore coastal and offshore).
- Coral and rocky reefs.
- Seagrass meadows.

Most of the PAOI consists of unconsolidated soft sediment habitat comprising muds and sands. This includes most of Orokolo Bay and the offshore export pipeline route. Water depths extend to 100 m. Deeper offshore waters associated with the continental shelf provide pelagic habitat for oceanic fauna species.

There is a single rocky reef identified at Orokolo Bay, south of the Vailala River mouth. This reef supports a mixed assemblage of filter-feeding soft corals, sponges, ascidians and echinoderm species that are exposed to periodic high turbidity and low salinity conditions.

Coral reefs occur in Caution Bay. Reef types represented in Caution Bay are: (i) barrier reefs between Vari Vari and Idihi islands; (ii) fringing reefs which extend along the coast; and (iii) smaller patch reefs and atolls between the barrier reef and coast. The barrier reefs have higher coral cover than nearshore (fringing) reefs and are in an undisturbed condition (i.e., there is no evidence of anthropogenic impacts or natural disturbance). The most abundant hard coral genera for these reefs are *Acropora*, *Montipora* and *Porites*. Human disturbances, particularly fishing practices that use explosives, have adversely affected fringing reefs; however, they appear to be recovering, which is attributed to a reduction in these fishing practices.

Seagrass meadows occur in Caution Bay between the fringing reef and shoreline, and comprise *Enhalus acoroides*, *Syringodium isoetifolium* and *Cymodocea* spp. A large but sparse seagrass meadow also occurs in the northern embayment of the bay (east of Redscar Head), comprising *Halophila* spp.

The Caution Bay coastline has a strip of mangroves extending 7 km along the coast and up to 1 km wide, in the vicinity of the PNG LNG Facilities.

The PAOI supports habitat for a wide variety of marine and estuarine fauna species, including several sensitive marine species, i.e., threatened species, near threatened species, species of high fisheries significance or other listed species under Papua New Guinean legislation or the IUCN Red List.

Orokolo Bay supports the narrow sawfish (*Anoxypristis cuspidata*) which has been identified recently (based on villager catch), and other species (e.g., threatened sawfish and river shark species) may also occur there. Positive sighting of other fish species in this area include the Endangered winghead shark (*Eusphyra blochii*) and the endemic Papua seerfish (*Scomberomorus multiradiatus*), both known from the catches of Orokolo Bay villagers. Additionally, Orokolo Bay may support other threatened shark and ray species (e.g., *Carcharhinus leucas*, *Hemiscyllium hallstromi*, *Glaucostegus typus*, *Aetobatus narinari*, *Epinephelus fuscoguttatus*, *Scomberomorus commerson*). The migratory saltwater crocodile (*Crocodylus porosus*) is known to occur in the Purari River and is likely to be present in Orokolo Bay.

Coastal and oceanic shark and fish species are also likely to occur in Caution Bay, with the Near Threatened hardnose shark (*Carcharhinus macloti*) confirmed during Project baseline surveys. The seagrass and coral reef habitat in Caution Bay may also support threatened marine turtle species (*Chelonia mydas*, *Caretta caretta*, *Eretmochelys imbricata*, *Lepidochelys olivacea*, *Natator depressus*), the Vulnerable reef manta ray (*Manta alfredi*) and the Near Threatened guinea's sea krait (*Laticauda guineai*), although none of these species have been confirmed to be present. The most likely of the marine turtles to occur in Caution Bay is the Vulnerable green turtle, with a mapped aggregation area located north of Caution Bay.

Dolphin species occur across the Gulf of Papua, including species known to occur in nearshore waters. The most likely species in the PAOI consist of the migratory but not threatened common bottlenose (*Tursiops truncatus*), Indo-Pacific bottlenose (*T. aduncus*), spinner (*Stenella longirostris*), pantropical spotted (*S. attenuata*) and short-beaked common (*Delphinus delphis*) dolphins, the Near Threatened Australian snubfin (*Orcaella heinsohni*) and vulnerable Australian humpback (*Sousa sahulensis*) dolphins. Dugongs (*Dugong dugon*) could possibly occur but are unlikely based on lack of recent sightings in the gulf.

Important fishery species in the PAOI include the ornate rock lobster (*Panulirus ornatus*) which is part of the tropical rock lobster fishery and a known migratory species. The rock lobster migrates from Torres Strait through the Gulf of Papua to breeding grounds at Yule Island located east of the offshore export pipeline route, approximately 75 km northwest of Caution Bay (see Figure 8.27).

Other significant fishery species include prawns which are commercially harvested by the Gulf of Papua Prawn Fishery. Prawn species include banana, tiger and endeavor prawns, which occur throughout the water column from nearshore to the edge of the continental shelf. These species rely on mangroves as nursery habitat. Based on historical fishing records, sea cucumbers (bêche-de-mer) are expected to occur in nearshore habitats at Orokolo Bay and Caution Bay, and include a variety of IUCN listed threatened species. Overfishing has led to closure of the commercial bêche-de-mer fishery.

All these species differ in their habitat requirements. Seagrass and coral reef habitats represent preferred high value habitat for many species of turtle, dolphins, dugong, rays, fish and snakes. Turbid waters near the coastline and mangroves of Orokolo Bay and the Purari River delta represent potential high value habitat for sawfish, river sharks and crocodiles. Soft sediment habitats and pelagic waters also represent habitat or fauna movement corridors for species (e.g., lobsters, mackerel and rays) that prefer reef and seagrass habitats.

Few invasive or introduced species have been documented in Papua New Guinea; however, many of the reef-associated species of northern Australia and the Great Barrier Reef are common to Papua New Guinea. Current marine pests of northern Australia include the Asian green mussel (*Perna viridis*) and Caribbean tubeworm (*Hydroides sanctaecrucis*). *Acanthaster planci* (crown-of-thorns seastar), although native to the Indo-Pacific reefs, can be considered an invasive species when in high abundance and can devastate coral reefs.

12.3.2 Discipline-specific Impact Assessment Method

The significance assessment approach described in Chapter 3 was used to characterize impacts to marine biodiversity. Magnitude and sensitivity descriptors used to assess impacts to marine biodiversity are presented in Table 12.9 to 12.11. The assessment is a function of the magnitude[4]

4 Magnitude is assessed considering combinations of (1) geographic extent and (2) the higher of severity and duration.

of impact on a resource or receptor and the sensitivity of that resource or receptor. Together, they determine the significance of the residual impact as shown Table 12.12.

The impact assessment assumes that the pipeline will be trenched at water depths less than 20 m below lowest astronomical tide (LAT)[5] and that the trench disturbance corridor will be 6 m wide. Assessment of impacts considers potential direct and indirect impacts to habitats and species.

Table 12.9 – Impact Magnitude Descriptors Relevant to Marine Biodiversity

Geographic Extent of Impact*		Severity and Duration of Impact		
			Severity	Duration
5	Impact to ♦ >15% of an ecosystem's or habitat type's range in the region; or ♦ >10% of a species' distribution in the subregion.	5	Impact to habitat, ecosystem or species that: ♦ Is very large or severe relative to natural variability; or ♦ Severely reduces ecosystem viability in the affected area; or ♦ Causes a significant change in the ecosystem community composition, including functional loss of keystone species and potentially leading to ecosystem collapse; or ♦ Causes a very large decline in a species population that threatens the viability of a subregional population and/or that may threaten the viability of the regional population.	Impact lasts >30 years
4	Impact to ♦ 5 to 15% of an ecosystem's or habitat type's range in the region; or ♦ 5 to 10% of a species' distribution in the subregion.	4	Impact to habitat, ecosystem or species that: ♦ Is large relative to natural variability; or ♦ Reduces ecosystem viability in the affected area; or ♦ Causes a loss or decline of multiple species populations that alters the composition and may reduce the viability of ecosystem communities or keystone populations; or ♦ Causes a large decline in a species population that may threaten the viability of a subregional population.	Impact lasts 5 to 30 years
3	Impact to: ♦ <5% of an ecosystem's or habitat type's range in a region; or ♦ 1 to 5% of a species' distribution in a subregion.	3	Impact to habitat, ecosystem or species that: ♦ Is moderate and readily detectable with respect to natural variability; or ♦ May reduce ecosystem viability in the affected area; or ♦ Causes a decline of multiple species populations, with moderate changes to community composition that is unlikely to reduce the viability of ecosystem communities or keystone populations; or ♦ Causes a moderate decline in the population of a species that is unlikely to threaten the viability of a subregional population.	Impact lasts <5 years
2	Impact to: ♦ <1% of a species' distribution in a subregion ♦ Any environmental feature in a localized area.	2	Impact to habitat, ecosystem or species that: ♦ Is low and marginally detectable with respect to natural variability, and readily able to regenerate on remaining habitat; or ♦ Causes a minor decline in one or more species populations; although with no detectable change in the composition or viability of ecosystem communities and populations; or ♦ Causes a minor decline that does not threaten the viability of a subregional population.	Impact lasts <1 year

5 Trenching to a water depth of -15 m LAT was adopted for sediment plume modeling studies to assess impacts due to trenching (see Section 12.1), based on information available during the modeling. The extension of trenching to a water depth of -20 m LAT is not expected to cause additional sedimentation impacts to high-value habitat such as seagrass and corals, as these are not found along this extended section of the alignment. The modeling outputs are considered sufficient to assess impacts due to sediment plumes and sedimentation due to trenching.

Table 12.9 – Impact Magnitude Descriptors Relevant to Marine Biodiversity (cont'd)

Geographic Extent of Impact*		Severity and Duration of Impact		
		Severity		Duration
1	Impact to any environmental feature in a highly localized area.	1	Impact to habitat, ecosystem or species that: ♦ Is very low and undetectable with respect to natural variability; or ♦ Causes no measurable decline in a species population.	Impact lasts days to weeks

Region = Area greater than 20,000 km^2 (being approximately 25% of the Gulf of Papua ecoregion (~75,000 km^2) and approximately 10% of the Southeast Papua New Guinea ecoregion (~225,000 km^2)).
Subregion = Area more than 2 km from the Project footprint but less than 20,000 km^2.
Localized = Area up to 2 km from the Project footprint.
Highly localized = Area up to 0.5 km from the Project footprint.

Table 12.10 – Impact Magnitude Matrix Relevant to Marine Biodiversity

Severity/ Duration	Geographic Extent				
	1	2	3	4	5
1	Minimal	Low	Medium	Medium	High
2	Low	Low	Medium	High	High
3	Low	Medium	High	Very High	Very High
4	Medium	Medium	High	Very High	Very High
5	Medium	Medium	Very High	Very High	Very High

Table 12.11 – Receptor Sensitivity Descriptors Relevant to Marine Biodiversity

Rating	Descriptor – Ecosystems and Habitats	Descriptor – Species
Very High	♦ Ecosystem or habitat supports IUCN Critically Endangered species (or equivalent based on expert opinion). ♦ Ecosystem or habitat is critical to the survival of a species. ♦ Ecosystem or habitat is unique or very rare locally and regionally.	♦ IUCN Critically Endangered species. ♦ Lower-listed IUCN species whose true conservation status is likely to be equivalent to IUCN Critically Endangered at the national or global scale, according to expert opinion. ♦ Endemic or restricted-range species with very low abundance in the area of occurrence.
High	♦ Ecosystem or habitat supports high or regionally important concentrations of conservation-listed species (or equivalent based on expert opinion) or endemic or restricted-range species. ♦ Ecosystem or habitat supports a unique assemblage or high proportion of habitat specialist species. ♦ Ecosystem or habitat is of local or regional importance for migratory species. ♦ Ecosystem or habitat is in a protected area. ♦ Ecosystem or habitat is unmodified. ♦ Ecosystem or habitat is rare locally and regionally with limited connectivity to comparable ecosystems or habitats.	♦ IUCN Vulnerable or Endangered species. ♦ Lower-listed IUCN species whose true conservation status is likely to be equivalent to IUCN Vulnerable or Endangered at the national or global scale, according to expert opinion. ♦ Endemic or restricted-range species with low abundance in the area of occurrence. ♦ Species that are highly adapted habitat specialists.
Medium	♦ Ecosystem or habitat supports viable assemblages of native flora and fauna species that are largely unaltered from their original composition; conservation-listed species may be present. ♦ Ecosystem or habitat has not been significantly modified in terms of primary ecological functions and composition.	♦ Species Protected under the *Fauna (Protection and Control) Act 1966.* ♦ CITES Appendix I species. ♦ IUCN Near Threatened species. ♦ IUCN Data Deficient, Not Evaluated or Least Concern species whose true conservation status is likely to be equivalent to IUCN Near

Table 12.11 – Receptor Sensitivity Descriptors Relevant to Marine Biodiversity (cont'd)

Rating	Descriptor – Ecosystems and Habitats	Descriptor – Species
Medium (cont'd)	♦ Ecosystem or habitat has several local and regional equivalents with some connectivity to comparable ecosystems or habitats.	Threatened at the national or global scale according to expert opinion. ♦ Endemic or restricted-range species with moderate to high abundance in the area of occurrence. ♦ Species that are habitat specialists but able to occur in other marginal habitats. ♦ Fish or macrocrustacean species of fisheries significance.
Low	♦ Ecosystem or habitat supports viable assemblages of some native species, but flora and fauna communities are significantly altered from their original composition found elsewhere locally; invasive species may be present. ♦ Ecosystem or habitat is subject to some degradation. ♦ Ecosystem or habitat is common locally and regionally with moderate connectivity to other comparable ecosystems or habitats.	♦ CITES Appendix II species. ♦ IUCN Least Concern species. ♦ IUCN Data Deficient or Not Evaluated species considered common or widespread according to expert opinion.
Minimal	♦ Ecosystem or habitat supports few or no native species, or invasive species are prevalent. ♦ Ecosystem or habitat is highly degraded. ♦ Ecosystem or habitat is common and widespread locally, regionally and nationally, and has high connectivity to other comparable ecosystems or habitats.	♦ Native species well adapted to habitat loss or degradation. ♦ Invasive species.

Table 12.12 – Impact Significance Assessment Matrix Relevant to Marine Biodiversity

Magnitude of Impact	Sensitivity of Receptor				
	Very High	**High**	**Medium**	**Low**	**Minimal**
Very High	Severe	Major	Major	Moderate	Moderate
High	Major	Major	Moderate	Moderate	Minor
Medium	Major	Moderate	Moderate	Minor	Minor
Low	Moderate	Moderate	Minor	Minor	Negligible
Minimal	Minor	Minor	Negligible	Negligible	Negligible

Areas of direct habitat loss or disturbance have been calculated based on mapped areas of sensitive receptor habitat, i.e., coral reef and seagrass. These sensitive habitat types are limited to Caution Bay in the PAOI. The offshore export pipeline route intersects several unsurveyed areas in Caution Bay. Any reefs in these areas have been excluded in calculations except where habitat can be inferred based on adjacent surveyed areas. LNG facilities inside the PNG LNG Plant lease boundary are excluded from the scope of this EIS, however indicative information is presented here; that will be refined as part of the downstream Papua LNG EIS.

The impact assessment also considers results from numerical modeling undertaken to predict increases in suspended sediment concentrations and sedimentation on the seabed due to the proposed trenching works (Section 12.1).

Ecological impacts associated with Project-generated TSS and sedimentation due to trenching were assessed using the outputs from the predictive numerical model to present impact predictions as 'zones of impact'. The 'zones of impact' approach is recognized as good international industry practice in dredging environmental assessments and is commonly used in

environmental assessments of dredging projects in Australia, based on approaches described in dredging environmental assessment guidelines produced by the Western Australia Environmental Protection Agency (WA EPA, 2016). This approach provides additional quantitative data to assess the geographic extent and severity of impacts according to the descriptors in Table 12.9.

The zones adopted for the assessment are illustrated in Figure 12.10 and include the following:

- Zone of high impact: Predicted mortality of ecological receptors with recovery time greater than 24 months.
- Zone of moderate impact: Predicted degradation, harm or injury to ecological receptors or mortality with recovery or recolonization between six months (lower end of range) to 24 months (upper end of range).
- Zone of influence: Extent of detectable[6] plume, but no predicted ecological impacts.

The recovery times outlined for the various zones should are indicative only; life history parameters and ecological responses to pressures are unknown for all species, making recovery times difficult to accurately predict.

Deriving the impact zones requires selecting thresholds related to the increase in TSS and sediment deposition due to trenching. TSS threshold values used in the impact assessment are based on thresholds developed for low turbidity offshore waters in Western Australia (DHI, 2010) and Queensland (AECOM and BMT WBM, 2016). These threshold values are presented in Tables 12.13 and 12.14.

Considering the short duration of the trenching campaign, the most appropriate thresholds for impact assessment are the median case (50th percentile) thresholds for the increase in TSS (as higher thresholds represent extremely short duration spikes) and the final sediment deposition case. These values are shown in bold in Tables 12.13 and 12.14.

Table 12.13 – Impact Thresholds for Total Suspended Solids

Impact Zone	Total Suspended Solids (mg/L) Thresholds Above Background			
	20th Percentile	50th Percentile	80th Percentile	95th Percentile
Zone of high impact	5	**10**	25	NA
Zone of moderate impact	2	**5**	10	NA
Zone of influence	NA	**1**	5	10

Note: Threshold values are based on thresholds developed for low turbidity offshore waters in Western Australia (DHI, 2010) and Queensland (AECOM and BMT WBM, 2016). Values are increases above background levels. NA: Not applicable; threshold is not reached for the length of time necessary to cause an impact.

