TOTAL
TOTAL E&P PNG LIMITED

PAPUA LNG PROJECT

UPSTREAM ENVIRONMENTAL IMPACT STATEMENT

VOLUME 1: MAIN REPORT

Chapter 11: Impacts - Terrestrial

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11. Impacts: Terrestrial

11.1 Landforms and Soils

11.1.1 Context

11.1.1.1 Landforms

Ridge and Ravine Landform

The northern section of PRL-15 is in the foothills of the frontal part of the Papuan Fold and Thrust Belt (see Figure 7.1). The relief in this area is pronounced, with landforms shaped by tectonic processes forming ridges and ravines with significant cliffs (Plate 11.1). The landforms are underlain by thickly bedded to massive sandstone and are scarred by numerous slumps, landslides and gullying. The maximum elevation of the ridge and ravine landform in PRL-15 is about 410 m asl. The ridge and ravine landform continues south at a lower relief (i.e., 10 to 50 m asl) along the eastern edge of the export pipeline route toward the coast.

Plate 11.1 – Ridge and Ravine Landform in Northern Area of PRL-15

Photo: SLR Consulting.

Composite Meander and Levee Alluvial Landform

South of PRL-15, the lower Purari River and delta are formed of a central meander, back plains and swamp landform (Plate 11.2). The back plains are subject to frequent flooding and are permanently swampy where drainage is impeded by levees or meander plains. The drainage status varies greatly, depending on local conditions, from poorly to well drained.

Plate 11.2 – Meandering River and Levee Alluvial Plains Landform

Photo: SLR Consulting.

Recent Littoral Landform

In the southern portion of the export pipeline route adjacent to Orokolo Bay, the littoral landform consists of beach, beach ridge complexes and beach plains. These beach terrain systems and plains are composed of recent sediments shaped as long parallel ridges and swales. Immediately west of this area, the landform is dominated by the main eastern river mouth distributary of the Purari River, which discharges into the Gulf of Papua. The drainage is tidal with a maze of channels that are mainly made up of swamps, marshes and estuaries. Mud banks along the channels support mangrove vegetation.

11.1.1.2 Soils

Soil units in the Project area are dominated by Entisol and Inceptisol soil orders. These are poorly formed soils with limited soil pedological development.

In the ridge and ravine areas in PRL-15, ongoing erosion prevents soil from developing over the bedrock parent material. These are denudational soils formed from weathering of the Earth's surface and are grouped into Soil Complex 1 (see Figure 7.5). In other areas of Project activities, soil complexes are aggradational soils that are formed from material deposition. On the alluvial plains in the southwestern parts of PRL-15 and along the export pipeline route (Soil Complex 2) and in beach landforms near the coast (Soil Complex 3), the soils are poorly formed because of ongoing deposition preventing the young soil from developing. The inundated tidal flats, swamps and saturated alluvial soils near the coast are dominated by Histosol soils (Soil Complex 4), which typically form under saturated conditions and have high organic matter in the upper layers.

The PAOI contains several soil units with acid sulfate soils potentially present. Such soils are prone to releasing acid leachate if disturbed or drained and exposed to the atmosphere. Except for one site in the southern extent of PRL-15 (located on a saturated drainage line of Kuku Creek), all sites that indicated potential acid sulfate soil (PASS) were located on alluvial flood plains, beach ridges, and plains in the lower Purari River delta, which experience frequent inundation. These soils are typically Psammaquents and Sulfaquents of Soil Complexes 2 and 3.

The coastal soils, represented by Histosols and Hydraquents of Soil Complex 4, are also considered likely to be PASS.

Soil complexes in the PAOI are categorized to be limited in their capability for conventional 'western' agriculture. Notwithstanding, local communities have managed to successfully grow tree crops of sago, coconut, papaya, betel nut, and mustard and other food crops for many generations. This is achieved with considerable intervention and shaping by villagers to provide drainage and compost mounding to assist plant growth.

Metal concentrations in soils are well below human health-based screening levels for contaminants; however, there are exceedances for cobalt, copper, lead, manganese, nickel, selenium, vanadium and zinc when compared to ecological screening levels for soils. Concentrations of chromium, selenium, vanadium and zinc that were high compared to other sites were recorded in samples from two sites inland from the coast in the southern part of the export pipeline route. It is not known if the source of these metals is related to anthropogenic activities or natural conditions. There is no evidence of hydrocarbon contamination of soil at any of the sampling sites. Levels of total petroleum hydrocarbons (TPHs) and benzene, toluene, ethylbenzene and xylene (BTEX) in all samples tested were below the limits of reporting and below ecological screening levels.

11.1.2 Discipline-specific Impact Assessment Method

The significance assessment method described in Chapter 3 was adopted to qualitatively assess the potential impact on landforms and soils from each phase of the Project.

The significance assessment method examines the degree to which the existing environment may potentially change because of Project-related activities. This assessment method is a function of the magnitude of impact on a resource or receptor and the sensitivity of that resource or receptor, as described in Chapter 3. Together, they determine the significance of the impact.

Sensitivity is defined as the susceptibility of a resource or receptor to change, including its capacity to adapt to or accommodate the kinds of changes that the Project may bring about. It also considers the intrinsic value of a resource, e.g., capacity to support natural vegetation and food crops in the case of soils.

Table 11.1 defines the categories for assessment of sensitivity for landforms and soils and considers:

- Landform stability and susceptibility to erosion.
- Soil capacity, considering pedological development, fertility and any adverse properties, such as the presence of PASS.

Table 11.1 – Landforms and Soils Sensitivity of Resource or Receptor

Category	Description
Very high	♦ Landform is very steep to precipitous, very highly unstable and very highly susceptible to erosion. ♦ Soil is very poorly developed, highly infertile with very low organic matter and is very highly erosion prone if exposed, or has very high adverse properties, e.g., PASS. Soil does not recover or recovers minimally from disturbance with very low natural vegetation recovery or by very extensive remedial measures. ♦ Soil is not contaminated, with concentrations of contaminants below human health and ecological screening levels and having undetectable levels of hydrocarbons.

Table 11.1 – Landforms and Soils Sensitivity of Resource or Receptor (cont'd)

Category	Description
High	♦ Landform is steep, highly unstable and highly susceptible to erosion. ♦ Soil is poorly developed, has low fertility and organic matter content and is highly erosion prone if exposed, or has high adverse properties, e.g., PASS. Soil recovers very slowly from disturbance with low natural vegetation recovery or by extensive remedial measures. ♦ Soil is minimally contaminated, with concentrations of contaminants below human health and ecological screening levels but having detectable levels of hydrocarbons.
Medium	♦ Landform is moderately undulating, moderately unstable and moderately susceptible to erosion. ♦ Soil is minimally developed, moderately fertile with moderate organic matter and is moderately erosion prone if exposed, or has moderate adverse properties, e.g., PASS. Soil recovers slowly from disturbance with moderate natural vegetation recovery or by moderate remedial measures. ♦ Soil has low levels of contamination, with no exceedances of human health screening levels but occasional exceedances of ecological screening levels.
Low	♦ Landform is gently undulating, slightly unstable and minimally susceptible to erosion. ♦ Soil is moderately well developed, highly fertile with high organic matter and is slightly erosion prone if exposed or has minimal adverse properties, e.g., PASS. Soil recovers moderately quickly from disturbance with relatively rapid natural vegetation recovery or by some active remedial measures. ♦ Soil is highly contaminated, with occasional exceedances of human health screening levels and ecological screening levels.
Minimal	♦ Landform is flat, highly stable and not susceptible to erosion. ♦ Soil is very well developed, very highly fertile with very high organic matter and is not erosion prone if exposed, or has no adverse properties, e.g., PASS. Soil recovers very quickly from disturbance with very rapid natural vegetation recovery and minimal active remedial measures. ♦ Soil is very highly contaminated, with numerous exceedances of human health screening levels and ecological screening levels.

Magnitude of impact is defined by the impact's severity, and spatial and temporal extents. Table 11.2 defines the categories adopted for assessing the magnitude of Project impacts on landforms and soils. Assessment of the magnitude of impact is undertaken assuming proposed mitigation measures have been successfully implemented, i.e., it provides a residual impact assessment.

Table 11.2 – Landforms and Soils Magnitude of Impact Criteria

Category	Factor	Description
Very High	Severity	Impact degrades soils or reduces landform stability with no potential for recovery to pre-disturbance condition. Spoil volumes are very high, and the propensity for slumping and erosion is very high. Active stabilization and regeneration that need very close monitoring are required at very high cost.
	Spatial extent	Impact to landform and soils from disturbance or displacement occurs more than 1,000 m from Project activity or component causing the impact.
	Temporal extent	Impact is very long-term, extending beyond 10 years.
High	Severity	Impact degrades soils or reduces landform stability with some potential for recovery to pre-disturbance condition. Spoil volumes are high, and the propensity for slumping and erosion is high. Active stabilization and regeneration that need close monitoring are required at high cost.
	Spatial extent	Impacts to landform and soils from disturbance or displacement occur more than 500 m but less than 1,000 m from Project activity or component causing the impact.
	Temporal extent	Impact is medium- to long-term, extending up to 10 years.

Table 11.2 – Landforms and Soils Magnitude of Impact Criteria (cont'd)

Category	Factor	Description
Medium	Severity	Impact degrades soils or reduces landform stability with reasonable potential for recovery to predisturbance condition. Spoil volumes are moderate, and the propensity for slumping and erosion is moderate. Active stabilization and regeneration with regular monitoring are required at moderate cost.
	Spatial extent	Impact to landform and soils from disturbance or displacement occurs more than 200 m but less than 500 m from Project activity or component causing the impact.
	Temporal extent	Impact is medium-term, extending up to five years.
Low	Severity	Impact degrades soils or reduces landform stability with moderate potential for recovery to predisturbance condition. Spoil volumes are low, and the propensity for slumping and erosion is low. Stabilization and regeneration with some monitoring are required at low cost.
	Spatial extent	Impact to landform and soils from disturbance or displacement occurs more than 50 m but less than 200 m from Project activity or component causing the impact.
	Temporal extent	Impact is short-term, extending up to one year.
Minimal	Severity	Impact causes no to minimal degradation to soils or effects to landform stability with full recovery expected. Spoil volumes are minimal, and the propensity for slumping and erosion is minimal. Minimal stabilization, regeneration or monitoring is required, at minimal cost.
	Spatial extent	Impact to landform and soils from disturbance or displacement is localized (within 50 m from Project activity or component causing the impact).
	Temporal extent	Impact is very short-term, less than three months.

A matrix combining the magnitude of impact category with the sensitivity category determines the significance of the impact due to the Project's activities. Table 11.3 presents the matrix used to establish the significance of Project impacts on landform and soils.

Table 11.3 – Landforms and Soils Significance of Assessment Matrix

Magnitude of Impact	Sensitivity of Resource/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

11.1.3 Identification of Potential Impacts

Potential impacts to groundwater 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.

11.1.3.1 Landform Destabilization

Impact to landform considers events associated with Project activities and normal climatic events. Potential impacts associated with major natural hazards and unplanned events, such as landslides due to seismic events, are considered in Chapter 18.

Project activities, particularly excavations and earthworks in PRL-15 and along the export pipeline route, may destabilize landforms, increasing the incidence of landslides or mass movements. These soil movements may contribute to the degradation of soil structure by burying structured and fertile topsoil and plant propagules, degrading soil aggregates and exposing more dispersive subsoils.

Other potential impacts include increased soil erosion during rain events. Sediment-laden water may enter streams, degrading water quality and smothering aquatic fauna due to increased turbidity and in-stream sedimentation, respectively. Such impacts are considered in Sections 11.3, 11.4 and 11.5.

Impacts on landforms are dependent upon site-specific landform conditions and climate factors in the area of Project activities. Specific landform conditions identified in the PAOI are described in Section 7.2.4 and Section 11.1.1. Table 11.4 identifies the various Project components and the landform type upon which they will be constructed. The susceptibility of these various landforms to Project activities is further discussed in the following sections.

Table 11.4 – Project Components and Landform Types

Project Component	Landform Type		
	Ridge and Ravine	Composite Meander and Levee Alluvial	Recent Littoral
Wellpads (including water supply dams)	✓	-	-
Roads, flowline/trunklines and water supply pipelines	✓	✓	-
Pipe yards and construction accommodation camps	-	✓	-
Spoil disposal sites	✓	✓	-
CPF, operations accommodation camp and Logistics Base	-	✓	-
Quarries and landfills	✓	✓	-
Purari Airstrip extension	-	✓	-
Onshore export pipelines (including valve stations)	-	✓	✓

Ridge and Ravine Landform

The wellpads, flowline/trunklines, water supply pipelines, roads and spoil disposal sites, quarries and landfills are located on ridge and ravine landforms in PRL-15 (see Figure 4.4, Figure 4.8 and Figure 4.9).

These landform locations experience very high rainfall and the landforms are prone to landslides or mass movements. Activities associated with construction, operations and decommissioning can increase this risk. The steepness of the landform and the scale of the Project infrastructure will necessitate localized excavation, filling or cut and fill of the ground surface during construction and then again during decommissioning to recontour and stabilize the modified landform. Minor works associated with maintaining infrastructure, particularly roads, may also occur during operations. These activities may destabilize slopes, particularly in steep to precipitous terrain.

Composite Meander and Levee Alluvial Landform

The CPF, operations accommodation camp, Logistics Base, water supply and discharge pipelines, Purari Airstrip, quarries and landfills are located on the alluvial plain of the Purari River at the foot of the ridge and ravine landform in PRL-15 (see Figure 4.4). The onshore export pipeline route and ROW access road also traverses the eastern alluvial plain of the Purari River from PRL-15 to the coast (see Figure 4.6). Pipe yards and associated construction accommodation camps will also be located on this landform during the construction phase.

The landform locations experience high rainfall and considerable flood events. Given the flat nature of these river plain landforms, they are quite stable and unlikely to experience landslides or mass movements; however, localized excavation, filling, or cut and fill of the ground surface associated with construction, operations and decommissioning may destabilize landforms, e.g., steep watercourse banks.

Recent Littoral Landform

The export pipeline route traverses beach ridge complexes and beach plains adjacent to the coast. This area experiences moderate rainfall and considerable flooding; however, the landform is very stable and unlikely to experience landslides or mass movements due to the flat terrain. Activities associated with construction, operations and decommissioning are unlikely to increase the potential for such landslides or mass movements. Localized excavations, e.g., on steep watercourse banks, will present the greatest risk to landform stability, especially during Project construction.

11.1.3.2 Degradation of Soil Capacity

Project activities may adversely impact soil characteristics, including soil structure; stability from sheet, rill and gully erosion; and land capability class.

Construction will initially involve removing vegetation, thereby exposing soils to rainfall, which may degrade soil pedological structure, making the soils considerably more susceptible to erosion. Erosion may also degrade soil structure by removing structured and fertile topsoil and plant propagules, breaking soil aggregates, and exposing more dispersive subsoils. Degrading soil structure may also reduce the quantity of good-quality topsoil available for reuse in site rehabilitation works.

Excavating, reshaping, transporting, stockpiling or windrowing, and dumping of spoil may also significantly mix the subsoil and topsoil profiles. This may reduce the soil's capability to support vegetation communities and any agricultural or horticultural uses, thus reducing its land capability classification.

Earthworks may expose unoxidized acid sulfate soils to the atmosphere generating acid leachate and mobilizing metals, thereby affecting the chemical properties of the soil. Soil contamination may also occur due to accidental hydrocarbon or chemical spills, or leaks of reservoir fluids from flowline/trunklines or condensate from the onshore export pipeline. Soil contamination can degrade soil structure and reduce soil fertility, and may be toxic to soil-associated biota. Soil acidification due to disturbance of ASS soils may also corrode buried infrastructure made from concrete and steel.

Constructing the wellpads, pipe yards, flowline/trunklines and onshore export pipelines, roads, quarries, spoil sites, CPF, accommodation camp, Logistics Base, landfills and the Purari Airstrip extension will involve soil exposure, excavation and movement, and; therefore, has the potential to impact on soil structure and character.

Key risk areas for PASS are soils of Soil Complexes 2 and 3 on the alluvial flood plains, beach ridges, and plain in the lower Purari River delta, which experience frequent inundation (see Figure 7.5). The coastal soils of Soil Complex 4 are also considered likely to be PASS.

Key risk areas for accidental hydrocarbon and chemical spills are the CPF and Logistics Base where the largest volumes of fuels, oils and chemicals will be stored and handled; however, accidental spills and leaks, including leaks of reservoir fluids from flowline/trunklines or condensate leaks from the onshore export pipeline, may potentially occur in all areas of Project activities. Assessment of such incidental and small-scale spills or leaks is undertaken in Section 11.1.5.

11.1.3.3 Embedded Design Controls

The following embedded design controls will address impacts to the degradation of soil capacity resulting from accidental hydrocarbon or chemical release. These controls are also relevant to other sections throughout this chapter that deal with accidental or planned releases of contaminants such as wastewater, chemicals or hydrocarbons:

- 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].
- The drilling will be performed using water-based mud [ED004].
- The landfill will be designed to comply with TOTAL's general specification for landfills, and will be designed, located, constructed and operated in general accordance with the intent of the Code of Practice for Sanitary Landfill Sites (DEC, 2001) and other applicable standard industry practices [ED005].
- Minimize chemical use and select chemicals considering the following criteria:
  - Lowest toxicity, lowest bioaccumulation potential and highest biodegradation;
  - Chemicals subject to bans or phase-outs [ED006].
- Use low-pressure detection alarms to detect pipeline leaks [ED007].
- Use fiber optic cable laid in the same trench to monitor pipelines. This cable will detect intrusions and ground movements [ED008].

- Locate valve stations along the onshore pipeline route to isolate pipeline sections if a leak occurs [ED009].
- 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].
- The CPF will have an open drain system to manage rainwater; the system will have three separate networks:
  - OD1 = permanently hydrocarbon-contaminated drains.
  - OD2 = accidentally hydrocarbon-contaminated drains.
  - OD3 = hydrocarbon-free drains.

  Water from each system will be treated separately and discharged to the environment according to applicable limits [ED015].
- All OD1 waters will undergo water treatment by a hydrocarbon/water separation system prior to discharge to the Purari River according to applicable standards. All OD2 waters and water from primary treatment will be sent to an observation basin and treated by the hydrocarbon/water separation system prior to release if required. The clean OD2 water will be discharged to the Purari River. Non-contaminated stormwater (OD3) will be disposed of by natural percolation and evaporation [ED016].
- All OD1 water from wellpads will be collected in a dedicated closed tank and transported to the CPF for treatment prior to being discharged [ED017].
- The produced water generated at the CPF will be injected back into the reservoir. Produced water will be retained in a tank with a capacity to contain five days of water production, as a backup if injection is unavailable [ED018].
- All vehicles (including vessels 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].
- Rainwater infiltration into hazardous materials storage areas will be prevented [ED020].
- Requirements for hazardous material transfer, overfill protection, and alarms will be implemented, e.g.,
  - Using dedicated fittings, pipes, and hoses specific to materials in tanks.
  - Providing secondary containment, drip trays, etc. at connection points or other possible overflow points.
  - Using dripless hose connections for vehicle tank and fixed connections with storage tanks.
  - Providing automatic fill shutoff valves on storage tanks to prevent overfilling.
  - Using piping connections with automatic overfill protection (float valve).
  - Fitting tanks with high-level alarms with both audible and visible annunciation [ED021].
- Hydrotest water discharges will be managed according to applicable requirements [ED040].

Impacts associated with increased soil erosion causing potential declines in water quality and harm to aquatic fauna due to increased turbidity and in-stream sedimentation are considered in Sections 11.3, 11.4 and 11.5.

11.1.3.4 Summary of Potential Impacts to Landforms and Soils

Potential impacts to landforms and soils due to the Project that have been considered in the impact assessment are as follows:

- Destabilized landforms causing increased incidence of landslides or mass movements.
- Degraded soil capacity due to impacts on soil structure and developmental status, fertility or disturbance of soil profiles.
- Degraded soil capacity due to accidental soil contamination or adverse chemical properties, such as presence of PASS.

The consideration of spills or leaks is related to releases that are accidental (but controllable), as part of construction, operation and decommissioning of large projects. Potential impacts of large-scale accidental spills associated with major natural hazards and unplanned events are considered in Chapter 18.

11.1.4 Proposed Mitigation and Management Measures

Table 11.5 describes mitigation and management measures to further reduce impacts to landforms and soils.

Table 11.5 – Landforms and Soils Mitigation Strategies and Management Plans

Potential Impact	Mitigation Strategy	Relevant Management Plan
Destabilized landforms causing increased incidence of landslides or mass movements.	♦ Progressively clear vegetation and rehabilitate cleared areas as soon as practicable to minimize the time cleared areas are exposed; and allow fauna to move away from areas to be cleared, where practicable [EM002]. ♦ Cut trees where practicable to retain the rootstock and maintain soil stability [EM003]. ♦ Erosion and sediment control measures will be implemented for infrastructure components in accordance with good international industry practice to effectively manage stream and river flows, stormwater, surface erosion, sedimentation and scour, e.g., drainage diversion into surrounding vegetation, rip-rap aprons, rock armoring, energy dissipators, sediment control ponds, mulch berms and sediment fences, where required, until the area has been effectively stabilized and/or rehabilitated [EM004]. ♦ Areas of higher risk of landslides e.g., steep gradients, previously disturbed land, likely to occur from the works, or likely to be exacerbated by the works, will be stabilized to reduce the landslide risk. [EM006]. ♦ Actively or passively rehabilitating bare sites as soon as possible to promote a stable self-sustaining landscape. E.g., – Allow forest edges to naturally regenerate or create appropriate conditions to facilitate natural regeneration, e.g. rip the substrate, replace topsoil, apply mulch – Rehabilitate Pandanus habitats, e.g. recreate mounds, re-instate the intertidal surface between Pandanus mounds – Rip compact surfaces across the slope, as appropriate, to facilitate revegetation and minimize erosion.	Soil Management Plan; Site Restoration and Rehabilitation Plan

Table 11.5 – Landforms and Soils Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Destabilized landforms causing increased incidence of landslides or mass movements (cont'd).	– Spread stockpiled topsoil, organic matter and cleared vegetation over the rehabilitation area to promote natural regeneration. – Use native vegetation to revegetate sites when active rehabilitation measures are required. [EM029]	See above.
Degraded soil capacity due to impacts on soil structure and developmental status, fertility or disturbance of soil profiles.	♦ All sites proposed for development as part of the Project will be subject to a preconstruction survey to clearly identify acid sulfate soils, sensitive sites and habitats, e.g. roosting, breeding, nesting and threatened species sites, priority ecosystem services, archaeological sites, burial sites, sites of religious importance to be subject to specific mitigation measures [EM001]. ♦ Progressively clear vegetation and rehabilitate cleared areas as soon as practicable to minimize the time cleared areas are exposed; and allow fauna to move away from areas to be cleared, where practicable [EM002]. ♦ Stabilize spoil stockpiles and areas of ground disturbance as soon as practicable after initial disturbance using, e.g., mulched vegetation, aggregates and soil binders [EM005]. ♦ Areas of higher risk of landslides e.g., steep gradients, previously disturbed land, likely to occur from the works, or likely to be exacerbated by the works, will be stabilized to reduce the landslide risk. [EM006]. ♦ Where possible, separate and stockpile cleared topsoil (with the inherent seed bank and any coarse woody debris) to use for future rehabilitation [EM036].	Soil Management Plan; Site Restoration and Rehabilitation Plan
Degraded soil capacity due to adverse chemical properties, caused by oxidation of PASS disturbed during earthworks.	♦ Avoid disturbing acid sulfate soils, potentially in Soil Complex 4 coastal soils, and Soil Complex 2 and 3 on alluvial flood plains, beach ridge and plains in the lower Purari River delta, wherever possible, otherwise handle, store, treat, manage and dispose of acid sulfate soils according to good practice guidelines [EM007].	Soil Management Plan
Degraded soil capacity due to soil contamination from accidental hydrocarbon or chemical spills or leaks.	♦ 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].	Emergency Response Plan

11.1.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to landform and soils subject to the embedded design controls in Section 11.1.3 and the successful implementation of the proposed mitigation and management measures in Section 11.1.4. 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.

11.1.5.1 Landform Destabilization

The potential for Project activities to destabilize landforms and cause landslides is assessed in the following sections for the various landform types in the PAOI.

Ridge and Ravine Landform

The ridge and ravine landform in PRL-15 is highly susceptible to change from construction activities, as evidenced by the existing scars from slumps, landslides and gullying. Several faults and fractures are expressed in the topography by linear scarps.

Slopes developed on coarse-grained sedimentary rocks of the ridge and ravine landform, such as sandstone, are regular, infrequently dissected and have few, large deep-seated slumps. Although apparently reasonably stable, they are highly sensitive to change because of their steep slopes. The slopes tend to have fewer drainage lines dissecting them, and instability events tend to be less frequent than on slopes on fine-grained sedimentary rocks but larger in scale and impact. Slopes on fine-grained sedimentary rocks, such as mudstone and siltstone, tend to be more irregular, are frequently dissected and have numerous, small deep-seated slumps. The slopes tend to have more drainage lines dissecting them, and instability events tend to be more frequent than on slopes on course-grained sedimentary rocks but smaller in scale and impact.

The ridge and ravine landform in PRL-15 includes areas that are very steep, highly unstable and susceptible to erosion. Given that the Project design has avoided locating infrastructure in areas with the greatest risk of destabilization, the sensitivity is categorized as ***High*** (see Table 11.1).

The extent of reducing impact magnitude depends on the size of the infrastructure site (spatial extent), the duration and nature of the activities to construct the infrastructure, and the duration of the impact; hence, magnitude of impact will vary for each Project component constructed on the ridge and ravine landform.

Mitigation will include stabilization of areas with a higher risk of landslides and implementation of erosion and sediment control measures, thus reducing the potential for landslide or mass movement events to occur due to Project activities; and will reduce the scale of impact of any such events.

The magnitude of impact associated with the various Project components located on the ridge and ravine landform, assuming successful implementation of mitigation measures, is assessed to range from ***Low*** to ***Minimal*** during construction and operations, based on the categories described in Table 11.2. The roads, flowline/trunklines and spoil sites have a higher destabilization risk due to their greater geographical extent. Potential impacts to landforms from any landslides are expected to be limited to within 200 m of the Project activity or component causing the impact and be short-term with active stabilization, and with moderate potential for recovery to the predisturbance condition. Section 11.1.5.3 provides the individual ranking for each Project component. Considering the high sensitivity of the terrain unit and the ***Low*** to ***Minimal*** magnitude of impact, the residual impact significance is ***Minor*** to ***Moderate***. Decommissioning would involve leaving infrastructure sites in a stable condition, with any problematic locations identified during operations; hence impacts during decommissioning are expected to be similar to, or less than, those during the construction and operations phases.

Composite Meander and Levee Alluvial Landform

This river plain landform is quite stable in regard to landslides or mass movements due to its gently undulating to flat topography. The landform is moderately resilient, with soil recovering relatively quickly from disturbance. Its sensitivity to destabilization is therefore categorized to be ***Medium*** in accordance with Table 11.1.

Most Project components and construction activities will occur on this terrain type, as discussed in Section 11.1.3.1 and shown in Table 11.4. Project design to locate infrastructure on this terrain type rather than ridge and ravine terrain has minimized the risk of impacts from landslides.

Considering other mitigation measures to be implemented, as described in Section 11.1.4, impacts of the various Project components and activities on landform stability during construction and operations are expected to be minimal. They would be located near the Project disturbance (within 50 m), require minimal stabilization and be short-term. The magnitude of impact is therefore assessed to be ***Minimal***. This provides an overall impact significance rating of ***Negligible*** for all Project components on this landform.

Impacts during decommissioning are expected to be similar, or lesser, to the construction and operations phases.

Recent Littoral Landform Stability

The recent littoral landform of beach ridge complexes and beach plains adjacent to the coast is stable in regard to landslides or mass movements due to the flat terrain but would be susceptible to ground movement and erosion adjacent to excavations due to the sandy profile. Its sensitivity to destabilization is therefore categorized to be ***Medium***.

The potential for ground movements would be restricted to trench walls collapsing during pipeline installation in sandy soils; however, this would be avoided by using appropriate land stabilization techniques (e.g., sheet piling) in areas susceptible to collapse. The magnitude of impacts due to such ground movements would be very localized (e.g. less than 50 m), require minimal stabilization and be short-term. The magnitude of impact is therefore assessed to be ***Minimal*** during construction (and insignificant during operations and post-closure). The overall impact significance rating is ***Negligible***.

11.1.5.2 Degradation of Soil Capacity

The Project may potentially degrade soil capacity due to:

- Impacts on soil structure and developmental status, fertility or disturbance of soil profiles.
- Development of adverse chemical properties due to acid sulfate soil disturbance or accidental soil contamination.

The potential for Project activities to have such impacts is assessed in the following sections.

Soil Structure and Developmental Status

Project components that will involve soil exposure, excavation and movement and; therefore, have the potential to degrade soil structure and developmental status include wellpads, roads, flowline/trunklines, spoil disposal sites, CPF, operations accommodation camp, Logistics Base, pipe yards and construction accommodation camps, quarries, landfills, the Purari Airstrip extension and the onshore export pipeline.

Soil units in the Project area are poorly formed soils with limited soil pedological development and fertility (as described in Section 11.1.1). This poor development makes them more susceptible to erosion. Given that the soils are minimally developed and have only moderate fertility, they would be expected to recover slowly from any disturbance if topsoil is not appropriately managed. The sensitivity of soils to change in soil capacity in the area of all Project activities is therefore categorized to be ***Medium***.

The most significant and largest areas of exposed soils where topsoil management will be important to achieve rehabilitation and vegetation growth are the flowline/trunklines, export

pipeline route and spoil disposal sites. Erosion and sediment control measures will be implemented for infrastructure components in accordance with good international industry practice where required, until the area has been effectively stabilized and/or rehabilitated. Spoil stockpiles and areas of ground disturbance will be stabilized as soon as practicable after disturbance.

The disturbance of soil profiles may degrade soil structure with moderate potential for recovery to the pre-disturbance condition, and some stabilization may be required in the short term. Impacts to soil structure would; however, be confined to the direct area of ground disturbance or spoil placement. The magnitude of impact is; therefore, categorized to be ***Low*** for flowline/trunklines, the export pipeline route and spoil sites. The magnitude of impact for other Project components is ***Negligible***, given their much smaller spatial extent. The final end use and site rehabilitation of these areas will be considered in decommissioning planning.

This provides an overall impact significance rating of ***Minor*** for flowline/trunklines, export pipeline route and spoil sites and ***Negligible*** for other Project components.

Development of Adverse Chemical Properties

Project activities may create adverse chemical properties in soils due to:

- Generation of acidic leachate and metal mobilization due to exposing acid sulfate soils to the atmosphere.
- Soil contamination due to accidental hydrocarbon or chemical spills or leaks.

Acid Sulfate Soils

The soil complexes in the area of Project components are shown in Figure 11.1. The PAOI contains several soil units with acid sulfate soils potentially present, including Soil Complexes 2, 3 and 4 (as described in Section 7.2.5.1). Such soils are prone to releasing acid leachate if disturbed or drained and exposed to the atmosphere. Sites, which laboratory tests indicated have potential acid sulfate soils (PASS), were located on the alluvial flood plains and beach ridges. Soils on the plains in the lower Purari River delta, which experience frequent inundation, are also highly likely to be PASS given their formation in decomposed plant matter and therefore high sulfide content, their low position in the landscape and their near continuous saturation. These soils have not yet been sampled due to access and safety constraints, as these soils are largely underwater, and the potential for crocodiles to be present, respectively.

The sensitivity of the various soil complexes considering adverse properties due to the presence of PASS is categorized as follows, based on ratings described in Table 11.1:

- Soil Complex 1 – ***Minimal***.
- Soil Complex 2 – ***Medium***.
- Soil Complex 3 – ***Medium***.
- Soil Complex 4 – ***Medium***.

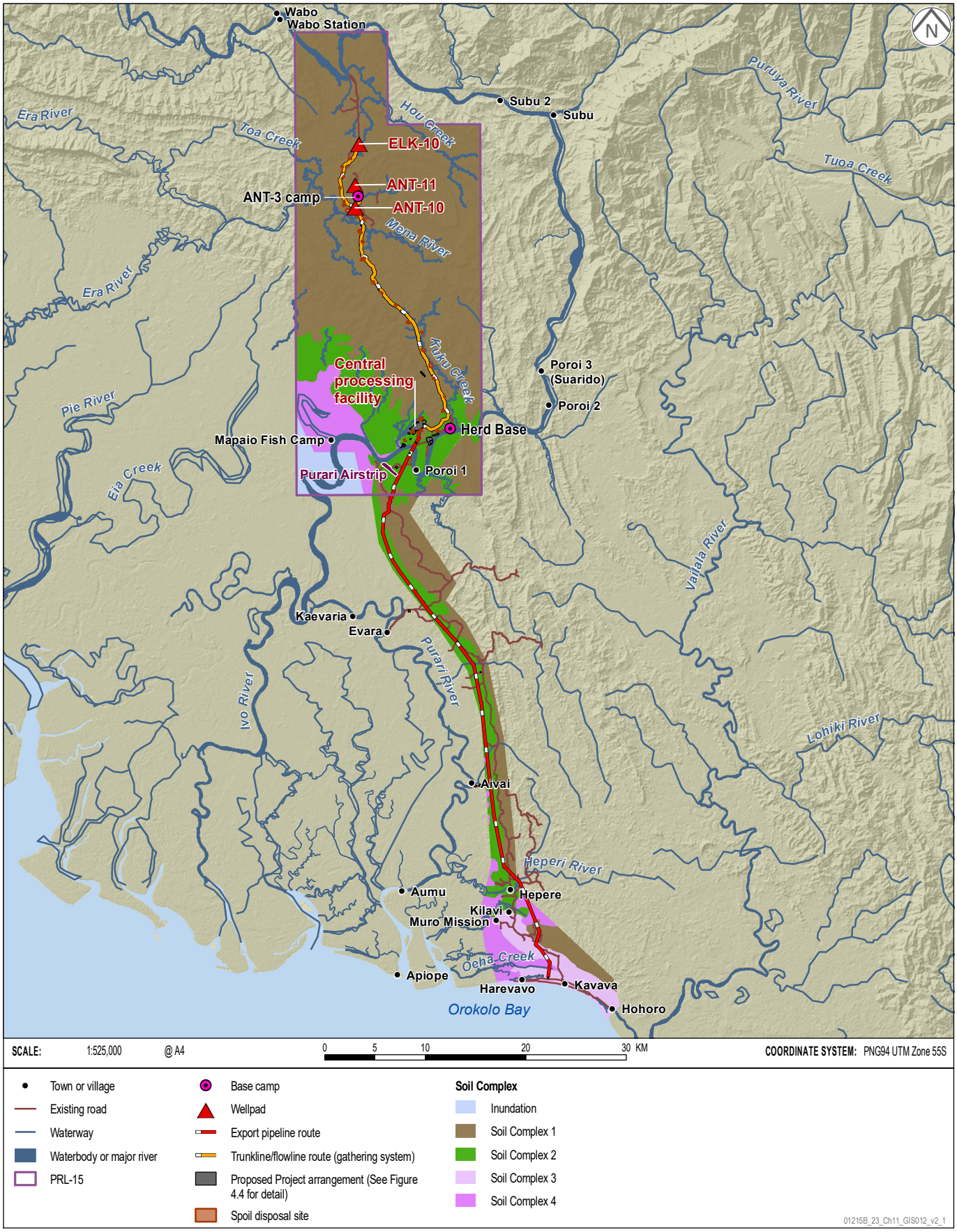
ASS/PASS will be mapped during preconstruction surveys. Disturbance to soils identified to be ASS/PASS will be avoided where practicable. Where disturbance of ASS is unavoidable, soils will be handled, stored, treated, managed and disposed of according to good practice guidelines, to mitigate any impacts.

With mitigation, minimal soil degradation is expected to occur due to acid generation and mobilization of metals. Any impacts to soils would be localized (within 50 m of the Project activity or component), and impacts would be short term with appropriate treatment of identified PASS.

SOIL COMPLEXES IN PRL-15 AND ALONG THE EXPORT PIPELINE ROUTE

Papua LNG Project | Environmental Impact Statement

FIGURE 11.1



Source: Figure theme data from BMT, 2019.

The magnitude of impact to soil capacity is therefore categorized to be ***Minimal***. This provides an overall significance rating of ***Negligible*** for activities in all soil complexes.

Soil Contamination

Accidental hydrocarbon or chemical spills or leaks may potentially occur at any area of Project activities within the PAOI where these are used or handled. Leaks of reservoir fluids from flowline/trunklines or condensate from the onshore export pipeline may also potentially occur.

Existing metal concentrations are well below health-based screening levels for contaminants (as described in Section 7.2.5); however, some metal concentrations exceed ecological soil screening levels. There is no evidence of hydrocarbon contamination of soil at any of the sampling sites. The soil within the PAOI is therefore categorized to have ***Medium*** sensitivity in accordance with Table 11.1.

Standard good industry practices will be adopted to prevent and protect against ground pollution due to accidental hydrocarbon and chemical spills or leaks during construction, operation and decommissioning activities, and to remediate where it occurs (as described in Sections 11.1.3 and 11.1.4). Hydrotesting, monitoring and maintenance of flowline/trunklines and the onshore export pipelines will either avoid or limit the occurrence and extent of any reservoir fluid or condensate leaks.

With the implementation of these measures, impacts to soil capacity would be expected to have moderate potential to recovery to the pre-disturbance condition and be limited to within 200 m of the Project component or activity causing the impact. The magnitude of impact for Project components in all locations is therefore categorized to be ***Low***, resulting in a significance rating of ***Minor***.

11.1.6 Summary of Assessment of Residual Impact Significance

Table 11.6 provides a summary of the assessment of residual impacts to landform and soils, including when and where (in which Project phase and location) these impacts are expected to occur. The table should be read in conjunction with the specific mitigation measures provided in Table 11.5.

All residual impacts are assessed to be ***Negligible*** to ***Minor***, except for impacts described below which are assessed to have a ***Moderate*** residual impact:

- Landslide or mass movement due to landform destabilization from road, flowline/trunklines and spoil site construction in the ridge and ravine landform.

Table 11.6 – Summary of Assessment of Residual Impact Significance for Landforms and Soils

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Land stability	Earthworks	Destabilization causing landslide/mass movement.	***Ridge and Ravine Landform***		♦ EM002 ♦ EM003 ♦ EM004 ♦ EM006 ♦ EM029		
			Wellpads	C, O, D		High/Minimal	Minor
			Roads and flowline/trunklines	C, O, D		High/Low	Moderate
			Spoil disposal sites	C, O, D		High/Low	Moderate
			Quarry	C, O, D		High/Minimal	Minor
			Composite Meander and Levee Alluvial Landform				
			Roads and flowline/trunklines	C, O, D		Medium/Minimal	Negligible
			Pipe yards and fly camps	C, O, D		Medium/Minimal	Negligible
			Spoil disposal sites	C, O, D		Medium/Minimal	Negligible
			CPF, Logistics Base and accommodation camp	C, O, D		Medium/Minimal	Negligible
			Quarries and landfills	C, O, D		Medium/Minimal	Negligible
			Airstrip extension	C, O, D		Medium/Minimal	Negligible
			Export pipelines	C, O, D		Medium/Minimal	Negligible
			Export pipeline route spoil disposal sites	C, O, D		Medium/Minimal	Negligible

Table 11.6 – Summary of Assessment of Residual Impact Significance for Landforms and Soils (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Land stability (cont'd)	Earthworks (cont'd)	Destabilization causing landslide/mass movement (cont'd)	***Recent Littoral Landform***		See above.		
			Export pipelines	C, O, D		Medium/Minimal	Negligible
Soil capacity	Earthworks	Adverse impacts on soil structure and developmental status, fertility or disturbance of soil profiles.	Flowline/trunklines, export pipelines and spoil disposal sites.	C	♦ EM001 ♦ EM002 ♦ EM005 ♦ EM006 ♦ EM036	Medium/Low	Minor
			Other Project components.	C, O		Medium/Minimal	Negligible
	Earthworks	Adverse effects on chemical properties, due to oxidation of PASS.	Soil Complex 1 (wellpads, roads, flowlines/ trunkline, spoil disposal sites, quarry).	C	♦ EM007	Minimal/Minimal	Negligible
			Soil Complex 2 (roads, spoil disposal sites, quarries, landfills, CPF, Logistics Base, accommodation camp, pipe yards, fly camps, airstrip extension, export pipelines).	C		Medium/Minimal	Negligible

Table 11.6 – Summary of Assessment of Residual Impact Significance for Landforms and Soils (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Soil capacity (cont'd)	Earthworks (cont'd)	Adverse effects on chemical properties, due to oxidation of PASS (cont'd).	Soil Complex 3 (export pipelines).	C	♦ EM007	Medium/Minimal	Negligible
			Soil Complex 4 (export pipelines).	C		Medium/Minimal	Negligible
	Use of hazardous materials.	Adverse effects on chemical properties, due to soil contamination from accidental hydrocarbon or chemical spills or leaks.	PRL-15 and export pipeline route, (all land-based Project activities and components).	C, O, D	♦ EM018	Medium/Low	Minor

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

11.2 Groundwater

11.2.1 Context

Shallow, unconfined, perched groundwater occurs as localized bodies in surficial material in the area of the wellpads in the northern part of PRL-15. This perched groundwater is considered likely to exist within 10 m below ground surface (bgl) where present. The surficial material in this area is thought to have a high capacity to contain and transmit water, releasing it slowly from springs and seeps, and to act as a buffer that sustains stream baseflow for some time after rain. These shallow groundwater systems are thought to be localized (e.g., confined to single valleys) with recharge and discharge areas near each other.

Information regarding deeper groundwater in PRL-15 is limited; however, it is likely that permanent groundwater occurs in more extensive alluvial deposits in the valleys of major large streams (see Section 7.5). This groundwater is likely to be connected with surface water. The prevalence of low-permeability siltstones and mudstones is unlikely to support sufficient groundwater to classify aquifers as being present with the possible exception of sandstones in the Era Beds.

Small quantities of groundwater may occur in the geology of the gas resource target, the Kapau Limestone; however, exploration drilling to date has shown very little water is associated with gas and condensate. This geology is over 1,600 m deep, and the thickness of the low-permeability material overlying the hydrocarbon resource will effectively confine any water occurring in this unit.

Local, shallow perched groundwater occurs in superficial materials in the areas of the CPF and Logistics Base, as evidenced by seeps and spring-type erosion. Again, recharge and discharge areas for these minor systems are likely to be close together. Permanent shallow groundwater is also known to be present in alluvial sediments close to the confluence of Kuku Creek and the Purari River, where abstraction bores up to 50 m deep target groundwater from the alluvial material to supply water for use at Herd Base (see Figure 7.15). This alluvial material is thought to be connected to the surface waters of Kuku Creek and the Purari River. The depth to water-bearing material (i.e., greater than 15 m) and overlying low-permeability fine silts and clay materials helps protect this resource from potentially contaminating surface activities.

Weathered material overlying competent geology is likely to support perched groundwater following rains along the export pipeline route. Evidence of spring erosion is seen in this area. No information on deeper groundwater is known for this area; however, mudstones and siltstones that are not thought to represent aquifer materials dominate the geology of the ridgelines (Orubadi Formation). The groundwater present is unlikely to have been exposed to widespread contamination; although this area does include commercial logging camps and associated tracks that may be potential contamination sources.

The coastal and inland communities along the export pipeline route use shallow groundwater extensively (Plate 11.3). Groundwater is predominantly sourced from shallow wells and used for washing; but during dry periods, groundwater is relied on as a drinking water resource. The quality of the water encountered meets the relevant drinking water standards with respect to chemical properties. Widespread microbiological contamination is evident; however, and is likely to be due to domestic animals (e.g., pigs and dogs) and wildlife having open access to the wells and the closeness of the wells to latrines at some locations. The groundwater resource targeted by villagers is generally less than 1 m bgl; therefore, it is susceptible to contamination from surface activities and processes (Plate 11.4).

Plate 11.3 – Harevavo Coastal Village

Photo: Iain Woxvold.

Plate 11.4 – Groundwater Well at Harevavo

Photo: John Leyland.

11.2.2 Discipline-specific Impact Assessment Method

The significance assessment method described in Chapter 3 was adopted to qualitatively assess the potential impact on groundwater from Project construction and operation. This method considers the magnitude of impact on an environmental value and the sensitivity of that value.

Magnitude of impact is defined by the impact's severity, and spatial and temporal extents. Table 11.7 defines the categories adopted for assessment of the magnitude of Project impacts on groundwater. Assessment of the magnitude of impact is undertaken assuming proposed mitigation measures have been successfully implemented, i.e., provides a residual impact assessment.

Table 11.7 – Groundwater Magnitude of Impact Criteria

Category	Description
Very High	♦ Impact likely to be severe on the groundwater quality or quantity at a scale comparable to the extent of the aquifer and over a long period of time (decades). ♦ Impact has the potential to substantially exceed water quality guidelines (where exceedances do not already exist). ♦ Impact is likely to cause the loss of water supply to all existing domestic users of the aquifer or other environmental values.
High	♦ Impact is likely to be major on the groundwater quality or quantity over the area of local use from that aquifer and over a period of 5 to 10 years. ♦ Impact has the potential to exceed water quality guidelines (where exceedances do not already exist). ♦ Impact is likely to significantly constrain the water supply to a large proportion of existing domestic users of the aquifer or other environmental values.
Medium	♦ Impact is likely to be moderate on the groundwater quality or quantity over the area of local use from that aquifer and for 1 to 5 years. ♦ Impact has the potential to cause only minor exceedance of water quality guidelines (where exceedances do not already exist). ♦ Impact constrains the water supply to some existing domestic users of the aquifer or other environmental values.
Low	♦ Impact is likely to be low on the groundwater quality or quantity, at a scale less than the extent of local use from that aquifer and less than a year. ♦ Impact does not exceed water quality guidelines (where exceedances do not already exist). ♦ Impact does not constrain water supply to existing domestic users or environmental values.
Minimal	♦ Impact is unlikely to be detectable.

Sensitivity considers the susceptibility of an environmental resource or receptor to change and its intrinsic importance considering factors such as:

- Capacity of the resource or receptor to adapt to change without adverse effects on the value's inherent attributes, i.e., its resilience.
- Rarity or uniqueness of the resource or receptor.
- Importance of the resource to the environment, e.g., support of groundwater-dependent ecosystems or stream baseflows.
- Domestic uses of the resource, e.g., for potable water supply, washing, bathing or food production.
- Importance to local communities, and/or the resource or receptor's iconic or symbolic importance to cultural value systems.

Table 11.8 defines the categories for assessment of sensitivity adopted in the groundwater assessment.

Table 11.8 – Groundwater Sensitivity of Resource or Receptor

Category	Description
Very High	♦ Surficial or shallow aquifers where water is used for local domestic supply (e.g., wells) or where water supports springs and provides the only available water supply for potable use.
High	♦ Surficial or shallow aquifers where water is used for local domestic purposes such as washing and bathing but is not the only water available for potable use. ♦ Areas adjacent to creeks and rivers where shallow aquifers rise to interact with surface waters and potentially therefore provide stream baseflow or support to groundwater-dependent ecosystems.
Medium	♦ Deeper aquifers that are less exposed to the surface and therefore are likely not used for local domestic purposes. ♦ Areas of lowland forest and swamplands that may rely on groundwater during the dry season (i.e., temporal groundwater-dependent ecosystems).
Low	♦ Environment where aquifers are deeper and therefore are likely not used for local domestic purposes.
Minimal	♦ Environment where aquifers are deep and confined and are not used for local domestic purposes or by groundwater-dependent ecosystems.

Significance of the impact from the Project's activities is determined by a matrix combining the magnitude of impact category on the groundwater resource or receptors with the sensitivity category of the groundwater resource or receptors. Table 11.9 presents the matrix used to establish the significance of Project impacts on groundwater resource/receptors.

Table 11.9 – Groundwater Significance of Assessment Matrix

Magnitude of Impact	Sensitivity of Resource/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

11.2.3 Identification of Potential Impacts

Potential impacts to groundwater 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.

11.2.3.1 Overview

Potential Project impacts on groundwater are discussed and assessed based on the infrastructure that will be constructed and activities that will be undertaken during different Project phases. The assessment of potential impacts also considers whether the activities have the potential for direct or indirect effects on individual groundwater values.

Project construction and operation will involve activities that may influence groundwater, including well drilling and construction and operation of flowlines, trunkline, export pipelines, CPF, Logistics Base and other supporting infrastructure. These activities and Project components are described in the following sections with the potential impacting processes to groundwater summarized in Section 11.2.3.6.

11.2.3.2 Gas and Condensate Production Wells

Gas and condensate production for the Project involves developing nine wells on three wellpads. Further description of these wells and the drilling campaign is provided in Section 4.3 with the overall upstream Project layout shown in Figure 4.4.

Drilling will use drilling mud that will contain chemical additives. The mud acts as a lubricant to keep the drill bit cool and clean, lifts cuttings from the drill holes and controls well pressure to prevent well blowout. Water to make up the muds will be sourced from temporary dam structures on nearby watercourses (i.e., Hou and Boa creeks). Groundwater is not proposed to be used.

Well drilling has the potential to introduce drilling muds and cuttings, and reservoir fluids, into aquifers if they are present.

The following embedded design controls address these impacts:

- The drilling will be performed using water-based mud [ED004].
- Wells are to be cased and cemented to insulate and protect any aquifers [ED010].
- 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].

11.2.3.3 Gas and Condensate Transfer Systems

The key components of the Project's gas and condensate transfer systems, as shown in Figures 4.4 and 4.6, include:

- The gas gathering systems for each wellpad.
- Flowlines and a trunkline that transport the reservoir fluids from the wellpads to the CPF.
- Export pipelines from the CPF.

Groundwater is not proposed to be used in the construction or operations of this infrastructure.

A water injection pipeline will also convey produced water separated from the condensate in the condensate stabilization process from the CPF back to the ANT-11 produced water injection well.

Horizontal directional drilling is to be used for the export pipelines crossing of the Purari River. Similar to drilling of the wells, drill cuttings and muds associated with horizontal directional drilling have the potential to enter and degrade groundwater if inappropriately managed.

The accidental loss of reservoir fluids or condensate from the pipelines, e.g., from pipe weld failure, corrosion or pipeline damage during operations, may degrade the groundwater quality of shallow groundwater systems.

The reservoir fluids will contain chemical constituents in the gaseous and liquid phases (refer to Sections 4.2.2 and 4.2.3); including methane, the primary resource and main constituent, ethane, propane, butane, pentane and hexane and traces of aromatic organic compounds that are considered to be impurities (e.g., benzene, toluene, ethylbenzene and xylenes). Other constituents include sulfur compounds (e.g., hydrogen sulfide), carbon dioxide, nitrogen, mercury

and arsenic compounds. The organic compounds are volatile, i.e., evaporate very easily into the air under ambient temperatures and pressures, and; therefore, are not considered a significant risk for groundwater contamination in the event of an accidental release. Of the non-organic compounds, only mercury and arsenic are potential groundwater contaminants, as carbon dioxide, nitrogen and hydrogen sulfide are all gases at ambient temperatures and pressures.

The onshore export pipelines will be laid in a trench that is typically 2.3 m deep and 4.1 m wide (as described in Section 4.10.5.2). Groundwater is therefore likely to be intercepted during trenching at the southern end of the onshore export pipeline corridor. This groundwater occurs at shallow depths, and inland village communities access groundwater from springs and wells excavated to approximately 2 m deep (see Section 7.5.3.2). Villagers on the coast also use shallow groundwater wells, which target shallow freshwater approximately 1 m bgl in marine, sandy beach and back beach deposits. This freshwater is likely to lie on top of more saline water in the deeper sediments below. Village groundwater use is predominantly for washing, but during dry periods groundwater is relied on as a drinking water resource.

Given the groundwater resource is very shallow, it is susceptible to contamination from surface activities and processes. The pipeline trenching may also cause shallow groundwater to discharge into the trench, potentially causing drawdown of water in nearby village wells.

The embedded design controls outlined in Section 11.1.3.3 are also relevant to addressing these impacts.

11.2.3.4 Central Processing Facility

Reservoir gas and fluids will be processed at the CPF to separate the gas from the condensate and to remove carbon dioxide, water and hydrogen sulfide, before being transported along the export pipelines to the liquefied natural gas (LNG) facilities. Further description of these facilities is provided in Section 4.5.3, including the layout of the CPF (see Figure 4.5).

No reservoir water is expected to be produced during Project gas production; however, relatively small quantities (3,000 barrels, or 475,000 L, of water per day) of condensation water will be produced during condensate stabilization. This produced water containing residual hydrocarbons will be injected back into the Antelope reservoir at the ANT-11 wellpad and therefore has the potential to degrade groundwater quality.

During the first years of production, prior to the Elk reservoir being depleted, acid gas will be treated using a thermal oxidizer and flue gas desulfurization process. The treatment process involves incineration of acid gas in the thermal oxidizer to convert sulfur compounds, including hydrogen sulfide, into sulfur dioxide (SO_2). The sulfur dioxide will then be removed from the flue gas by a flue gas desulfurization process that uses liquid caustic soda (NaOH) that is injected directly into the flue gas stream converting sulfur dioxide to sulfite salts. This desulfurization process will be based on a pH control system, maintained between pH 6 and 7, which selectively removes sulfur dioxide from the flue gas but leaves carbon dioxide. The liquid effluent containing the dissolved sulfite salts will be injected into the ANT-11 well, along with produced water from the condensate stabilization unit. Injection will occur into the gas zone of the reservoir in the dolomite carbonate formation at a depth of approximately 1,500 m. The liquid effluent from the desulfurization process will have a near neutral pH of 6 to 7 and be at a temperature of about 80ºC prior to mixing with the produced water. It will mostly comprise water (90%), with the remaining volume comprising dissolved sodium bisulfite ($NaHSO_3$) (6.4%) and sodium sulfite (Na_2SO_3) (3.6%).

Acid gas containing hydrogen sulfide and carbon dioxide that is removed from the raw gas by the AGRU will be injected into the Elk reservoir once it is depleted. The compressed acid gas will be

transported to the ELK-10 wellpad via the Elk trunkline where it will be injected into the reservoir using the ELK-10 well, which will be converted to a gas injection well.

Injection of the desulfurization process liquid effluent into the Antelope reservoir and acid gas into the Elk reservoir has the potential to degrade groundwater quality.

Other chemicals and hazardous materials directly associated with and stored at the CPF that have the potential to contaminate groundwater resources include the following:

- Chemicals necessary in the CPF and required for chemical injection at the wellpads, comprising hydrate inhibitor (i.e., monoethylene glycol and triethylene glycol), corrosion inhibitor, biocide, oxygen scavenger and sodium hydroxide.
- Diesel (420-m^3 capacity) for diverse small equipment.
- Foam for the firewater system (21-m^3 capacity).
- Rainwater runoff from areas that have a permanent risk of hydrocarbon contamination in the open drain system and observation basin (2,340-m^3 capacity).

Accidental hydrocarbon and chemical leaks and spills from the various stores during CPF construction and operation may enter the shallow groundwater system and degrade groundwater quality. The embedded design controls outlined in Section 11.1.3.3 are also relevant to addressing these impacts.

No groundwater will be extracted for use as process water at the CPF.

11.2.3.5 Supporting Infrastructure

A variety of logistics infrastructure is required for Project construction, operation and decommissioning, including:

- Herd Base.
- Logistics Base.
- Operations accommodation camp.
- Access tracks and roads.
- Purari Airstrip extension.
- Pipeline construction pipe yards.
- Temporary construction accommodation camps.
- Fuel storage and refueling areas.
- Quarries.
- General waste landfills.

Construction, operation and decommissioning of this supporting infrastructure will involve storing and distributing fuels, oils, and other hazardous materials, which have the potential to contaminate shallow groundwater resources if accidental spills or leaks occur. Spills can percolate through soils resulting in groundwater contamination. Leachate from the general waste landfills also represents another potential source for contaminants to enter groundwater. The embedded design controls outlined in Section 11.1.3.3 are also relevant to addressing these impacts.

11.2.3.6 Summary of Potential Impacts

The following potential impacts to groundwater have been identified from the described Project activities and components:

- Groundwater contamination due to:
  - Introduction of drilling muds and cuttings during the drilling of wells.
  - Injection of produced water and liquid effluent from the flue gas desulfurization process prior to depletion of the Elk reservoir into ANT-11 well.
  - Acid gas injection into the ELK-10 well, following depletion of the Elk reservoir.
  - Accidental leaks of reservoir fluids from flowline/trunklines or condensate from the export pipeline.
  - Accidental hydrocarbon or chemical spills or leaks at Project facilities and various areas of activities.
  - Leachates from the general waste landfills.[1]
- Reduction in the quantity of shallow groundwater at inland and coastal villages due to drawdown in the pipeline trench.

The consideration of spills or leaks is related to releases that are accidental (but controllable), as part of construction, operation and decommissioning of large projects. Potential impacts of large-scale accidental spills associated with major natural hazards and unplanned events are considered in Chapter 18.

11.2.4 Proposed Mitigation and Management Measures

There are no additional mitigation or management measures required as the embedded design controls outlined in Section 11.2.3 address all of the impacts.

11.2.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to groundwater subject to the embedded design controls in Sections 11.1.3 and 11.2.3. 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.