6 Detectable plume means being detectable above background conditions by instrumentation deployed in the water column.

CONCEPT DESIGN OF IMPACT ZONES

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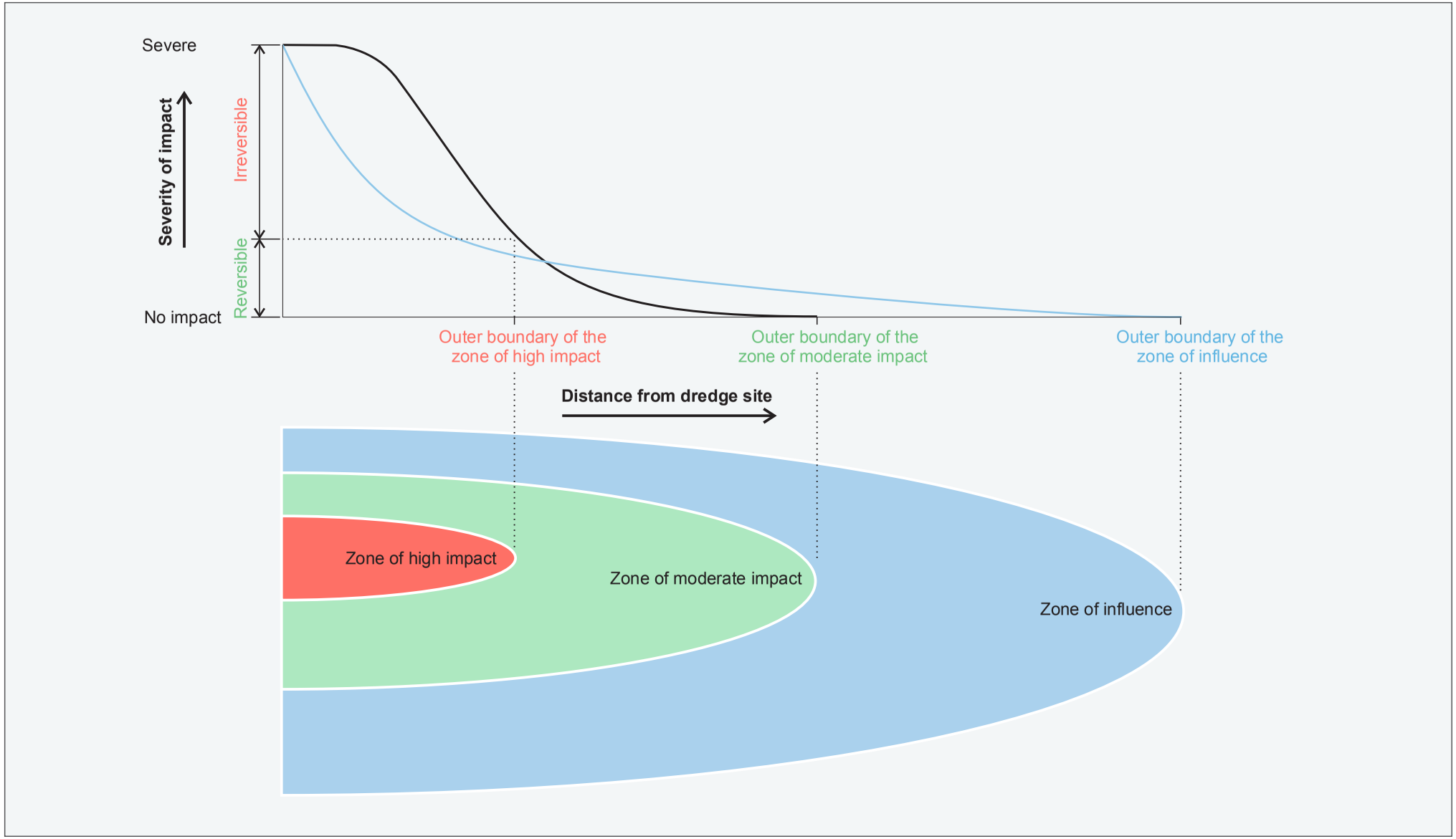
FIGURE 12.10



Source: WA EPA, 2016

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Table 12.14 – Impact Thresholds for Sediment Deposition

Impact Zone	50th Percentile i.e., 15 days per month ($mg/cm^2/day$)	95th Percentile i.e., 1.5 days per month ($mg/cm^2/day$)	Final Deposition (mg/cm^2)
Zone of high impact	>70	>700	**>700**
Zone of moderate impact	20 to 70	200 to 700	**200 to 700**
Zone of influence	3 to 20	30 to 200	**30 to 200**

Note: Threshold values are based on thresholds developed for low turbidity offshore waters in Western Australia (DHI, 2010) and Queensland (AECOM and BMT WBM, 2016). Values are increases above background levels.

12.3.3 Identification of Potential Impacts

Potential impacts to marine biodiversity can be avoided or minimized through Project design which is based on a risk-management approach, considering geotechnical constraints (e.g., flooding, landslides risks, geohazards) and anticipating and avoiding, or where avoidance is not possible, minimizing environmental and social impacts (e.g., avoidance of sensitive features, physical and economic displacement, priority ecosystem services, and minimization of project footprint, land clearing and disturbance, emissions and discharges) [ED013]. Specific embedded design controls are identified throughout this section where they address potential impacts.

12.3.3.1 Loss or Disturbance of Benthic Habitat and Marine Fauna from Trenching and Pipelaying

Benthic Habitat

Trenching and pipelaying will directly remove or bury benthic habitat. Figures 12.11 and 12.12 show the extent and location of benthic habitats directly disturbed by pipeline trenching in Orokolo Bay and Caution Bay, respectively. Habitats directly disturbed by trenching are soft sediments in Orokolo Bay and soft sediments, coral reef and seagrass meadows in Caution Bay. Caution Bay (Figure 12.12) benthic habitats are shown based on sidescan sonar transect readings, interpolated acoustic habitat mapping and historical nearshore habitat mapping (see Section 8.5). The actual extent of impacts due to removing or burying benthic habitat may differ slightly from mapped amounts for this area following more detailed survey of a finalized route. No changes to predicted impacts are expected in Orokolo Bay due to the absence of sensitive benthic habitats (i.e., seagrass and coral reef) in this area.

The areas of benthic habitat removal due to trenching are described in Table 12.15, based on a trench width of 6 m. Habitats directly disturbed by trenching are unconsolidated sediments in Orokolo Bay and unconsolidated sediments, coral reef and seagrass meadows in Caution Bay. Trenching is not proposed to occur in waters deeper than -20 m LAT, where the pipeline will be laid on the seafloor. Pipelaying in these waters deeper than -20 m LAT between Orokolo Bay and Caution Bay will also cause the direct loss of unconsolidated soft sediment habitat for benthic fauna in addition to that shown in Table 12.15, which considers habitat loss from trenching only. Losses of this habitat type will be the highest of all marine habitats found in the PAOI; however, this habitat type is also the most widespread in the PAOI and more broadly in the Gulf of Papua and is considered a low value habitat. The impact to unconsolidated soft sediment habitat due to pipelaying is therefore considered insignificant and is not further assessed in the residual risk assessment. The residual impacts to the high value seagrass and coral reef habitats, and marine fauna, are assessed in Section 12.3.5.

OROKOLO BAY PIPELINE ALIGNMENT AND AREAS OF DIRECT IMPACT

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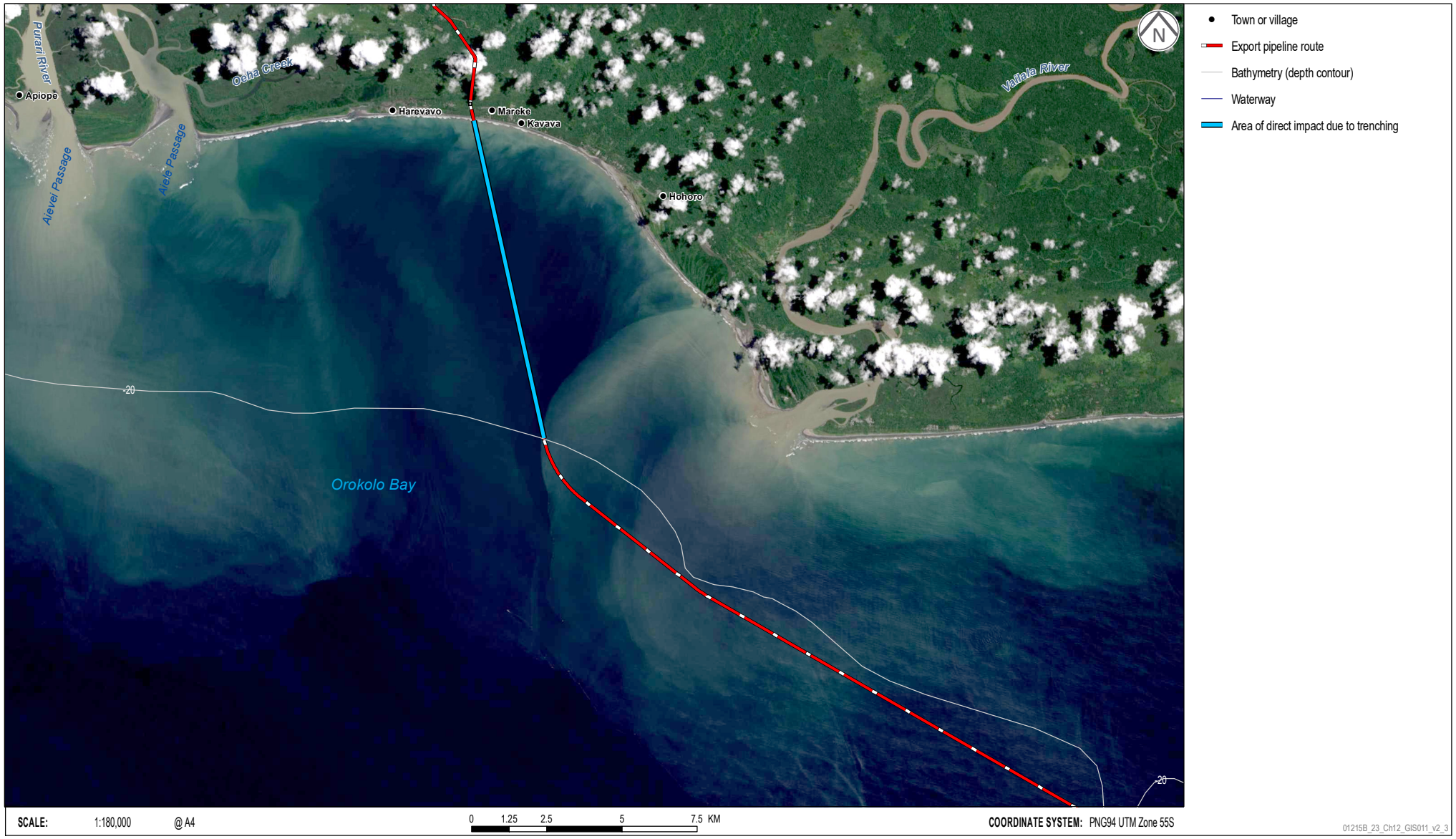
FIGURE 12.11



Source: Figure theme data from Part 4 of Volume 3.

CAUTION BAY PIPELINE ALIGNMENT AND AREAS OF DIRECT IMPACT

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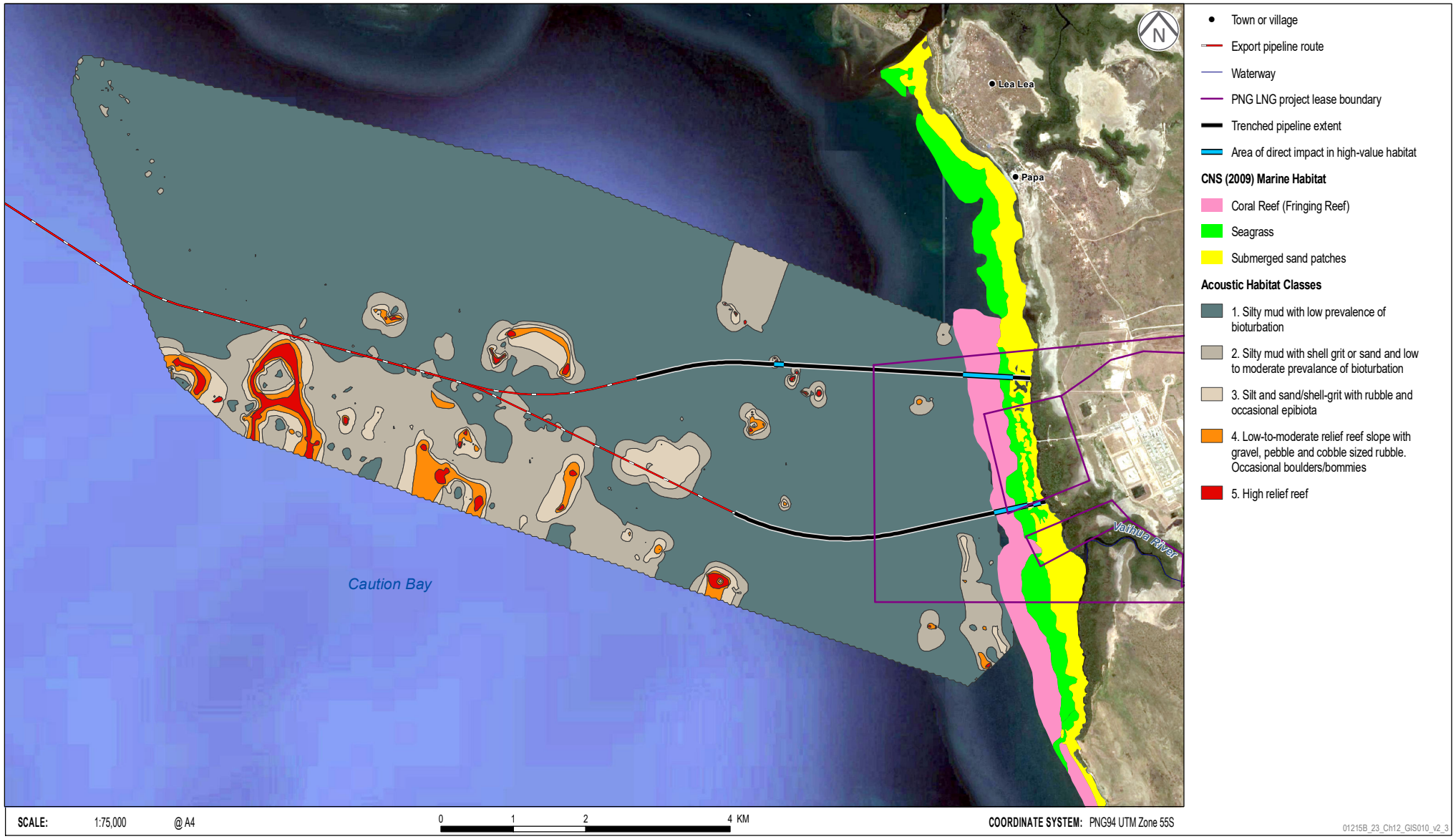
FIGURE 12.12



Source: Figure theme data from Part 4 of Volume 3.

Table 12.15 – Benthic Habitat Directly Removed by Trenching

Benthic Habitat Type	Orokolo Bay	Caution Bay	
		Southern Alignment	Northern Alignment
Seagrass (High-value Habitat)			
Linear distance (m)	0	300	200
Area of disturbance (m^2)	0	1,800	1,200
Total area of seagrass habitat in Caution Bay (m^2)	0	2,175,000	
Approximate loss of seagrass habitat in Caution Bay (%)	0	0.08	0.06
Coral Reef (High-value Habitat)			
Nearshore fringing reef linear distance (m)	0	280	500
Isolated bombora linear distance (m)	0	0	200
Area of coral reef disturbance (m^2)	0	1,680	4,200
Total area of coral reef habitat (fringing and bombora reefs) in Caution Bay (m^2)	0	5,140,000	
Approximate loss of coral reef habitat in Caution Bay (%)	0	0.03	0.08
Unconsolidated Sediment (Low-value Habitat)			
Seabed – linear distance (m)	10,800	3,820	4,600
Seabed – total area (m^2)	64,800	22,920	27,600
Approximate loss of unconsolidated sediment habitat (%)	<1	<1	<1
Total Habitat Loss (m^2)	**64,800**	**26,400**	**33,000**

Marine Fauna

Trenching will cause the mortality of small invertebrates such as mollusks, worms, and crustaceans living in or on the seabed. Trenching in Caution Bay is also likely to directly remove larger sessile invertebrates such as soft corals and sponges. Highly motile fauna such as fishes and mobile invertebrates, such as lobsters, are expected to be able to evade the dredge.

Indirect impacts may also potentially occur to other marine fauna, due to changes to benthic habitats and assemblages in the trenching footprint causing localized changes to food and habitat resource availability. These impacts could include increased feeding competition and associated health issues for species that depend on benthic fauna for feeding. The occurrence of flow-on effects to other fauna groups (e.g., fish, turtles and dugongs) largely depends on:

- The spatial scale of the impact relative to the total area of habitat available. The total extent of habitat removed is very small relative to the extent of available habitat, even at localized spatial scales (i.e., in Orokolo and Caution bays) (see Table 12.15). None of the affected areas are known or expected to support unique or otherwise critical food or habitat resources at a local scale, based on habitat assessments.
- Recovery timeframes for habitat and food resources. Soft sediment benthic fauna are expected to commence recovery within weeks (see case studies in Wilber and Clarke, 2007), while some seagrass species could take years to recover following disturbance (see Cabaco et al., 2008). Coral recolonization is expected to take five to 10 years (Erftemeijer et al., 2012).

Mobile fauna are predicted to temporarily avoid disturbed areas during the recovery period. This is expected to cause highly localized changes in foraging patterns until such times as benthic communities recolonize the disturbed area. It is highly unlikely that detectable flow-on effects to

local fauna populations outside the disturbance footprint will occur, given the small extent of habitat disturbance relative to available habitat.