11.2.5.1 Contamination of Groundwater

Introduction of Drilling Muds and Cuttings

Localized bodies of shallow, unconfined, perched groundwater occur in surficial material in the north of PRL-15 (as described in Section 11.2.1); however, given that the wellpads are located on the top of ridgelines, shallow groundwater occurrence is expected to be limited in the drilling areas. The deeper formations consist of siltstones and mudstones that are unlikely to support the occurrence of deeper aquifers in the area. The sensitivity of groundwater in the area of the wellpads is therefore assessed to be ***Minimal***.

1 Sludge generated by the sewage treatment plant will be disposed of in the general waste landfill; hence, potential sewage contamination of groundwater is considered in the landfill assessment.

The wells will be cased and cemented, which will insulate and protect any aquifers that may be present from the introduction of drilling muds, and reservoir fluids and drilling will be undertaken using water-based mud that has low toxicity and is biodegradable.

Adverse impacts on groundwater quality due to the introduction of drilling muds and cuttings in the groundwater during construction are therefore likely to be low. The magnitude of impacts to groundwater is therefore considered to be ***Low***, providing an overall significance rating of ***Negligible***.

Injection of Produced Water and Desulfurization Process Liquid Effluent

The sensitivity of groundwater in the area of the wellpads is assessed to be ***Minimal***.

Liquid effluent from the flue gas desulfurization process will be injected into the Antelope reservoir along with the produced water, prior to the depleted Elk reservoir becoming available for acid gas injection. The desulfurization process liquid effluent will represent between 60 to 70% of the volume injected into the reservoir during these first, approximately four years, with the remaining 30 to 40% being the treated produced water.

The desulfurization process liquid effluent will have a near neutral pH of 6 to 7 and will mostly comprise water (90%), with the remaining volume comprising dissolved sodium bisulfite ($NaHSO_3$) (6.4%) and sodium sulfite (Na_2SO_3) (3.6%). The USEPA has verified these chemicals to be of low human health concern based on experimental and modeled data (USEPA, 2019). They are used as food additives to prevent oxidation and inhibit bacterial growth, and are also used in drinking water treatment to remove residual chlorine. Industry also use them as oxygen scavengers in piping systems to avoid corrosion problems.

The produced water and desulfurization process liquid effluent will be injected into the Antelope reservoir at a depth of over 1,600 m below ground level, and therefore will be contained well below the depth of any usable groundwater. The magnitude of impact on groundwater resources from the injection of produced water and desulfurization process liquid effluent into the Antelope reservoir is assessed to be ***Low*** and the residual risk is assessed to be ***Negligible***.

Injection of Acid Gas

Shallow groundwater is expected to be of limited occurrence in the area of the Elk wellpad. Deeper formations consist of siltstones and mudstones that are unlikely to support aquifers being present in the area, hence the sensitivity of groundwater in the area of the acid gas injection is assessed to be ***Minimal***.

Disposal of acid gas into a deep formation allows the economic production of sour gas while minimizing hydrogen sulfide (H_2S) and carbon dioxide (CO_2) atmospheric emissions (BCOGC, 2018). Suitable disposal formations for injection are generally greater than 1,000 m below ground level and have containment from contact with usable water or the environment. Disposal into a depleted hydrocarbon reservoir is recognized to be an effective method of containing acid gas, provided that rigorous design and maintenance is undertaken of the acid gas disposal well and due consideration is given to the condition of any other existing or abandoned wells that subsurface acid gas plumes may contact (BCOGC, 2018).

The acid gas will be injected into the depleted Elk reservoir at a depth of over 1,600 m below ground level and; therefore, will be contained well below the depth of any usable groundwater resource. The proposed embedded design controls will maintain wellbore integrity and contain acid gas within the reservoir such that migration to any shallow groundwater aquifers is not expected to occur. The magnitude of impacts due to acid gas contaminating groundwater and

effecting environmental values is therefore considered to be ***Low***. The residual risk is; therefore ***Negligible***.

Accidental Leaks from Flowlines, Trunkline or Export Pipelines

Groundwater occurrence and use varies along the length of the pipeline corridors (as described in Section 11.2.1). The resource sensitivity; therefore, varies in the PAOI. The sensitivity in PRL-15 and along the export pipeline route is ***Minimal*** in elevated areas where aquifers are deep and are not used for local domestic purposes or by groundwater-dependent ecosystems. In lower elevation areas in PRL-15 and along the export pipeline route where shallow aquifers potentially support areas of lowland alluvial forest and freshwater swamp vegetation during dry periods (see Figures 7.20 and 7.21), and are not used for local domestic purposes, sensitivity of groundwater is assessed to be ***Medium***. The groundwater sensitivity is assessed to be ***High*** near the coast, where coastal and inland villages use shallow groundwater aquifers for local domestic potable supply, but they are not the sole source of potable water.

Consideration of pipeline leaks in this section relates to minor accidental releases of reservoir fluids or condensates, such as might occur from pipeline weld failures. Leaks can percolate through soils resulting in groundwater contamination, particularly in loose sandy soils and where the groundwater is shallow, such as along the coastline. Potential impacts of large-scale accidental releases associated with major natural hazards and unplanned events are considered in Chapter 18. Design and mitigation measures to minimize impacts from such an event to as low as reasonably practicable are also described in Chapter 18.

Hydrotesting will be undertaken following pipelaying to test pipeline weld integrity. Valve stations will isolate pipeline sections in the event of leaks. Low-pressure detection alarms will detect accidental leaks from pipelines during operations and fiber optic cables will detect any ground movements near the pipelines.

The closest villages from the onshore export pipeline route are Iuku and Mareke and are approximately 400 m from the pipeline, however there are houses approximately 350 m away from the pipeline route. Impacts on the groundwater quality in village wells are not expected given this distance, the highly volatile nature of the condensate and the embedded design controls proposed. Based on these considerations, the magnitude of impacts due to pipeline leaks contaminating groundwater used by villagers or supporting groundwater-dependent ecosystems is assessed to be ***Minimal***.

Considering the various groundwater sensitivities in the PAOI, the residual significance of impacts is:

- ***Negligible*** for elevated areas of PRL-15 and along the export pipeline route.
- ***Negligible*** for areas adjacent to creeks and rivers in PRL-15.
- ***Minor*** near coastal and inland villages along the export pipeline route.

Accidental Hydrocarbon and Chemical Spills or Leaks

As discussed, the sensitivity elevated areas of PRL-15 and along the export pipeline route is ***Minimal***, and ***Medium*** in areas adjacent to creeks and rivers in PRL-15. The groundwater sensitivity is categorized to be ***High*** near the coast.

Accidental hydrocarbon or chemical spills or leaks may potentially occur at any area of Project activity in the PAOI. Standard good industry practices will be adopted to prevent and protect against pollution due to accidental hydrocarbon and chemical spills or leaks during preparatory works, construction, operation and decommissioning activities, and to remediate where it occurs

(as described in Section 11.2.3). These measures will limit the potential for contaminants to enter and contaminate groundwater. Impacts on groundwater quality are unlikely to be detectable, and the magnitude of impact is assessed to be ***Minimal***.

The residual significance of impacts is:

- ***Negligible*** for elevated areas of PRL-15 and along the export pipeline route.
- ***Negligible*** for areas adjacent to creeks and rivers in PRL-15.
- ***Minor*** near coastal and inland villages along the export pipeline route.

Leachates from the General Waste Landfill

The general waste landfill will be located between the CPF and the Purari River (see Figure 4.4). Local, shallow, perched groundwater occurs in alluvial sediments in this area and is considered likely to be connected with the surface water of nearby streams (as described in Section 11.2.1); however, the groundwater near the landfill provides an insignificant contribution to stream baseflow within the catchment and does not support groundwater-dependent ecosystems. There are also no local domestic uses of the groundwater in this area. The groundwater sensitivity in this area is therefore categorized to be ***Medium***.

The landfill will be designed, located, constructed and operated in general accordance with the intent of the Code of Practice for Sanitary Landfill Sites (DEC, 2001) and other applicable standard industry practices, whichever is the more stringent. Given the design standard applied, impacts on groundwater quality are expected to be low, not affecting domestic water uses. The magnitude of impact is therefore categorized to be ***Low***, providing an overall significance rating of ***Minor***.

11.2.5.2 Reduction in the Quantity of Coastal and Inland Shallow Groundwater

The groundwater sensitivity in the coastal area is categorized to be ***High***, given it is periodically used for domestic water supply but is not the sole source of potable water (as described in Section 11.2.1).

This fresh groundwater occurs approximately 1 m bgl in marine, sandy beach and back beach deposits, and is likely to lie on top of more saline water in the deeper sediments below. Communities further inland also access groundwater from springs and wells excavated to approximately 2 m deep.

The pipeline will be laid in a trench that is approximately 2.3 m deep; therefore, groundwater may be intercepted during trenching at the southern end of the onshore export pipeline route. The trenching may cause groundwater to discharge into the trench potentially causing drawdown of fresh groundwater in shallow aquifers. Such impacts would occur until the trench is backfilled and the natural groundwater flow re-establishes.

The closest receptors to the pipeline are houses located about 350 m away (as described in Section 11.2.5.1). It is unknown what the extent of groundwater drawdown will be; however, the water supply to some existing domestic users of the aquifer may be constrained hence the magnitude of impact is categorized as ***Medium***, giving an overall significance rating of ***Moderate***.

11.2.6 Summary of Residual Impacts to Groundwater

Table 11.10 provides a summary of the assessment of residual impacts to groundwater, including in which Project phase and location these impacts are expected to occur.

Most residual impacts to groundwater are assessed to be ***Negligible*** to ***Minor***, with the exception of the potential for a reduction in the shallow groundwater quantity at inland and coastal villages due to the groundwater drawdown into the pipeline trench, which is assessed as ***Moderate***.

Table 11.10 – Summary of Assessment of Residual Impact Significance for Groundwater

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Groundwater quality	Drilling of wells.	Groundwater contamination due to the introduction of drilling muds and cuttings.	PRL-15 (wellpads)	C	None	Minimal/Low	Negligible
	Produced water and desulfurization process liquid effluent disposal.	Groundwater contamination due to produced water and desulfurization process liquid effluent injection into ANT-11.	Antelope gasfield	O	None	Minimal/Low	Negligible
	Acid gas injection.	Groundwater contamination due to acid gas injection into ELK-10.	Elk gasfield	O	None	Minimal/Low	Negligible
	Pipeline operations.	Groundwater contamination due to accidental leaks of reservoir fluids from flowline/trunklines or condensate from the export pipeline.	Elevated areas of PRL-15 and the export pipeline route.	O	None	Minimal/ Minimal	Negligible
			Adjacent to creeks and rivers in PRL-15 and along the export pipeline route.	O		Medium/ Minimal	Negligible
			Coastal and inland villages along the export pipeline route.	O		High/Minimal	Minor

Table 11.10 – Summary of Assessment of Residual Impact Significance for Groundwater (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Groundwater quality (cont'd)	Use of hazardous materials.	Groundwater contamination from accidental hydrocarbon or chemical spills or leaks at Project facilities and various areas of activities.	Elevated areas of PRL-15 and the export pipeline route.	C, O	None	Minimal/ Minimal	Negligible
			Areas adjacent to creeks and rivers in PRL-15 and along the export pipeline route.	C, O		Medium/ Minimal	Negligible
			Coastal and inland villages along the export pipeline route.	C, O		High/Minimal	Minor
	Landfill construction and operation.	Groundwater contamination due to leachates from the general waste landfill.	PRL-15	C, O, D	None	Medium/Low	Minor
Groundwater quantity	Onshore pipeline trenching.	Reduction in the shallow groundwater quantity at inland and coastal villages due to the groundwater drawdown into the pipeline trench.	Coastal villages along the export pipeline route.	C	None	High/Medium	Moderate

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

11.3 Hydrology, Fluvial Geomorphology and Sediment Processes

11.3.1 Context

The Project is located in the lower Purari River catchment and the upper reaches of the Era River catchment (see Figure 7.6). The Purari River catchment is the third largest catchment in Papua New Guinea, extending from Mount Wilhelm to Orokolo Bay in the Gulf of Papua. The Purari River is a large meandering river in the PAOI below Hathor Gorge, with deep channels on the outside of bends and shallow depositional environments on the inside of bends (Plate 11.5). The river splits into several distributaries and forms a delta, eventually discharging into the Gulf of Papua. Shallow bars are formed across the mouths of most distributaries due to the high sediment loads in the river and the processes operating at the delta.

Plate 11.5 – Purari River

Photo: Bruno de Vals.

The Aure River is the primary tributary of the Purari River downstream of Hathor Gorge. The tributary streams in PRL-15 provide a negligible contribution to the total annual flow of the Purari River. The Purari River has characteristically low interannual flow variability; however, at daily timescales river levels can rapid change in response to rainfall.

The Purari River lower catchment is prone to flooding and consists of a large floodplain. High rainfall occurs throughout the year, and flood events can occur in any month; however, there are seasonal differences in rainfall and associated flow patterns. The Era River experiences more frequent flood events and higher flow during the southeast winds season (May to October). The Purari River also has more frequent flooding during the southeast trade winds season but can also experience low flows during this season when rainfall in the upper catchment is low.

Table 11.11 presents the flow rates for several waterways in the PAOI. These are based on stream flow assessments associated with catchment modeling described in Section 7.3.2.3.

Table 11.11 – Mean Daily Baseflow for Selected PAOI Waterways

Waterway	Measurement Location	Catchment	Mean Daily Flow (ML/day)	Mean Annual Flow (ML/a)
Purari River	Near Wabo	Purari	17,500	6,325,430
Hou Creek	Confluence with Purari River	Purari	102	36,791
Kuku Creek	Confluence with Purari River	Purari	58	20,929
Purari River	Above Purari, Ivo-Urika and Wame-Varoi distributary rivers	Purari	22,400	8,106,615
Era River	Confluence with Toa Creek	Era	40	14,389
Boa Creek	Confluence with Mena River	Era	133	48,076

The soils of the Purari River catchment are highly erodible which, combined with high year-round rainfall, results in large sediment loads entering the catchment's waterways. Up to 80% of the sediment load estimated for the Purari River downstream of PRL-15 is derived from catchment areas upstream of PRL-15. Approximately 20% is derived from the Aure River and approximately 0.2% is derived from the tributaries in PRL-15 (see Section 7.3).

The Purari River has higher turbidity than the tributary streams in PRL-15. Turbidity in tributary streams is both spatially and temporally variable. It is possible that commercial logging that has occurred south of PRL-15 (see Section 7.7.5.3) has degraded local waterways, especially from sediment runoff from cleared areas. Degradation in PRL-15 is more limited at present, without a history of extensive logging or other broad-scale disturbance activities.

11.3.2 Discipline-specific Impact Assessment Method

11.3.2.1 Impact Assessment Approach

The significance assessment method described in Chapter 3 was used to characterize impacts relevant to hydrology, fluvial geomorphology and sediment processes. Tables 11.12 to 11.15 describe the magnitude and sensitivity matrices used. Magnitude is assessed considering combinations of (1) geographic extent and (2) the higher of severity and duration.

Table 11.12 – Impact Magnitude Descriptors Relevant to Hydrology, Fluvial Geomorphology and Sediment Processes

Geographic Extent of Impact*		Severity and Duration of Impact		
		Severity		Duration
5	Impact to any environmental feature that extends significantly beyond the *subregion* (close to *regional*) scale	5	Extreme impact to hydrology, fluvial geomorphology or sediment transport such that: ♦ Intensity, frequency and duration of the 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 the *subregion* (but not close to *regional*) scale	4	Severe impact to hydrology, fluvial geomorphology or sediment transport such that: ♦ Intensity, frequency and duration of the impact is slightly outside the range of natural variability; or ♦ One or more environmental values (social and biodiversity) are adversely affected but are supported in a highly modified condition.	Impact lasts 5 to 30 years.

Table 11.12 – Impact Magnitude Descriptors Relevant to Hydrology, Fluvial Geomorphology and Sediment Processes (cont'd)

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

**Region* = Area greater than 15,000 km^2 (25% of the Kikori-Purari river basin).
Subregion = Area more than 2 km from the Project footprint but less than 15,000 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 11.13 – Impact Magnitude Matrix Relevant to Hydrology, Fluvial Geomorphology and Sediment Processes

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 11.14 – Hydrology, Fluvial Geomorphology and Sediment Processes Sensitivity of Resource or Receptor

Rating	Descriptor
Very High	♦ Environment is in a natural condition with no evidence of modification. ♦ Environment supports physical properties or processes that are considered rare or exceptional at the regional scale.
High	♦ Environment is in a near-natural condition with minimal human-induced modification. ♦ Environment supports physical properties that are considered rare or exceptional at the local scale but are well represented regionally.
Medium	♦ Environment is in a near-natural condition with some human-induced modification. ♦ 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 and floods).
Low	♦ Environment is moderately degraded compared to equivalent areas. ♦ Environment supports physical properties or processes that have very high natural variability due to extreme events (e.g., cyclones and floods) that have a frequency of <1 per year. ♦ Environment supports physical properties or processes that are resilient to change, experiencing extreme natural events (e.g., cyclones and floods) every few years.
Minimal	♦ Environment is highly degraded compared to equivalent areas. ♦ Environment supports physical properties or processes that are very resilient to change, experiencing extreme natural events (e.g., cyclones and floods) every year.

Table 11.15 – Hydrology, Fluvial Geomorphology and Sediment Processes Significance of Assessment Matrix

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

11.3.2.2 Information Used in Assessment

The impact assessment was informed by numerical modeling and other analyses, as follows:

- Analysis of sediment generation, which was based on generic erosion rates.
- Hydraulic (flood) modeling, which was undertaken in subcatchments where significant Project works will occur to identify areas most at risk of flooding.
- Scour risk assessment, which was derived from the hydraulic modeling to assess potential scour risks at pipeline crossings of representative waterways.

Catchment modeling was also undertaken for the Purari and Era rivers to estimate baseline flow volumes and sediment loads from various subcatchments in the PAOI. The results were used to calculate the order of magnitude contribution of subcatchments to flow volumes and sediment loads in the overall catchments. The absolute sediment loads derived from this modeling are considered indicative only since flow records for subcatchments are unavailable to enable model calibration.

Hydraulic modeling activities are described in Part 2 of Volume 2. Other assessment approaches are described further below.

Sediment Generation from Erosion

For the impact assessment, Project-generated sediment loads have been estimated based on standard erosion equations using the following erosion rates:[2]

- Undisturbed areas – 2 mm/a. This is a conservative estimate based on previous monitoring of denudation rates in the Ok Tedi catchment, reported in Alluvium (2015).
- Disturbed areas – 50 mm/a. This is the rate adopted for the PNG LNG Project (Hydrobiology, 2008) and the P'nyang Development Project (Alluvium, 2015).
- Roads (once stabilized) – 20 mm/a. This is the rate adopted for the P'nyang Development Project (Alluvium, 2015).

Erosion rates are multiplied by the area over which the disturbance occurs to estimate the sediment load (cubic meters) generated from disturbed areas. The difference between the sediment load derived from the disturbed area rate compared with the undisturbed area rate provides the net sediment load due to the Project. The sediment generated per annum changes based on the Project development stage. For simplicity; however, only two scenarios were considered:

- Maximum construction phase disturbance, which is the total disturbed area at the disturbed erosion rate compared to the total disturbed area at the undisturbed rate.
- Operations phase disturbance, which is the total road area at the road erosion rate compared to the total road area at the undisturbed rate.

Scour Risk Assessment

The scour risk assessment involved applying the hydraulic modeling outputs to empirical formulae developed for scour assessments. These formulae account for the following factors that affect general scour:

- Change in cross-sectional area of flow.
- Change in discharge.
- Sediment grading.
- Upstream sediment supply.
- Duration of flow.

The assessment also included evaluating the critical velocity at which scour occurs, based on the United States National Engineering Handbook Technical Supplement 14B (NRCS, 2007). All relevant formulae for the assessment (both scour and critical velocity) are presented in Table 11.16. The assessments were undertaken at the locations assessed by hydraulic modeling during baseline studies, described in Part 2 of Volume 2.

2 These rates are not based on site-specific soil data but are adopted from studies in similar catchments in Papua New Guinea.

Table 11.16 – Formulae for Scour Depth and Critical Velocity Assessments

Source	Formula*	
Blench (1969)	$z_t = y_{ms} - y_0$	Where: z_t = Scour depth (m) $y_{ms} = 1.20[\frac{q^{(\frac{2}{3})}}{D_{50}^{\frac{1}{6}}}]$ for sand-bed of 0.06<D_{50}≤2mm $y_{ms} = 1.23[\frac{q^{(\frac{2}{3})}}{D_{50}^{\frac{1}{12}}}]$ for gravel-bed of D_{50} >2 mm
Blench (1970) and Lacey (1931)	$z_t = KQ_d^a W_f^b D_{50}^c$	Where: z_t = scour depth (m) K = 0.03 (Blench) or 0.162 (Lacey) a = 1/3 (Blench) or 2/3 (Lacey) b = 0 (Blench) or -2/3 (Lacey) c = -1/6 (Blench) or -0.1092 (Lacey)
Blodgett (1986)	$z_{t(mean)}=KD_{50}^{-0.1}$ $z_{t(max)}=KD_{50}^{-0.11}$	Where: z_t = scour depth (m) K = 0.84 (mean) or 3.8 (max)
Pemberton and Lara (1984)	$d_S = K(q)^{0.24}$	Where: d_S = depth of scour below streambed (m) K = 1.32 q = unit water discharge (m^3/s per m of width)
Technical Supplement 14B (NRCS, 2007)	$V_c = Ky^{\frac{1}{6}}D_{50}^{\frac{1}{3}}$	Where: V_c = critical velocity (m/s) y = average flow depth in the reach in question (m) K = 6.19

* D_{50} in all equations represents the particle diameter that represents 50% of the mass of the sample.

All scour assessment equations rely on the sediment size at the pipeline crossings of representative waterways. In lieu of detailed data on the sediment for each crossing site, the assessment was based on three sediment sizes: 0.1 mm (very fine sand), 1.0 mm (coarse sand) and 10 mm (gravel). These are considered representative of the range of sediment sizes that would likely occur in the relevant waterways.

As scour assessments have been based on hydraulic modeling outputs, which were developed during baseline assessments, not all pipeline waterway crossings have been captured; however, representative waterway locations have been assessed to cover a range of conditions such that waterways not assessed would be expected to experience scour that is equal to or lesser than scour at assessed locations.

11.3.3 Identification of Potential Impacts

Potential impacts to hydraulic processes and sediment transport 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.

11.3.3.1 Changes to Hydraulic Processes and Sediment Transport

11.3.3.1.1 Earthworks and Physical Infrastructure

Figures 11.2 to 11.4 show the location of various Project infrastructure and associated earthworks in relation to soil types in the PAOI. Pipeline and road waterway crossing locations are shown in Figure 11.5. Table 11.17 describes the areas of disturbance and infrastructure that will be located throughout the various PAOI catchments and subcatchments.

Table 11.17 – Waterways Potentially Affected by Changes in Surface Drainage Patterns

Infrastructure Element	Disturbance to Waterways and Physical Processes	Affected Subcatchments	
Access roads	The right of way (ROW) will be cleared where new roads are required. Part of the ROW will be stabilized as a road structure (e.g., with crushed aggregate) while the remainder will be retained as a grassed verge. Drains will adjoin roads to divert flow from the road and surrounding areas. These drains will discharge into local waterways at road crossing locations. Access roads will cross waterways where required over culverts or bridges (to maintain flow).	Hou Creek Kuku Creek Oyomo Creek	Purari River
		Boa Creek Mena River Purari River banks in PRL-15	Era River
Flowlines, trunklines, injection lines and export pipelines	Pipelines and roads will share a ROW. The pipelines will be placed in a trench and then buried. The buried area will be retained free of vegetation except grass. Pipelines will be buried under waterways where required using trenches, except the Purari River which will be bored under using horizontal directional drilling (HDD).	Hou Creek Kuku Creek Oyomo Creek Purari River tributaries along the export pipeline route	Purari River
		Boa Creek Mena River	Era River
Wellpads	A new wellpad will be established at ANT-10. Other wells will be located at existing wellpads.	Boa Creek Mena River	Era River
Impoundments	Dams will be used to impound water to provide supply for drilling during construction. The dams will allow overflow during normal flow conditions.	Hou Creek	Purari River
		Boa Creek	Era River
Quarries	Quarries will require clearing and earthworks and will create depressions in the landscape that could capture water, depending on topography. Quarries will use perimeter channels to divert overland flow to minimize ponding.	Kuku Creek Banks of Purari River	Purari River
Spoil disposal sites	Spoil from excavations will be placed in natural depressions. These stockpiles will be stabilized and left in place. Dump locations will include perimeter drains to divert overland flow to prevent soil erosion.	Hou Creek Kuku Creek Oyomo Creek Purari River tributaries along the export pipeline route	Purari River
		Boa Creek Mena River	Era River
CPF	The CPF will require clearing and earthworks, and filling and diversion of several tributary streams. Once completed, a perimeter drain will surround the CPF to divert clean water from overland flow.	Oyomo Creek	Purari River

Table 11.17 – Waterways Potentially Affected by Changes in Surface Drainage Patterns (cont'd)

Infrastructure Element	Disturbance to Waterways and Physical Processes	Affected Subcatchments	
Logistics Base	The Logistics Base will require clearing and earthworks.	Purari River banks in PRL-15	Purari River
Purari Airstrip	The Purari Airstrip expansion will require clearing and earthworks.	Purari River banks in PRL-15	Purari River
Camps, landfills, check valve stations and pipe yards	These elements will require clearing and earthworks and will likely be bunded to contain spills and to divert overland flow.	Oyomo Creek Purari River banks in PRL-15 Purari River tributaries along the export pipeline route	Purari River

Earthworks are required throughout the PAOI, particularly for wellpads, quarries, spoil disposal sites, roads, pipelaying and the construction of the CPF, Logistics Base and Purari Airstrip extension. For this assessment, earthworks include site clearing, scrubbing and grubbing, topsoil stripping, spoil (subsoil) excavation, stockpiling and disposal, spoil or rock cut and fill, transportation of soil/spoil and rock materials in the work areas, drainage, and disposal of excess, stripped and unusable spoil material. Project physical infrastructure to be constructed that will intersect with waterways includes water supply dams for drilling of wells, pipelines, roads and the CPF. These earthworks and infrastructure are described in further detail in Chapter 4.

Earthworks and Project infrastructure have the potential to cause the following impacts:

- Changes to hydraulic processes (e.g., water flow direction, velocity and volume), caused by:
  - Changes in topography (i.e., cut and fill).
  - Development of site drainage networks.
  - Construction of infrastructure and spoil disposal sites in drainage depressions, floodplains and waterways.
  - Decreased vegetation and increased impervious surfaces.
- Increased suspended sediment and sedimentation levels in waterways due to:
  - Increased soil erosion and sediment loads.
  - Increased scour potential from changes in drainage patterns.

Changes to Hydraulic Processes

The main Project activities affecting hydraulic processes are:

- Diversion of overland flows (and associated operation of stormwater infrastructure) and defined stream channels.
- Vegetation clearance.
- Installation of pipelines across waterways.
- Installation of culverts to maintain flows.

Details on the potential impacts on these process changes are provided in the following sections. Further design of drainage, waterway crossings and infrastructure alignments will be undertaken during the FEED and detailed design phases of the Project. These design activities will provide an inherent level of mitigation or avoidance of impacts, as described in the following sections.

PROJECT INFRASTRUCTURE AND SOIL TYPES IN HOU CREEK AND ERA RIVER CATCHMENTS

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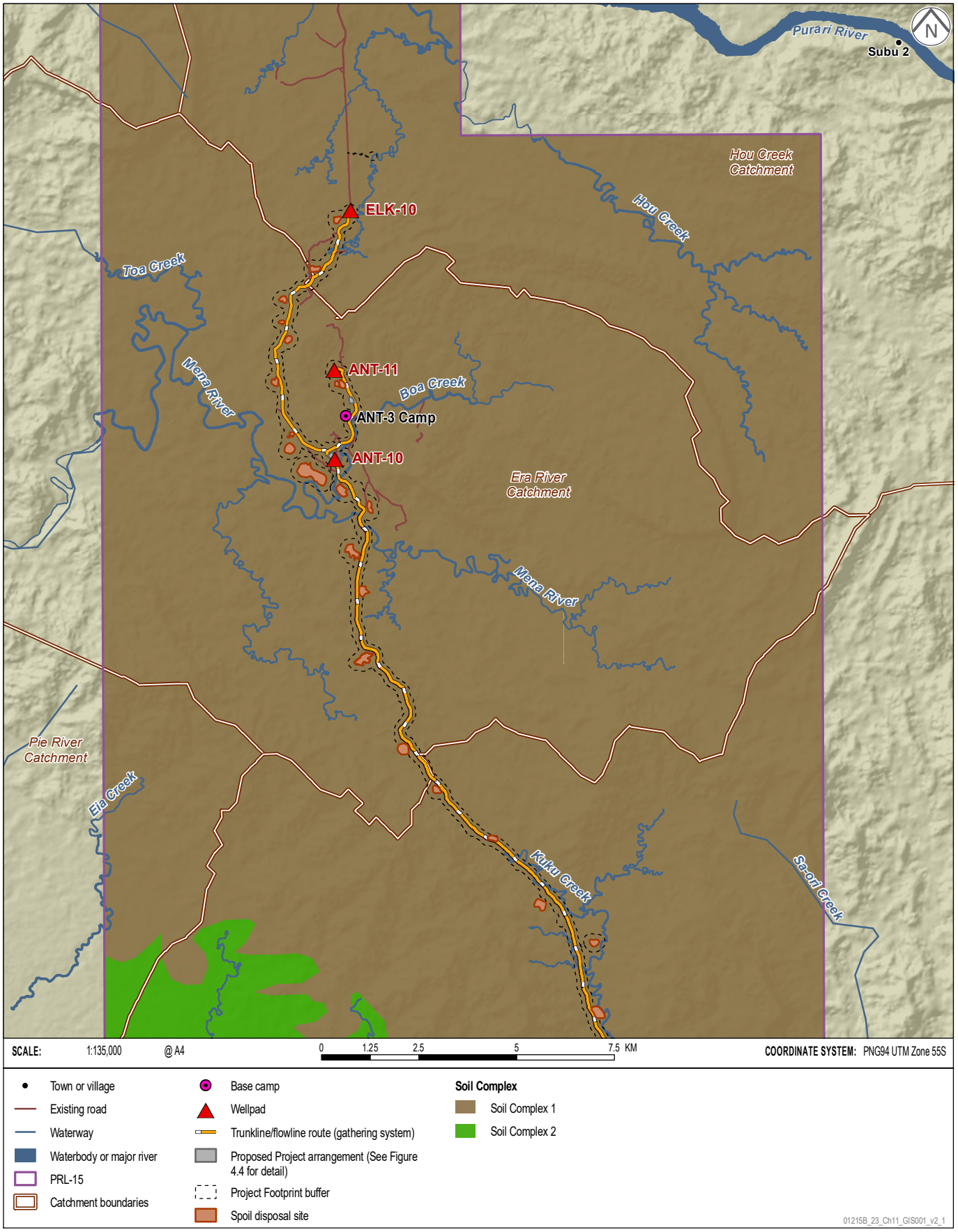
FIGURE 11.2



Source: Figure theme data from BMT, 2019.

PROJECT INFRASTRUCTURE AND SOIL TYPES IN KUKU CREEK AND OYOMO CREEK CATCHMENTS

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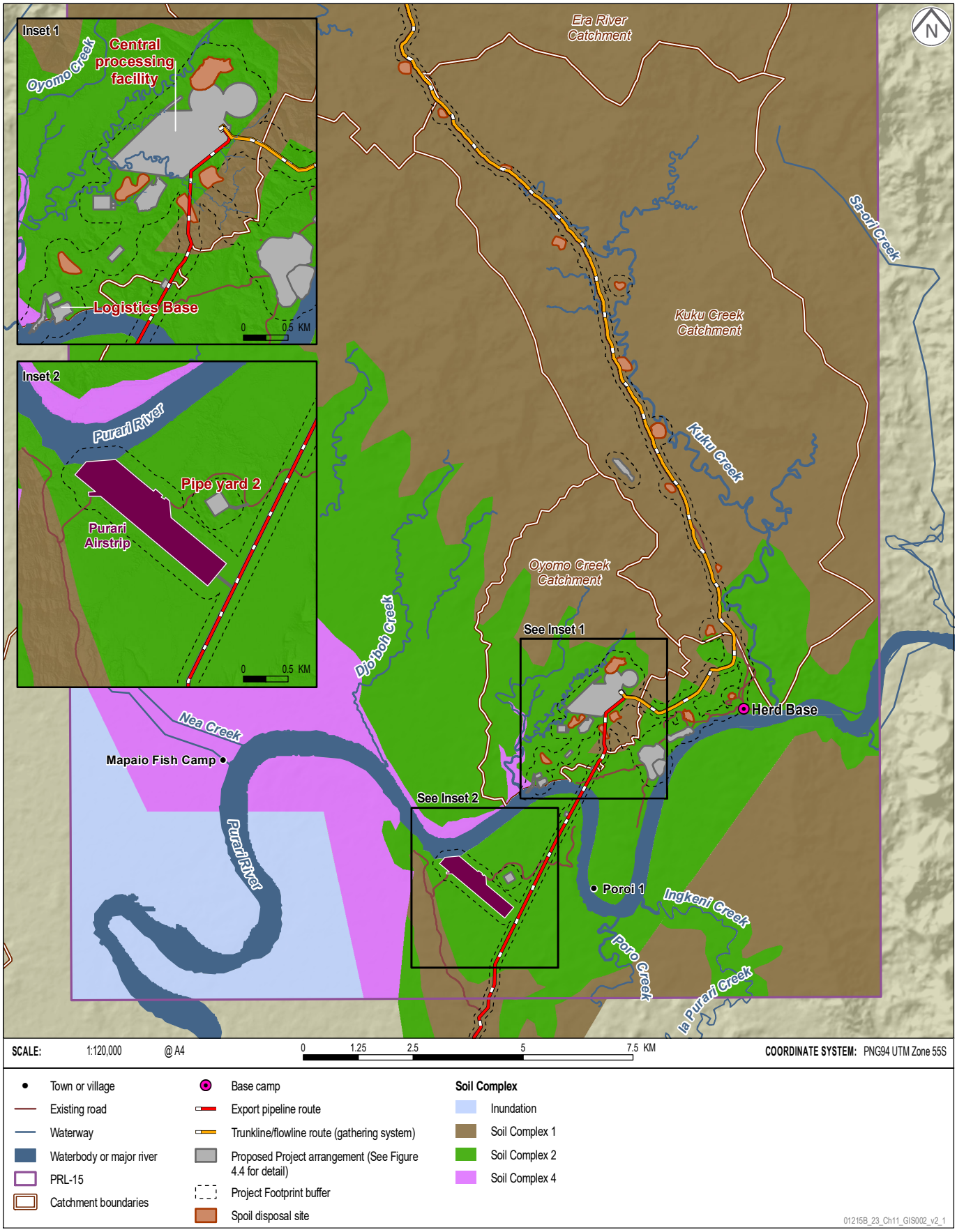
FIGURE 11.3



Source: Figure theme data from BMT, 2019.

SOIL TYPES ALONG THE EXPORT PIPELINE ROUTE

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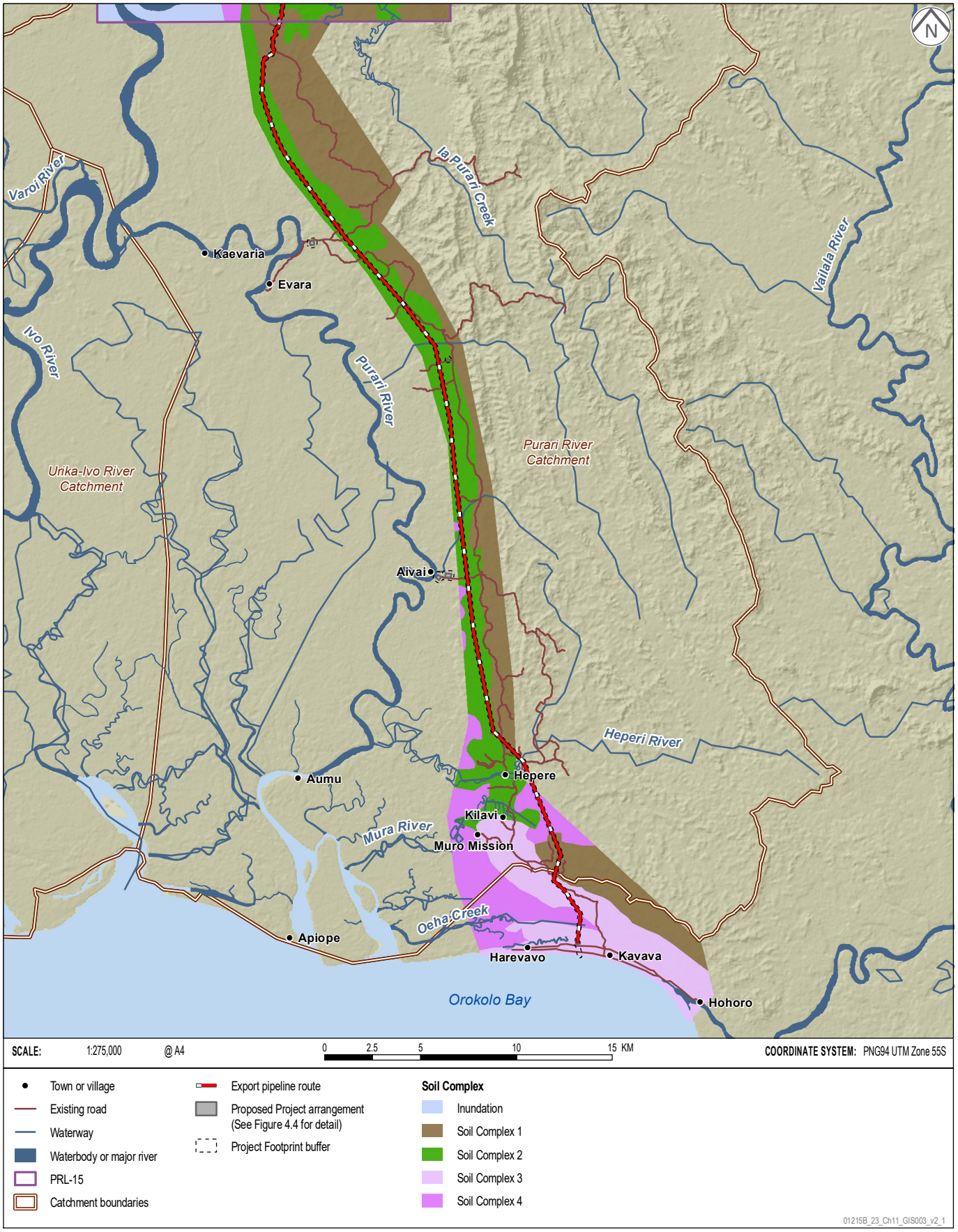
FIGURE 11.4



Source: Figure theme data from BMT, 2019.

WATERWAY CROSSING LOCATIONS

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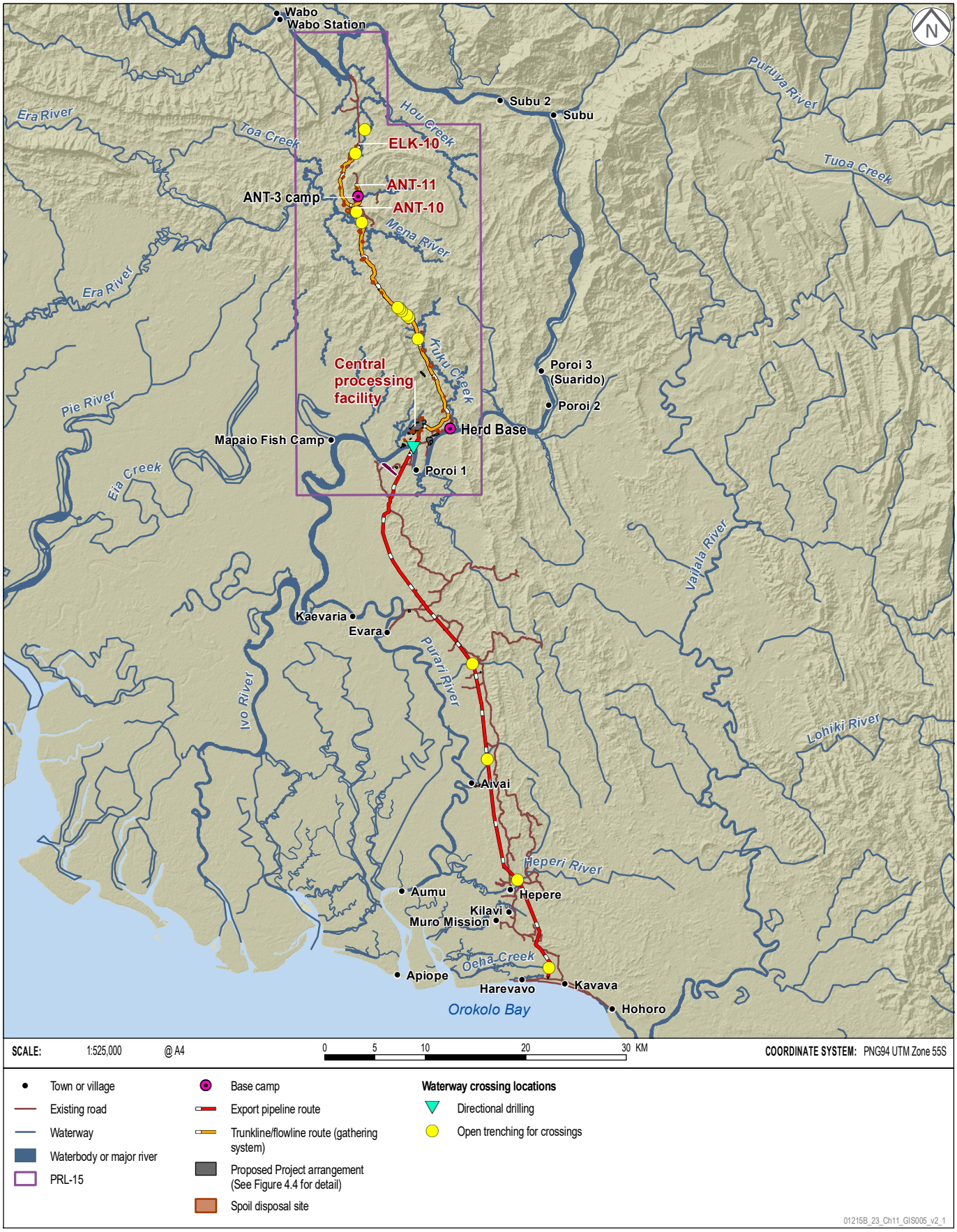
FIGURE 11.5



Source: Figure theme data from BMT, 2019.

Diversion of Overland Flows

Overland flows (i.e., outside defined channels) will be diverted around Project infrastructure (including new quarries). This could cause highly localized changes to overland drainage patterns in and adjacent to the disturbance footprint; however, defined waterways will typically be retained in their present form and will not be diverted. The exceptions are streams in the proposed CPF footprint, which will be diverted around the CPF. This will disturb approximately 92 ha of the 2,250 ha (i.e., less than 5%) of the Oyomo Creek catchment, as shown in Figure 11.6. Importantly, the diversion of flows into different subcatchments is not proposed.

Vegetation Clearance

Vegetation clearing and earthworks will increase the volume of runoff by replacing previously vegetated areas with surfaces with an increased runoff potential (e.g., roads and grassed areas). Increased runoff can cause localized scour, especially where runoff is channeled through drainage networks to a single discharge point.

Installation of Pipelines Across Waterways

The crossing of the Purari River will use horizontal directional drilling (HDD) beneath the river and therefore has no implications for earthworks or surface level changes.

Pipelines will be installed under other waterways using open trenching, which will be backfilled immediately to a depth equivalent to the original conditions. Pipelines will; therefore, not interfere with stream flows when first constructed; however, natural channel scour at crossing locations may occur during periods of high flows.

Based on the scour assessment using formulae from the United States National Engineering Handbook Technical Supplement 14B (NRCS, 2007), the critical velocity for scour (i.e., the stream velocity at which scour will occur if exceeded) is not exceeded at any modeled waterway crossing; however, as this assessment has not been based on detailed site soil data, a risk of scour remains at all waterway crossings with highly dispersive soils. Table 11.18 presents the potential scour depths for each of the modeled waterways (i.e., Boa Creek, Mena River and unnamed streams along the export pipeline route). Scour assessment of crossings at Hou and Kuku creeks and the Heperi River were not conducted, as these areas were excluded from hydraulic models as part of baseline assessments; however, a comparison of these crossings to modeled crossings indicated scour at these creek crossings would be less than or equivalent to scour at other crossings.

The results presented in Table 11.18 are the mean results derived from the scour formulae described in Table 11.16, with individual results for the separate formulae presented in Table 11.19.

The results indicate a scour depth of at least 1 m at each crossing, which is expected to partly or fully expose the pipeline. The exposed pipeline is expected to cause highly localized changes to stream flows and morphological processes (e.g., sediment accretion and further scour). Sediment deposition will occur during periods of low flows, potentially leading to full or partial pipeline reburial.

CHANGES TO OYOMO CREEK DRAINAGE

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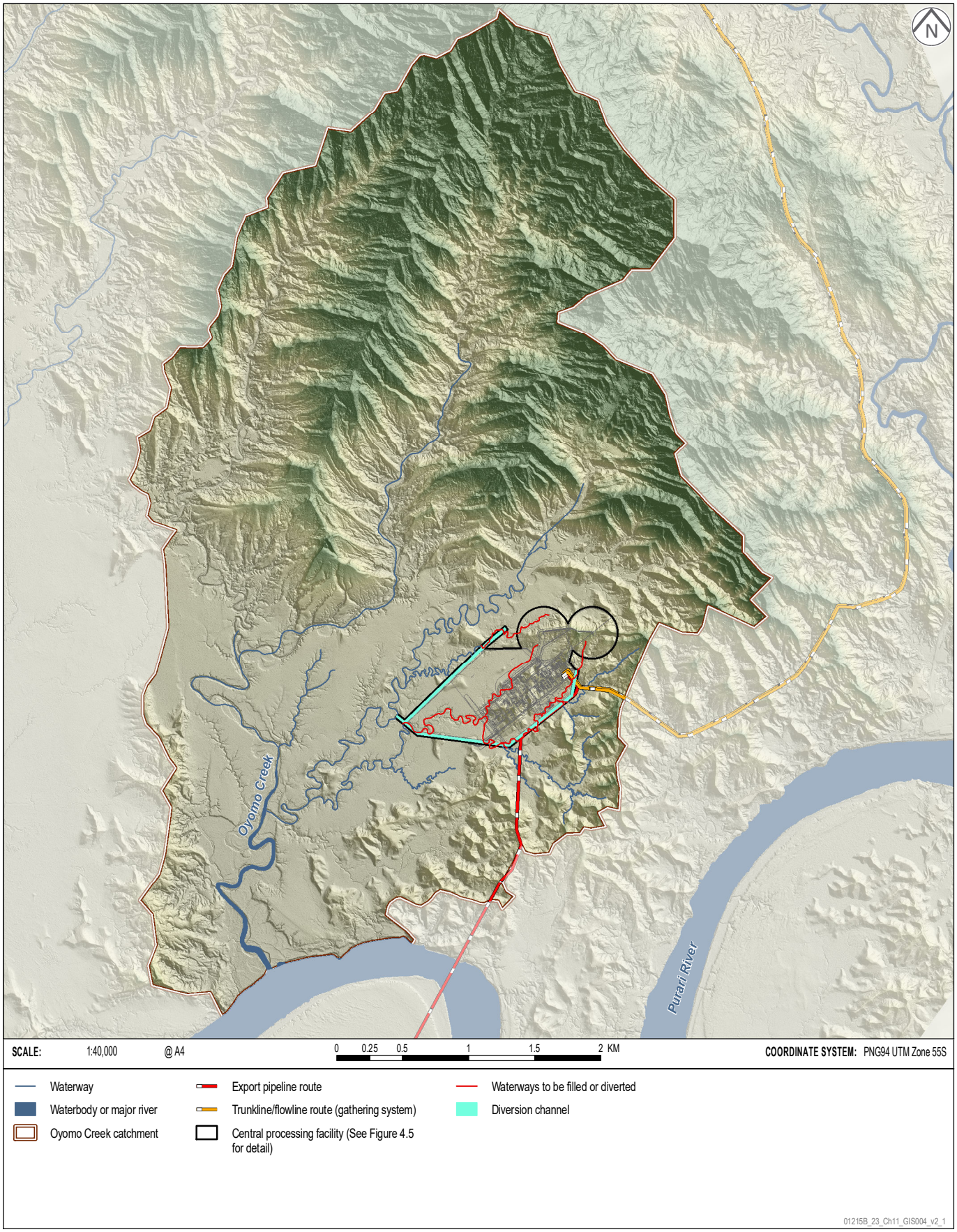
FIGURE 11.6



Source: Figure theme data from BMT, 2019.

Installation of Culverts to Maintain Flows

Culverts will be installed to maintain flows; however, inappropriately designed culverts can interfere with stream flows and associated morphological processes. Upstream flooding can occur during high flow events when the culvert flow capacity is exceeded causing scour.

Increased Levels of Suspended Sediment and Sedimentation

Construction works will remove vegetation and disturb soils, with approximately 930 ha of ground disturbance proposed to occur in the PAOI (Section 4.10.7). Table 11.20 provides an indicative breakdown of ground disturbance areas in the main PAOI catchments.

Figures 11.2 to 11.4 show that the disturbance occurs across all four mapped soil complexes for the PAOI. Each of these complexes is highly erodible soil. Additionally, ROWs in PRL-15 are aligned close to areas of steep topography, including Kuku Ridge and the Mena plateau. Clearing and ground disturbance in or downslope of these features can cause a heightened risk of landslides.

Disturbed soils will; therefore, be prone to erosion, which will increase sediment yield in the affected catchments. This will be particularly pronounced where disturbance occurs in areas of steeper gradients, such as around Boa and Kuku creeks. Furthermore, gullying on roads will represent a significant sediment source, especially in areas where road drains flow along unstable slopes. Fugitive sediment from disturbed areas and roads may potentially be transported in runoff to the streams that drain the construction areas.

Additionally, excess spoil is intended to be stockpiled permanently in low-lying depressions at various locations (see Figure 11.2 and Figure 11.3). Rain could mobilize soil from these stockpiles. Sediment mobilization may also degrade water quality and harm freshwater and estuarine biodiversity, with such impacts considered in Sections 11.4 and 11.5.

The following embedded design control addresses potential impacts to hydraulic processes and sediment transport:

- All facilities and infrastructure will be constructed with surface-water drainage systems to reduce the potential for soil loss and degradation both on and off construction areas, and to limit soil erosion and discharge of sediment-laden water to local drainage lines and watercourses. Bridges and culverts will be designed to allow for high flow events following heavy rainfall and to replicate natural flow characteristics as far as practicable. The design is to:
  - Account for local rainfall conditions and catchment size of works areas.
  - Allow avoiding unseasonal waterlogging.
  - Allow for rainfall events with an ARI of at least two years for temporary roads and up to 20 to 50 years for long-term major haulage routes as far as practicable [ED014].

Table 11.18 – Mean Critical Stream Velocities and Scour Depths for Pipeline Waterway Crossings

Waterway*	Scour Assessment Reporting Location*	Modeled Velocity (m/s)	Critical Velocity† (m/s)			Mean Scour Depth† (m)		
			D_{50} 0.1 mm	D_{50} 1.0 mm	D_{50} 10 mm	D_{50} 0.1 mm	D_{50} 1.0 mm	D_{50} 10 mm
Boa Creek	S1-11	1.99	3.66	7.89	17.00	0.59	0.18	-0.01
Mena River	S2-5	0.42	3.31	7.12	15.34	0.63	0.28	0.13
Unnamed rivers and minor tributaries along the export pipeline route	S14-19	0.32	2.50	5.39	12.67	0.24	0.16	0.11
	S17-9	0.67	2.53	5.46	11.76	0.30	0.20	0.14

* Reporting locations are shown in the hydraulic modeling results in Part 2 of Volume 2. Scour assessment of crossings at Hou and Kuku creeks and the Heperi River were not conducted, as these areas were excluded from hydraulic models as part of baseline assessments; however, a comparison of these crossings to modeled crossings indicated scour at these creek crossings would be less than or equivalent to scour at other crossings.
† As described in Section 11.3.2.2, assessment was undertaken considering three different sediment sizes (i.e., 0.1 mm (very fine sand), 1.0 mm (coarse sand) and 10 mm (gravel) considered representative of the range of sediment sizes that would likely occur in the relevant waterways. The mean was determined using the average of results presented in Table 11.20, excluding Blodgett maximum scour depth.

Table 11.19 – All Scour Depth Results for Relevant Waterway Crossings

Crossing Point ID	Peak Flow (m^3/s)	Flow Width (m)	Velocity (m/s)	Mean Flow depth (m)	Blodgett Mean Scour Depth (m)			Blodgett Maximum Scour Depth (m)			Lacey Scour Depth (m)			Blench (1969) Scour Depth (m)			Blench (1970) Scour Depth (m)			Pemberton and Lara Scour Depth (m)		
					D_{50} 0.1 mm	D_{50} 1.0 mm	D_{50} 10 mm	D_{50} 0.1 mm	D_{50} 1.0 mm	D_{50} 10 mm	D_{50} 0.1 mm	D_{50} 1.0 mm	D_{50} 10 mm	D_{50} 0.1 mm	D_{50} 1.0 mm	D_{50} 10 mm	D_{50} 0.1 mm	D_{50} 1.0 mm	D_{50} 10 mm	D_{50} 0.1 mm	D_{50} 1.0 mm	D_{50} 10 mm
S1-11	143.16	31.77	1.99	4.27	1.06	0.84	0.67	4.9	3.8	2.95	0.23	0.16	0.11	0.53	-1.0	-1.5	0.57	0.44	0.34	0.57	0.44	0.34
S2-5	212.38	66.3	1.63	2.91	1.06	0.84	0.67	4.9	3.8	2.95	0.26	0.18	0.12	0.92	-0.30	-0.70	0.45	0.35	0.27	0.45	0.35	0.27
S14-19	25.98	375.2	0.32	0.44	1.06	0.84	0.67	4.9	3.8	2.95	0.13	0.09	0.06	-0.14	-0.23	-0.26	0.04	0.03	0.02	0.13	0.09	0.06
S17-9	64.31	417.2	0.67	0.47	1.06	0.84	0.67	4.9	3.8	2.95	0.18	0.12	0.08	0.04	-0.13	-0.18	0.06	0.05	0.04	0.18	0.12	0.08

Table 11.20 – Ground Disturbance Profile for PAOI Catchments

Subcatchment	Size (ha)	Construction Phase Disturbance		Operations Phase Disturbance		
		Disturbance Area (ha)	Percentage of Subcatchment (%)	Non-road Infrastructure (ha)	Road Infrastructure (ha)	Percentage of Subcatchment (%)
Era River Catchment						
Boa Creek	4,615	64	1.39	38	39	1.67
Mena River	7,185	56	0.78	10	53	0.88
Era River (downstream of Mena River and Boa Creek confluence)	163,000	69	0.04	24	49	0.04
Total	**174,800**	**189**	**0.11**	**72**	**141**	**0.12**
Purari River Catchment						
Hou Creek	74,970	26	0.03	7	34	0.05
Kuku Creek	8,208	133	1.62	31	117	1.80
Oyomo Creek	2,250	146	6.49	127	23	6.67
Purari River and subcatchments downstream of the Purari River export pipeline crossing (excludes Ivo-Urika and Wame-Varoi distributaries)	84,190	402	0.48	146	424	0.68
Total	**169,618**	**707**	**8.62**	**311**	**598**	**0.54**

11.3.3.1.2 Wastewater, Stormwater and Hydrotesting Releases

Controlled wastewater and stormwater discharges from various Project areas will occur to the Purari River via one or more outlets at the Logistics Base. These discharges will consist of treated sewage effluent and treated contaminated stormwater runoff from the CPF. Hydrotest water will be discharged to a site in accordance with the environmental permit, which may be the Purari River, however the exact location(s) will be determined during FEED. Discharges to the river have the potential to cause erosion and scour.

The following embedded design control addresses this potential impact:

- Hydrotest water discharges will be managed according to applicable requirements [ED040].

Impacts of Project discharges on water quality are considered in Section 11.4.

11.3.3.1.3 Dredging

Construction of the Logistics Base along the Purari River will require dredging of a berth pocket and installation of in-stream structures as part of the quay line and jetty.

The dredging will be required to provide underkeel clearance for berthing vessels. This dredged area is likely to be maintained for the life of the Project, with the expected frequency of dredging and dredge volumes to be determined during FEED.

Detailed design of the area to be dredged has not yet been undertaken; however, up to 6,000 m^3 may be excavated from the riverbed. The area to be dredged has been estimated based on river bathymetry and the likely dredge depth that will be required for vessels (i.e., 3 to 3.5 m based on a draught of 2.5 m for a fully loaded barge). The likely dredge area is shown in Figure 11.7 and has a surface area of approximately 1.5 ha.