Pipelines will be laid on the seafloor in waters deeper than -20 m LAT, directly smothering benthic fauna under the pipeline. It is expected that fish, sea turtles and other motile organisms would have the capacity to evade the pipeline. It is possible some motile benthic fauna could evade the pipeline placement, but it is expected that infauna directly in the pipeline footprint will be lost, with benthic fauna recovering within months for most benthic communities. This impact to benthic fauna from pipeline installation is considered insignificant given the widespread availability of similar habitats that support similar benthic faunal assemblages in the Gulf of Papua, and this impact is not further assessed in the residual impact assessment.

12.3.3.2 Pipeline Barrier to Marine Fauna Movements

Over time, the pipelines are expected to settle in areas of soft unconsolidated sediments, but the pipeline is likely to protrude above the seafloor up to a height of 40 inches, excluding the concrete collar. Benthic fauna are the species most likely to interact with the exposed pipeline.

The pipelines are not expected to affect fish, ray and sawfish movements, as they are strong swimmers.

Prawns migrate seasonally out of the Purari River delta into the coastal zone and subsequently out to the deeper waters of the continental shelf during the northwest monsoon season from December to March. Penaeid prawns are the primary species of this area and are known to be active swimmers (Zhang et al., 2006; Kenyon et al., 2004; Watson and Turnbull, 1993). The export pipeline route leaves the shoreline east of the Purari River delta perpendicular to the coast, and is therefore unlikely to present a barrier to prawns migrating from inshore waters to the deeper waters of the gulf. Additionally, these prawns are expected to swim over the pipeline if encountered. As such, the pipeline is unlikely to restrict prawn movements and is not considered further in the residual impact assessment.

The ornate rock lobster (*Panulirus ornatus*) regularly migrates from the Torres Strait through the Gulf of Papua to the Yule Island spawning grounds (see Section 8.6.2.2). The route for this migration crosses the export pipeline route and the existing PNG LNG Gas Pipeline. Lobsters walk along the seafloor and have relatively weak swimming ability, except over short distances and in short bursts. The pipelines may therefore present a physical obstruction of the migration to spawning grounds near Yule Island (see Figure 8.27). This may impact the population by decreasing the number of migrating lobsters reaching the spawning area and successfully spawning, thereby potentially decreasing larval supply and recruitment.

The ornate rock lobster also has important artisanal value in the Cape Suckling to Yule Island region and commercial significance in the Torres Strait. Any potential decline in future lobster populations may therefore also reduce ecosystem service provision, which is assessed in Chapter 16.

12.3.3.3 Sediment Mobilization from Trenching

Trenching for pipeline installation will temporarily increase suspended sediment concentrations and sediment deposition rates, as described and assessed in Section 12.1. The ecological impacts depend on the sensitivity of the environments and associated fauna and characteristics (i.e., intensity, duration and frequency) of turbid plumes. As noted in Section 12.3.2, modeling of sedimentation deposition was undertaken from trenching to the -15 m LAT mark rather than to the -20 m LAT mark; however, this altered scenario is not expected to cause additional impacts to high-sensitivity habitat (i.e., seagrass and coral reef) due to the absence of such habitat between

the area modeled and the -20 m LAT mark. The model results are therefore considered acceptable for assessing impacts from sedimentation due to trenching.

Orokolo Bay

The modeled plumes for Orokolo Bay will not interact with any receptors sensitive to elevated suspended sediment levels, as the nearest reef is over 3 km from the trenching. Due to the high existing TSS levels and sediment deposition rates in Orokolo Bay, resident biota (including prawns) are highly tolerant to sediment disturbance and; therefore, are not expected to be impacted by the trenching. Section 8.5.4 describes the habitat of Orokolo Bay to have a moderate sensitivity; however, this rating was due to the highly turbid waters potentially providing preferential feeding habitat for some vulnerable species. Considering that these species have a tolerance or preference for highly turbid environments, biodiversity impacts at Orokolo Bay are not expected due to sediment mobilization and are not considered further in the residual impact assessment.

Caution Bay

Caution Bay has low turbidity levels and contains species that are sensitive to suspended sediments and sediment deposition. The main sensitive ecological receptors in Caution Bay are species that require light for nutrition, such as algae, seagrass and hermatypic corals. A decrease in health or an increase in mortality of these species may potentially occur due to reduced light penetration and sedimentation where trenching occurs close to coral reef or seagrass beds, or where currents carry mobilized sediment over these areas.

Potential impacts on aquatic biota due to increased suspended sediment and sedimentation levels include:

- Increased turbidity reducing light in the water column, thus reducing the productivity of phytoplankton and benthic microalgae.
- Increased turbidity reducing water clarity and the ability to detect prey.
- Physiological stress from high sediment concentrations, e.g., blocking of respiratory or feeding structures.
- Smothering and burial of sedentary species such as benthic microalgae and benthic invertebrates, including corals.

12.3.3.4 Planned Wastewater Discharges and Accidental Contaminant Releases

Contaminants may enter the environment from planned discharges of treated hydrotest water, domestic wastewaters and bilge water. Hazardous substances, including hydrocarbons and liquid wastes, may also be accidentally spilled or leaked from Project vessels. Condensate or gas leaks may also potentially occur if there are faulty joins in offshore pipelines.

The assessment undertaken in Section 12.3.5 relates only to spills or leaks that are typically incidental (but controllable) as part of construction and operation of large projects. Major accidental spills from unplanned events (e.g., bunker rupture from vessel collisions or groundings, or pipeline rupture) are considered in Chapter 18.

The potential impacts to marine biota from accidental contaminant releases depend on several factors, including the extent of contamination, duration of exposure and contaminant type. Oils and petroleum hydrocarbons are less dense than water and are biodegradable. The most toxic oil fractions to aquatic biota are lighter fractions that contain higher proportions of aromatic hydrocarbons; however, exposure of aquatic organisms in the water column to such fractions is

usually limited due to their high volatility. Conversely, fauna that inhabit the surface layer would be exposed to hydrocarbons and exposed to toxicity effects. Apart from direct toxic effects to aquatic biota, oils and hydrocarbons can also cause tainting of fish flesh, loss of invertebrates and food sources, and an increase in algal growth (ANZECC/ARMCANZ, 2000). Hydrocarbons present on the surface layer of the water column may also coat surface swimming marine fauna, potentially affecting the insulating ability of fur-bearing mammals and the water repellency of bird's feathers.

As discussed in Section 12.2.3, the following embedded design controls address these impacts:

- Adopt standard industry practices to prevent and protect against soil/water contamination, due to Project activities, such as:
  - Preparing hydrocarbon and chemical management procedures, as part of the Hazardous Materials Management Plan.
  - Building infrastructure on impervious surfaces where required.
  - Providing permanent fuel and chemical stores, and maintenance and refueling areas with secondary containment of an appropriate volume to prevent loss to the environment or mixing with incompatible materials.
  - Installing interceptor pits or similar to collect contaminated surface water runoff and treat where required.
  - Installing tanks above ground with impermeable liners and bunds around tanks.
  - Regularly inspect and maintain the containers, storage and transfer infrastructure to prevent/control spills or leaks.
  - Installing readily accessible spill kits and training staff in their use.
  - Appropriately treating and disposing of any accidentally contaminated soils. [ED003].
- Chemical use will be minimized, and selection of chemicals will be made considering lowest toxicity, lowest bioaccumulation potential, highest biodegradation and bans or phase-outs [ED006].
- Ballast waters, liquid effluents and waste from vessels will be managed according to MARPOL 73/78 requirements [ED022].

12.3.3.5 Vessels Striking Fauna

Vessels operating in marine waters may strike marine fauna. This is especially the case for mobile megafauna that swim near the surface or frequent the surface to breath, such as whales, dolphins, dugongs, crocodiles and turtles. Fish practice avoidance behavior around vessels and are unlikely to be injured due to vessel strike.

Vessel strike risk depends on many factors including the fauna type and abundance, vessel type, vessel speed and location. Slow moving fauna, such as turtles, near the water surface may be unable to evade fast moving watercraft such as support vessels. Large vessels, e.g., pipelaying vessels, barges and dredges, are slow-moving and may provide marine fauna time to evade the approaching vessel. They also typically have large powerful propellers and a lower draft, and, as such, present a risk to slow moving fauna throughout the upper parts of the water column. Interactions may occur in the offshore export pipeline footprint and shipping lanes between Port Moresby and the Purari River delta.

During trenching, it is possible for the suction at the dredge head to entrain fauna, potentially causing fauna injury or mortality. Of the marine megafauna potentially present in the PAOI, turtles are the group most likely to be affected. Turtles are highly mobile and will tend to avoid the dredge, typically returning to the surface to breath every few minutes; however, they can remain underwater for as long as two hours without breathing when they are resting. There are recorded incidences of turtles being injured by suction type dredges (Reine and Clarke, 1998). Other megafauna species (e.g., cetaceans and dugong) are not considered to be prone to dredge entrainment and will not be impacted by such interactions. The dredge may also entrain benthic fauna and demersal fish and mortality for these fauna is expected.

Assessment of impacts to marine fauna associated with underwater noise generated by vessels is undertaken separately in Section 12.4.

12.3.3.6 Spread of Marine Pests, Diseases and Pathogens

The dredge and other vessels could translocate marine pests from their port of origin to Port Moresby, the Gulf of Papua and to the Purari River system during all Project stages. There are two key vectors for translocating marine pests: Biofouling of the vessel hull or releasing pests into the marine environment in ballast waters (Hewitt and Campbell, 2010).

Vessel hulls and dredge plant can provide habitat for biofouling marine pest species. In particular, dredges and associated construction equipment can provide complex habitats that may be difficult to clean and inspect (Hewitt and Campbell, 2010).

Ballast water is typically discharged from each ship as it enters port, at the port anchorage areas, and at the berths as it is loaded. Most vessels discharge only a small percentage of their ballast water in outer approach channels to conform to navigational requirements. Most ballast water is discharged alongside the wharf to balance the trim of the vessel and stresses in the vessel's hull, as materials are loaded.

If conditions are suitable, introduced marine species can survive and establish a reproductive population in the host environment and can become invasive whereby they outcompete native species and multiply into pest proportions. Introduced species can replace native species through direct competition for resources (i.e., food and space) or, indirectly, by flow-on effects through ecosystem or food web changes. The environmental impacts due to the introduction of exotic marine pests can be significant. Marine pests, once established, can be difficult to eradicate and can have serious and permanent consequences for the marine environment, marine productivity and public health (see Chapter 8).

There is little information on the present status of invasive marine species in Papua New Guinea or the wider Pacific Island Countries and Territories. Raaymakers (2006) notes that introduced species of concern in the region include the barnacle (*Chthamalus proteus*), several macro-algae species, harmful planktonic algae species and the black striped mussel (*Mytilopsis sallei*). Asian green mussel (*Perna viridis*), which have a natural range within South East Asia, also represent a key potential risk species for tropical environments in Australia (Hayes et al., 2005) and Papua New Guinea.

Ships originating from colder, temperate waters have a lower risk of establishing marine pest populations than those originating from tropical ports, because foreign organisms from temperate ports are generally considered to be less likely to survive or proliferate in the warmer tropical waters.

Diseases and pathogens are not commonly spread in the marine environment but, when translocation does occur, the same vectors as marine pests generally spread them. Antifouling

techniques and appropriate ballast water exchanges to manage marine pests will therefore also address risks associated with diseases and pathogens.

The following embedded design control addresses these potential impacts:

- Ballast waters, liquid effluents and waste from vessels will be managed according to the MARPOL 73/78 requirements [ED022].

12.3.3.7 Summary of Potential Impacts to Marine Biodiversity

Potential Project impacts to marine biodiversity that have been considered in the residual impact assessment are as follows:

- Loss or disturbance of benthic habitat and marine fauna from trenching and pipelaying.
- Pipeline presenting a barrier to marine fauna movements.
- Sediment mobilization from trenching, causing impacts to aquatic biota due to increased levels of suspended sediment and sedimentation on the seabed.
- Planned wastewater discharges or contaminant releases reducing water quality, with potential acute or chronic toxicity effects on aquatic fauna.
- Project vessels striking fauna.
- Project vessels and equipment spreading marine pests, diseases and pathogens

12.3.4 Proposed Mitigation and Management Measures

Table 12.16 describes mitigation and management measures to further reduce impacts to marine biodiversity. Mitigation and management in Caution Bay in the lease area for the PNG LNG Project will be further aligned with the PNG LNG Project and downstream Papua LNG Project.

Table 12.16 – Marine Biodiversity Mitigation Strategies and Management Plans

Potential Impact	Mitigation Strategy	Relevant Management Plan
Direct loss of benthic habitat and loss of or injury to marine fauna from trenching and pipelaying	♦ Where required, implement adaptive management to minimize dredging impacts on sensitive habitats and species [EM037].	-
Pipeline barrier to marine fauna movements	♦ Where required, implement adaptive management, including appropriate monitoring, to minimize the project's impacts on lobster migration [EM038].	Biodiversity Action Plan
Sediment mobilization from trenching	♦ Where required, implement adaptive management to minimize dredging impacts on sensitive habitats and species [EM037].	Water Management Plan
Contaminant releases	♦ Sewage effluents from Project facilities will be treated to meet the environment (waste discharge) permit before discharge, in accordance with applicable standards. [EM008]. ♦ Hydrotest water management will consider: – The definition of volume and discharge rates and discharge locations. – Chemical additive selection, according to requirements defined in embedded design controls.	Water Management Plan; Hazardous Materials Management Plan

Table 12.16 – Marine Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Contaminant releases (cont'd)	– Reusing hydrotest water to minimize the discharge volume. – Reducing the need for chemicals by minimizing the time hydrotest water remains in the pipeline. – Monitoring hydrotest water discharges to the environment against applicable limits. [EM015] ♦ An Emergency Response Plan will be developed to effectively manage the preparedness and response to emergency events. It will contain: – Site Contingency Plans, that will consider fire management measures – An Oil Spill Contingency Plan, that will consider spill risks for construction, operation and decommissioning of facilities and associated infrastructure, and supply services on land and in aquatic and marine environments. – A Blow Out Contingency Plan including well blowout control and contingency measures [EM018]. ♦ Vessels will be required to have shipboard Oil Pollution Emergency Plans/Oil Spill Contingency Plans as per TOTAL requirements and Marine Pollution (Ships and Installations) Act 2013 [EM019].	Water Management Plan; Hazardous Materials Management Plan
Vessels striking fauna	♦ Implement lower speeds past aquatic fauna when observed in the water [EM022]. ♦ All Project personnel, workers, contractors and 3rd party operators will be educated during inductions and safety training about: – Fire risks, including the heightened risk during extreme drought years and smoking. – Wildlife values. – Weed, pathogen and animal pest hygiene and control measures. Identification of cultural heritage, cultural heritage awareness, measures for avoiding impacts and the Chance Finds Procedure [EM028].	Traffic and Transport Management Plan; Biodiversity Action Plan
Spread of marine pests, diseases and pathogens	♦ Management controls will be developed for weed, pathogen and pest that pose a significant threat to biodiversity, including: – Specific risk-based control methods, and procedures targeting Priority 1 and 2 weeds and pest fauna. – A quarantine management program for moving people, equipment and supplies in accordance with PNG law. – Tools for field personnel to identify Priority 1 and 2 weeds and pest fauna. [EM023]. ♦ All Project personnel, workers, contractors and 3rd party operators will be educated during inductions and safety training about: – Fire risks, including the heightened risk during extreme drought years and smoking.	Biodiversity Action Plan

Table 12.16 – Marine Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Spread of marine pests, diseases and pathogens (cont'd)	– Wildlife values. – Weed, pathogen and animal pest hygiene and control measures. – Identification of cultural heritage, cultural heritage awareness, measures for avoiding impacts and the Chance Finds Procedure [EM028].	Biodiversity Action Plan

Note: A dash (-) denotes no management plan is required.

12.3.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to marine biodiversity subject to the embedded design controls in Section 12.3.3 and the successful implementation of the mitigation and management measures in Section 12.3.4. A summary of the residual impact assessments is provided at the end of this section, including when and where (in which Project phase and location) these impacts are expected to occur.

As indicated earlier, LNG facilities inside the PNG LNG Plant lease boundary are excluded from the scope of this EIS; the related indicative information presented here will be refined as part of the downstream Papua LNG EIS.

12.3.5.1 Loss or Disturbance of Benthic Habitat and Marine Fauna from Trenching and Pipelaying

Trenching and pipelaying will cause direct impacts to benthic habitats and biota that is unavoidable. Route selection will be refined during FEED to minimize impacts to high value habitats, wherever practicable. The residual impacts to seagrass and coral reef habitats and marine fauna are assessed below. As described in Section 12.3.3, the impact to unconsolidated sediment habitat due to pipeline installation is considered insignificant.

Seagrass

The direct loss of seagrass habitat due to trenching in Caution Bay is estimated to be 0.08% of the total seagrass habitat for the southern alignment and 0.06% of the total seagrass habitat for the northern alignment (see Table 12.15).

Seagrass species recorded in Caution Bay are *Enhalus acoroides, Syringodium isoetifolium, Cymodocea* spp. and *Halophila* spp. (see Section 8.5). These species have a range of adaptations that allow for rapid recovery following disturbance (Table 12.17) including the ability to reproduce both sexually and asexually. Where some shoots or roots remain intact, vegetative growth through rhizomes can allow recovery in a relatively short time frame (Carruthers et al., 2002; Unsworth et al., 2015). It is expected that recovery will take up to 10 years[7], depending on the level of initial impact and ambient environmental conditions during the recovery period.