For the impact assessment, dredging is assumed to be undertaken using a backhoe dredge or similar excavation-based dredger, with material placed directly in a barge for onshore or in-river disposal. This technique is most likely based on the volume and location of dredging. A backhoe dredge operates by directly removing riverbed sediment using an excavation arm and bucket.

The logistics base quay line and jetty will likely use sheet piles and similar structures rather than freestanding piles. This provides for a more stable environment for the docking, loading, unloading and departing of vessels. As shown in Figure 11.7, there are two locations where the sheet piles would be used: the southwest corner of the logistics base, immediately downstream of a natural outcrop, upstream of the dredging footprint; and immediately downstream of the dredging footprint.

Dredging of the berth and installation of sheet piles have the potential to cause the following impacts:

- Changes to hydraulic processes (i.e., hydrology, flow characteristics and scouring) associated with changes to the riverbed and introduction of physical barriers.
- Increased levels of suspended sediment and sedimentation from sediment mobilized during dredging (capital and maintenance) and disposal (if in-river disposal is undertaken).

Changes to Hydraulic Processes

A net removal of material from the Purari River from dredging can change overall morphology due to a change in the amount of sediment available in the river for natural fluvial processes (e.g., scour and deposition). These downstream changes may persist where the dredged basin is a long-term feature.

LIKELY AREA OF DREDGING FOR LOGISTICS BASE

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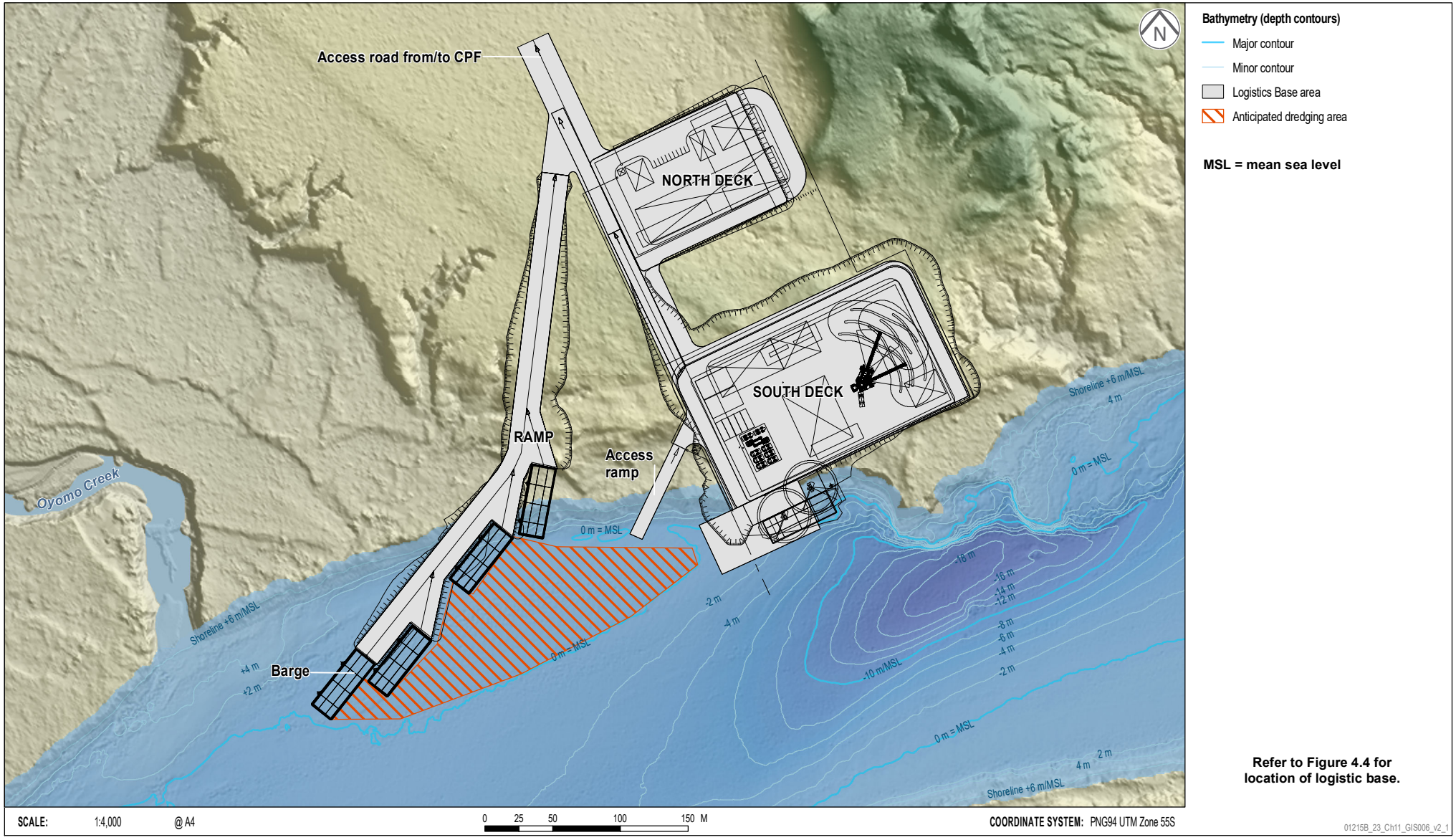
FIGURE 11.7



Source: Figure theme data from BMT, 2019.

Additionally, scour and slumping may occur adjacent to the dredging footprint due to the change in local hydrodynamics from the deepening. This could cause the loss of riparian habitat and the release of additional sediment into the river.

Installation of sheet piles will cause a localized change in fluvial processes due to the diversion of water naturally flowing downstream. Depending on the prevailing hydrodynamic forces at the sheet pile locations, this would likely cause some deposition upstream and scour downstream, due to the 'blocking' of sediment transport.

Additionally, scour and slumping may occur adjacent to the dredging footprint due to the change in local hydrodynamics. This could cause the loss of riparian habitat and the release of additional sediment into the river.

Increased Suspended Sediment and Sedimentation Levels

Dredging of the riverbed will suspend sediments in the water column and increase water turbidity. The suspended sediment behavior will depend on particle size and hydrodynamic processes. Sediment sampling undertaken near the proposed dredge pocket indicates that riverbed sediment consists of a mixture of sand (particle size diameter 0.06 to 2 mm; 44%) and silt (particle size diameter 2 to 60 µm; 40%), with some clay (particle size diameter less than 2 µm; 16%). Sand-sized particles are expected to settle on the riverbed close to the dredging footprint. The more buoyant fine sediment fractions (i.e., silts and clays) will remain suspended and be transported further downstream.

This will increase total suspended solid (TSS) concentrations in and downstream of the dredge area, which will be transported downstream by river flows. The extent of the TSS changes will depend on a range of factors, including river flows, dredge location, type of dredge, working methods, duration of dredging and dredging rates.

The Purari River is known to cause reverse flow into Oyomo Creek during periods of high river flow. As Oyomo Creek, which is a clear water stream, is immediately downstream of the dredge pocket, turbid plumes from the dredging could extend into Oyomo Creek during periods of high flow in the Purari River, potentially increasing the sediment loads delivered to this system during high flows.

11.3.3.1.4 Vessel Traffic

Vessel traffic in the Purari River will increase during all Project phases. The most traffic will occur in the construction period during months 1 to 18 when barges bring aggregate materials for earthworks to the site. During the peak period (months 8 to 18), between four and five barge deliveries per day will be made to the Logistics Base, resulting in nine to ten barges on the river system at a given time.

River traffic can cause scour of the riverbed and banks due to propeller wash and vessel wake. An increase in vessel movements may increase scouring, especially where traffic is regular and at high densities. Long-term scour, if unaddressed, can cause river banks to slump and introduce sediment into the river.

Scour risk is expected to be highest on the outer bends of large meanders where natural erosion is occurring and in areas where riparian vegetation has been removed, such as commercial logging areas.

11.3.3.2 Reduction in Stream Flows from Water Extraction

Water will be required for the following Project activities:

- Creation of drilling mud for production drilling.

- Pressurizing of drilling mud for well control purposes.
- Pipeline cleaning and hydrotesting.
- Processing of reservoir fluids and gas at the CPF.
- Potable water supply for the CPF, Logistics Base and accommodation camps.

Approximately 200 m^3/day of water will be required at each well to create drilling muds, with occasional peaks of up to 1,300 m^3/day. Water is also needed to pressurize the drilling mud for well control purposes, and a flow rate of 100 m^3/day will be required. The total water demand during drilling is expected to be between 300 and 1,400 m^3/day at each well (see Section 4.10.3.6).

Water for the ANT-10 and ELK-10 drilling and wellpads is expected to be extracted from Boa Creek and Hou Creek, respectively. So that enough water is available during periods of low river flow, temporary dam structures 5-m high will be constructed on the creeks, which will create a water storage volume of 2,000 m^3. Preliminary locations of water extraction points for drilling and operations are shown in Figure 11.8. The final water extraction points and dam structure locations will be defined during FEED.

Water to clean and hydrotest the onshore pipelines is expected to be drawn from the Purari River at the Logistics Base. The volume of water required will be defined during FEED; however, it can be expected to be approximately equivalent to the total volume of the onshore pipelines, i.e., approximately 19,000 m^3 for flowlines and trunkline and 50,000 m^3 for export pipelines. The total volume of water required for hydrotesting is therefore estimated to be approximately 69,000 m^3; however, water extraction requirements will be less than this volume since hydrotest water will be recycled from one section of pipe to another.

The average minimum flow rate of the Purari River measured at Wabo is 1,920 m^3/s (see Section 7.3.2.3), which is equivalent to 165,000,000 m^3/day. At the extraction point at the Logistics Base, the flow rate is greater due to the additional inflows from the Aure River. The total water extraction requirements for hydrotesting (69,000 m^3); therefore, represents less than 0.05% of the total daily flow under minimum flow conditions.

Approximately 2,500 m^3/day of water will also be extracted from the Purari River for use at the CPF; 2,400 m^3/day is required for acid gas removal during the first years prior to acid gas injection into the depleted Elk reservoir and 100 m^3/day is required for domestic water supply for the accommodation camp. This volume represents less than 0.002% of the average minimum flow of the Purari River. The CPF water requirements will decrease to approximately 200 m^3/day when acid gas injection commences.

Reductions in water flows may potentially reduce impact environmental flows that sustain human livelihoods and aquatic ecosystems. Impacts on aquatic biodiversity are assessed in Section 11.5.

11.3.4 Proposed Mitigation and Management Measures

Table 11.21 describes mitigation and management measures to further reduce impacts to hydrology, fluvial geomorphology and sediment processes.

WATER EXTRACTION LOCATIONS

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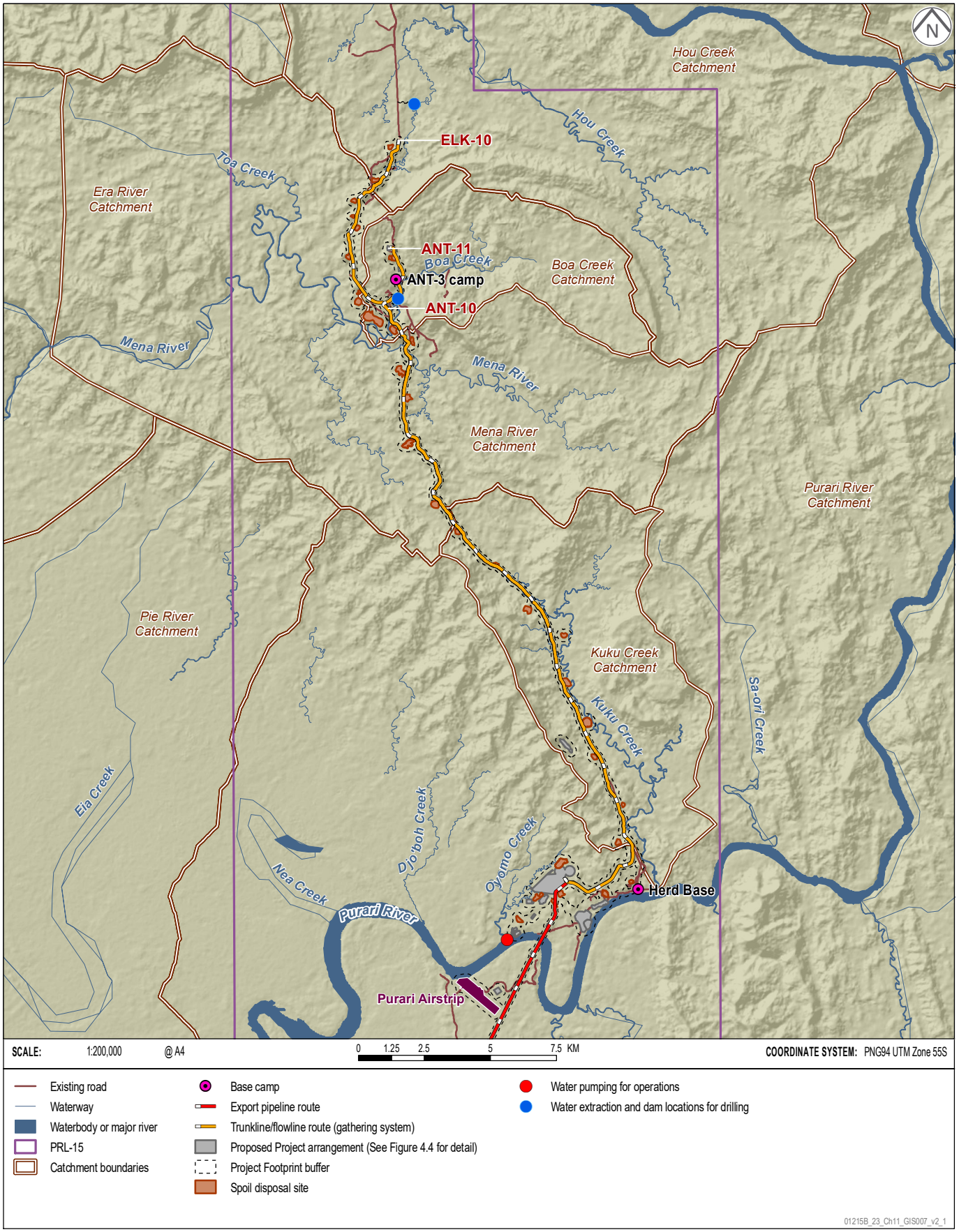
FIGURE 11.8



Source: Figure theme data from BMT, 2019.

Table 11.21 – Hydrology, Fluvial Geomorphology and Sediment Processes Mitigation Strategies and Management Plans

Potential Impact	Mitigation Strategy	Relevant Management Plan
Alterations to hydrology, flow characteristics and scouring (due to earthworks and physical infrastructure)	♦ Backfill trenches as soon as practicable after disturbance, using material originally excavated from the trench as much as possible. The backfilled trenches should not exceed the preconstruction levels after the material has settled [EM009]. ♦ Erosion and sediment control measures will be implemented for infrastructure components in accordance with good international industry practice to effectively manage stream and river flows, stormwater, surface erosion, sedimentation and scour, e.g., drainage diversion into surrounding vegetation, rip-rap aprons, rock armoring, energy dissipaters, sediment control ponds, mulch berms and sediment fences, where required, until the area has been effectively stabilized and/or rehabilitated [EM004].	Site Restoration and Rehabilitation Plan; Water Management Plan
Soil erosion causing increased TSS, turbidity and sedimentation of streams (due to earthworks and physical infrastructure)	♦ Progressively clear vegetation and rehabilitate cleared areas as soon as practicable to minimize the time cleared areas are exposed; and allow fauna to move away from areas to be cleared, where practicable [EM002]. ♦ Cut trees where practicable to retain the rootstock and maintain soil stability [EM003]. ♦ Erosion and sediment control measures will be implemented for infrastructure components in accordance with good international industry practice to effectively manage stream and river flows, stormwater, surface erosion, sedimentation and scour, e.g. drainage diversion into surrounding vegetation, rip-rap aprons, rock armoring, energy dissipaters, sediment control ponds, mulch berms and sediment fences, where required, until the area has been effectively stabilized and/or rehabilitated [EM004]. ♦ Stabilize spoil stockpiles and areas of ground disturbance as soon as practicable after initial disturbance using, e.g., mulched vegetation, aggregates and soil binders [EM005]. ♦ Areas of higher risk of landslides e.g., steep gradients, previously disturbed land, likely to occur from the works, or likely to be exacerbated by the works, will be stabilized to reduce the landslide risk. [EM006]. ♦ Minimize or avoid sidecasting during construction (e.g. for road, pipeline, wellpad and CPF works). Any sidecasting that does occur will avoid defined stream channels [EM010]. ♦ Water from trenches will be discharged in accordance with applicable water quality standards with erosion and sediment controls where relevant [EM011]. ♦ Maintain buffer zones between permanent surface water and project infrastructure, except to carry out works associated with the construction of watercourse crossing or where facilities are proposed to be located within that buffer [EM012]. ♦ Minimize in-stream and stream bank disturbance during high rainfall [EM013].	Soil Management Plan; Site Restoration and Rehabilitation Plan; Water Management Plan

Table 11.21 – Hydrology, Fluvial Geomorphology and Sediment Processes Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Sediment mobilization causing increased TSS, turbidity and sedimentation of streams (due to dredging)	♦ Where required, implement adaptive management to minimize dredging impacts on sensitive habitats and species [EM037].	Water Management Plan
Sediment mobilization causing increased TSS, turbidity and sedimentation of streams (due to riverbed scouring from vessel movements)	♦ Implement low speed limits through areas sensitive to vessel wash impacts [EM014].	Traffic and Transport Management Plan
Reduction in streamflow from water abstraction	♦ Hydrotest water management will consider: – The definition of volume and discharge rates and discharge locations. – Chemicals additives 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]. ♦ Maintain hydraulic and biological connectivity during construction and operations in natural flow lines across linear infrastructure, such as pipelines and roads, and in relation to water extraction, e.g., dams, including: – Install appropriately sized culverts, drains and structures to allow fish passage, according to good international industry practice standards. – Rehabilitate waterways after construction and decommissioning to a sustainable, stable state, that reflects the original character, and maintains waterway flows and connectivity [EM020].	Water Management Plan

11.3.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to hydrology, fluvial geomorphology and sediment processes subject to the embedded design controls in Section 11.3.3 and the successful implementation of the proposed mitigation and management measures in Section 11.3.4. 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.

11.3.5.1 Changes to Hydraulic Processes and Sediment Transport

11.3.5.1.1 Earthworks and Physical Infrastructure

Construction in Oyomo Creek catchment will occur over 92 ha and cause the loss and diversion of approximately 5,600 m of waterway, comprising 3,100 m of moderate gradient tributary and 2,500 m of low gradient tributary (see Figure 11.6). While the loss and diversion of waterways in the Oyomo Creek catchment will be long-term (beyond the life of the Project), this change is unlikely to have a material significance on overall drainage patterns and hydraulic processes in the PAOI. Impacts on hydrology and fluvial geomorphology will be localized around the area of the earthworks at the CPF; hence, the magnitude of impacts will be ***Low***. The sensitivity of the waterways is ***Medium*** as they are in near-natural condition***.*** This provides an overall impact significance rating of ***Minor****.*

While there is a risk of scour at pipeline waterway crossings, especially in Boa Creek (see Section 11.3.3.1), considering that crossings will be monitored and stabilized or remediated when scour occurs, impacts are expected to be highly localized and short-term and therefore of ***Minimal*** magnitude. Waterways in the PAOI are in near-natural condition with regards to hydrology and fluvial geomorphology, and therefore of ***Medium*** sensitivity, and the impact significance from scouring is assessed to be ***Negligible***.

Where culverts are appropriately designed at road crossings, changes in flow regimes and fluvial geomorphology of waterways in the PAOI compared to pre-existing conditions will be insignificant and of ***Minimal*** magnitude. Given the stream sensitivity of ***Medium***, the residual impacts significance is ***Negligible***.

Table 11.22 presents the potential sediment loads generated in PAOI waterway catchments during the Project construction phase, adopting the erosion rates described in Section 11.3.2 before mitigation is implemented. The overall sediment transport loads contributed by the Project are likely to be significantly less than the volumes indicated in the table given the application of proposed erosion and sediment control measures.

Sediment impacts in waterways are expected to be highly localized to localized (depending on the catchment size and the area of ground disturbance), with the overall magnitude of impact differing between waterways, as follows:

- Boa Creek and Mena River – ***Medium*** magnitude impact.
- Era River – ***Minimal*** magnitude impact.
- Hou Creek – ***Minimal*** magnitude impact.
- Kuku Creek – ***Medium*** magnitude impact.
- Oyomo Creek – ***High*** magnitude impact.
- Purari River (excluding Hou, Kuku and Oyomo creeks) – ***Low*** magnitude impact.

Table 11.22 – Anticipated Sediment Generation per PAOI Catchment During the Construction Phase Before Mitigation

Subcatchment	Catchment Area (ha)	Disturbance Area (ha)	Sediment Generated during Construction Disturbance* (m^3)	Sediment Generated under Existing Undisturbed Conditions* (m^3)	Sediment Generated by the Project* (m^3)	Total Sediment Generated in the Catchment with the Project* (m^3)	Project Contribution to the Total Sediment Generated* (%)
Era River Catchment							
Boa Creek	4,615	64	32,000	1,280	30,720	123,020	25%
Mena River	7,185	56	28,000	1,120	26,880	170,580	16%
Era River (downstream of the Mena River and Boa Creek confluence)	163,000	69	34,500	1,380	33,120	3,293,120	1%
	Total:	**189**	**94,500**	**3,780**	**90,720**	**3,586,720**	**-**
Purari River Catchment							
Hou Creek	74,970	26	13,000	520	12,480	1,511,880	1%
Kuku Creek	8,208	133	66,500	2,660	63,840	228,000	28%
Oyomo Creek	2,250	146	73,000	2,920	70,080	115,080	61%
Purari River and subcatchments downstream of the Purari River export pipeline crossing (excludes the Ivo-Urika and Wame-Varoi distributaries)	84,190	402	201,000	8,040	192,960	1,876,760	10%
	Total:	**707**	**353,500**	**14,140**	**339,360**	**3,731,720**	**-**

* Disturbance calculations:
Sediment Generated during Construction Disturbance (m^3) = Disturbance Area (ha) x 50 mm/a.
Sediment Generated under Undisturbed Conditions (m^3) = Disturbance Area (ha) x 2 mm/a.
Sediment Generated by the Project (m^3) = Sediment Generated during Construction Disturbance (m^3) – Sediment Generated under Existing Undisturbed Conditions (m^3).
Total Sediment Generated in the Catchment with the Project (m^3) = (Catchment Area (ha) – Disturbance Area (ha)) x 2 mm/a plus Disturbance Area (ha) x 50 mm/a.
Project Contribution to the Total Sediment Generated (%) = Sediment Generated by the Project (m^3)/Total Sediment Generated in the Catchment with the Project (m^3) (x100).

The sediment loads predicted during the operations phase are shown in Table 11.23, based on ongoing sediment generation from roads. The magnitude of these sedimentation impacts are all ***Low*** except that for the Era River and Hou Creek, which is ***Minimal*** for both.

All waterways listed have a ***Medium*** sensitivity with regards to sediment processes (i.e., near-natural condition with some human-induced modification), except the Purari River and adjoining subcatchments downstream of the export pipeline crossing. These waterways have a ***Low*** sensitivity due to the extensive ground disturbance in the catchment from logging operations.

Based on these ratings, the overall impact significance for sediment transport is as follows:

Construction Phase

- Mena River and Oyomo, Boa and Kuku creeks – ***Moderate***.
- Era River and Hou Creek – ***Negligible***.
- Purari River and adjoining subcatchments downstream of the export pipeline crossing – ***Minor***.

Operations Phase

- Mena River, Boa, Kuku and Oyomo creeks and Purari River and adjoining subcatchments downstream of the export pipeline crossing – ***Minor***.
- Era River and Hou Creek – ***Negligible***.

11.3.5.1.2 Wastewater, Stormwater and Hydrotesting Releases

No scour impacts are expected from point source discharges to the Purari River where the discharges occur over protective rip rap or other energy dissipator devices. The magnitude of impact is therefore ***Minimal*** and, given the waterway sensitivity is ***Medium***, the residual impact significance is ***Negligible***.

11.3.5.1.3 Dredging and In-stream Structures

Backhoe dredging involves the physical extraction of bed sediments using a crane bucket. While removing 6,000 m^3 of sediment from the Purari River represents a minor proportion of the overall volume of material in the shoals near the Logistics Base, regular removal of this volume, as part of maintenance dredging, could cause a net change in fluvial geomorphology in a localized area. Additionally, the installation of sheet piles for the jetty and quay line could cause changes in deposition and scour either side of the structures.

These changes would be highly localized to the dredging and sheet pile areas, less than that likely to be experienced during extreme flow events but may be detectable above natural variability; therefore, the magnitude of impacts on hydraulic processes due to dredging would be ***Low***. Dredging and sheet piles are not expected to cause scouring of the river bank. As the Purari River is highly dynamic with regards to hydrology and morphological changes, it is considered to have ***Low*** sensitivity in terms of hydraulic processes. This provides an overall significance rating of ***Minor*** for this impact.

Only small volumes of material are released into the water column using a backhoe dredge (PIANC, 2010), creating far less turbidity than other dredging methods where material is fluidized (e.g., cutter-suction dredging) (Envisan, 2013); therefore, any sediment plumes created by dredging at the new jetty in the Purari River are expected to be highly localized and, due to strong river flows and sediment advection and dispersion, of a short-term nature restricted to the dredging period (i.e., weeks).

Table 11.23 – Anticipated Sediment Generation per PAOI Catchment During the Operations Phase Before Mitigation

Subcatchment	Catchment Area (ha)	Road Area* (ha)	Sediment Generated during Operations Disturbance† (m^3)	Sediment Generated under Existing Undisturbed Conditions† (m^3)	Sediment Generated by the Project† (m^3)	Total Sediment Generated in the Catchment with the Project† (m^3)	Project Contribution to the Total Sediment Generated (%)
Era River Catchment							
Boa Creek	4,615	39	7,800	780	7,020	99,320	7.1%
Mena River	7,185	53	10,600	1,060	9,540	153,240	6.2%
Era River (downstream of the Mena River and Boa Creek confluence)	163,000	49	9,800	980	8,820	3,268,820	0.3%
	Total:	**141**	**28,200**	**2,820**	**25,380**	**3,521,380**	**-**
Purari River Catchment							
Hou Creek	74,970	34	6,800	680	6,120	1,505,520	0.4%
Kuku Creek	8,208	117	23,400	2,340	21,060	185,220	11.4%
Oyomo Creek	2,250	23	4,600	460	4,140	49,140	8.4%
Purari River and subcatchments downstream of the Purari River export pipeline crossing (excludes the Ivo-Urika and Wame-Varoi distributaries)	84,190	424	84,800	8,480	76,230	1,760,120	4.3%
	Total:	**598**	**119,600**	**11,960**	**107,640**	**3,500,000**	**-**

* The operations phase disturbance area includes both existing and newly constructed roads but excludes the area of the road right-of-way that is outside of the actual road footprint.

† Disturbance calculations:

Sediment Generated during Operations Disturbance (m^3) = Road Area (ha) x 20 mm/a.

Sediment Generated under Undisturbed Conditions (m^3) = Road Area (ha) x 2 mm/a.

Sediment Generated by the Project (m^3) = Sediment Generated during Operations Disturbance (m^3) – Sediment Generated under Existing Undisturbed Conditions (m^3).

Total Sediment Generated in the Catchment with the Project (m^3) = (Catchment Area (ha) – Road Area (ha)) x 2 mm/a + Road Area (ha) x 20 mm/a.

Project Contribution to the Total Sediment Generated = Sediment Generated by the Project (m^3)/Total Sediment Generated in the Catchment with the Project (m^3).

Field turbidity measurements near the proposed dredging area show high turbidity (150 to 250 NTU) and high TSS levels (100 to 150 mg/L), with much higher spikes during periods of high rainfall and runoff. Turbidity is also expected to be high in Oyomo Creek during the southeast trade winds season (previously measured to be 300 NTU near the confluence with the Purari River) but is lower during the northwest monsoon season (measured at 91 NTU). These existing high turbidity and TSS levels indicate that dredging disturbance is unlikely to significantly exceed natural variability. While temporary spikes may occur during the works, especially if pockets of silts and clay are encountered, these will not significantly change existing water quality conditions in the Purari River or Oyomo Creek. Given the high ambient turbidity, it is expected that the plume will be difficult to visually detect more than 0.5 km downstream of the dredge site; hence, the magnitude of impact is assessed to be ***Minimal***. The Purari River and Oyomo Creek are considered to have a sensitivity of ***Low*** and ***Medium***, respectively, as described in Section 11.3.5.1.1. This provides an overall impact significance rating of ***Negligible*** for both waterways.