7 Considering *Enhalus acoroides* which has the longest recovery time

Table 12.17 – Sensitivity to Disturbance of Seagrass Species Found in the PAOI

Species	Sensitivity to Disturbance
Cymodocea serrulata	♦ High light requirement. ♦ Large growing species with large energy reserves (rhizomes) and the capacity to endure short-term changes in turbidity. ♦ Low to moderate growth and reproductive output (compared to *Halophila*), high rhizome persistence. ♦ Recovery longer than *Halophila*. ♦ Classified as an intermediate taxon that can tolerate moderate levels of disturbance and is able to rapidly recover following disturbance.
Enhalus acoroides	♦ High light requirement. ♦ Large growing species with large energy reserves and a high capacity to endure short-term changes in turbidity. ♦ Low growth and reproductive output (compared to *Halophila* and *Cymodocea*). ♦ Recovery longer than *Halophila.* ♦ Can tolerate moderate levels of disturbance, but takes up to 10 years to fully recover.
Syringodium isoetifolium	♦ Small stores of energy reserves. ♦ Rapidly declines when conditions become unfavorable for growth. ♦ Reproduces from seed and vegetative growth. ♦ Fast growth and high reproductive output. ♦ Classified as an opportunistic species that can tolerate high levels of disturbance.
Halophila spp.	♦ Small energy reserves. ♦ Rapidly declines when conditions become unfavorable for growth. ♦ Reproduces from seed and vegetative growth. ♦ Colonizing growth strategy. ♦ Fast growth and high reproductive output. ♦ Classified as an ephemeral genus that can tolerate high levels of disturbance.

Sources: Collier and Waycott (2009); Carruthers et al., (2002); Unsworth et al., (2015); Duarte et al., (1997).

Trenching across seagrass meadows is expected to cause short-term loss of less than 0.1% of seagrass habitat in Caution Bay with recolonization expected to occur in one to five years. *Halophila* species will rapidly recolonize, with slower growing species such as *Enhalus acoroides*, recolonizing in subsequent years. Impacts are therefore temporary and highly localized, and will not cause long-term impacts to other marine components outside of the disturbance footprint; therefore, the magnitude of the impact will be ***Low***. These meadows have a ***Medium*** sensitivity, as they are in near natural condition; although, local and commercial fishing, and the development of the PNG LNG project have removed some seagrass meadow patches in the past. This provides a residual impact significance of ***Minor***.

Reefs

The direct loss of nearshore fringing coral reef due to trenching in Caution Bay is estimated to be 0.03% of the total coral habitat for the southern alignment (see Table 12.15). For the alternative northern alignment, the loss of fringing coral reef habitat is estimated to be 0.08% of the total coral habitat.

The trench footprint through the fringing reef will be backfilled using the excavated material, which is expected to largely consist of unconsolidated coral rubble that differs from the existing reef habitat. This represents a long-term change to habitat conditions, with recovery (e.g., cementation of reef substrates) possibly measured in tens of decades (Erftemeijer et al., 2012). Damage to or

loss of large coral heads, if present in the alignment, would be permanent as these features are several hundred years old.

The recovery timeframes of reef assemblages will vary among species. It is expected that there will be a successional change to a benthic assemblage, with initial colonization by an algae-dominated assemblage, and the eventual recolonization by reef fauna (i.e., hard corals, hydroids and sponges) (Pearson, 1981; Done, 1992). The reef assemblage in the footprint may differ from that prior to trenching due to the expected change in substrate types and their stability. The timeframe for establishing a relatively diverse and abundant benthic assemblage may be five to 10 years (Erftemeijer et al., 2012).

Although impacts would be limited to the trenching footprint and are therefore highly localized, the impact magnitude is ***Medium*** based on the recovery times for corals. As for seagrass, these reefs have a ***Medium*** sensitivity as local and commercial fishing, and the development of the PNG LNG project have removed or damaged coral patches in the past. This provides a residual impact significance rating of ***Moderate***.

Marine Fauna

Direct injury to or loss of benthic invertebrates from trenching in Orokolo and Caution bays will be highly localized and temporary, as surrounding fauna are likely to recolonize the sediment within weeks after the trench has been filled. These impacts will not threaten the viability of subregional populations and the impact magnitude is considered ***Low***. The sensitivity of benthic invertebrate is ***Minimal*** since they are species well adapted to habitat loss and there are widespread similar benthic faunal assemblages. The residual impact significance is therefore ***Negligible.***

The offshore export pipeline route through Caution Bay will pass through reef and seagrass habitat supporting marine species with significant conservation status including marine turtles, dugong and some fish; however, these species have not been sighted in Caution Bay during marine surveys for the Project, or the PNG LNG project, to date and local populations are likely to be very small if they are present. The total extent of habitat disturbance is very small relative to the extent of available habitat, even at a localized spatial scale (i.e., less than 0.1% of available habitat in Caution Bay). None of the affected areas are known or expected to support unique or otherwise critical food or habitat resources at a localized scale, based on habitat assessments.

This small and temporary reduction in foraging habitat for fish, marine turtles and dugong is unlikely to cause a measurable reduction in the species populations. The impact magnitude for all species is therefore ***Minimal***. Sensitivity ratings vary depending upon the relevant species. Table 12.18 provides the residual impact significance ratings per species, considering the different sensitivities.

Table 12.18 – Impact Significance Ratings for Habitat Loss or Disturbance for Relevant Species

Species	Likely Abundance	Status*	Sensitivity	Magnitude	Significance
Loggerhead turtle (*Caretta caretta*)	Low	VU, App I	High	Minimal	***Minor***
Green turtle (*Chelonia mydas*)	Low to medium	EN, App I	High	Minimal	***Minor***
Leatherback turtle (*Dermochelys coriacea*)	Very low (if present)	CR#, P, App I	Very High	Minimal	***Minor***
Hawksbill turtle (*Eretmochelys imbricata*)	Low to medium	CR, App I	Very High	Minimal	***Minor***

Table 12.18 – Impact Significance Ratings for Habitat Loss or Disturbance for Relevant Species (cont'd)

Species	Likely Abundance	Status*	Sensitivity	Magnitude	Significance
Olive ridley turtle (*Lepidochelys olivacea*)	Low	VU, App I	High	Minimal	***Minor***
Flatback turtle (*Natator depressus*)	Low	App I	Medium	Minimal	***Negligible***
Dugong (*Dugong dugon*)	Very low (if present)	VU, P, App I	High	Minimal	***Minor***
Spotted eagle-ray (*Aetobatus narinari*)	Low	NT	Medium	Minimal	***Negligible***
Brown marbled grouper (*Epinephelus fuscoguttatus*)	Low to medium	NT	Medium	Minimal	***Negligible***
Non-threatened fish species	Medium to high	Not IUCN listed or protected in PNG	Minimal to Low	Minimal	***Negligible***

* Status consists of IUCN Red List listing (CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened), National Status (P: Protected) and CITES Appendix I Listing (App I). Only the status relevant to sensitivity. is provided. # West Pacific population.

12.3.5.2 Pipeline Barrier to Marine Fauna Movement

The export pipelines may potentially obstruct the ornate rock lobster migration across the gulf to spawning grounds at Yule Island, as described in Section 12.3.3.2.

Dennis et al. (1996) demonstrated that lobsters can cross a 26-inch diameter pipeline to access a food source in experiments conducted in test tanks. The diameter of the existing PNG LNG Gas Pipeline is 34 inches and there is no evidence to indicate it has presented a barrier to lobster migration to Yule Island causing impacts on lobster populations, with the National Fisheries Authority not receiving any reports of negative impacts to lobster catches following its installation (Kasu, pers. com., 2019).

Uncertainty remains regarding the ability of ornate rock lobsters to traverse a 40-inch diameter pipeline, which is the diameter of the proposed gas export pipeline excluding the thickness of the concrete collar. Martec (2004) found that some American lobsters (*Homarus americanus*, a temperate lobster species in a different family but potentially with similar mobility) were unable to traverse a 32-inch pipeline with a rough coating in a test tank. Of the eight lobsters in the test, five were able to traverse a fully exposed pipeline and three were able to traverse a pipeline that was three-quarters exposed. In the same tests, nine of 10 lobsters were unable to traverse a 48-inch pipeline with a rough coating when fully exposed, and 13 of 16 lobsters when three-quarters exposed. Martec (2004) concluded that pipe diameter, burial and roughness determined the ability for *H. americanus* to traverse a pipeline to access a food source and a threshold diameter for this species may be between 32 and 48 inches.

The residual impact of the export pipelines, in particular the 40-inch diameter gas pipeline coated with a rough concrete collar, to the ornate rock lobster is therefore uncertain. Disruption of the ornate rock lobster migration may possibly occur. This could cause a decline in the number of migrating lobsters arriving at spawning sites in the Yule Island area. This has the potential to cause in a decline in the subregional population of the species, but is unlikely to threaten the viability of the regional population, which is also supported by spawning grounds elsewhere in the gulf including Parama Island near the mouth of the Fly River (see Section 8.6.2). The magnitude of impact is therefore assessed to be ***High***.

As the ornate rock lobster is of fisheries significance, it has a ***Medium*** sensitivity. Overall, the potential for the pipelines to be a barrier to lobster migration is therefore assessed to have a ***Moderate*** residual impact significance.

The pipeline is not expected to negatively affect prawn movements (see Section 12.3.3.2).

12.3.5.3 Sediment Mobilization from Trenching

Orokolo Bay

Plume and sedimentation impacts to marine biodiversity are not expected at Orokolo Bay due to the lack of sensitive receptors and the high adaptation levels of local marine biota to naturally occurring high levels of suspended sediment and sedimentation (see Section 12.3.3).

Caution Bay

Trenching for pipeline installation, which will occur in water depths less than -20 m LAT, will temporarily increase suspended sediment concentrations and sediment deposition rates, as described and assessed in Section 12.1. Comparison of modeling results for the predicted increase in suspended sediment and sedimentation to the impact thresholds provided in Tables 12.13 and 12.14 shows the following:

- The median (50th percentile) TSS concentration for both alignments during both seasons exceeds the threshold for the zone of influence (1 mg/L) and reaches, but does not exceed, the threshold for the zone of moderate impacts (5 mg/L) (see Figures 12.4 to 12.7). Thus, while there will be changes in TSS concentrations, these will be insufficient to degrade, harm or injure ecological receptors (Section 12.3.2).
- Final sediment deposition for both alignments during both seasons exceeds the threshold for the zone of high impact (700 mg/cm^3) up to 500 m from the trenching alignment (see Figure 12.8 and 12.9). This represents an area in which most sensitive receptors will die, with recovery by recolonization taking longer than 24 months (Section 12.3.2). Beyond this extent, there is an immediate drop-off in deposition and sedimentation rates to levels below the zone of influence threshold (<30 mg/cm^3), where there are no ecological impacts.

Table 12.19 shows the resulting areas of impact (i.e., those in the zone of high impact due to sediment deposition), based on the previously mapped extent of seagrass and coral habitats in Caution Bay (see Section 8.5.2 and Figure 8.21) and modeled sedimentation results (see Figure 12.8 and 12.9). This shows that the highest impact scenario with respect to coral reef habitat is the northern alignment with around 85,000 m^2 disturbed for both seasons. This is a potential loss of around 2% of total coral reef habitat found in Caution Bay due to smothering from deposition. The scenario with the lowest impact to coral habitat is the southern alignment, with trenching conducted during the northwest monsoon season (i.e., a potential loss of 1% of the total coral reef habitat). Impacts to seagrass habitat are not predicted to occur due to the narrower extent of mapped seagrass along the northern alignment. The area of impact on seagrass habitat along the southern alignment is approximately the same for either season (8,000 to 9,000 m^2, representing 0.4% of total seagrass in Caution Bay).

Table 12.19 – High-value Benthic Habitat Disturbed by Sedimentation During Trenching

Benthic Habitat Type	Caution Bay – Southern Alignment		Caution Bay – Northern Alignment	
	m^2	%	m^2	%
Northwest Monsoon Season				
Seagrass	8,000	0.4	0.0	0.0
Coral reef	44,000	1.0	85,000	2.0

Table 12.19 – High-value Benthic Habitat Disturbed by Sedimentation During Trenching (cont'd)

Benthic Habitat Type	Caution Bay – Southern Alignment		Caution Bay – Northern Alignment	
	m^2	%	m^2	%
Southeast Trade Winds Season				
Seagrass	9,000	0.4	0.00	0.0
Coral reef	67,000	1.6	84,300	1.9

Areas represent areal extent of seagrass and coral reef in the zone of high impact (mortality with recolonization time greater than 24 months) due to sediment deposition.

In summary, sediment deposition will adversely impact marine biodiversity in Caution Bay; however, increased suspended sediment levels are not expected to have adverse impacts. The zone of high impact is predicted to adversely affect less than 1% of seagrass habitat and 2% of fringing coral reef habitat in Caution Bay causing mortality in this zone. Impacts on fringing coral reefs and seagrasses will be temporary as wave action is expected to naturally and rapidly rework sediment deposited in the zone of impact. The magnitude of impact is dependent upon their ability to recover.

In seagrass meadows, some species such as *Halophila* species can recolonize in one to five years while slower growing species such as *Enhalus acoroides* may take up to 10 years to fully recover (Rollon et al., 1999). Sedimentation impacts to coral reefs are expected to last five to 10 years before plating and branching coral species recover. Impacts to large ancient coral heads (where they occur) could take hundreds of years to recover. The magnitude of impacts to these habitats is as follows:

- Seagrass impacts will be highly localized within 500 m of the trenching alignment and recolonization is expected to take between one to five years, with some species (e.g., *Halophila* spp.) recolonizing more rapidly than others (e.g., *Enhalus acoroides*). Therefore, the impact will be of ***Low*** magnitude.
- Fringing coral reefs impacts will be highly localized and large relative to natural variability and could take up to 10 years to recover equivalent habitat values; therefore, the impact will be of ***Medium*** magnitude. Impacts on coral heads habitat, if present on the fringing coral reefs, will also be highly localized and large relative to natural variability but could take hundreds of years to recover. The magnitude of impact is, however, similarly assessed to be ***Medium***.

Seagrass habitats in Caution Bay are considered to have a ***Medium*** sensitivity since they support seagrass species with moderate vulnerability, including *Enhalus acoroides* (see Section 8.5.4), and are in near natural condition providing habitat for marine fauna but with some minor historical and ongoing disturbance. Overall, the impact on seagrass due to sediment mobilization from trenching is therefore assessed to have a ***Minor*** residual impact significance.

Notwithstanding the high sensitivity rating given to coral reef habitats in general in Section 8.5.4, fringing and nearshore reefs in Caution Bay have been observed to be in poor condition, which is attributed to high intensity fishing and the suspension of sediment from strong winds and waves, although recovery in condition is occurring (see Section 8.5.2). The sensitivity of fringing reef in Caution Bay is therefore assessed to be ***Medium*** for the impact assessment, i.e., habitat is not significantly modified in terms of primary ecological function and composition, supports viable assemblages of native flora and fauna species and conservation-listed species may be present. The impact on fringing coral reef due to sediment mobilization from trenching is therefore assessed to have a ***Moderate*** residual impact significance.

The seagrass and reef habitats may support marine species with significant conservation status including marine turtles, dugong, and some fish. Impacts on these habitats will create small reductions in foraging habitat for fish, marine turtles, and dugong but are unlikely to cause a measurable reduction in the species populations. The magnitude of impact from sediment mobilization for marine species is therefore ***Minimal***. The residual significance of impact for various fauna due to sediment mobilization is the same as described in Table 12.18 for habitat loss or disturbance, given that the magnitude of impact is the same.

12.3.5.4 Planned Wastewater Discharges and Accidental Contaminant Releases

Assessment of the impacts on marine water quality of planned wastewater discharges and accidental contaminant releases is undertaken in Section 12.2. Embedded design controls and mitigation measures will be in place to: (i) prevent and minimize the occurrence of accidental contaminant spills or leaks; (ii) respond appropriately should a spill occur. Given the expected low volumes of any contaminant release assessed in this Chapter, the assimilation factor inherent in the marine environment, and taking into account the proposed embedded controls and mitigation and response measures (see Section 12.3.3 and Table 12.2.4), the residual impact significance of contamination in marine waterways was assessed as ***Negligible*** for planned wastewater discharges (see Section 12.2.5.1). The residual impact significance for accidental contaminant releases causing a deterioration of water quality was assessed as ***Minor*** (see Section 12.2.5.2).

The release of low volumes of contaminants is most likely to have insignificant impacts on habitats but may affect individual animals. The susceptibility of marine fauna to the potential physical or toxic effects of contaminants will depend on factors such as the fauna type, contaminant type, length of exposure and the contaminant concentration. When appropriately detected and managed, accidental spills and leaks would have a highly localized impact, and are unlikely to cause a measurable decline in marine fauna populations. The magnitude of the impact is therefore assessed as ***Minimal***.

Contaminants accidentally released into the marine environment have the potential to affect any marine fauna exposed to the release. The overall significance of impact for various fauna due to contaminant release is shown in Table 12.20 considering their different sensitivities.

Table 12.20 – Impact Significance Ratings for Contaminant Release for Various Species

Species	Likely Abundance	Status	Sensitivity	Magnitude	Significance
Loggerhead turtle (*Caretta caretta*)	Low	VU, App I	High	Minimal	***Minor***
Green turtle (C*helonia mydas*)	Low to medium	EN, App I	High	Minimal	***Minor***
Leatherback turtle (*Dermochelys coriacea*)	Very low (if present)	CR#, P, App I	Very High	Minimal	***Minor***
Hawksbill turtle (*Eretmochelys imbricata*)	Low to medium	CR, App I	Very High	Minimal	***Minor***
Olive ridley turtle (*Lepidochelys olivacea*)	Low	VU, App I	High	Minimal	***Minor***
Flatback turtle (*Natator depressus*)	Low	App I	Medium	Minimal	***Negligible***
Dugong (*Dugong dugon*)	Very low (if present)	VU, P, App I	High	Minimal	***Minor***
Australian snubfin dolphin (*Orcaella heinsohni*)	Low	EN, App I	High	Minimal	***Minor***

Table 12.20 – Impact Significance Ratings for Contaminant Release for Various Species (cont'd)

Species	Likely Abundance	Status	Sensitivity	Magnitude	Significance
Australian humpback dolphin (*Sousa sahulensis*)	Low	VU, App I	High	Minimal	***Minor***
Spotted eagle-ray (*Aetobatus narinari*)	Low to medium	NT	Medium	Minimal	***Negligible***
Brown marbled grouper (*Epinephelus fuscoguttatus*)	Low to medium	NT	Medium	Minimal	***Negligible***
Non-threatened marine fauna (includes fish, macrocrustaceans and dolphins)	Low to high	Not IUCN listed or protected in PNG	Minimal to Low	Minimal	***Negligible***

* Status consists of IUCN Red List listing (CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened), National Status (P: Protected) and CITES Appendix I Listing (App I). Only the status relevant to sensitivity is provided. # West Pacific population.