11.3.5.1.4 Vessel Traffic

The highest risk of scour from Project-induced river traffic, causing increased TSS and turbidity levels, will be naturally eroding areas (e.g., outer bends of rivers); however, in the context of the highly mobile and turbid nature of the Purari River, the low density of planned vessel movements are considered unlikely to cause changes outside the bounds of natural variability and to be highly localized. Increases in TSS levels and turbidity due to vessel movements are therefore considered to be of ***Minimal*** magnitude.

The Purari River has a ***Low*** sensitivity in terms of hydraulic processes due to its highly dynamic nature. These magnitude and sensitivity rankings provide a ***Negligible*** impact significance.

11.3.5.2 Reduction in Stream Flows from Water Extraction

Table 11.11 highlights that the estimated mean annual flow of the Hou and Boa creeks is 36,791 ML and 48,076 ML respectively. Extracting water from Hou and Boa creeks to drill wells will reduce downstream flow which may have implications for aquatic and terrestrial biodiversity, especially during periods of low rainfall; however, where sufficient environmental flows are maintained by appropriately designed water supply dams and water extraction management procedures, these flow reductions are unlikely to exceed that experienced during extreme weather events. Additionally, impacts will be temporary and occur only during periods of low flow, which may last a period of several months, and only during drilling of wells in the construction phase (estimated at around 25 months). This provides an overall magnitude rating of ***Low***. These waterways are in near-natural condition and have a ***Medium*** sensitivity, providing an overall significance rating of ***Minor*** for this impact.

Water extraction will not adversely affect the Purari River due to the low volumes of extraction compared to flow. The total water extraction requirements for hydrotesting represent less than 0.05% of the total daily flow of the Purari River under minimum flow conditions, as described in Section 11.3.3.2. Water extracted from the Purari River for use at the CPF and for potable water supply for the accommodation camps also represents a very small proportion of the total flow of the Purari River (less than 0.002%). The magnitude of impact of extracting water from the Purari River on the maintenance of environmental flows is therefore ***Minimal.*** The sensitivity of the Purari River is ***Low***, considering the very high natural variability in flow. This provides an overall impact significance rating of ***Negligible***.

11.3.6 Summary of Residual Impacts to Hydrology, Fluvial Geomorphology and Sediment Processes

Table 11.24 provides a summary of the assessment of residual impacts to hydrology, fluvial geomorphology and sediment processes, including in which Project phase and location these impacts are expected to occur. The table should be read in conjunction with the specific mitigation measures provided in Table 11.21.

All residual impacts are assessed to be ***Negligible*** to ***Minor***, except sediment impacts on several waterways due to earthworks in the construction phase. ***Moderate*** residual impacts are expected to occur on Oyomo Creek, associated with earthworks at the CPF site, and on Mena River, Kuku Creek and Boa Creek, due to earthworks associated with pipeline laying and road construction.

Table 11.24 – Summary of Assessment of Residual Impacts for Hydrology, Fluvial Geomorphology and Sediment Processes

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Impact	
						Sensitivity/ Magnitude	Significance
Changes to hydraulic processes and sediment transport	Earthworks and physical infrastructure	Diversion and filling of waterways in Oyomo Creek catchment.	PRL-15	C	♦ EM004 ♦ EM009	Medium/Low	Minor
		Scour of waterways at pipeline crossings.	Onshore pipeline routes	O		Medium/ Minimal	Negligible
		Change in drainage patterns at waterway road crossings.	Onshore pipeline routes	O		Medium/ Minimal	Negligible
		Soil erosion due to ground disturbance causing increased TSS, turbidity and sedimentation of Oyomo Creek.	PRL-15	C	♦ EM002 ♦ EM003 ♦ EM004 ♦ EM005 ♦ EM006 ♦ EM010 ♦ EM011 ♦ EM012 ♦ EM013	Medium/High	Moderate
		Soil erosion due to ground disturbance causing increased TSS, turbidity and sedimentation of the Mena River, Kuku Creek and Boa Creek.	PRL-15	C		Medium/ Medium	Moderate
		Soil erosion due to ground disturbance causing increased TSS, turbidity and sedimentation of the Era River and Hou Creek.	PRL-15	C		Medium/ Minimal	Negligible
		Soil erosion due to ground disturbance causing increased TSS, turbidity and sedimentation of the Purari River and adjoining subcatchments downstream of the export pipeline crossing.	PRL-15 Onshore pipeline routes	C		Low/Low	Minor
		Soil erosion from roads causing increased TSS, turbidity and sedimentation of Boa Creek, Mena River, Kuku Creek and Oyomo Creek.	PRL-15	O		Medium/Low	Minor
		Soil erosion from roads causing increased TSS, turbidity and sedimentation of Hou Creek and Era River.	PRL-15	O		Medium/ Minimal	Negligible

Table 11.24 – Summary of Assessment of Residual Impacts for Hydrology, Fluvial Geomorphology and Sediment Processes (cont'd)

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Impact	
						Sensitivity/ Magnitude	Significance
Changes to hydraulic processes and sediment transport (cont'd)	Earthworks and physical infrastructure (cont'd)	Soil erosion from roads causing increased TSS, turbidity and sedimentation of the Purari River and adjoining subcatchments downstream of the export pipeline crossing.	PRL-15 Export pipeline route	O	See above	Low/Low	Minor
	Discharge of wastewater, stormwater and hydrotest water	Scour at point source discharge locations.	River transport corridor	C, O		Medium/ Minimal	Negligible
	Dredging at the Logistics Base	Changes in fluvial geomorphology of the Purari River.	River transport corridor	C, O	♦ EM037	Low/Low	Minor
		Increased TSS or turbidity in the Purari River.	River transport corridor	C, O		Low/Minimal	Negligible
		Increased TSS or turbidity in Oyomo Creek.	River transport corridor	C, O		Medium/ Minimal	Negligible
	Logistics and transport (barging along the waterways)	Scour of high-risk areas, with consequent sediment mobilization.	River transport corridor	C, O	♦ EM014	Low/Minimal	Negligible
Reduction in stream flow	Water extraction	Reduced flows in Hou and Boa creeks (due to water extraction for drilling).	PRL-15	C, O	♦ EM015 ♦ EM020	Medium/Low	Minor
		Reduced flows in the Purari River (due to water extraction for the CPF, hydrotesting and potable water supply).	PRL-15	C, O		Low/Minimal	Negligible

C = Construction, O = Operations.

11.4 Surface Water Quality

11.4.1 Context

The PAOI includes a range of high-, moderate- and low-gradient tributary streams and the main Purari River. The Purari River, including the three main delta distributaries (i.e., the Purari, Urika-Ivo and Wame-Varoi rivers), consists of both freshwater and estuarine components, with the estuarine boundary delineated by the inland extent of mangrove vegetation.

The tributary streams of the Era and Purari rivers in PRL-15 are characterized by low electrical conductivity with minimal seasonal variability. These streams are slightly to moderately alkaline and contain high bicarbonate levels, reflecting the widespread presence of calcareous rocks in the catchment. Turbidity levels in these streams are generally lower than the main channel of the Purari River but increase near the confluences with the river. All the waterways have high levels of oxygenation except Nea Creek (which is a tie channel to the PRL-15 oxbow wetlands) where waters are tannin-stained and are likely to be influenced by wetland outflows.

The Purari River has elevated turbidity and suspended sediments levels year-round; although, these reach a peak during the northwest monsoon when river flow is highest flow due to higher rainfall in the upper catchment. Freshwater flows heavily dominate the river, with an underlying saltwater wedge present near the river mouth.

All waters in the PAOI have low levels of nutrients and metals; however, microbiological quality is poor, with coliform bacteria present at levels exceeding drinking water standards.

Baseline characterization has shown no sediment contamination in the Purari River or in other streams in PRL-15 by metals, total petroleum hydrocarbons or other organic contaminants.

11.4.2 Discipline-specific Impact Assessment Method

The significance assessment approach described in Chapter 3 was used to characterize impacts relevant to surface water quality and contamination. Tables 11.25 to 11.28 present magnitude and sensitivity descriptors and impact matrices. Magnitude is assessed considering combinations of (1) geographic extent and (2) the higher of severity and duration.

Compliance standard assessment was also undertaken where appropriate, with reference made to the following standards and guidelines for water quality:

- Papua New Guinea *Environment (Water Quality Criteria) Regulation 2002 (Water Quality Regulation)* for the protection of aquatic ecosystems.
- Papua New Guinea *Public Health (Drinking Water) Regulation 1984 (Drinking Water Regulation)*.
- Other examples of good international industry practice guidelines for ambient water quality, such as the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018) and the World Health Organization Guidelines for Drinking-water Quality (WHO, 2017).
- Emission limit values for discharge water quality provided by TOTAL General Specifications (TOTAL, 2015), International Finance Corporation Environmental, Health and Safety guidelines (IFC, 2007a, 2007b) and other examples of good international industry practice.

No numerical modeling studies were undertaken for the impact assessment given the Project's commitment that planned water discharges will meet relevant emission limit values and considering the large assimilative capacity of the Purari River, which is the third largest river in Papua New Guinea (see Section 7.3.1).

Table 11.25 – Impact Magnitude Descriptors Relevant to Surface Water and Contamination

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

**Region* = Area greater than 15,000 km^2 (25% of the Kikori-Purari river basin).
Subregion = Area more than 2 km from the Project footprint but less than 15,000 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 11.26 – Impact Magnitude Matrix Relevant to Surface 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 11.27 – Surface Water Quality Sensitivity of Resource or Receptor

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

Table 11.28 – Surface Water Quality Significance of Assessment Matrix

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

11.4.3 Identification of Potential Impacts

Potential impacts to surface water quality 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.

The embedded design controls outlined in Section 11.1.3.3 are also relevant to addressing the potential impacts described in Sections 11.4.3.1 to 11.4.3.3.

11.4.3.1 Planned Wastewater Discharges

This section considers impacts associated with planned Project wastewater discharges, which include:

- Hydrotest waters from onshore pipelines.
- Treated sewage effluent from Project facilities and accommodation camps.
- Treated stormwater captured at wellpads and the CPF and, potentially, produced water.

Treated sewage effluent and treated contaminated stormwater from the CPF are planned to be discharged at an outlet to the Purari River downstream from the Logistics Base (Figure 11.9). Hydrotest waters for the onshore pipeline may also potentially be discharged at this location. Contaminated stormwater from the wellpads will also be captured and transported to the CPF stormwater system for treatment prior to release to the Purari River.

Discharges will be tested for compliance with emission limit values described in the Project's water discharge permit, TOTAL General Specifications (TOTAL, 2015) and the International Finance Corporation Environmental, Health and Safety guidelines (IFC, 2007a, 2007b).

Drilling muds or cuttings will not be discharged to surface waters. Cuttings generated during drilling will be separated from the mud so the mud can be reused. The cuttings will then be passed through a dewatering unit and subsequently mixed with cement to produce a stable product that will be disposed of at the general waste landfill. Water produced from dewatering will be reused for drilling.

Produced water generated at the CPF, which will consist only of condensation water since no formation water is expected from the reservoir, will be injected back into the reservoir at the ANT-11 wellpad. This produced water will be routed to a water treatment plant comprising a degassing drum and a flotation unit to achieve an oil concentration in the injected produced water of less than 50 mg/L. As a backup in times of injection outage, produced water will be retained in a tank with sufficient capacity to contain five days of water production. If an injection outage exceeds five days, produced water will be treated as required to meet PNG standards, TOTAL General Specifications (TOTAL, 2015) and IFC (2007b) effluent limits for produced water prior to any discharge to the Purari River.

Further description of planned discharges is provided in the following sections.

Hydrotest Waters

Hydrotesting involves pressurizing the pipeline with water to confirm the integrity of the welds (see Section 4.10.5.2). Hydrotest water will contain a small amount of an oxygen scavenger, such as sodium bisulfite, to inhibit corrosion and a biocide to prevent the development of bacteria that can produce hydrogen sulfide under anaerobic conditions.

The total volume of the onshore pipelines is 69,000 m^3, as described in Section 4.10.5.2; however, the amount of hydrotest water requiring discharge to the environment is expected to be much less than this volume since the pipeline will be tested in sections and the hydrotest water will be recycled from one section of pipe to another. When no longer required, all hydrotest water will be discharged, in accordance with the Project's environment permit. The discharge locations

PROPOSED LICENSED DISCHARGE LOCATION

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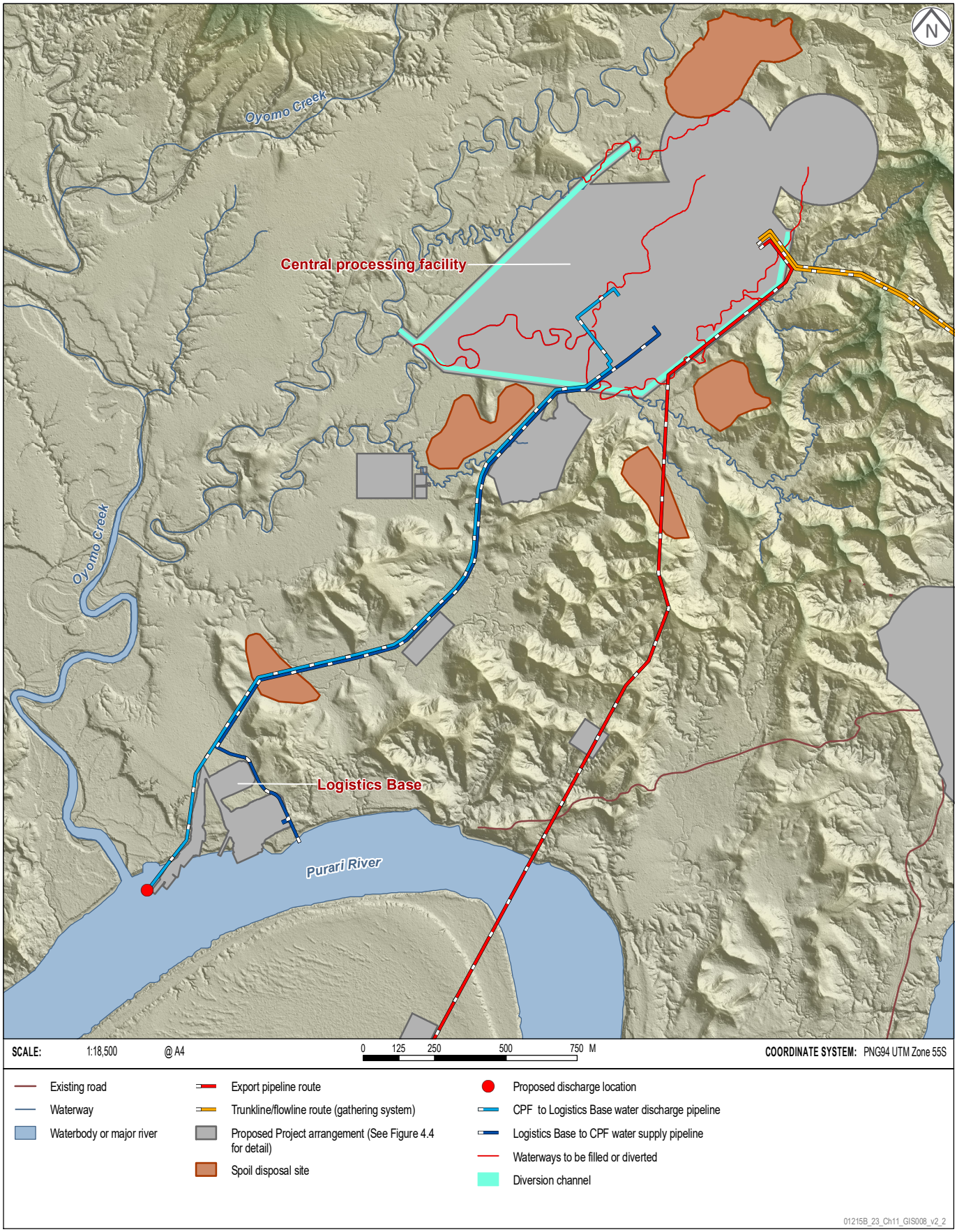
FIGURE 11.9



Source: Figure theme data from BMT, 2019.

and discharge rates will be defined during FEED, and will potentially include discharge to the Purari River.

Sewage Effluent

The Project will discharge treated effluent from sewage produced at the accommodation camps, CPF and Logistics Base facilities. Sewage includes grey water (i.e., effluents from sinks, showers and laundries) and black water (i.e., toilet effluents). This effluent will be treated on site to relevant emission limit values before being discharged to the Purari River at the nominated discharge location. The sludge retained from the treatment process will be managed as part of the camp waste management system and contained to avoid any release to surface waters. The discharge of treated effluent to the environment from construction and operations is expected to meet emission limit values without dilution at least 95% of the time that the plant or unit is operating, in accordance with IFC (2007a); however, even with treatment, sewage discharges will contain elevated nutrient levels. Elevated nutrient concentrations can degrade water quality and aquatic ecosystems in receiving waters. Sewage discharges may also contain pathogens, including *Escherichia coli* (E. coli), *Salmonella* and fecal coliforms.

Treated Stormwater

Stormwater from potentially contaminated areas of the CPF will be captured and treated by the OD1 and OD2 open drain system water collection and hydrocarbon-water separator system treatment system at the CPF (see Section 4.11.1.2). Discharge will take place according to applicable limits. Any contaminated drainage from wellpad areas will drain to a dedicated sump for collection and transport to the CPF where it will be treated with other OD1 wastewater.

Other stormwater discharges to waterways in the PAOI will occur as uncontrolled releases that may also degrade water quality. These relate mainly to sediment from eroded soils (considered in Section 11.3) and hydrocarbon or chemical spills (considered in in Section 11.4.3.3).

11.4.3.2 Discharge of Firefighting Foams

Firefighting foams will primarily be used only in emergency situations (see Chapter 18); however, discharges may also occur when fire system testing and training activities are undertaken; which will occur periodically throughout the life of the Project.

Chemicals in firefighting foams can have direct and indirect acute and chronic impacts on aquatic flora and fauna in waterways due to their persistence, bioaccumulation, toxicity and biochemical oxygen demand (DEHP, 2016). Firefighting foams are also highly dispersive (i.e., they are completely water soluble) in the aquatic environment (DEHP, 2016). All firefighting foams have high biochemical oxygen demand and, if released into a waterway, can cause asphyxiation of aquatic organisms due to depletion of dissolved oxygen concentrations. Most firefighting foams have low acute toxicity; however, the persistence and bioaccumulation of firefighting foam chemicals can have chronic toxicity to aquatic organisms, depending on the foam type (DEHP, 2016). Firefighting foams will not be released in sufficient quantities to accumulate and cause sediment contamination.

11.4.3.3 Accidental Hydrocarbon and Chemical Releases

The OD1 and OD2 open drain networks will capture any accidental hydrocarbon and other chemical spills at the CPF and wellpads and spills will be treated through the hydrocarbon-water separator system (see Section 4.11.1.2). In other parts of the PAOI; however, small volumes of hydrocarbons (including condensate) and other chemicals can be accidentally spilt or leaked to the environment and mobilized during flood events through both riverine and overland flows. These contaminants can degrade receiving environment water quality, degrading aquatic

ecosystems (see Section 11.5) and human uses of water resources (Chapter 13). The other parts of the PAOI most at risk of spills are the Logistics Base, jetty and Purari Airstrip (adjacent to the Purari River), where the largest volumes of fuels, oils and chemicals will be stored and handled. Spills and leaks may also potentially occur in other areas of Project activities, including from welded sections of the onshore export pipeline if a weld fails.

11.4.3.4 Dredging

Dredging undertaken adjacent to the jetty at the Logistics Base is not expected to mobilize contaminants from sediments into the water column. Baseline characterization has shown no evidence that metals and metalloids, total petroleum hydrocarbons or other organic contaminants have contaminated sediment in the Purari River or in other streams in PRL-15. The impact on water quality from contaminants mobilized by dredging is considered insignificant and not further assessed.

11.4.3.5 Summary of Potential Impacts

The following potential impacts to surface water quality have been identified:

- Contamination from planned wastewater discharges.
- Contamination caused by discharging firefighting foams during training and testing.
- Contamination caused by accidental hydrocarbon or chemical release.

The consideration of spills or leaks is related to releases that are accidental (but controllable), as part of construction, operation and decommissioning of large projects. Potential impacts of large-scale accidental spills associated with major natural hazards and unplanned events are considered in Chapter 18.

Impacts to water quality from contaminants mobilized by dredging and the potential for contaminants to accumulate in sediments as a result of planned or accidental discharges over time are considered negligible and are not assessed.

11.4.4 Proposed Mitigation and Management Measures

Table 11.29 describes mitigation and management measures to further reduce impacts to surface water quality.

11.4.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to surface water quality subject to the embedded design controls in Section 11.4.3 and the successful implementation of the proposed mitigation and management measures in Section 11.4.4. 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.

11.4.5.1 Planned Discharges of Wastewaters

Hydrotest Water

Waters of the Purari River are in near-natural condition with some potential human-induced modification of water quality, including high fecal coliform levels (see Section 7.4.2.1); however, apart from microbiological quality, ambient water quality guidelines are met and the sensitivity of the Purari River is ***Medium***.

Table 11.29 – Surface Water Quality Mitigation Strategies and Management Plans

Potential impact	Mitigation Strategy	Relevant Management Plan
Contamination from 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]. ♦ Water from trenches will be discharged in accordance with applicable water quality standards with erosion and sediment controls where relevant [EM011]. ♦ Hydrotest water management will consider: – The definition of volume and discharge rates and discharge locations. – Chemicals additives 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].	Waste Management Plan; Water Management Plan
Contamination caused by discharging firefighting foams during training and testing	♦ Training and test releases of firefighting foams at the CPF are to be contained within appropriate drainage water treatment networks. [EM016].	Water Management Plan; Hazardous Material Management Plan
Contamination caused by accidental hydrocarbon or chemical release	♦ Vehicle wash down and fuel handling will be undertaken considering possible receptors e.g., streams, Purari River and the marine environment [EM017]. ♦ 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].	Hazardous Material Management Plan; Emergency Response Plan

Small volumes of water (i.e., 0.05% of the daily flow of the Purari River) used for hydrotesting may potentially be discharged to the Purari River at the Logistics Base. Discharges will comply with effluent limits described in IFC Environmental, Health and Safety Guidelines for Onshore Oil and Gas Development (IFC, 2007b) and with criteria within relevant PNG environmental regulations. Chemical additives to hydrotest water will be selected considering lowest toxicity, lowest bioaccumulation potential and highest biodegradation. Therefore, any hydrotest water discharge impacts on the Purari River water quality would be highly localized, very short-term, and environmental values of waters would be maintained. The magnitude of impact is therefore expected to be ***Minimal***. This provides an overall impact significance rating of ***Negligible***.

Sewage Effluent

The sensitivity of the Purari River is ***Medium***. Treated sewage discharges to the Purari River will comply with effluent limits (IFC Environmental, Health and Safety General Guidelines (IFC, 2007a)) for discharges to receiving waters and with criteria within relevant PNG environmental regulations. Notwithstanding water treatment, sewage effluent contains nutrients. Increased nutrient concentrations can potentially cause algal blooms, leading to eutrophication; however, sewage discharges are unlikely to cause such impacts because of the rapid mixing and dilution that will occur given the high flow rates of the Purari River and the high turbidity of the river which will reduce light penetration and hence the potential for algal growth. Any impacts on the Purari River water quality from sewage discharge will therefore be highly localized, and existing environmental values will be maintained; hence, the magnitude of impact is ***Minimal***; therefore, the overall impact significance rating is ***Negligible***.

Contaminated Stormwater

The sensitivity of the Purari River is ***Medium***. Stormwater from potentially contaminated areas of the CPF and wellpads will be captured in the OD1 and OD2 open drain networks and treated by the water treatment system at the CPF. Discharge will take place according to applicable limits.

Impacts on the Purari River water quality will be highly localized and short-term given the large flow of the Purari River, and environmental values of waters will be maintained; hence, the magnitude of impacts is ***Minimal***, giving an overall impact significance rating of ***Negligible***.

Should produced water be required to be discharged to the Purari River in times of injection outage and exceedance of holding tank capacity, similar impacts would be expected given the similar water treatment that would be undertaken prior to discharge.

11.4.5.2 Discharge of Firefighting Foams

The sensitivity of the Purari River is ***Medium***. Firefighting foams will be selected in consideration of the lowest toxicity, lowest bioaccumulation potential, highest biodegradation and those subject to bans or phase-outs. They will only be tested in contained areas at the CPF, reducing the risk of pollution of waterways. The foams will be captured in the OD1 and OD2 open drain networks and directed to an observation basin where degradation will occur and the effluent will be treated prior to it being discharged to the Purari River. Such discharges will only occur following routine fire response training and equipment testing exercises, or in the event of a fire, which is considered in Chapter 18.

Given the proposed mitigation measures, impacts on Purari River water quality from these periodic fire response exercises will be highly localized and very short-term, and environmental values of waters would be maintained. The magnitude of impacts is therefore ***Low***, giving an overall impact significance rating of ***Minor***.

11.4.5.3 Accidental Hydrocarbon and Chemical Releases

Waterways in the PAOI are in near-natural condition, with some human-induced modification but with most ambient water quality criteria met, and therefore have ***Medium*** sensitivity.

The assessment addresses spills or leaks that are typically accidental (but controllable) as part of construction, operation and decommissioning of large projects. Large-scale accidental spills associated with major natural hazards and unplanned events are considered in Chapter 18.

Impacts on stream water quality from hydrocarbon or chemical spills or leaks will be avoided or contained and remediated by implementing the embedded design controls outlined in Section 11.1.3.3 and the mitigation measures described in Section 11.4.4. The OD1 and OD2 open drain networks will capture any fuel or chemical spills at the CPF and wellpads and treated prior to discharge to the Purari River. These discharges are planned discharges that are addressed in Section 11.4.5.1. For other areas of Project activities, e.g., construction activities along the export pipeline route, potential accidental releases to surface water would not be controlled to a known discharge location however, they would be avoided or contained in the first instance.

Given the dispersive nature of hydrocarbons due to their density being lighter than water and their propensity to be transported on the water surface, rather than to mix through the water column, should a spill reach surface waters, the impact on surface water quality may potentially extend up to 2 km downstream (see Table 11.25). Impacts from incidental spills of chemicals would be expected to extend to a smaller extent due to their less hydrophobic properties, depending on the particular chemical involved, allowing dispersion and dilution through the water column. Impacts would be for a short period, and the environmental values of the waterways will not be adversely affected over the longer term. The magnitude of impacts is therefore categorized to be ***Low***.

The overall significance rating for impacts on water quality of PAOI waterways due to accidental hydrocarbon or chemical releases is therefore ***Minor***.

Barge traffic and transfers at the Logistics Base may also cause small amounts of hydrocarbons or chemicals to be spilt or leaked into the Purari River. Such spills (particularly fuel) have the potential to be difficult to contain, despite implementing oil spill response procedures. Impacts on water quality from a spill would only be for a short period, given the high assimilative capacity of the river due to its large flows; however, such a spill may extend further than 2 km downstream, depending on the volume and nature of the spill. Water quality would be expected to recover to its previous condition prior to the spill within days. The magnitude of impact is therefore categorized to be ***Medium***. Given the sensitivity of the Purari River is ***Medium***; the overall impact significance rating is ***Moderate***.

11.4.6 Summary of Residual Impacts to Surface Water Quality

Table 11.30 provides a summary of the assessment of residual impacts to surface water quality, including in which Project phase and location these impacts are expected to occur. The table should be read in conjunction with the specific mitigation measures provided in Table 11.29.

All residual impacts are assessed to be ***Negligible*** to ***Minor***, except impacts from accidental hydrocarbon or chemical spills directly into the Purari River. Any such accidental spills associated with barge traffic along the Purari River, and fuel and chemical transfers at the Logistics Base may potentially have ***Moderate*** residual impacts on surface water quality. This assessment assumes that, while impacts would only be of short duration, the spill would extend further than 2 km downstream, which would be dependent upon the volume and nature of the spill. Water quality would be expected to recover to its previous condition prior to the spill in hours.

Table 11.30 – Summary of Assessment of Residual Impact Significance for Surface Water Quality

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Contamination from planned wastewater discharges.	Disposal of pipeline hydrotest water.	Deterioration in the Purari River water quality.	PRL-15	C	♦ EM008 ♦ EM011 ♦ EM015	Medium/ Minimal	Negligible
	Sewage effluent discharge.	Deterioration in the Purari River water quality.	PRL-15	C, O		Medium/ Minimal	Negligible
	Treated stormwater discharge and produced water discharge.	Deterioration in the Purari River water quality.	PRL-15	O		Medium/ Minimal	Negligible
Contamination from discharge of firefighting foams.	Firefighting foam discharge during fire response training and equipment testing.	Deterioration in the Purari River water quality.	PRL-15	O	♦ EM016	Medium/Low	Minor
Contamination from accidental hydrocarbon or chemical releases.	Use of hazardous materials.	Deterioration in water quality of the PAOI waterways.	PRL-15 Onshore pipeline routes	C, O	♦ EM017 ♦ EM018 ♦ EM019	Medium/Low	Minor
		Deterioration in the Purari River water quality.	River transport corridor	C, O		Medium/ Medium	Moderate

C = Construction, O = Operations.