12.3.5.5 Vessels Striking Fauna

Implementing a protocol to minimize interactions with marine fauna, including lower speeds past aquatic fauna when observed in the water will reduce the risk of Project vessels striking fauna. The risk of strike may be higher in Caution Bay than elsewhere due to the greater possibility of fauna (especially marine turtles) being present in shallower waters with coral reef and seagrass habitats. The magnitude of impacts across the PAOI for all species is considered ***Minimal,*** as the possible injury or death of individuals is unlikely to cause a measurable decline in fauna populations.

The species most likely to be at risk are large marine fauna that can occur at the surface, namely dolphins, marine turtles and dugongs. The sensitivity of these species differs, leading to variable impact significance as shown in Table 12.21.

Table 12.21 – Impact Significance Ratings for Vessel Strike for Relevant Species

Species	Status	Sensitivity	Magnitude	Significance
Loggerhead turtle (*Caretta caretta*)	VU, App I	High	Minimal	***Minor***
Green turtle (*Cheloni mydas*)	EN, App I	High	Minimal	***Minor***
Leatherback turtle (*Dermochelys coriacea*)	CR#, P, App I	Very High	Minimal	***Minor***
Hawksbill turtle (*Eretmochelys imbricata*)	CR, App I	Very High	Minimal	***Minor***
Olive ridley turtle (*Lepidochelys olivacea*)	VU, App I	High	Minimal	***Minor***
Flatback turtle (*Natator depressus*)	App I	Medium	Minimal	***Negligible***
Dugong (*Dugong dugon*)	VU, P, App I	High	Minimal	***Minor***
Australian snubfin dolphin (*Orcaella heinsohni*)	EN, App I	High	Minimal	***Minor***
Australian humpback dolphin (*Sousa sahulensis*)	VU, App I	High	Minimal	***Minor***
Non-threatened dolphins (*Delphinus delphis, Stenella attenuate, Tursiops aduncus* and *Tursiops truncates*)	Not IUCN listed or protected in PNG	Low	Minimal	***Negligible***

* Status consists of IUCN Red List listing (CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened), National Status (P: Protected) and CITES Appendix I Listing (App I). Only the status relevant to sensitivity is provided. # West Pacific population.

12.3.5.6 Spread of Marine Pests, Diseases and Pathogens

A quarantine management program for moving people, equipment and supplies will be developed and implemented during Project construction and operation in accordance with PNG law. Biosecurity measures detailed in these procedures, including compliance with the *Marine Pollution [Ballast Water Control Act] Act 2013,* will minimize the risk of marine pests, diseases and pathogens being introduced into marine waters from either the discharge of ballast water or via the hulls of vessels. Vessels will transit the gulf to PRL-15 during all Project[8] phases; however, most vessels will be based locally and so have a much lower risk of introducing marine pests, diseases and pathogens compared to vessels arriving from overseas. Given the short-term duration of construction and the small number of vessels required (up to four barges per day during the peak period in Year 2) during all Project phases, introduction of marine pests, diseases and pathogens is unlikely to occur; however, any impacts would be expected to be localized and not threaten the viability of a sub-regional species population. The magnitude of impact is therefore assessed as ***Low***.

The existing environment has a ***Medium*** sensitivity as it is in a near-natural condition but with some minor human-induced modification and an ongoing risk of marine pest introduction (e.g., international shipping traffic). This provides a residual impact significance rating that is ***Minor***.

12.3.6 Summary of Residual Impacts to Marine Biodiversity

Table 12.22 provides a summary of the assessment of residual impacts to marine biodiversity, including in which Project phase and location these impacts are expected to occur. The table should be read in conjunction with the mitigation measures provided in Table 12.16.

All residual impacts are assessed to be ***Negligible*** to ***Minor***, except for the following:

- Direct loss or decline in the health of fringing coral reef habitat in Caution Bay due to: i) direct trenching and ii) indirect sedimentation, associated with trenching for the pipeline installation, which are assessed to have a ***Moderate*** residual impact rating. The impacts to this habitat will be localized and, although pipelaying will be a short-term activity (e.g., less than one week), moderate impacts are expected due to the long recovery periods required for coral reefs to re-establish (i.e., more than five years).
- Decline in ornate rock lobster spawning and abundance due to possible obstruction of their migration across the gulf to spawning grounds at Yule Island. This is assessed to have ***Moderate*** residual impact rating; however, there is some uncertainty regarding these impacts and further assessments are to be undertaken and appropriate management measures developed if required.

8 This assessment excludes LNG tankers exporting gas from the PNG LNG Facilities, which are not considered in this environmental impact assessment.

Table 12.22 – Summary of Assessment of Residual Impact Significance – Marine Biodiversity

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Loss or disturbance of habitat and benthic biota	Trenching in water depths <-20 m LAT and pipelaying	Direct loss of seagrass habitat	Caution Bay	C	♦ EM037	Medium/Low	Minor
		Direct loss of coral reef habitat	Caution Bay			Medium/Medium	Moderate
		Direct mortality or injury of benthic invertebrates	Orokolo Bay and Caution Bay			Minimal/Low	Negligible
		Indirect impacts to marine fauna due to habitat loss (e.g., decrease in heath due to a reduction in food resources) – leatherback turtles and hawksbill turtles	Caution Bay			Very High/Minimal	Minor
		Indirect impacts to marine fauna due to habitat loss (e.g., decrease in heath due to a reduction in food resources)– loggerhead turtles, green turtles, olive ridley turtle and dugongs				High/Minimal	Minor
		Indirect impacts to marine fauna due to habitat loss (e.g., decrease in heath due to a reduction in food resources)– flatback turtles, spotted eagle-rays and brown marbled groupers				Medium/Minimal	Negligible
		Indirect impacts to marine fauna due to habitat loss (e.g., decrease in heath due to a reduction in food resources)– non-listed fish species				Minimal to Low/Minimal	Negligible
Barrier to marine fauna movement	Offshore pipeline	Disruption to ornate rock lobster migration to spawning grounds and possible associated impact on population	Offshore export pipeline route	O, D	♦ EM038	Medium/High	Moderate

Table 12.22 – Summary of Assessment of Residual Impact Significance – Marine Biodiversity (cont'd)

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Sediment mobilization	Trenching in water depths <-20 m LAT	Smothering of seagrass from sedimentation	Caution Bay	C	♦ EM037	Medium/Low	Minor
		Smothering of coral from sedimentation				Medium/Medium	Moderate
		Habitat loss or disturbance to marine fauna from sedimentation – leatherback turtles and hawksbill turtles				Very High/Minimal	Minor
		Habitat loss or disturbance to marine fauna from sedimentation – loggerhead turtles, green turtles, olive ridley turtle and dugongs				High/Minimal	Minor
		Habitat loss or disturbance to marine fauna from sedimentation – flatback turtle, spotted eagle-rays and brown marbled groupers				Medium/Minimal	Negligible
		Habitat loss or disturbance to marine fauna – non-threatened fish species				Minimal to Low/Minimal	Negligible
Contaminant release	Planned wastewater discharges and accidental contaminant releases	Acute and chronic toxicity impacts to aquatic fauna individuals – leatherback turtles and hawksbill turtles	Orokolo Bay, offshore export pipeline route, Caution Bay and logistics supply route	C, O, D	♦ EM008 ♦ EM015 ♦ EM018 ♦ EM019	Very High/Minimal	Minor
		Acute and chronic toxicity impacts to aquatic fauna individuals – loggerhead turtles, green turtles, olive ridley turtles, dugongs, Australian snubfin dolphins and Australian humpback dolphins	Orokolo Bay, offshore export pipeline route and Caution Bay	C, O, D		High/Minimal	Minor

Table 12.22 – Summary of Assessment of Residual Impact Significance – Marine Biodiversity (cont'd)

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Contaminant release (cont'd)	Planned wastewater discharges and accidental contaminant releases	Acute and chronic toxicity impacts to aquatic fauna individuals – flatback turtles, spotted eagle-rays and brown marbled groupers	Orokolo Bay, offshore export pipeline route and Caution Bay	C, O, D	♦ EM008 ♦ EM015 ♦ EM018 ♦ EM019	Medium/Minimal	Negligible
		Acute and chronic toxicity impacts to aquatic fauna individuals – non-threatened marine fauna				Minimal to Low/Minimal	Negligible
Fauna strike	Project vessel operations	Marine fauna mortality or injury from vessel strikes – leatherback turtles and hawksbill turtles	Orokolo Bay, offshore export pipeline route, Caution Bay and logistics supply route	C, O, D	♦ EM022 ♦ EM028	Very High/Minimal	Minor
		Marine fauna mortality or injury from vessel strikes – loggerhead turtles, green turtles, olive ridley turtles, dugongs, Australian snubfin dolphins and Australian humpback dolphins				High/Minimal	Minor
		Marine fauna mortality or injury from vessel strikes – flatback turtles				Medium/Minimal	Negligible
		Marine fauna mortality or injury from vessel strikes – non-threatened dolphin species				Low/Minimal	Negligible
Spread of marine pests, diseases and pathogens	Project vessel operations	Introduction of pests and diseases that cause mortality and replacement of native fauna	Orokolo Bay, offshore export pipeline route, Caution Bay and logistics supply route	C, O, D	♦ EM023 ♦ EM028	Medium/Low	Minor

C = Construction, O = Operations, D = Decommissioning and closure

12.4 Underwater Noise

The assessment of the residual impacts of underwater noise addresses marine, estuarine and freshwater environments and has been placed in this chapter so that it can be treated as one integrated assessment for the aquatic environment.

12.4.1 Context

The PAOI includes a variety of underwater acoustic environments including rivers, estuaries and nearshore and offshore marine waters. Table 12.23 presents a summary of existing underwater sound levels and the key contributing sound sources at representative assessment locations in the riverine environments of PRL-15 and the river transport corridors, and the nearshore and offshore marine segments of the export pipeline corridor. Further description of these noise sources is provided in Section 8.7 and the assessment locations are shown in Figure 8.29.

Table 12.23 – Summary of Existing Underwater Noise Levels and Key Noise Sources

Project Area	Assessment Location	Water Depth (m)	Key Noise Sources	Baseline Noise (dB re 1µPa$_{rms}$*)	
				Mean	Range
Offshore export pipeline route	1 (Caution Bay)	30	Soniferous fish, snapping shrimp, commercial shipping traffic including LNG carriers and tugboats.	110	90 to161
	2 (south of Kerema)	80	Wind, waves, snapping shrimp, barges and trawlers.	105	75 to 127
	3 (south of Ihu)	50			
	4 (Orokolo Bay)	12	Wind, waves, rainfall, soniferous fish, snapping shrimp, marine mammals, barges and community vessels.	110	85 to 163
River transport corridors (Purari River delta)	5 (Aievi Passage)	6	Rainfall, soniferous fish, marine mammals, barges and community vessels.	110	75 to 175
	6 (Port Romilly)	8			
PRL-15	7 (Purari River)	6	Wind, rainfall, soniferous fish, barges and community vessels.	120	75 to 170

* Received sound pressure level and root mean square (rms).

Freshwater and marine fauna considered to be sensitive to potential impacts from underwater noise, and known or expected to occur in the PAOI, are marine and freshwater fish, freshwater turtles, freshwater and estuarine crocodiles, cetaceans, dugongs and sea turtles.

12.4.2 Discipline-specific Impact Assessment Method

The significance assessment approach described in Chapter 3 was primarily used to assess the impacts of underwater noise to aquatic fauna. This approach is based on determining significance through a combination of magnitude (of the impact) and sensitivity (of the receptor). The discipline-specific criteria used to categorize magnitude and sensitivity of underwater noise impacts are described in Section 12.4.2.1 and Section 12.4.2.2, respectively.

Assessment of the sensitivity of receptors and magnitude of impacts also considers whether acoustic thresholds for impacts, where available, are exceeded based on calculating underwater noise attenuation with distance from Project noise sources (see Part 1 of Volume 3). The impact

assessment is therefore a combination of the qualitative significance assessment approach and the semi-quantitative modeling.

12.4.2.1 Magnitude of Impact

The magnitude of the impact for underwater noise is a combination of the geographical extent of radiated noise, intensity (severity) and its duration. In aquatic environments, impacts have the potential to be widespread, e.g., low frequency noise propagation, but with a differing level of significance based on the intensity and duration of the impact.

Magnitude has been categorized as per the descriptors in Table 12.24. Further description of the various impacts that underwater noise may have on marine fauna is provided in Section 12.4.3.

Table 12.24 – Criteria for the Magnitude of Impacts

Magnitude	Description
Very high	♦ Aquatic fauna exposed to very high levels of impulsive continuous or intermittent noise. ♦ Aquatic fauna exposed to very high levels of non-impulsive, continuous or intermittent noise. ♦ Fatality or trauma causing rupture of swim bladder and non-auditory bleeding and substantial hemorrhaging of eyes and tissues (e.g., kidney or liver). ♦ Permanent hearing loss via a permanent threshold shift that is irreversible. ♦ All aquatic fauna permanently displaced vertically or horizontally from the sound field for the duration of the noise-generating activity. ♦ High level of auditory masking of biologically important sounds (e.g., vocalization) in non-injurious sound field.
High	♦ Aquatic fauna exposed to high levels of impulsive, continuous or intermittent noise. ♦ Aquatic fauna exposed to high level of non-impulsive, continuous broadband noise. ♦ Permanent hearing loss via a permanent threshold shift that is irreversible. ♦ Noise-sensitive aquatic fauna that are temporarily displaced vertical or horizontally from the sound field for the duration of the noise-generating activity. ♦ Medium level of auditory masking of biologically important sounds (e.g., vocalization).
Medium	♦ Aquatic fauna exposed to moderate levels of impulsive continuous or intermittent noise. ♦ Aquatic fauna exposed to moderate level of non-impulsive, continuous broadband noise that is tolerated. ♦ Temporary hearing loss via a temporary threshold shift that is reversible within a few days. ♦ Noise-sensitive aquatic fauna that are temporarily displaced vertically or horizontally from the sound field but return to previously occupied areas during the noise-generating activity. ♦ Low level of auditory masking of biologically important sounds (e.g., vocalization).
Low	♦ Aquatic fauna exposed to low levels of non-impulsive, continuous broadband noise. ♦ Temporary hearing loss via a temporary threshold shift that is reversible within a few hours. ♦ Aquatic fauna not displaced vertically or horizontally from the sound field during the noise-generating activity through habituation. ♦ Temporary hearing loss via a temporary threshold shift that is reversible within a few hours. ♦ Auditory masking is weak except near the noise source.
Minimal	♦ Aquatic fauna exposed to low levels of non-impulsive, continuous or intermittent noise. ♦ Aquatic fauna remain in the sound field during the noise-generating activity through habituation or perceiving the sound field as non-threatening. ♦ Temporary hearing loss via a temporary threshold shift that is reversible within a few minutes. ♦ Auditory masking absent but may occur near the noise source. ♦ Aquatic animal is unlikely to approach a high intensity noise source due to the detection of an underwater noise gradient or is exposed for a very short period that is insufficient to cause auditory damage.

12.4.2.2 Sensitivity of Receptors

Table 12.25 shows the descriptors used to categorize the sensitivity of receptors to underwater noise. This differs to the approach used to assess the sensitivity of aquatic biodiversity in Sections 11.5 and 12.3, which is largely based on IUCN Red List threatened species status. Instead, categorization is based on species sensitivity with specific regard to underwater noise. The difference in approach is illustrated by considering the largetooth sawfish (*Pristis pristis*) and the northern river shark (*Glyphis garricki*). Both these species are classified as Critically Endangered under the IUCN Red List and therefore have a sensitivity of Very High in the freshwater and marine biodiversity impact assessments (Sections 11.5 and 12.3). Considering sensitivity to underwater noise, these two fish are cartilaginous fish species, which are only sensitive to particle motion and vibration and not to sound pressure (Myrberg, 2001); therefore, the former approach giving a sensitivity rating of Very High is inappropriate for underwater noise since these fish do not hear or sense sound pressure and therefore have a ***Low*** sensitivity.

Table 12.25 presents sensitivity criteria for noise-sensitive aquatic fauna used in the impact assessment whereby sensitivity relates solely to sensitivity to underwater noise. The acoustic threshold criteria, behavioral responses, modification of vocalization and distribution apply to a range of aquatic fauna, including cetaceans, sea turtles, freshwater turtles, crocodiles and dugongs. Additional emphasis is placed on fish sensitivity in the descriptors, as they are the most abundant sensitive receptors in the PAOI likely to be exposed to underwater noise. Other abundant faunal groups include zooplankton, micronekton (e.g., larval stages of fish and decapods) and invertebrates, which do not respond to sound pressure but rather to particle motion and vibration. Most zooplankton studies relate to the effects of very high-energy impulsive noise from marine geophysical surveys using air guns (e.g., McCauley et al., 2017) with fewer studies for non-impulsive noise sources. A lack of acoustic damage or disturbance threshold criteria exists for both impulsive and non-impulsive noise impacts to zooplankton and micronekton, and threshold criteria for particle motion or vibration do not exist; therefore, water column zooplankton and micronekton, and benthic invertebrates have not been considered further in this assessment.