11.5 Freshwater and Estuarine Biodiversity

11.5.1 Context

Several different types of waterways and aquatic ecosystems occur in the PAOI, including:

- The main channel of the Purari River and the delta distributaries (i.e., the Purari, Urika-Ivo, and Wame-Varoi rivers), which are characterized by high turbidity and morphological variability.
- High-, moderate- and low-gradient tributary streams of the Purari and Era river catchments.
- Freshwater swamp forests and woodlands.
- Oxbow lakes and off-river waterbodies.
- Estuarine wetlands and mangroves.

These ecosystems are located in the Southwest New Guinea – Trans-Fly Lowland ecoregion (No. 815) (Abell et al., 2008). This region is noted for high levels of endemism (mostly in the Fly and Kikori river catchments) and strong affinities to the north Australian fauna.

Many freshwater fish and macrocrustacean species of the lower Purari and Era river catchments have marine origins or complete part of their lifecycle in marine and estuarine environments. Estuarine areas have higher species numbers than freshwater environments, and many of the species occurring in estuaries also are found in freshwater habitats. The most abundant species recorded in the Purari River surveys are estuarine glass perchlet (*Ambassis macracanthus*), spoon-snouted catfish (*Nedystoma novaeguineae*) and greenback mullet (*Planiliza subviridis*), while a variety of freshwater prawns, gudgeons, gobies, grunters and rainbowfish dominated tributary streams.

Threatened and otherwise important aquatic vertebrate species known or likely to occur in the Purari River include sawfish (*Pristis pristis*, *P. zijsron*, *Anoxypristis cuspidata*), sharks (*Glyphis garricki*, *G. glyphis*, *Carcharhinus leucas*), rays (*Glaucostegus typus*, *Urogymnus granulatus*), river dolphin (*Sousa sahulensis*, *Orcaella heinsohni*), freshwater turtle (*Carettochelys insculpta*, *Pelochelys bibroni*) and crocodile (*Crocodylus porosus*).

A variety of aquatic macroinvertebrates are supported in these ecosystems, with mayflies and copepods dominating in freshwater habitats, and polychaete worms in estuarine areas. Two species of endemic aquatic macroinvertebrate (*Ciliometra setosa* and *Iobates ivimka*) could occur in the PAOI, based on Polhemus et al. (2004) but have not been confirmed.

No exotic fish species were identified in the PAOI during baseline surveys; however, anecdotal evidence indicates the potential presence of common carp (*Cyprinus carpio*) and tilapia (*Oreochromis mossambica*) in the Purari River catchment. Similarly, only one aquatic weed species, the water hyacinth (*Eichhornia crassipes*), was identified in the PAOI; but other species that may occur or present a future threat include the giant salvina (*Salvinia molesta*), water cabbage (*Pistia stratiotes*) and hydrilla (*Hydrilla verticillata*).

11.5.2 Discipline-specific Impact Assessment Method

The freshwater and estuarine biodiversity impact assessment is based on the significance assessment approach. Tables 11.31 to 11.34 present magnitude and sensitivity descriptors and impact matrices which have been developed by specialists based on expertise, experience and precedents from other peer reviewed impact assessments. Magnitude is assessed considering combinations of (1) geographic extent and (2) the higher of severity and duration. Sensitivity

ratings have been assigned for ecosystems and habitats or species based on a conservative approach (i.e., if descriptors from a range of ratings apply, the highest rating is assigned).

Table 11.31 – Impact Magnitude Descriptors Relevant to Freshwater and Estuarine 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 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 a species population 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; or ♦ 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 is 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.
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 15,000 km^2 (25% of the Kikori-Purari river basin).
Subregion = Area more than 2 km from the Project footprint but less than 15,000 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 11.32 – Impact Magnitude Matrix Relevant to Freshwater and Estuarine 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 11.33 – Freshwater and Estuarine Biodiversity Sensitivity of Resource or Receptor

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 the original composition; conservation-listed species may be present. ♦ Ecosystem or habitat has not been significantly modified in terms of primary ecological functions and composition. ♦ Ecosystem or habitat has local and regional equivalents with some connectivity to comparable ecosystems or habitats.	♦ 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 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 habitat. ♦ Fish or macrocrustacean species of fisheries significance.

Table 11.33 – Receptor Sensitivity Descriptors Relevant to Freshwater and Estuarine Biodiversity (cont'd)

Rating	Descriptor – Ecosystems and Habitats	Descriptor - Species
Low	♦ Ecosystem or habitat supports viable assemblages of some native species, but flora and fauna communities are significantly altered from original composition found elsewhere locally; invasive species may be present. ♦ Ecosystem or habitat has 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 to be 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.

Note: these sensitivity ratings differ from those assigned as part of the baseline characterization in Chapter 7, which were specific to species, ecosystems and sensitive habitat features. Ratings in this table consider the descriptors for these baseline sensitivity ratings and how they relate to broader receptors discussed in the impact assessment.

Table 11.34 – Freshwater and Estuarine Biodiversity Significance of Assessment Matrix

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

11.5.3 Identification of Potential Impacts

Potential impacts to freshwater and estuarine 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 minimizing the Project footprint, land clearing and disturbance, emissions and discharges) [ED013]. Specific embedded design controls are identified throughout this section where they address potential impacts.

11.5.3.1 Direct Disturbance and Habitat Fragmentation

11.5.3.1.1 Vegetation Clearing and Earthworks

Figures 11.10 to 11.12 show the Project infrastructure footprint and the different types of aquatic biotopes. They show that the aquatic biotopes that occur in infrastructure footprints and that will be directly disturbed are mostly moderate- and low-gradient tributary streams.

The largest area of direct disturbance is the filling of tributary streams located in the CPF footprint (see Figure 11.6 and Figure 11.11). Approximately 5.5 km of streams will be lost, all of which occurs in the unnamed eastern tributaries of the Oyomo Creek catchment.

DIRECT DISTURBANCE TO AQUATIC HABITATS IN THE HOU CREEK AND ERA RIVER CATCHMENTS

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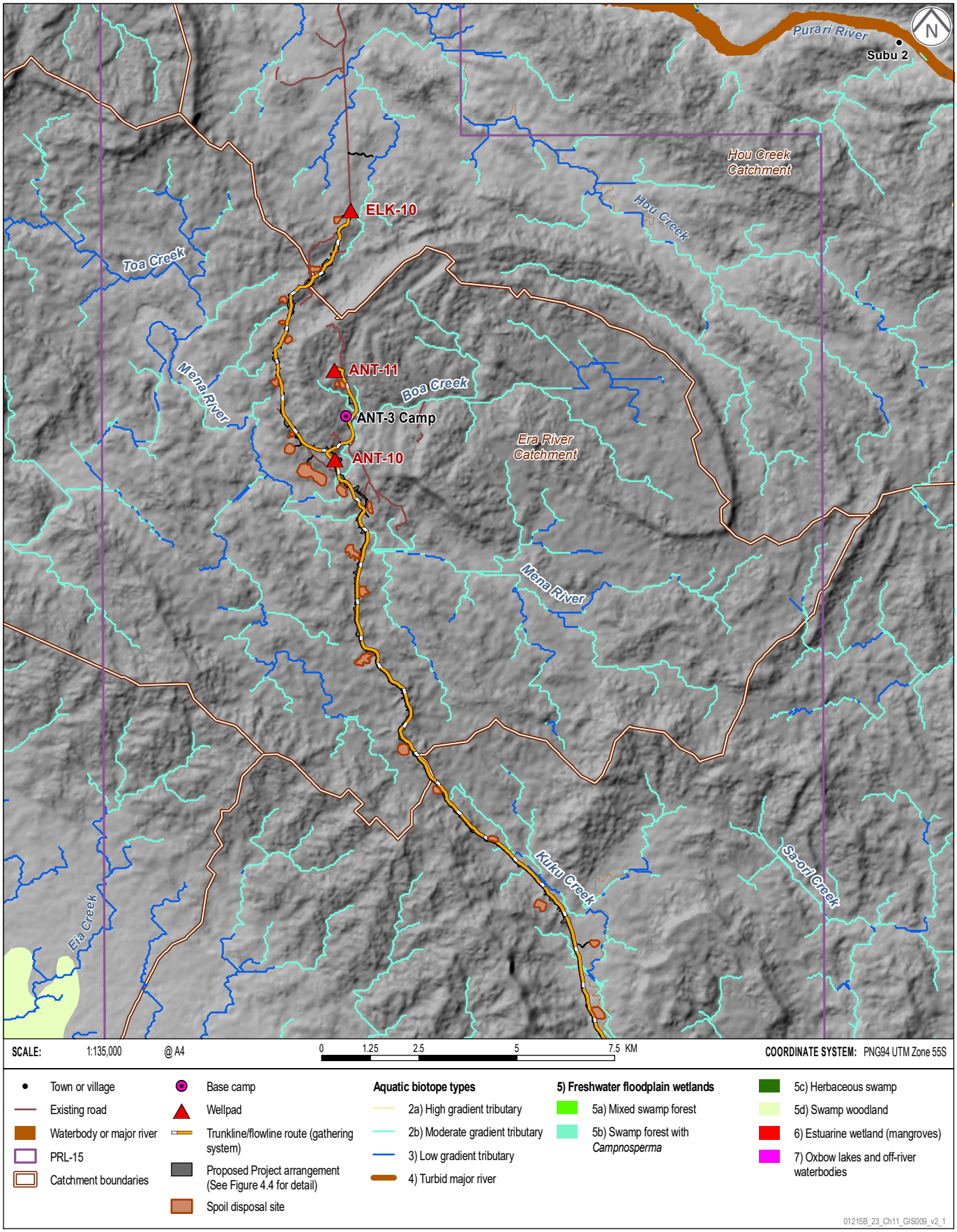
FIGURE 11.10



Source: Figure theme data from BMT, 2019.

DIRECT DISTURBANCE TO AQUATIC HABITATS IN THE KUKU CREEK AND OYOMO CREEK CATCHMENTS

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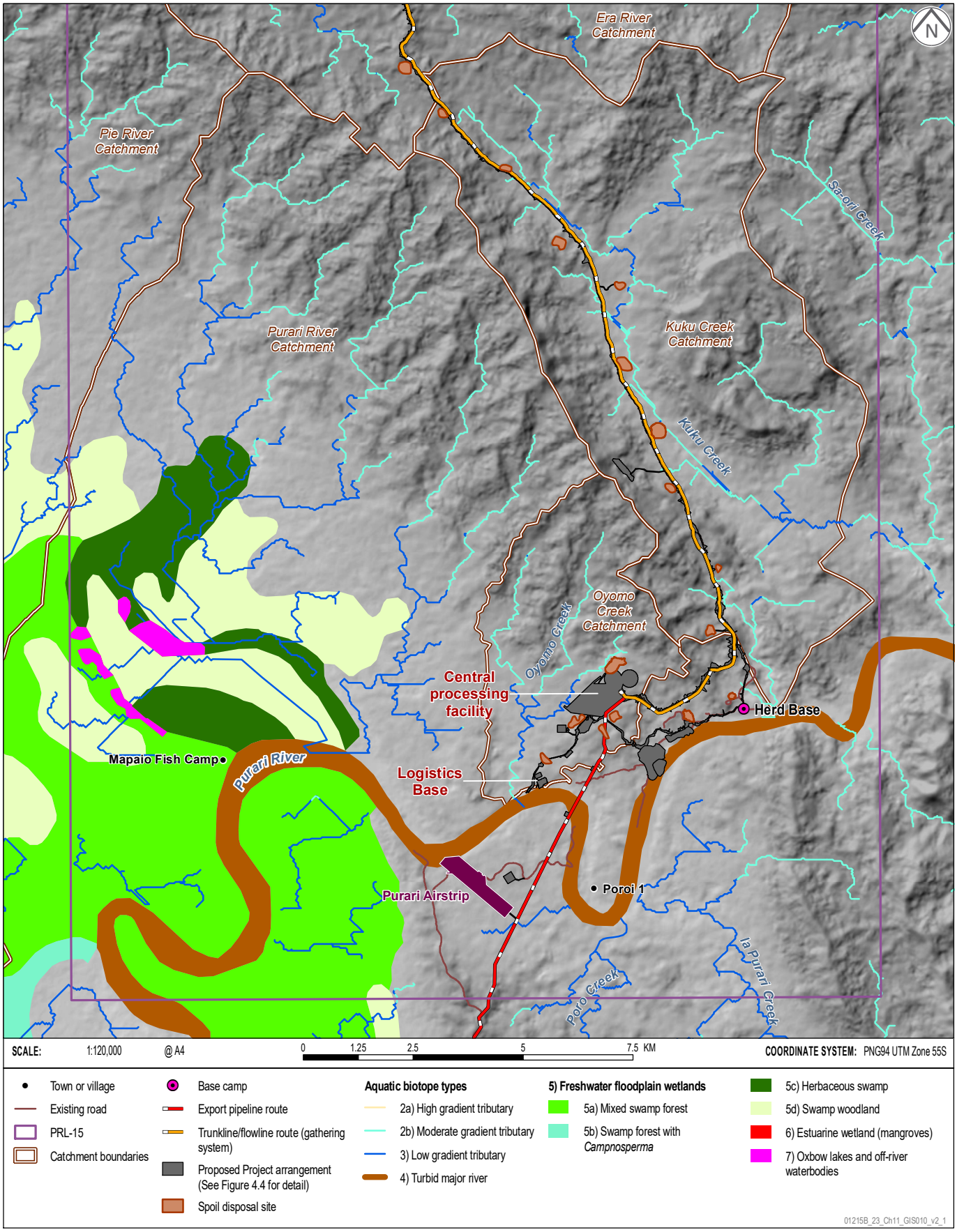
FIGURE 11.11



Source: Figure theme data from BMT, 2019.

DIRECT DISTURBANCE TO AQUATIC HABITATS ALONG THE EXPORT PIPELINE ROUTE

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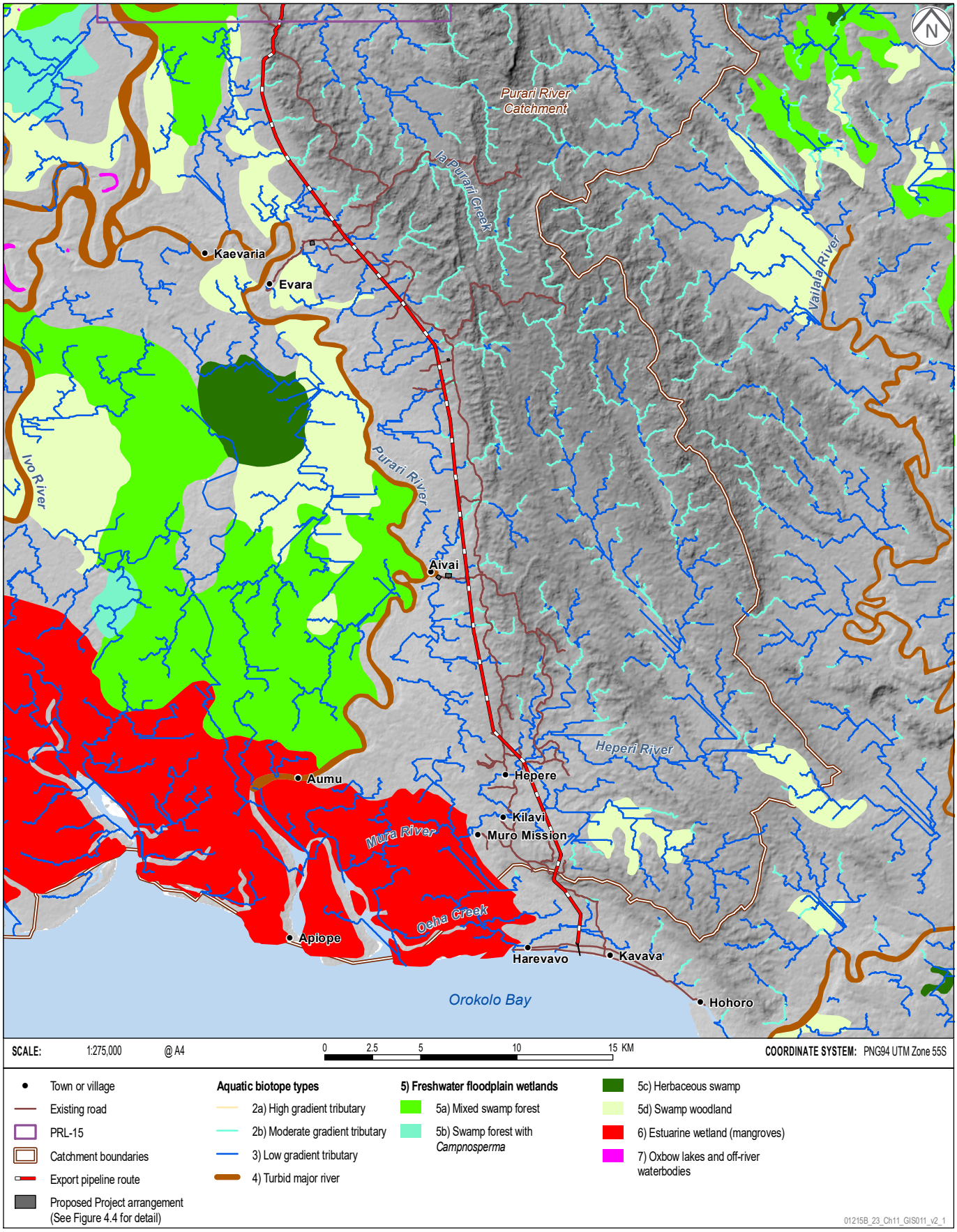
FIGURE 11.12



Source: Figure theme data from BMT, 2019.

Plate 11.6 – Oyomo Creek Tributary (Site 2) During July 2016

Photo: BMT WBM.

Plate 11.7 – Oyomo Creek Tributary (Site 2) During February 2017

Photo: BMT WBM.

Habitat loss associated with road crossings is discussed in Section 11.5.3.1.2. The affected waterways are low-gradient tributary streams that are largely intact, as shown in Plates 11.6 and 11.7, which show a tributary of Oyomo Creek sampled during the freshwater baseline survey in July 2016 and February 2017 (Site 2). These streams:

- Provide habitat for a wide range of stream-dwelling invertebrate species and a fish fauna mostly comprising small-bodied fish species and freshwater prawns. The small area of habitat that will be affected is well represented outside the CPF footprint in the Oyomo subcatchment in the wider Purari River catchment.
- Are unlikely to provide critical habitat for threatened aquatic species. All stream reaches upstream of the CPF footprint are headwater streams; therefore, habitat loss in the CPF would not fragment or isolate important habitat for threatened aquatic species in upstream areas.
- Are not unique in the PAOI, as similar waterways occur nearby, including the tributary streams of Nea and Kuku creeks.

11.5.3.1.2 Pipeline and Road Crossings of Waterways

Project pipeline and road infrastructure will cross waterways, as shown in Figures 11.10 to 11.12. The pipeline crossing of the Purari River will be undertaken using horizontal directional drilling (see Section 4.10.5.3). For all other waterways, open trenches will be developed into which pipes will be laid before immediate backfilling. The likely method for watercourse crossings will be to temporarily dam the watercourse and pump water around the work area. Each pipeline crossing location will also involve a road crossing, using a flume pipe to maintain flows.

The waterways crossed by roads and open trenching include Hou Creek, Boa Creek, Mena River and Kuku Creek in PRL-15, and several named and unnamed waterways along the export pipeline route.

Construction of waterway crossings has the potential to cause the following impacts:

- Direct loss or degradation of in-stream habitat during construction.
- Creation of barriers to aquatic fauna movements and associated fragmentation of aquatic habitat.

Direct Loss or Degradation of Habitat

Trenching for the pipeline crossings will likely involve installing coffer dams on both sides of the trench to prevent the ingress of stream waters, excavating a trench using a backhoe or other excavating machine, placing the pipeline in the trench, and the subsequent filling of the trench (with parent bed material) and burial of the pipeline. The excavation, removal and subsequent refilling of the pipeline trench will disturb bed and bank environments. Coffer dams will be removed following installation of the pipeline.

Trenching and culvert construction will also cause localized impacts to bed and bank structure (i.e., bed and bank erosion, slumping and bed aggradation), which could cause temporary disturbance or mortality to aquatic fauna.

Construction works will also cause sedimentation and higher turbidity near the works footprints. These impacts are discussed in Section 11.5.3.2.

Habitat Fragmentation and Fish Movement Barriers

Aquatic habitat in the footprint of road crossings will be permanently altered due to:

- Shading in the culvert: inadequate light can deter fish passing through culverts.
- Changes to local hydraulic conditions in the culvert: inadequately sized culverts can create excessive turbulence and flow velocities or reduce water depths, presenting a barrier to fish movements.

Instream barriers could restrict migratory and daily movement patterns of aquatic fauna. Several catadromous and potamodromous fish species and invertebrates (freshwater prawns) occur in the PAOI and rely on passage between upstream and downstream environments to complete their life cycles. Inappropriately sized or positioned culverts for road crossings can limit the ability of these species to navigate through the infrastructure under certain flow conditions. Design measures will be required to maintain flow conditions and fish passage.

11.5.3.1.2 Water Extraction and Impoundment

Several water supply options are under consideration for the Project, as discussed in Section 11.3.3.2:

- Extraction from the Purari River to supply water for the CPF and accommodation camps.
- Extraction from Hou and Boa creeks to supply water for drilling wells during the construction period. This will involve direct extraction and temporary installation of a dam and extraction of impounded waters.

The approximate locations of proposed extraction points are shown in Figure 11.8.

Extraction from the Purari River will have a negligible impact on flow, as discussed in Section 11.3.3.2, and has no implications for aquatic biodiversity.

Impoundment of parts of Hou and Boa creeks during the installation period for the temporary dams has the potential to change downstream hydraulic habitat conditions and modify and fragment habitat. The dams will be in place for up to 25 months and are likely to be constructed using water diversion techniques (e.g., coffer dams) to provide a dry construction area.

The two potential dam sites correspond closely to two freshwater baseline survey sites: Site 4 (Boa Creek) and Site 9 (Hou Creek). These sites are shown in Plates 11.8 to 11.11 and description of the existing conditions at these locations is provided in Table 11.35. While both waterways are high- to moderate-gradient streams, Site 9 is in the headwaters of the Hou Creek catchment, while Site 4 is further downstream and fed by multiple upstream tributaries.

Table 11.35 – Description of Existing Condition of Potential Dam Sites

Parameter	Site 4 (Boa Creek)	Site 9 (Hou Creek)
Aquatic ecosystems represented	Lotic: perennial stream (high gradient)	Lotic: perennial stream (moderate gradient)
Hydraulic habitat units	Run, riffle cascades and pool	Run, riffle, glide and pool
Approximate mean stream width – southeast winds season	30 m	3 m
Approximate mean stream width – northwest monsoon season	30 m	3 m
Maximum stream depth – southeast trade winds season	>2 m	0.3 m
Maximum stream depth – northwest monsoon season	1.5 m	0.3 m

Due to the smaller flows of Boa and Hou creeks, compared with the Purari River, water extraction has a greater potential to degrade downstream aquatic ecosystems, especially during periods of

low flow. Potential impacts to downstream aquatic ecosystems due to changes in flow regimes include changes to aquatic habitat availability and connectivity, altered fauna movement patterns, alterations to reproductive processes, and loss of aquatic productivity.

Plate 11.8 – Boa Creek (Site 4) During Southeast Trade Winds Season (July 2016)

Photo: BMT WBM

Plate 11.9 – Boa Creek (Site 4) During Northwest Monsoon Season (February 2017)

Photo: BMT WBM

Plate 11.10 – Hou Creek (Site 9) During Southeast Trade Winds Season (July 2016)

Photo: BMT WBM.

Plate 11.11 – Hou Creek (Site 9) During Northwest Monsoon Season (February 2017)

Photo: BMT WBM.

Modifications to Hydraulic Conditions

Smakhtin et al. (2004) undertook a global-scale pilot assessment of environmental water requirements for freshwater-dependent ecosystems, which included Papua New Guinea. They suggested that freshwater-dependent ecosystems required approximately 20 to 50% of the total renewable water resources (i.e., long-term mean annual runoff) to maintain ecosystems in 'fair' condition. Papua New Guinea streams were estimated to require approximately 37% of the total renewable water resource to maintain ecosystem condition, but this greatly depended on site-specific conditions and sensitivities. Aquatic biota in catchments with more stable, perennial flows, as occurs in most tributary streams in the PAOI, are considered to be more intolerant of extended periods of low to no flow and are therefore more sensitive to human-induced flow changes. Furthermore, low flow requirements are considered important in maintaining environmental water requirements for aquatic biota in such systems. Water extraction by the Project; therefore, has the potential to alter aquatic ecosystems in receiving environments downstream of impoundment points if inappropriately managed.

Aquatic Habitat Modification and Fragmentation

The dam impoundments will represent a change to aquatic habitat conditions. Depending on the dam design, this could include:

- Conversion of waters in the impoundment from lotic (flowing waters) to lentic (non-flowing) habitat.
- Increase in waterway extent and depth in the impoundment, potentially flooding riparian vegetation.
- Creation of suitable habitat for aquatic macrophytes, including aquatic weeds.
- Creation of suitable habitat for aquatic fauna that prefer non-flowing waters, including a range of alien fish species and pest insects.

The severity of impact from waterway impoundment is largely dependent on the dam design and site characteristics.

The dams may also present an aquatic fauna movement barrier, depending on dam design (e.g., wall height, spillway height, spillway water depth). Aquatic macroinvertebrate taxa most affected by 'barrier effects' are those typically without adult winged stages, such as crustaceans and mollusks (Brooks et al., 2018). Various fish species found in the Purari River catchment undertake movements as part of their day to day foraging activities, and many species also undertake migrations as a part of their life cycles.

11.5.3.1.3 Dredging

Construction activities at the Logistics Base will include dredging of a small basin in front of the jetty to allow barge access (see Figure 11.7 for the expected dredging area). The dredge depth will be determined during FEED, but the change to bed elevation is expected to be less than 2 m relative to its existing level. The total volume of material to be dredged is estimated to be approximately 6,000 m^3 over 1.5 ha, to provide a water depth of 3.5 m. Maintenance dredging may also be required.

Dredging will remove soft sediment habitat and benthic biota from the dredge footprint. These direct impacts are assessed in Section 11.5.5.1.4.

The dredge footprint is likely to have lower fish feeding habitat values than adjacent undisturbed areas. The dredge footprint does not; however, occur in an area known to be of high importance

to fish species for feeding or other activities. Furthermore, given the very small dredge area compared to the total area of available habitat in the Purari River, modifications to benthic communities are extremely unlikely to cause flow-on effects to species populations that feed on benthic fauna. These potential indirect effects from disturbance of benthic habitat are therefore not considered further in the residual impact assessment.

11.5.3.2 Increased Suspended Sediment and Sedimentation Levels

11.5.3.2.1 Earthworks and Spoil Stockpiling

The Project's construction phase includes earthworks and spoil stockpiling for roads, pipelines, the CPF, Logistics Base and Purari Airstrip extension. The location of these works in relation to aquatic environments is shown in Figures 11.10 to 11.12. These earthworks and the relevant infrastructure are described further in Chapter 4. These works will cause increase suspended sediment and sedimentation levels in waterways, with the streams most adversely affected expected to be the tributary streams in PRL-15 (i.e., Hou, Boa, Kuku and Oyomo creeks, and the Mena and Era rivers) (see Section 11.3.5.1).

Sediment deposition in aquatic ecosystems can lead to adverse impacts on fauna species, and degradation or loss of aquatic habitat. Potential impacts to biota and changes in habitat condition from sediment loading and deposition are described in the following sections. Few aquatic macrophytes occur in the PAOI; hence, these are not considered as ecological receptors.

Sedimentation Effects on Aquatic Biota

Potential sedimentation impacts on biota include:

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

Studies have not specifically examined the tolerances of aquatic invertebrates from the Purari River catchment to high sediment concentrations. Background turbidity and sediment transport conditions of the study area are important considerations when assessing the risk to resident aquatic flora and fauna communities and their habitat. Highly turbid environments are unlikely to support biota that are highly sensitive to suspended sediment. Turbidity varies markedly among tributary streams and over time, with most sites in the range of 0.1 to 90 NTU (described in Section 7.4.2). Turbidity in the Purari River typically ranges between 200 and 400 NTU (based on measurements at Herd Base) with spikes up to 1,000 NTU (see Figure 7.13). Resident aquatic fauna of the study area would; therefore, need to tolerate high turbidity levels.