Table 12.25 – Criteria for the Sensitivity of a Receptor

Sensitivity	Description
Very High	♦ Acoustic threshold criteria for acoustic damage (tissue or gas-filled organs) are exceeded. ♦ Acoustic threshold criteria for onset of permanent threshold shift are exceeded causing permanent hearing loss due to auditory cell death or nerve damage that is irreversible.
High	♦ Acoustic threshold criteria for onset of permanent threshold shift are not exceeded. ♦ Acoustic threshold criteria for onset of temporary threshold shift are exceeded. ♦ Acoustic threshold criteria for disruptive behavioral disturbances* are exceeded. ♦ Highly noise-sensitive fish with a swim bladder connected to their ear or gas-containing spheres (prootic bullae) (e.g., sardines, anchovies, freshwater herrings and catfish). ♦ Group 4# fish that hear sounds below 1,000 Hz in a similar manner to fish in Group 1 see below) but their hearing range extends up to at least 4 kHz and some species are able to detect sounds to over 180 kHz. ♦ Major changes in locomotion speed, direction or dive profile and major avoidance of sound sources and major shift in individual or group distribution (aggregation or separation). ♦ Prolonged cessation or modification of vocal behavior.
Medium	♦ Acoustic threshold criteria for onset of permanent threshold shift and temporary threshold shift or behavioral disturbance are not exceeded. ♦ Moderately noise-sensitive fish with a swim bladder close to their ear and a type of structure mechanically coupled to the inner ear (e.g., marine catfish and sciaenids [croakers and drummers]).

Table 12.25 – Criteria for the Sensitivity of a Receptor (cont'd)

Sensitivity	Description
Medium (cont'd)	♦ Group 3# fish that hear sounds to 3,000 Hz or more, and their hearing sensitivity (which is pressure driven), is better than in fish of Groups 1 and 2 (see below). ♦ Moderate changes in locomotion speed, direction or dive profile and moderate avoidance of sound sources (temporary vertical and lateral displacement) and moderate shift within group distribution (aggregation or separation). ♦ Minor cessation or modification of vocal behavior.
Low	♦ Acoustic threshold criteria for onset of permanent threshold shift and temporary threshold shift or behavioral disturbance are not exceeded. ♦ Potentially noise-sensitive fish with a swim bladder distant from their ear but have no known structures in the auditory system that would enhance hearing of sound pressure (e.g., wide range of fish species including some tuna with swim bladders which includes yellowfin tuna). ♦ Group 2# fish that hear sounds from below 50 Hz and up to 800 to 1,000 Hz (though several probably only detect sounds to 600 to 800 Hz). ♦ Minor but temporary avoidance of anthropogenic sound sources. ♦ Brief but minor shift within group distribution (aggregation or separation). ♦ Minor changes in locomotion speed, direction or dive profile but no avoidance of sound sources, and temporary orientation behavior within sound fields during noise-generating activity. ♦ Brief or minor cessation or modification of vocal behavior during noise-generating activity.
Minimal	♦ Acoustic threshold criteria for onset of permanent threshold shift and temporary threshold shift or behavioral disturbance are not exceeded. ♦ Noise-insensitive fish that do not have a swim bladder or other gas-filled organ and respond to particle motion or vibration only (e.g., sharks and skates, mackerels and most tuna), flatfish and other bottom living fish, and also include fish eggs and larvae. ♦ Group 1# fish are likely to use only particle motion for sound detection and the highest sound frequency detected is likely to be no greater than 400 Hz, with poor sensitivity compared to fish with swim bladders. ♦ Insensitivity to underwater noise at or just above ambient background noise levels; that is within natural variability of baseline noise. ♦ Brief and temporary orientation response to sound field during noise-generating activities. ♦ No significant cessation or modification of vocal behavior. ♦ Zero sensitivity if an aquatic animal is not present within a sound field.

* Disruptive behavioral disturbance includes changes in social interaction, feeding, movement, separation distance between mother and infant, and temporary or permanent habitat abandonment.
# Classification of fish hearing group sensitivities by Popper (2012).

12.4.2.3 Impact Significance

The significance of an impact on a receptor is determined by combining the likely magnitude of the impact on that receptor shown in Table 12.24 with its sensitivity shown in Table 12.25 via the significance assessment matrix shown in Table 12.26.

Table 12.26 – Impact Significance Matrix Relevant to Underwater Noise

Magnitude of Impact	Sensitivity of Receptor				
	Very High	High	Medium	Low	Minimal
Very High	Severe	Major	Major	Moderate	Moderate
High	Major	Major	Moderate	Moderate	Minor
Medium	Major	Moderate	Moderate	Minor	Minor
Low	Moderate	Moderate	Minor	Minor	Negligible
Minimal	Minor	Minor	Negligible	Negligible	Negligible

12.4.2.4 Spatial and Temporal Scope

The spatial scope of the underwater noise impact assessment is centered on the navigable Purari River transport corridor in PRL-15 and the Purari River delta (i.e., estuaries and distributaries), and the marine section of the proposed export pipeline route from nearshore Orokolo Bay to the offshore Gulf of Papua to a nearshore point immediately to the west of Caution Bay, which is the lowest astronomical tide (LAT) mark.

The temporal scope covers underwater noise generated during the construction, operations and decommissioning Project phases.

12.4.2.5 Assessment Criteria

No explicit underwater noise acoustic threshold criteria or guidelines exist for aquatic fauna in Papua New Guinea; therefore, a literature search was conducted to collate overseas underwater noise level criteria to protect noise-sensitive aquatic fauna. The assessment criteria adopted in this impact assessment are based on peer-reviewed and widely accepted literature. When acoustic threshold criteria for aquatic fauna were unavailable, a literature review was undertaken to identify the distances at which noise-sensitive aquatic fauna may show behavioral reaction to various identified noise sources and the received sound pressure or sound exposure levels that initiated the reaction.

Desktop modeling and assessment of underwater noise was undertaken to inform the impact assessment (see Part 1 of Volume 3). Project-related underwater noise was assessed at representative locations in the riverine environments of PRL-15 and the river transport corridors, and the nearshore and offshore marine segments of the offshore export pipeline route described in Section 12.4.1 and shown in Figure 8.29.

Tables 12.27 to 12.32 summarize the acoustic threshold criteria adopted for the underwater noise impact assessment and identify the literature source for the adopted criteria. Part 1 of Volume 3 provides further detail regarding the source information for the criteria. Further explanation of the technical units and terms used to describe underwater noise levels in Table 12.27 to 12.32 is provided in Section 8.7.

Table 12.27 – Adopted Acoustic Threshold Criteria for Cetacean Behavioral Disturbance for All Noise Sources

Acoustic Impact	Acoustic Threshold Criterion (dB re 1μPar$_{ms}$)
Potential high-level behavioral reaction to impulsive noise and potential permanent physiological auditory damage (i.e., irreversible reduction in hearing sensitivity).	180
Potential moderate-level behavioral reaction to impulsive noise and potential temporary physiological auditory damage (i.e., reversible reduction in hearing sensitivity with full recovery after exposure).	160
Potential moderate-level behavioral reaction to non-impulsive, continuous broadband noise but with no physiological auditory damage.	120

Source: McCauley et al. (2000); Environment Australia (2001); Southall et al., (2007); DEWHA (2008); NMFS (2018).

Table 12.28 – Adopted Non-impulsive Noise Acoustic Threshold Criteria for Cetaceans

Hearing Group	Hearing Range (Frequency)	Non-impulsive Sound Exposure Level (dB re 1 μPa²•s)	
		Permanent Threshold Shift	Temporary Threshold Shift
Low frequency cetaceans (baleen whales)	7 Hz to 35 kHz	199	179
Mid frequency cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz	198	178
High frequency cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* and *L. australis*)	275 Hz to 160 kHz	173	153

Source: NMFS (2018); Finneran (2016).

Table 12.29 – Adopted Impulsive Noise Acoustic Threshold Criteria for Cetaceans

Hearing Group	Hearing Range (Frequency)	Permanent Threshold Shift		Temporary Threshold Shift	
		Sound Exposure Level	Peak Sound Pressure Level (SPL_{pk})	Sound Exposure Level	Peak Sound Pressure Level (SPL_{pk})
		dB re 1μPa²•s	dB re 1μPa_{rms}	dB re 1μPa²•s	dB re 1μPa_{rms}
Low frequency	7 Hz to 35 kHz	183	219	168	213
Mid frequency	150 Hz to 160 kHz	185	230	170	224
High frequency	275 Hz to 160 kHz	155	202	140	196

Source: NMFS (2018). SEL threshold criteria include a marine mammal auditory weighting (Finneran, 2016).

Table 12.30 – Adopted Acoustic Threshold Criteria for Fish

Acoustic Impact	Acoustic Threshold Criterion
Fish injury thresholds and onset of permanent threshold shift (bony fish)	Received peak sound pressure level of 206 dB re 1 μPa_{pk} rms
	Cumulative sound exposure level of 203 dB re 1 μPa²•s
Behavioral disturbance (bony and cartilaginous fish)	150 dB re 1 μPa_{rms}

Source: Halvorsen et al. (2012a, 2012b); Casper et al. (2012a, 2012b); Casper et al. (2013 a, 2013b); WSDOT (2019).

Table 12.31 – Summary of Adopted Acoustic Threshold Criteria for Turtles and Crocodiles

Acoustic Impact	Acoustic Threshold Criterion
Physical injury and onset of permanent threshold shift	Received peak sound pressure level of 208 dB re 1 μPa_{pk}
Behavioral disturbance (increased swimming speed and behavior becomes increasingly erratic with avoidance probable)	Received average sound pressure level of 175 dB re 1 μPa_{rms}

Source: Gavrilov et al. (2016); Popper et al. (2006); McCauley et al. (2000).

Table 12.32 – Summary of Adopted Acoustic Threshold Criteria for Dugongs

Acoustic Impact	Acoustic Threshold Criterion	
	Peak Sound Pressure Level (dB re 1 μPa$_{pk}$)	Weighted Sound Exposure Level (dB re 1 μPa^2•s)
Impulsive Noise		
Physical injury and onset of permanent threshold shift	226	190
Non-injurious and onset of temporary threshold shift	220	175
Non-impulsive Noise		
Behavioral disturbance (increased swimming speed and behavior becomes increasingly erratic with avoidance probable)	220	175

Source: Impulsive noise criteria by Finneran, 2016). Non-impulsive noise criterion by McPherson et al. (2017).
* Unit is dB re 1 μPa$_{rms}$. – Denotes not applicable.

12.4.3 Identification of Potential Impacts

Potential impacts to underwater noise can be avoided or minimized through Project design which is based on a risk-management approach, considering geotechnical constraints (e.g., flooding, landslides risks, geohazards) and anticipating and avoiding, or where avoidance is not possible, minimizing environmental and social impacts (e.g., avoidance of sensitive features, physical and economic displacement, priority ecosystem services, and minimization of project footprint, land clearing and disturbance, emissions and discharges) [ED013]. Specific embedded design controls are identified throughout this section where they address potential impacts.

12.4.3.1 Potential Impacts of Underwater Noise

The potential impacts of underwater noise on aquatic fauna will vary depending on a range of factors including the noise sensitivity of the aquatic fauna, characteristics of the noise source (e.g., impulsive or non-impulsive continuous noise), noise propagation and transmission loss, and river, estuary or sea bathymetry and bottom substrate composition.

The response or potential impacts associated with underwater noise to aquatic fauna may be broadly categorized into the following five categories, which increase in severity from the lowest to the highest: i) audibility; ii) auditory masking; iii) behavioral response; iv) physiological impacts; and v) trauma or fatality. Further detail regarding the five categories of potential impacts to aquatic fauna is provided in the following sections.

Figure 12.13 summarizes the theoretical impact zones for these impact categories relative to an underwater noise source (represented by a black dot), which is located in the center. Received noise levels at the edge of these zones have been calculated on the estimated noise source levels due to Project activities and sound transmission loss. These calculations are provided in Part 1 of Volume 3. The calculated noise levels were then compared to the acoustic threshold criteria (see Section 12.4.2) to assess the residual impacts of underwater noise (see Section 12.4.5).

Audibility

Project-generated underwater noise is at a level that can be perceived by aquatic fauna but will depend on ambient background noise. The distances of audible detection of Project-generated noise by aquatic fauna will be larger when there is low ambient noise and smaller under high ambient noise conditions.

POTENTIAL UNDERWATER NOISE IMPACT ZONES SURROUNDING A NOISE SOURCE

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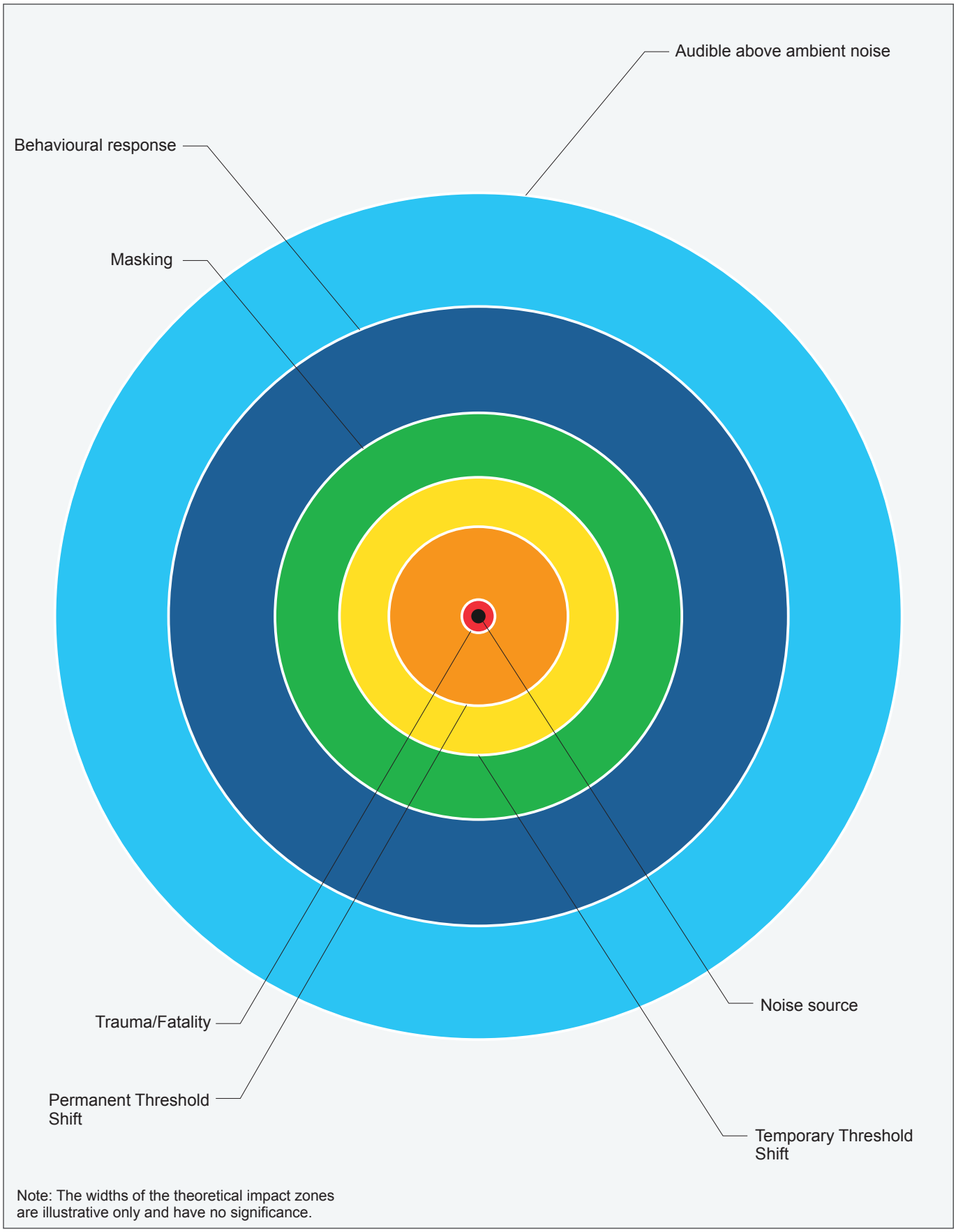
FIGURE 12.13



Adapted from Richardson et al. (1995).

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Auditory Masking

Project-generated underwater noise has the potential to mask communication amongst those aquatic fauna that produce sound for social cohesion, reproductive displays and territorial defense. Auditory masking occurs when anthropogenic noise prevents an aquatic animal from hearing these sounds. Masking of biologically important sounds may interfere with communication and social interaction and cause behavioral changes.

Behavioral Response

Behavioral responses of aquatic fauna to underwater noise include changes in vocalization, resting, diving and breathing patterns, changes in mother-infant spatial relationships, and potential avoidance of a noise source (NRC, 2003). Potential behavioral impacts can be categorized as disruptive or non-disruptive. Disruptive behavioral impacts include substantial changes in behavior of aquatic animals exposed to a sound. This may include long-term changes in behavior and distribution, such as moving from preferred sites for feeding and reproduction, or alteration of migration patterns. Potential non-disruptive impacts relate mainly to temporary behavioral responses to increased underwater noise, with aquatic fauna showing subtle behavioral changes (e.g., increased swimming, breathing or diving rates).

Physiological Impacts

Potential physiological impacts to aquatic fauna may be auditory or non-auditory. These impacts are discussed in more detail in the following sections.

Auditory Physiological Impacts

Exposure to loud or intense noise levels may cause permanent or temporary hearing loss, due to physiological damage to an aquatic animal's auditory system. Two types of potential auditory impact have been identified and are described in the following sections.

Temporary Threshold Shift

The onset of temporary threshold shift represents a temporary effect on hearing that is reversible. The effect on hearing will typically decrease over time after the underwater noise source is stopped and an aquatic animal's hearing will return to pre-disturbance noise levels in a few days, hours or minutes depending on the intensity and duration of the noise to which an aquatic animal was exposed. The effect on hearing is therefore reversible and does not represent physical injury or permanent hearing loss.

Permanent Threshold Shift

Exposure of an aquatic animal to intense underwater noise levels can produce a permanent threshold shift, which is a permanent shift in hearing sensitivity caused by irreversible damage to the sensory hair cells of the ear. Such a threshold shift represents a physical injury that causes hearing loss or degradation that is irreversible due to the permanent nature of auditory tissue damage.

Non-auditory Physiological Impacts

Intense underwater noise can induce physiological responses to noises that are non-auditory, such as minor internal bleeding or hematomas. There are no published guidelines or acoustic threshold criteria for potential non-auditory physiological impacts. The most sensitive aquatic fauna are species with swim bladders or other gas-filled organs, especially those fish species that have a swim bladder connected to the ear.

Trauma or Fatality

Exposure of an aquatic animal to extremely intense underwater noise levels can cause physical trauma or death. There are published acoustic threshold criteria above which the mortality of an aquatic animal is predicted to occur if it remains within the intense sound field.

The most sensitive aquatic fauna are species with swim bladders or other gas-filled organs, especially those that have a swim bladder connected to the ear.

12.4.3.2 Project Sources for Underwater Noise

Project activities that generate underwater noise and may potentially cause adverse impacts on aquatic fauna, and are considered in the residual impact assessment, are:

- Impact pile driving operations at the quay in the Purari River at the Logistics Base in PRL-15.
- Nearshore trenching and pile driving operations in Orokolo Bay and nearshore trenching in Caution Bay for the export pipeline.
- River dredging operations at the quay in the Purari River.
- Offshore construction (e.g., pipelaying and existing PNG LNG Gas Pipeline crossing works).
- River and marine vessel traffic.

The following embedded design controls address these potential impacts:

- All vehicles (including vehicles and aircraft) and machinery, plant and equipment will be regularly maintained to the manufacturer's specifications; defective items will be removed from service until they are repaired. [ED019].
- Minimize noise from machinery, plant and equipment, as far as practicable [ED031].

As indicated earlier, LNG facilities inside the PNG LNG Plant lease boundary are excluded from the scope of this EIS, the related indicative information presented here will be refined as part of the downstream Papua LNG EIS.

12.4.4 Proposed Mitigation and Management Measures

Table 12.33 describes mitigation and management measures to further reduce impacts due to underwater noise. Project underwater noise reduction strategies focus mainly on the Project's construction phase. No additional mitigation or management measures are proposed for Project operations or decommissioning, as the impacts relate primarily to shipping and barging activities where there is limited scope for underwater noise reduction. Mitigation and management in Caution Bay in the PNG LNG project lease area will be further aligned with the PNG LNG project and downstream Papua LNG project.

The Project's principle impulsive noise sources relate to the use of diesel-driven or hydraulic impact hammers to drive steel pipe casings or sheet piles at the quay of the Logistics Base on the Purari River in PRL-15, and during trenching for the shoreline crossing at Orokolo Bay. The noise from impact hammers is impulsive in nature and results from the impact of the hard surface of the hammer with that of the steel pile, which creates sounds that are short, sharp and high in amplitude.

Table 12.33 – Underwater Noise Mitigation and Management Measures

Potential Impact	Mitigation Strategy	Relevant Management Plan
Physiological injury or behavioral disturbance to freshwater fauna due to underwater noise from impact driving of: ♦ Steel pipe casings or sheet piles at the Purari River quay. ♦ Sheet piles during trenching at Orokolo Bay.	♦ Provide for a 'soft start' for impact hammer piling activities to allow transitory and resident fauna in the vicinity the opportunity to move away before sound levels reach maximum levels [EM039]. ♦ If noise-sensitive aquatic species are sighted during the piling activities, initiate shut down procedures and stop the operations until the animal is observed to leave the noise exclusion zone or a set period has passed [EM040].	Biodiversity Action Plan
Physiological injury or behavioral disturbance to freshwater fauna due to underwater noise from river dredging at the quay	No additional mitigations measures proposed.	-
Physiological injury or behavioral disturbance to aquatic fauna due to underwater noise from vessel traffic in the Gulf of Papua and along the river transport corridor.	No additional mitigations measures proposed.	-
Physiological injury or behavioral disturbance to marine fauna due to underwater noise from offshore pipelaying and existing PNG LNG Gas Pipeline crossing works along the export pipeline route in the Gulf of Papua.	No additional mitigations measures proposed.	-

Note: A dash (-) denotes no management plan is required.

12.4.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to underwater noise subject to the embedded design controls in Section 12.4.3 and the successful implementation of the mitigation and management measures in Section 12.4.4. A summary of the residual impact assessments is provided at the end of this section, including when and where (in which Project phase and location) these impacts are expected to occur.

The impact assessment presented in this section is based on the underwater noise modeling and information presented in Part 1 of Volume 3. Where residual impacts have been assessed as being more than ***Negligible,*** further detail on the assessment is provided in the following sections. Detail on impacts assessed to be ***Negligible*** is not always provided; however, for all negligible impacts, this impact significance was based on a ***Minimal*** magnitude combined with sensitivities between ***Minimal*** and ***Medium***, depending on the faunal group and the underwater noise source. The results of these individual assessments are also presented in the summary table provided in Section 12.4.6.

12.4.5.1 Disturbance or Injury of Freshwater Fauna from Pile Driving at the Quay

During the construction phase, pile driving of steel pipes and sheet piles is required when installing the quay at the Logistics Base. The quay is located about 10 km downstream of the

existing wharf at Herd Base. The residual impacts to freshwater fish, crocodiles and freshwater turtles are described in the following sections.

Freshwater Fish

The adopted acoustic damage threshold criterion of a peak sound pressure level of 206 dB re 1μPa_{pk} rms for bony fish is predicted to be exceeded within 5 m of impact hammer pile driving. Peak noise levels are predicted to only affect those individual fish that are stationary and in this impact zone. The soft start of the impact hammer noise levels is expected to drive fish away from the immediate vicinity of pile driving; therefore, acoustic damage to fish is not predicted.

Exceedance of the acoustic behavioral disturbance threshold criterion of 150 dB re 1 μPa_{rms} for all fish is predicted to occur up to 562 m from the source. The Purari River at this location is about 250 m wide; therefore, the threshold is exceeded across the total width of the river. This suggests that migration or other longitudinal fish movements could be temporarily disrupted during impact pile driving, although breaks between pile driving would allow for uninhibited movement during daylight hours and at nighttime.

Noise-sensitive fish (i.e., with a swim bladder connected to their ear, such as catfish and anchovies) have a ***High*** sensitivity to impact hammer pile driving, while the magnitude of impact is assessed as ***Minimal***. The residual impacts to noise-sensitive fish are therefore assessed to be ***Minor.*** This conclusion is based on the medium-term duration (i.e., two months) of impact pile driving, its intermittent nature, and the ability of fish to detect underwater noise gradients and avoid areas of higher noise levels closer to the pile driving sound source.

Residual impacts to noise-tolerant fish (i.e., without a swim bladder or other gas-filled organ, such as sawfish species) are assessed as ***Negligible***.

Crocodiles

Both saltwater crocodiles (*Crocodylus porosus*) and freshwater New Guinea crocodiles (*Crocodylus novaeguineae*) are known to respond to low frequency sounds in the 50 to 1,500 Hz range and, in addition to their hearing system, the scales of their face and bodies are sensitive to vibrations travelling through water (Kaplan, 2014). Crocodiles are likely to sense the vibrations from impact pile driving and may avoid the river segment affected by impact pile driving noise when active pile driving is taking place; however, given that both saltwater and freshwater crocodiles tend to be nocturnal, they may pass through this area during the night when pile driving is not occurring. Consequently, crocodile sensitivity to pile driving noise is ***Low***, while the magnitude is ***Medium***. The residual impact rating of pile driving on crocodiles is therefore assessed to be ***Minor***.

Freshwater Turtles

Exceedance of the behavioral disturbance threshold criterion of 175 db re 1 μPa_{rms} for turtles is predicted to occur up to 32 m from the pile driving noise source, while injury thresholds are not exceeded. A ‘soft start’ will be implemented to allow noise-sensitive species to move away before maximum noise levels are reached, and shutdown procedures will be initiated if sensitive species are sighted. Residual impacts to turtles are therefore assessed to be ***Negligible.***

12.4.5.2 Disturbance or Injury of Freshwater Fauna from River Dredging

Dredging requirements will be determined during FEED; however, it is anticipated that dredging of approximately 6,000 m^3 of sand and sediment from the Purari River adjacent to the Logistics Base will be required to accommodate the drafts of various Project vessels and barges.

Freshwater Fish

Exceedance of the acoustic damage threshold criterion for all bony fish of a peak sound pressure level of 206 dB re 1μPa_{pk} rms is not predicted to occur at the dredging site; therefore, acoustic damage to fish is not predicted from the non-impulsive, continuous or intermittent broadband noise generated by dredging. Exceedance of the behavioral disturbance threshold criterion of 150 dB re 1 μPa_{rms} for all fish is predicted to occur up to 32 m from the dredging noise source. This distance represents a localized impact zone around the dredge, which would not inhibit fish migration or other longitudinal movements in adjacent parts of the river near the active dredging site. Fish are expected to avoid areas of higher noise levels closer to river dredging.

The sensitivity of noise-sensitive freshwater fish (e.g., those with a swim bladder connected to their inner ear, such as catfish and anchovies) to dredging noise is assessed as ***High*** while the magnitude is ***Minimal***. The residual impact rating of dredging noise for noise sensitive freshwater fish is therefore assessed to be ***Minor***.

The residual impact rating of noise-tolerant (or insensitive) fish (i.e., without a swim bladder or other gas-filled organ, such as sawfish species) is assessed to be ***Negligible***.

Freshwater Turtles and Crocodiles

Injury to freshwater turtles is not predicted to occur from the non-impulsive, continuous or intermittent noise generated by dredging given that exceedances of the acoustic threshold criterion for injury of a peak sound pressure level of 208 dB re 1μPa_{pk} is not predicted to occur during dredging. Exceedance of the behavioral disturbance threshold criterion of 175 dB re 1 μPa_{rms} for freshwater turtles and crocodiles is predicted to only occur within 2 m of the river dredging noise source. Residual impacts to freshwater turtles and crocodiles are therefore assessed to be ***Negligible***.

12.4.5.3 Disturbance or Injury of Marine Fauna from Nearshore Trenching and Piling Activities

Nearshore trenching is proposed at the shore crossing of the offshore export pipeline route in Orokolo Bay and Caution Bay for excavation, pipeline installation and post-installation burial. Sheet piles will also be driven near the water's edge at Orokolo Bay to support trench walls. The assessment of nearshore trenching and piling activities has been completed for Orokolo Bay given the additional high impact sound generating activity at this location; however, the assessment is also applicable to trenching at Caution Bay.

Cetaceans

Low frequency hearing cetaceans, i.e., baleen whales, are unlikely to be found in the shallow nearshore waters of Orokolo Bay or Caution Bay, given their rare occurrence in the Gulf of Papua in general. Nonetheless, if present, acoustic damage impacts are not expected given the mitigation and management measures outlined in Section 12.4.4. Exceedance of the impulsive noise behavioral disturbance threshold of 160 dB re 1 μPa_{rms} for low frequency cetaceans is predicted to occur up to 100 m from the nearshore pile driving operation. Given the habitat availability in the Gulf of Papua, this is a very small impact zone. The residual impact of nearshore trenching and pile driving is assessed as ***Negligible*** for all cetacean hearing groups (i.e., low, mid and high frequency).

Dugongs

Neither the physical injury threshold of 226 dB re 1 μPa_{pk} or the behavioral disturbance threshold of 220 dB re 1 μPa_{pk} for dugongs are exceeded at the in-water nearshore pile driving noise

source. The residual impact of nearshore trenching and in-water pile on dugongs is assessed as ***Negligible.***

Sea Turtles and Crocodiles

The physical injury threshold of 208 dB re 1 μPa_{pk} for sea turtles or crocodiles is not exceeded at the nearshore trenching and in-water piling operation. The behavioral effects threshold of 175 dB re μPa_{rms} for turtles and crocodiles is predicted to be exceeded up to 2.2 m from nearshore trenching and in-water piling activities, which represents a small and highly localized impact zone. Residual impacts are therefore assessed to be ***Negligible***.

Fish

Exceedance of the acoustic behavioral disturbance threshold criterion of 150 dB re 1 μPa_{rms} for all fish is predicted to occur up to 100 m from the nearshore pile-driving activity, which represents a small and localized area. Thresholds for injury to bony fish are not predicted to occur from the non-impulsive, intermittent broadband noise generated during the backhoe trenching cycle. Residual impacts from in-water piling activities are therefore assessed to be ***Negligible***.

12.4.5.4 Disturbance or Injury of Freshwater Fauna from River Vessel Noise

The assessment of residual impacts of river vessel traffic has focused on Assessment Location 7, which is located downstream of the Logistic Base and is representative of other main channel river corridors (see Section 12.4.1 and Figure 8.29).

Fish

Exceedance of the acoustic behavioral disturbance threshold criterion of 150 dB re 1 μPa_{rms} for all fish is predicted to occur within 10 m from a typical barge, which represents a small area or volume of water mainly below and astern of the vessel. Noise above the threshold when the vessel is passing may cause behavioral responses in fish such as temporary vertical or horizontal displacement. The non-impulsive, broadband noise generated by vessel engines and propellers is unlikely to exceed thresholds for injury to bony fish. Residual impacts are therefore assessed to be ***Negligible***.

Freshwater Turtles and Crocodiles

River vessel noise does not exceed the thresholds for behavioral effects or injury to turtles and crocodiles. Residual impacts are therefore assessed to be ***Negligible***.

12.4.5.5 Disturbance or Injury of Marine Fauna from Offshore Construction Activities

The assessment of residual impacts of offshore construction has focused on underwater noise generated by pipelaying activities and concrete mattress installation to cross the existing PNG LNG Gas Pipeline (Section 4.10.6).

During their review of impacts on marine mammals due to underwater noise, Richardson et al. (1995) did not specifically note marine pipelaying as a distinct source of anthropogenic noise. It is reasonable to conclude that actual laying of the pipe on the seabed is unlikely to be a source of any noise of environmental significance. Most of the underwater noise generated by offshore construction relates to the non-impulsive, intermittent or continuous broadband noise generated by the construction support vessels (e.g., propulsion and thrusters) rather than the quieter noise levels generated by either the laying of the pipeline on the seabed or installing concrete mattresses to cross the existing PNG LNG Gas Pipeline.

Cetaceans

The non-impulsive broadband noise behavioral disturbance threshold of 120 dB re 1 μPa_{rms} for low-frequency hearing cetaceans (e.g., baleen whales) extends up to 15 km from pipelay activities and pipeline crossing construction activities. Given the habitat availability in the wider Gulf of Papua, this represents a relatively small area in the wider Gulf of Papua. Low-frequency hearing cetaceans, if present, are expected to detect the underwater noise gradient and not approach the sites of offshore construction activities. The residual impact of offshore construction is assessed as ***Negligible*** for all cetaceans, including mid- and high frequency hearing cetaceans that are less sensitive to non-impulsive broadband underwater noise.

Dugongs

Dugongs are generally absent in the offshore waters of the Gulf of Papua but do occur along the coast where they may be exposed to underwater noise propagating towards the coast from offshore construction activities. While there are no acoustic threshold criteria for behavioral disturbance in dugongs, McPherson et al. (2017), recommended that the non-impulsive broadband noise behavioral disturbance threshold of 120 dB re 1 μPa_{rms} for cetaceans also be adopted for dugongs; although, this is likely to be overprotective given the poorer hearing ability of dugongs compared to low-frequency cetaceans.

The adopted non-impulsive broadband noise behavioral disturbance threshold of 120 dB re 1 μPa_{rms} for dugongs extends up to 15 km from pipelay activities and pipeline crossing construction activities. Given that dugongs live or transit close to the coast where ambient noise levels are around an average of between 110 and 120 dB re 1 μPa_{rms}, the residual impacts of offshore construction are assessed to be ***Negligible***.

Sea Turtles and Crocodiles

The acoustic threshold criterion of 175 dB re 1 μPa_{rms} for behavioral disturbance in sea turtles and saltwater crocodiles is not exceeded further than 3.4 m from an offshore construction activity, which represents a very small acoustic disturbance impact zone. The residual impacts of offshore marine construction on sea turtles and crocodiles are assessed as ***Negligible***.

Fish

Acoustic thresholds for injury to marine fish are not predicted to be exceeded due to the non-impulsive, broadband noise generated during pipelay and pipeline crossing construction activities.

The acoustic disturbance threshold of 150 dB re 1 μPa_{rms} for marine fish is exceeded up to 158 m from pipelaying or concrete mattress installation. This represents a small behavioral disturbance impact zone of limited duration, as the pipelaying progresses along the export pipeline route. Overall, the residual impacts of offshore construction on bony and cartilaginous marine fish species are assessed to be ***Negligible***.

12.4.5.6 Disturbance or Injury of Marine Fauna from Marine Vessel Noise

The residual impacts of marine vessel traffic have focused on vessels transiting the Gulf of Papua. Background noise levels have been estimated at Assessment Location 2 (South of Kerema) and Assessment Location 3 (South of Ihu), and are representative of other locations along the offshore marine segment of the export pipeline route.

Cetaceans

Cetaceans are unlikely to be found in the shallow nearshore waters of Caution Bay, given their very rare occurrence in the Gulf of Papua in general. Nonetheless, if present, the underwater

noise radiated by Project vessels crossing the Gulf of Papua does not exceed the acoustic damage threshold criterion of 180 dB re 1 μPa_{rms} for all cetaceans, as the vessel source sound pressure level does not exceed 175 dB re 1 µPa at 1 m. Exceedance of the acoustic behavioral disturbance threshold criterion of 120 dB re 1 μPa_{rms} for cetaceans is predicted to occur within 562 m from the vessels. This represents a small area in the Gulf of Papua. Low frequency hearing cetaceans (i.e., baleen whales) passing through the gulf sense underwater noise gradients and are anticipated to avoid or deviate around Project vessels, as they would do with other third-party ships and shipping lanes in general in the gulf. Mid-frequency and high frequency hearing cetaceans, such as toothed whales and dolphins, are less affected by vessel noise than low frequency cetaceans. Overall residual impacts are assessed to be ***Negligible*** for all cetacean hearing groups (i.e., low, mid and high frequency).

Dugongs

As for cetaceans, exceedance of the non-impulsive noise behavioral disturbance threshold criterion of 120 dB re 1 μPa_{rms} for dugongs is predicted to occur within 562 m of the vessels passing through the nearshore waters of the Gulf of Papua, while thresholds for injury are not exceeded. This represents a small acoustic impact zone in which transiting dugongs may be behaviorally disturbed by the transient non-impulsive, broadband noise generated by passing vessels. Seagrass meadows (i.e., source of dugong food) do not occur in the nearshore areas adjacent to the Purari Delta or Orokolo Bay; hence dugongs are unlikely to be present in these locations. The residual impact of marine vessel noise is therefore assessed to be ***Negligible.***

Sea Turtles

Acoustic thresholds for behavioral effects or injury for turtles are not exceeded further than 1 m from marine vessels. Residual impacts are therefore assessed to be ***Negligible***.

Fish

Exceedance of the acoustic behavioral disturbance threshold criterion of 150 dB re 1 μPa_{rms} for all fish is predicted to occur up to 18 m from a typical Project vessel, which represents a very small area or volume of water mainly below and astern of the vessel. Noise above the threshold when the vessel is passing may cause behavioral responses in fish such as temporary vertical or horizontal displacement. These effects are expected to be limited to near-surface pelagic fish, since fish in deeper water will not be exposed to sound levels exceeding the threshold. The non-impulsive, broadband noise generated by vessel engines and propellers will not exceed thresholds for injury to bony fish. Residual impacts for all fish are therefore assessed to be ***Negligible***.

12.4.6 Summary of Residual Impacts for Underwater Noise

Table 12.34 provides a summary of the assessment of residual impacts due to underwater noise including in which Project phase and location these impacts are expected to occur. The table should be read in conjunction with the mitigation measures provided in Table 12.33.

All residual impacts to aquatic fauna due to underwater noise from Project activities are assessed to be ***Negligible*** to ***Minor***.

Table 12.34 – Summary of Assessment of Residual Impact Significance for Underwater Noise

Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Key Sensitive Receptor	Residual Impact	
						Sensitivity/ Magnitude	Significance
Jetty construction (Logistics Base) – impact driving of steel pipe casings or sheet piles at the river quay.	Physiological injury or behavioral disturbance to freshwater fauna due to underwater noise	River transport corridor	C	♦ EM039 ♦ EM040	Freshwater fish with swim bladders connected to the inner ear	High/ Minimal	Minor
					Freshwater and estuarine crocodiles	Low/ Medium	Minor
					Freshwater turtles	Minimal/ Minimal	Negligible
					Freshwater fish without swim bladders	Minimal/ Minimal	Negligible
Dredging at the Logistics Base	Physiological injury or behavioral disturbance to freshwater fauna due to underwater noise	River transport corridor	C, O	None	Freshwater fish with swim bladders connected to the inner ear	High/ Minimal	Minor
					Freshwater without swim bladders	Minimal/ Minimal	Negligible
					Freshwater turtles	Minimal/ Minimal	Negligible
					Crocodiles	Minimal/ Minimal	Negligible
Construction of shore crossings – marine nearshore trenching and impact pile driving of sheet piles.	Physiological injury or behavioral disturbance to marine fauna due to underwater noise	Orokolo Bay and Caution Bay	C	♦ EM039 ♦ EM040	Low frequency cetaceans	Medium/ Minimal	Negligible
					Mid frequency cetaceans (e.g., small toothed whales and dolphins)	Minimal/ Minimal	Negligible
					High frequency cetaceans (e.g., turbid water dolphins)	Minimal/ Minimal	Negligible
					Dugongs	Low/ Minimal	Negligible

Table 12.34 – Summary of Assessment of Residual Impact Significance for Underwater Noise (cont'd)

Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Key Sensitive Receptor	Residual Impact	
						Sensitivity/ Magnitude	Significance
Construction of shore crossings – marine nearshore trenching and impact pile driving of sheet piles (cont'd)	Physiological injury or behavioral disturbance to marine fauna due to underwater noise	Orokolo Bay and Caution Bay	C	♦ EM039 ♦ EM040	Sea turtles and crocodiles	Minimal/ Minimal	Negligible
					Marine fish in general	Low/ Minimal	Negligible
Offshore construction – pipelaying activity	Physiological injury or behavioral disturbance to marine fauna due to underwater noise	Offshore Gulf of Papua and Caution Bay (export pipeline route)	C	None	Low frequency cetaceans	Medium/ Minimal	Negligible
					Mid- and high-frequency cetaceans	Minimal/ Minimal	Negligible
					Dugongs	Low/ Minimal	Negligible
					Sea turtles and crocodiles	Minimal/ Minimal	Negligible
					Marine fish in general	Low/ Minimal	Negligible
Offshore construction – PNG LNG Gas Pipeline crossing	Physiological injury or behavioral disturbance to marine fauna due to underwater noise	Offshore Gulf of Papua and Caution Bay (export pipeline route)	C	None	Low frequency cetaceans	Medium/ Minimal	Negligible
					Mid- and high-frequency cetaceans	Minimal/ Minimal	Negligible
					Dugongs	Low/ Minimal	Negligible
					Sea turtles and crocodiles	Minimal/ Minimal	Negligible
					Marine fish in general	Low/ Minimal	Negligible

Table 12.34 – Summary of Assessment of Residual Impact Significance for Underwater Noise (cont'd)

Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Key Sensitive Receptor	Residual Impact	
						Sensitivity/Magnitude	Significance
Vessel traffic between the Gulf of Papua and PRL-15	Physiological injury or behavioral disturbance to estuarine and freshwater fauna due to underwater noise	River transport corridor	C, O, D	None	Freshwater fish in general	Low/ Minimal	Negligible
					Freshwater turtles	Low/ Minimal	Negligible
					Freshwater and estuarine crocodiles	Low/ Minimal	Negligible
Vessel traffic in the Gulf of Papua	Physiological injury or behavioral disturbance to marine fauna due to underwater noise	Orokolo Bay, offshore export pipeline route, Caution Bay and logistics supply route	C, O, D	None	Low frequency cetaceans (e.g., baleen whales)	Medium/ Minimal	Negligible
					Mid-frequency cetaceans (e.g., small toothed whales and dolphins) and high frequency cetaceans (e.g., nearshore turbid water dolphins)	Minimal/ Minimal	Negligible
					Dugongs	Low/ Minimal	Negligible
					Sea turtles.	Low/ Minimal	Negligible
					Marine pelagic and mid-water fish	Low/ Minimal	Negligible

C = Construction, O = Operations, D = Decommissioning and closure.

12.5 References

AECOM and BMT WBM. 2016. Townsville Port Expansion Project. Additional Information to Environmental Impact Statement. Section 6 Marine Water Quality. Report prepared by AECOM and BMT WBM for Port of Townsville Limited, Townsville.

ANZECC/ARMCANZ. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand. Canberra.

Cabaço, S., Santos, R. and Duarte, C. M. 2008. The impact of sediment burial and erosion on seagrasses: A review. *Estuarine, Coastal and Shelf Science* 79:354–366.

Carruthers, T.J.B., Dennison, W.C., Longstaff, B.J., Waycott, M., Abal, E.G., McKenzie, L.J. and Lee-Long, W.J. 2002. Seagrass habitats of northeast Australia: models of key processes and controls. *Bulletin of Marine Science* 71(3):1153–1169.

Casper, B. M., Halvorsen, M. B., and Popper, A. N. 2012a. Are sharks even bothered by a noisy environment? In: The effects of noise on aquatic life Eds. A. N. Popper and A. S. Hawkins. Springer, New York. pp 93–98.

Casper, B.M., Popper, A. N., Matthews, F., Carlson, T. J. and Halvorsen, M. B. 2012b. Recovery of barotrauma injuries in Chinook salmon, *Oncorhynchus tshawytscha* from exposure to pile driving sound. PLoS ONE 7(6):e39593.

Casper, B.M., Halvorsen, M.B., Matthews, F., Carlson, T.J. and Popper, A.N. 2013a. Recovery of barotrauma injuries resulting from exposure to pile driving sound in two sizes of hybrid striped bass. PLoS ONE 8(9):e73844.

Casper, B. M., Smith, M. E., Halvorsen, M. B., Sun, H., Carlson, T. J. and Popper, A. N. 2013b. Effects of exposure to pile driving sounds on fish inner ear tissues. *Comparative Biochemistry and Physiology Part A: Molecular and Integrative Physiology* 166(2):352–360.

CNS. 2009. PNG LNG Project Environmental Impact Statement. Coffey Natural Systems. Prepared for Esso Highlands Ltd.

Collier, C and Waycott, M. 2009. Drivers of change to seagrass distributions and communities on the Great Barrier Reef: Literature Review and Gaps Analysis. Marine and Tropical Sciences Research Facility, Cairns, Queensland.

DEWHA. 2008. *Environment Protection and Biodiversity Act Policy Statement 2.1: Interactions Between Offshore Seismic Exploration and Whales*. Department of the Environment and Water Resources, Canberra, Commonwealth of Australia.

DHI. 2010. Dredge Plume Impact Assessment. Appendix N2 of Draft Environmental Impact Statement/Environmental Review and Management Programme for the Proposed Wheatstone Project. Report prepared by DHI Australia for Chevron Australia Pty Ltd.

Done, T.J. 1992. Phase shifts in coral reef communities and their ecological significance. *Hydrobiologia* 247:121–132.

Duarte, C., Terrados, J., Agawin, N., Fortes, M., Bach, S. and Kenworthy, W. 1997. Response of a mixed Philippine seagrass meadow to experimental burial. *Marine Ecology Progress Series* 147:285–295.

Environment Australia. 2001. Guidelines on the application of the Environment Protection and Biodiversity Conservation Act to interactions between offshore seismic operations and larger

cetaceans. Marine Species Section, Department of the Environment and Heritage, Government of Australia. Canberra, ACT.

Erftemeijer, P. L. A., Riegl, B., Hoeksema, B. W. and Todd, P. A. 2012. Environmental impacts of dredging and other sediment disturbances on corals: A review. *Marine Pollution Bulletin* 64:1737–1765.

Finneran, J. J. 2016. Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise. Appendix A, pp. 37-107. In: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing. Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. NOAA Technical Memorandum NMFS-OPR-55. July.

Gavrilov, A., Wilkes, D. and Romero, M. G. 2016. Wheatstone Project. Underwater Noise Monitoring and Review Program Results. Modelling and measurements of underwater noise from marine pile driving. Final Report. Prepared by the Centre for Marine Science and Technology, Curtin University for Chevron. January.

Halvorsen, M. B., B. M. Casper, C. M. Woodley, T. J. Carlson, and A. N. Popper. 2012a. Threshold for onset of injury in Chinook salmon from exposure to impulsive pile driving sounds. PLoS ONE, 7(6):e38968.

Halvorsen, M. B., Casper, B. M., Matthews, F., Carlson, T. J. and Popper, A. N. 2012b. Effects of exposure to pile driving sounds on the lake sturgeon, Nile tilapia, and hogchoker. *Proceedings of the Royal Society Biological Sciences* 279:4705–4714.

Hayes, K.R., Cannon, R., Neil, K. and Inglis, G. 2005. Sensitivity and cost considerations for the detection and eradication of marine pests in ports. *Marine Pollution Bulletin* 5:823–834.

Hewitt, C. and Campbell, M. 2010. The relative contribution of vectors to the introduction and translocation of invasive marine species. Department of Agriculture, Fisheries and Forestry, Canberra, Australian Capital Territory.

IFC. 2007. International Finance Corporation. Environmental, Health, and Safety General Guidelines. April.

IFC. 2015. International Finance Corporation. Environmental, Health, and Safety Guidelines for Offshore Oil and Gas Development. June.

Kasu, J. Managing Director, National Fisheries Authority, NCD, Papua New Guinea. Letter to J. Noiray of Total E&P PNG Limited. 27 June 2019.

Kaplan, M. 2014. Reptile Hearing. A WWW publication at http://www.anapsid.org/reptilehearing.html accessed on 20 March 2019.

Kenyon, R.A., Loneragan, N.R., Manson, F.J., Vance, D.J. and Venables, W.N. 2004. Allopatric distribution of juvenile red-legged banana prawns (*Penaeus indicus*) and juvenile banana prawns (*Penaeus merguiensis*), and inferred extensive migration, in the Joseph Bonaparte Gulf, northwest Australia. *Journal of Experimental Marine Biology and Ecology* 309(1):79–108.

McCauley, R. D., Day, R.D., Swadling, K. M., Fitzgibbon, Q. P., Watson, R. A. and Semmens, J. M. 2017. Widely used marine seismic survey air gun operations negatively impact zooplankton. *Nature Ecology and Evolution* 1(7):0195.

McCauley, R. D., Fewtrell, J., Duncan, A., Jenner, C., Jenner, M-N., Penrose, J. D., Prince, R I. T., Adhitya, A., Murdoch, J. and McCabe, K. 2000. Marine seismic surveys: analysis and propagation of air-gun signals and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid. Prepared by Centre for Marine Science and Technology, Curtin University for the Australian Petroleum Exploration Association. August.

McPherson, C., Yurk, H., McPherson, G., Racca, R. and Wulf, P. 2017. Great Barrier Reef Underwater Noise Guidelines. Prepared by Jasco Applied Sciences for the Great Barrier Reef Marine Park Authority. August 2017.

Myrberg, A. 2001. Acoustic biology of elasmobranches. *Environmental Biology of Fishes* 60(31):31–45.

NMFS. 2018. 2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0). Underwater thresholds for onset of permanent and temporary threshold shifts. Office of Protected Resources. National Marine Fisheries Service. National Oceanic and Atmospheric Administration. U.S. Department of Commerce. NOAA Technical Memorandum NMFS-OPR-59. April.

NRC. 2003. Ocean noise and marine mammals. Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. Ocean Studies Board, Division of Earth and Life Studies, National Research Council. A WWW publication accessed on 13 October 2015 at www.nap.edu/books/0309085365/html/. Washington, DC, USA.

Pearson, R.G. 1981. Recovery and recolonization of coral reefs. *Marine Ecology–Progress Series* 4:105–122.

Popper, A. N. 2012. Fish Hearing and Sensitivity to Acoustic Impacts. Appendix J. Atlantic OCS Proposed Geological and Geophysical Activities, Mid-Atlantic and South Atlantic Planning Areas, Draft Programmatic Environmental Impact Statement. OCS EIS/EA BOEM 2012-005. March 2012.

Popper, A. N., Carlson, T. J., Hawkins, A. D., Southall, B. L. and Gentry, R. L. 2006. Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper. Report prepared for Washington State Department of Transportation.

Raaymakers, S. 2006. Shipping-related Introduced Marine Pests in the Pacific Islands: A regional strategy. Secretariat of the Pacific Regional Environment Programme, Apia, Samoa.

Reine, K and Clarke, D. 1998. Entrainment by hydraulic dredges—A review of potential impacts, Technical Note DOER-E1, United States Army Corp of Engineers, Environmental Laboratory, Vicksburg.

Richardson, W.J., Green Jr, C.R., Malme, C.I. and Thomson, D.H. 1995. *Marine Mammals and Noise*. Academic Press. New York, NY, USA.

Rollon, R., de Ruyter van Steveninck E., Van Vierssen, W. and Fortes, M. 1999. Contrasting recolonization strategies in multi-species seagrass meadows. *Marine Pollution Bulletin* 37:450–459.

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R .L., Greene, C. R. J., Kastak, D., Ketten, D. R., Miller, J. H., Nachtigall, P. E., Richardson, W. J., Thomas, J. A., Tyack, P. L. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals* 33:411–521.

TOTAL. 2015. General Specification. Environment. GS EP ENV 001. Environmental Requirements for Projects Design and E&P Activities. TOTAL S.A. May.

Unsworth, R.K.F., Colliuer, C.J., Waycott, M., McKenzie, L.J. and Cullen-Unsworth, L.C. 2015. A framework for the resilience of seagrass ecosystems. *Marine Pollution Bulletin* Volume 100:34–46.

WA EPA. 2016. Technical Guidance: Environmental Impact Assessment of Marine Dredging Proposals. Environmental Protection Authority, Perth, Western Australia.

Watson, RA and Turnbull, CT. 1993. Migration and growth of two tropical penaeid shrimps within Torres Strait, northern Australia. *Fisheries Research* 17:353–368.

Wilbur, D. H. and Clarke, D. G. 2007. Defining and assessing benthic recovery following dredging and dredged material disposal. Proceedings of the World Dredging Congress 1:603–618, World Dredging Congress, WODCON XVIII.

WSDOT. 2019. Chapter 7: Construction noise impact assessment. In: Biological Assessment Preparation Manual. Washington State Department of Transportation. Updated March 2019.

Zhang, P., Zhan, X., Li, J. and Huang, G. 2006. Swimming ability and physiological response to swimming fatigue in whiteleg shrimp, *Litopenaeus vannamei*. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* 145(1):26–32.