A long-term change in turbidity; however, could cause the loss of some species in the impacted area with sediment-tolerant species possibly replacing them. This includes invasive species expected to occur in the Purari River catchment (see Section 11.5.3.5).

Crocodiles and turtles are not known to be sensitive to high suspended sediment levels.

Habitat Disturbance from Sediment Loading and Deposition

Increased sediment loading and deposition may change benthic habitat, with fine sediment smothering coarse substrate such as gravel and cobbles, which could lead to a decline in abundance and diversity of macroinvertebrates, algae and fish communities.

11.5.3.2.2 Dredging

Dredging adjacent to the jetty at the Logistics Base will also mobilize sediment into the water column increasing turbidity and suspended sediment levels, with potential associated sedimentation impacts on aquatic biota (as described in Section 11.5.3.2.1).

11.5.3.3 Contamination of Waterways

Waterways may potentially be contaminated by the following releases (see Section 11.4.3), with associated toxicity effects on aquatic biota:

- Planned wastewaters discharges, including:
  - Hydrotest waters from onshore pipelines.
  - Sewage effluent from Project facilities and accommodation camps.
  - Treated stormwater captured at the wellpads and the CPF and, potentially, produced water.
- Discharges of firefighting foams.
- Accidental hydrocarbon or chemical releases. The potential impacts of these releases on aquatic biota are described in the following sections, and the embedded design controls relevant to addressing these are outlined in Section 11.1.3.3.

Dredging of the Purari River adjacent to the jetty is expected to have insignificant impacts on water quality due to contaminant mobilization (see Section 11.4.3.4).

11.5.3.3.1 Planned Wastewater Discharges

Hydrotest Water

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. Any oxygen scavengers present in discharges to surface waters will decrease dissolved oxygen levels and may kill fish. Biocides, if present at sufficiently high concentrations, may also be toxic to aquatic biota.

Sewage Effluent

Effluent generated from operations and construction camps will be treated and discharged to the Purari River from a nominated discharge point at the Logistics Base. Even after treatment, effluent will contain elevated nutrient levels, i.e., nitrogen and phosphorus.

The release of waters with elevated nutrients can cause eutrophication, i.e., excess production of microalgae, which occurs as dense algal blooms. This can stress aquatic species due to depleted dissolved oxygen levels from microbial decomposition of decaying algae. These zones of low dissolved oxygen levels can kill fish and change aquatic community structure.

Captured Stormwater and Produced Water

Stormwater from the wellpads and CPF that could mix with hydrocarbons and other contaminants will be captured and treated before being discharged to the Purari River. Additionally, produced

waters could be discharged at this point during injection outages and when the backup storage tank capacity is exceeded. Discharge will take place according to applicable limits

Oils and petroleum hydrocarbons are less dense than water and are biodegradable. The most toxic fractions of oils to aquatic biota are lighter fractions that contain higher proportions of aromatic hydrocarbons; however, exposure of aquatic organisms to such fractions is usually limited due to their high volatility. 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 increases in algal growth (ANZECC/ARMCANZ, 2000).

11.5.3.3.2 Discharge of Firefighting Foams

Firefighting foams have high biochemical oxygen demand and constituents that may be toxic to aquatic fauna (DEHP, 2016). Releasing firefighting foams with high biochemical oxygen demand into surface waters may asphyxiate aquatic organisms due to depleted dissolved oxygen concentrations, as naturally occurring aerobic microorganisms degrade organic components of the foam. The occurrence of this impact is dependent on the level of biochemical oxygen demand of the firefighting foam and environmental factors such as water temperature, dilution and the existing waterway condition. Most firefighting foams are not acutely toxic; however, the persistence and bioaccumulation of some chemicals present in firefighting foams can cause chronic impacts to aquatic organisms, depending on the foam type. The extent of these chronic impacts is currently not well understood; however, evidence exists that all classes of perfluorochemicals potentially have such adverse effects (DEHP, 2016).

11.5.3.3.3 Accidental Hydrocarbon and Chemical Releases

Accidental release of fuel and other chemicals into the environment may be toxic to aquatic biota. Key potential contaminants are polycyclic aromatic hydrocarbons, metals, metalloids and a range of other synthetic compounds, which may have lethal or sublethal toxic effects or may bioaccumulate in biota.

The potential risk to aquatic biota depends on several factors, most notably the spatial extent of contamination, the duration of exposure, the contaminant type and the hydrological (flushing) characteristics of the affected waterway. Many contaminants are persistent in the environment, particularly when present in sediments, and can have long-term impacts if remediation is not undertaken. Aquatic environments with poor flushing (i.e., smaller tributary streams with low flow and palustrine wetlands) are most at risk of chemicals persisting in the environment.

Waterways most at risk of accidental releases are those closest to areas where large hydrocarbon and chemical volumes are stored or transferred. The Purari River near the Logistics Base and the Purari Airstrip; therefore, has a higher risk of occurrence of accidental hydrocarbon and chemical releases. This reach of the Purari River provides habitat for a wide range of aquatic fauna, including threatened sawfish, river shark and ray species (*P. pristis*, *G. garricki*, *G. glyphis*, *C. leucas*, *Glaucostegus typus* and *Urogymnus granulatus*), turtles (*Carettochelys insculpta* and *Pelochelys bibroni*), potentially river dolphins (*Orcaella heinsohni* and *Sousa sahulensis*) and macrocrustacean and macroinvertebrate species.

11.5.3.4 Fauna Strike

Vessels traversing the Purari River may collide with aquatic fauna, causing injury or death. Dredging of the Purari River adjacent to the jetty at the Logistics Base also has the potential to injure or kill any fauna in the dredging area. Such injuries could occur due to vessels or the backhoe dredge arm or bucket striking fauna.

11.5.3.5 Introduction and Spread of Aquatic Pest Species

11.5.3.5.1 Introduction of New Species to the PAOI

Project construction material, equipment and vessels will be brought from outside the Purari and Era river catchments. These elements could contain seeds or other fragments of aquatic weeds in quarry material or in sediment lodged in equipment and machinery.

Aquatic weeds introduced into the PAOI can degrade existing habitat and out-compete native species. Three aquatic weed species known to occur in Papua New Guinea, but not identified in the PAOI to date, are *Salvinia molesta*, *Pistia stratiotes* and *Hydrilla verticillata*. All three species are high-risk species that can form dense vegetation mats that may damage aquatic ecosystems by shading and altering flows. Additionally, dense vegetation mats provide breeding grounds for mosquitoes, which are disease vectors for malaria. Vessels and machinery that have operated in areas containing infestations are key potential weed vectors relevant to the Project.

Introduced fish species can change indigenous fish and invertebrate species populations by out-competing native species for food resources, predation and changing habitats. Introduced fish species known to occur in Papua New Guinea include rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), mosquitofish (*Gambusia holbrooki*), green swordtails (*Xiphophorus helleri*), blue panchax (*Aplocheilus panchax*) and gourami (*Trichogaster pectoralis* or *Trichogaster trichopterus*) (Polhemus et al., 2004). These species are not presently known to occur in the PAOI but may possibly occur in the upper catchment of the Purari River. The main vector for introduced fish species is deliberate introductions by people. Table 11.36 describes the potential impacts associated with introduced fish species.

11.5.3.5.2 Spread of Existing Pest Species

Project construction works have the potential to spread existing aquatic pest species by:

- Creating habitat preferred by pest species.
- Spreading environmental weeds in machinery, soil and other materials from an area of the PAOI in which they currently occur to an area in which they do not occur.

This can lead to aquatic habitat degradation from aquatic weeds and impacts on aquatic fauna from alien fish, as stated in Section 11.5.3.5.1.

Water hyacinth (*Eichhornia crassipes*) is the one confirmed aquatic weed species in the PAOI. This species is currently known to occur in Nea Creek, the associated PRL-15 oxbow wetlands, and near the Purari Airstrip. This weed can form large floating rafts that can change aquatic habitat conditions (e.g., by reducing water flow, light penetration through the water column, or dissolved oxygen concentrations), which can directly and indirectly harm or kill native aquatic flora and fauna species. Water hyacinth prefers still or slow flowing waters, so drainage ditches and backwaters of tributary streams are most at risk of infestations. The weed may spread by seeds or other plant parts attached to machinery and equipment being transported from areas of existing outbreaks to unaffected waterways.

Fisheries resource interviews indicate that the common carp (*Cyprinus carpio*), tilapia (*Oreochromis mossambica*) and Putitor mahseer (*Tor putitora*) already occur in the PAOI. Additionally, as described in Part 5 of Volume 2, other invasive fish species may possibly occur; although, they have not been observed during baseline surveys. Table 11.36 describes these species and their preferred habitat. In addition, pest insect species such as mosquitos and biting midges also occur in the catchment.

Table 11.36 – Invasive Species Known or Possibly Occurring in the PAOI and Their Preferred Habitat

Common Name	Scientific Name	Preferred Habitat	Flow Regime	Potential Impacts
Philippine catfish	*Clarias batrachus*	Swamps, particularly in stagnant, pools with low dissolved oxygen levels.	Low to no flows	Preys on small native fish, out-competes native fish for food.
Common carp	*Cyprinus carpio*	Rivers, creeks and wetlands with low to no flow, particularly in areas with abundant aquatic vegetation.	Low to no flows	Riverbed disturbance causing increased turbidity, competition with native species for food and space.
Mosquitofish	*Gambusia affinis/holbrooki*	Shallow rivers, creeks, lagoons and wetlands with low flow, particularly in clear waters.	Low to no flows	Preys on native fish eggs and larvae, competition for food and space.
Mozambique tilapia	*Oreochromis mossambicus*	Shallow rivers, creeks, lagoons and wetlands with low flow, but they can also colonize faster-flowing waters.	Low to no flows, tolerates moderate flows	Out-competes native species for food and space.
Putitor mahseer	*Tor putitora*	Streams and rivers, particularly rapid streams with a rocky bottom, riverine pools and lakes.	Moderate to high flows	Impacts unknown.
Green swordtail	*Xiphophorus helleri*	Generalist; occurs in rivers, creeks, lakes, wetlands, typically in areas with low flow and with aquatic vegetation.	Low to no flows	Impacts unknown.
Striped snakehead	*Channa striata*	Streams and ponds, particularly in stagnant pools with low dissolved oxygen levels. Tolerant of turbid and clear waters.	Low to no flows	Preys on native fish, out-competes native species.
Climbing perch	*Anabas testudineus*	Pond, swamps and drainage channels. Adaptive air-breathing organ allowing it to survive outside of water.	Low to no flows	Out-competes native species for food and space. Well-developed gill plates and spines that may choke and kill predatory species.
Blue panchax	*Aplocheilus panchax*	Wetlands, ponds, ditches and reservoirs.	Low to no flows	Impacts unknown.

Table 11.36 – Invasive Species Known or Possibly Occurring in the PAOI and Their Preferred Habitat (cont'd)

Common Name	Scientific Name	Preferred Habitat	Flow Regime	Potential Impacts
Snakeskin gourami	*Trichogaster pectoralis*	Wetlands, ponds and ditches, particularly in stagnant pools with low dissolved oxygen levels	Low to no flows	Impacts unknown.
Rainbow trout	*Oncorhynchus mykiss*	Lakes and streams with gravel substrate and well oxygenated water.	Low to moderate flows	Preys on native fish for food, out-competes native species for food and space.
Brown trout	*Salmo trutta*	Streams, lakes and reservoirs.	Low to moderate flows	Preys on native fish for food, out-competes native species for food and space.

Most of these alien fish species and pest insects prefer low-flow environments, such as quiescent pools. Creating and modifying drainages, and changing stream flows (e.g., by constructing water supply dams and sediment and erosion control infrastructure) could create preferred habitat for these species. As described in Table 11.36, the potential impacts of introduced species include:

- Predating native fish species, including eggs and larvae.
- Outcompeting native fish species for food and habitat.
- Disturbing bed and banks, leading to decreased water quality with associated impacts to flora and fauna sensitive to increased suspended sediment or sedimentation.

Such impacts could lead to localized declines in native fauna populations and fauna displacement of fauna from existing habitat. Alien species are likely to persist in the PAOI once introduced and they can be difficult to eradicate.

11.5.3.6 Underwater Noise

The impact of underwater noise on freshwater and estuarine fauna is addressed in the marine impact assessment in Section 12.4.

11.5.4 Proposed Mitigation and Management Measures

Table 11.37 describes mitigation and management measures to further reduce impacts to freshwater and estuarine biodiversity.

11.5.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to surface water quality subject to the embedded design controls in Section 11.5.3 and the successful implementation of the proposed mitigation and management measures in Section 11.5.4. 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.

11.5.5.1 Direct Disturbance and Habitat Fragmentation

11.5.5.1.1 Vegetation Clearing and Earthworks

The Project will remove 5.5 km of Oyomo Creek tributary stream habitats in the CPF footprint. The habitat that will be removed has a ***Medium*** sensitivity since the streams:

- Are presently in an unmodified condition, like most other streams in the PAOI.
- Provide good-quality habitat for invertebrate and fish species but are not habitat for threatened aquatic species recorded in the Purari River.
- Are not unique but rather are representative of the tributary stream habitat found throughout the PAOI and broader region.

The impact is irreversible but is not expected to extend beyond the CPF footprint or to threaten the viability of a subregional population. Drainage channels will be constructed to divert runoff and stream flows around the CPF. Depending on their design, the drainage channels could create habitat for aquatic biota, albeit of a lower quality and modified nature to the habitats that they replace. This provides for a ***Medium*** magnitude rating. Combining these scores, the direct disturbance to waterways in the CPF footprint will have a ***Moderate*** impact significance.

Table 11.37 – Freshwater and Estuarine Biodiversity Mitigation Strategies and Management Plans

Potential Impact	Mitigation Strategy	Relevant Management Plan
Direct disturbance of habitat from vegetation clearing and earthworks.	♦ All sites proposed for development as part of the Project will be subject to a preconstruction survey to clearly identify acid sulfate soils, sensitive sites and habitats, e.g. roosting, breeding, nesting and threatened species sites, priority ecosystem services, archaeological sites, burial sites, sites of religious importance to be subject to specific mitigation measures [EM001]. ♦ Maintain a minimum practical distance from sensitive features to minimize potential degradation and disturbance. Buffer distances shall be ecologically relevant, considering: – Sensitive habitats, i.e. primary alluvial forest, mangroves, riparian vegetation along forest streams. – Habitats that provides focal breeding, roosting or feeding sites for sensitive fauna, e.g. caves, rock shelters, rock outcrops, large trees with hollows, large trees with nests, bird-of-paradise display trees, forest pools, large fig trees (Ficus spp.) and vines of the family Aristolochiaceae. – Sites that support populations of IUCN Threatened or rare and localized plant species [EM024].	Biodiversity Action Plan
Direct disturbance of habitat and fragmentation of waterways by pipeline and road crossings.	♦ All sites proposed for development as part of the Project will be subject to a preconstruction survey to clearly identify acid sulfate soils, sensitive sites and habitats, e.g. roosting, breeding, nesting and threatened species sites, priority ecosystem services, archaeological sites, burial sites, sites of religious importance to be subject to specific mitigation measures [EM001]. ♦ Erosion and sediment control measures will be implemented for infrastructure components in accordance with good international industry practice to effectively manage stream and river flows, stormwater, surface erosion, sedimentation and scour, e.g., drainage diversion into surrounding vegetation, rip-rap aprons, rock armoring, energy dissipaters, sediment control ponds, mulch berms and sediment fences, where required, until the area has been effectively stabilized and/or rehabilitated [EM004]. ♦ Maintain hydraulic and biological connectivity during construction and operations in natural flow lines across linear infrastructure, such as pipelines and roads, and in relation to water extraction, e.g., dams, including: – Install appropriately sized culverts, drains and structures to allow fish passage, according to good international industry practice standards. – Rehabilitate waterways after construction and decommissioning to a sustainable, stable state, that reflects the original character, and maintains waterway flows and connectivity [EM020]. ♦ Maintain a minimum practical distance from sensitive features to minimize potential degradation and disturbance. Buffer distances shall be ecologically relevant, considering: – Sensitive habitats, i.e. primary alluvial forest, mangroves, riparian vegetation along forest streams.	Water Management Plan; Biodiversity Action Plan

Table 11.37 – Freshwater and Estuarine Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Direct disturbance of habitat and fragmentation of waterways by pipeline and road crossings (cont'd).	– Habitats that provides focal breeding, roosting or feeding sites for sensitive fauna, e.g. caves, rock shelters, rock outcrops, large trees with hollows, large trees with nests, bird-of-paradise display trees, forest pools, large fig trees (Ficus spp.) and vines of the family Aristolochiaceae. – Sites that support populations of IUCN Threatened or rare and localized plant species [EM024].	See above
Direct disturbance and fragmentation of habitat from water extraction and impoundment.	♦ All sites proposed for development as part of the Project will be subject to a preconstruction survey to clearly identify acid sulfate soils, sensitive sites and habitats, e.g. roosting, breeding, nesting and threatened species sites, priority ecosystem services, archaeological sites, burial sites, sites of religious importance to be subject to specific mitigation measures [EM001]. ♦ Maintain hydraulic and biological connectivity during construction and operations in natural flow lines across linear infrastructure, such as pipelines and roads, and in relation to water extraction, e.g., dams, including: – Install appropriately sized culverts, drains and structures to allow fish passage, according to good international industry practice standards. – Rehabilitate waterways after construction and decommissioning to a sustainable, stable state, that reflects the original character, and maintains waterway flows and connectivity [EM020]. ♦ Minimize fish entrainment by water extraction equipment e.g. screens [EM021]. ♦ Maintain a minimum practical distance from sensitive features to minimize potential degradation and disturbance. Buffer distances shall be ecologically relevant, considering: – Sensitive habitats, i.e. primary alluvial forest, mangroves, riparian vegetation along forest streams. – Habitats that provides focal breeding, roosting or feeding sites for sensitive fauna, e.g. caves, rock shelters, rock outcrops, large trees with hollows, large trees with nests, bird-of-paradise display trees, forest pools, large fig trees (Ficus spp.) and vines of the family Aristolochiaceae. – Sites that support populations of IUCN Threatened or rare and localized plant species [EM024].	Water Management Plan; Biodiversity Action Plan
Increased levels of suspended sediment and sedimentation in waterways from earthworks and stockpiling.	♦ Progressively clear vegetation and rehabilitate cleared areas as soon as practicable to minimize the time cleared areas are exposed; and allow fauna to move away from areas to be cleared, where practicable [EM002]. ♦ Cut trees where practicable to retain the rootstock and maintain soil stability [EM003]. ♦ Erosion and sediment control measures will be implemented for infrastructure components in accordance with good international industry practice to effectively manage stream and river flows, stormwater, surface erosion, sedimentation and scour, e.g., drainage diversion into surrounding vegetation, rip-rap aprons, rock armoring, energy dissipaters, sediment control ponds, mulch	Soil Management Plan; Site Restoration and Rehabilitation Plan; Water Management Plan

Table 11.37 – Freshwater and Estuarine Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Increased levels of suspended sediment and sedimentation in waterways from earthworks and stockpiling (cont'd).	berms and sediment fences, where required, until the area has been effectively stabilized and/or rehabilitated [EM004]. ♦ Stabilize spoil stockpiles and areas of ground disturbance as soon as practicable after initial disturbance using, e.g., mulched vegetation, aggregates and soil binders [EM005]. ♦ Areas of higher risk of landslides e.g., steep gradients, previously disturbed land, likely to occur from the works, or likely to be exacerbated by the works, will be stabilized to reduce the landslide risk. [EM006]. ♦ Minimize or avoid sidecasting during construction (e.g. for road, pipeline, wellpad and CPF works). Any sidecasting that does occur will avoid defined stream channels [EM010]. ♦ Water from trenches will be discharged in accordance with applicable water quality standards with erosion and sediment controls where relevant [EM011]. ♦ Maintain buffer zones between permanent surface water and project infrastructure, except to carry out works associated with the construction of watercourse crossing or where facilities are proposed to be located within that buffer [EM012]. ♦ Minimize in-stream and stream bank disturbance during high rainfall [EM013].	Soil Management Plan; Site Restoration and Rehabilitation Plan; Water Management Plan
Increased levels of suspended sediment and sedimentation in waterways from dredging.	♦ Where required, implement adaptive management to minimize dredging impacts on sensitive habitats and species [EM037].	Water Management Plan
Contamination from 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. – Chemicals additives 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; Waste Management Plan
Contamination from discharge of firefighting foams during training and testing.	♦ Training and test releases of firefighting foams at the CPF are to be contained within appropriate drainage water treatment networks. [EM016].	Hazardous Material Management Plan

Table 11.37 – Freshwater and Estuarine Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Water contamination from accidental release of hydrocarbons or chemicals.	♦ Vehicle wash down and fuel handling will be undertaken considering possible receptors e.g., streams, Purari River and the marine environment [EM017]. ♦ 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].	Hazardous Material Management Plan; Emergency Response Plan; Oil Spill Contingency Plan
Vessels striking fauna.	♦ Implement lower speeds past aquatic fauna when observed in the water [EM022].	Traffic and Transport Management Plan; Biodiversity Action Plan
Introduction or spread of invasive species, 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 third-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].	Biodiversity Action Plan

11.5.5.1.2 Pipeline and Road Crossings of Waterways

Waterways being crossed by roads or pipelines have a ***Medium*** sensitivity considering that they are not unique habitat but rather are representative of the riverine habitats found throughout the PAOI and broader Purari River catchment and threatened aquatic species are unlikely to occur.

If Project roads are maintained beyond the life of the Project, this will permanently modify tributary stream habitats in culvert footprints for the roads. However, mitigation is proposed to rehabilitate waterways after construction and decommissioning to a sustainable, stable state, that reflects the original character, and maintains waterway flows and connectivity. Even if roads become permanent, this represents a highly localized loss of habitat in the crossing footprint.

Culverts will be sized and constructed to maintain stream flows. If culverts are inappropriately designed, fish passage may be affected under certain flow conditions (e.g., very low flows if the culvert dries or high flows if water velocities are too high for fish movement); however, since waterway crossings are to be constructed according to good international industry practice guidelines to promote fish passage, habitat fragmentation is unlikely to occur under such flow conditions.

Fragmentation and disturbance during construction activities will be for a limited time and is unlikely to have any residual impacts on species populations once connectivity is restored. Aquatic macroinvertebrates, which have limited mobility, will be temporarily lost in the trenching and culvert footprints; however, impacts are expected to be short-term, with recolonization and recovery expected to occur in weeks to months. Most fish (i.e., bony and cartilaginous fish) and crocodiles will avoid the construction areas and therefore are unlikely to be directly impacted. Impacts are expected to be highly localized, short-term and not to result in measurable declines in species populations over a broader area, the magnitude of impact is therefore assessed to be ***Low.***

The waterway crossings therefore have a ***Minor*** impact significance on aquatic habitat and species.

11.5.5.1.3 Water Impoundment and Extraction

Hou and Boa creeks at the likely dam and extraction sites both have a ***Medium*** sensitivity based on the following:

- Both waterways are in a mostly unmodified condition, although historical disturbance such as sediment inputs from earthworks is possible at both sites from the nearby drilling sites. Additionally, a road that potentially limits fish passage crosses Boa Creek, downstream of the likely dam location.
- Both waterways provide habitat for invertebrate and fish species but are unlikely to support threatened aquatic species as the key species occur in larger waterways.
- Neither site is a unique habitat feature but rather is representative of the riverine habitats found throughout the PAOI and broader Purari River catchment.

The Project will temporarily modify tributary stream habitats in the water extraction infrastructure footprint (i.e., water extraction pipelines and dams on Hou and Boa creeks). Habitat may be modified for approximately two years; however, impacts will be highly localized (measured in meters to tens of meters), marginally detectable with respect to natural variability, with populations readily able to regenerate on remaining habitat. This provides a ***Low*** magnitude rating.

Water extraction from these tributary creeks will be undertaken in such a way that flow regimes (i.e., base, low, medium and high flows) past the dams are maintained to protect environmental values in downstream environments. Upstream environments will not be affected by water extraction. On this basis, impacts to aquatic biodiversity associated with water extraction are unexpected. Water extraction from the Purari River for use at the CPF and potable water for the accommodation camps is expected to cause negligible impacts to flow regimes (see Section 11.3.5.2); hence, no impacts on aquatic communities in the Purari River are expected.

Impoundment dams are expected to have over-dam flow to allow fish passage when flooded; however, fish passage could be blocked during periods of low flow. As these structures will only be installed for about two years, implementation of special measures to maintain fish passage during periods of low flow is considered unnecessary. This temporary fragmentation of fish passage during these periods is expected to have low impact on fish species, being marginally detectable with respect to natural variability, and with the fish species readily able to reproduce in the remaining habitat. This is due to the location of the impoundments in the upper part of the tributaries, thereby limiting the extent of waterway that is fragmented. Fish entrainment by water extraction equipment will be minimized through the installation of physical barriers, such as screens.

Installing dams will also modify some habitat immediately upstream of the dam (i.e., change from run to pool habitat). These impacts will be highly localized, not affect viability of ecosystem communities (i.e., without significant change compared to natural variability), and would only occur for two years. Based on these considerations, the impact to aquatic biodiversity due to water impoundment and extraction for drilling is assessed to have a ***Low*** magnitude.

Combining these scores, water impoundment and extraction will have a ***Minor*** impact significance in relation to both direct habitat loss from dam and water extraction infrastructure and habitat modification from water impoundment and extraction.

11.5.5.1.4 Dredging

The habitat in the proposed dredging footprint has a ***Medium*** sensitivity based on it:

- Being in an unmodified condition.
- Providing habitat for invertebrate and fish species, and potentially providing suitable habitat for threatened aquatic species recorded in the Purari River.
- Not being unique, but rather being representative of riverine habitat throughout the broader Purari River.

Initial construction dredging and ongoing maintenance dredging will lower the river bed in the dredging footprint and modify aquatic habitat for the life of the Project.

Dredging will remove soft sediment habitat and biota from the dredging footprint, causing a temporary loss of biota from the footprint. Biota will rapidly recolonize the dredging footprint but may continue to be subject to similar disturbance through ongoing maintenance dredging, if it is required to maintain the required water depth. The new benthic fauna community in the dredging footprint is likely to have a lower fauna abundance and diversity compared to undisturbed soft sediment habitats nearby, but changes are unlikely to affect habitat or benthic species populations outside of the range of natural variability. The impact will also occur only in the dredging footprint. The magnitude of impact is therefore considered to be ***Low***.

Combining these scores, direct habitat loss from dredging is assessed to have ***Minor*** impact significance.

11.5.5.2 Increased Suspended Sediment and Sedimentation Levels

11.5.5.2.1 Earthworks and Spoil Stockpiling

Increases in suspended sediment levels and in-stream sedimentation from earthworks and spoil stockpiling will occur in waterways located directly adjacent to construction sites subject to ground disturbance, including the:

- Purari River, adjacent to the Purari Airstrip and Logistics Base and downstream of most Project earthworks.
- Oyomo Creek catchment, which includes the CPF, roads and pipelines, and spoil stockpiling locations.
- Hou Creek, Boa Creek and Mena River catchments, which include the wellpads, roads and pipelines, and spoil stockpiling locations.
- Kuku Creek and Era River catchments and the waterways catchments along the export pipeline route, which include roads, pipelines and spoil stockpiling locations.

These waterways have low levels of human disturbance except for several creek crossings on the Herd Base Road over Mena River and Boa Creek, and catchments along the export pipeline route that have existing high levels of disturbance and sediment loading due to commercial logging activities. The PRL-15 waterways and the Purari River provide good-quality habitat for a wide range of invertebrate and fish species. This includes the threatened and endemic aquatic species identified as occurring or possibly present in the PAOI (see Section 11.5.1). These waterways; therefore, have a ***Medium*** sensitivity. The disturbed waterways along the export pipeline route are likely to have lower habitat values and are considered unlikely to support threatened or endemic species due to existing sedimentation impacts and; therefore, have a ***Low*** sensitivity.

Localized sediment loading impacts to these waterways (see Section 11.3.5.1) are likely to occur, even with the application of mitigation measures. These impacts will be most severe during the construction phase, with higher turbidity and possibly smothering of creek bed habitats, especially immediately downstream of works areas.

Localized declines in microalgae, invertebrate and fish communities are expected to occur, especially in stream reaches directly adjacent to construction footprints and in downstream depositional environments. These impacts are expected to exceed natural variability for the tributary streams in PRL-15; although, they are less likely to be significant in the Purari River and export pipeline route waterways due to existing high sediment loads. Long-term impacts (i.e., the life of the Project) could occur immediately downstream of works areas. Habitat and biological community recovery is expected post-construction outside the immediate zone of influence of sediment discharges. The recovery timeframes of biological communities further downstream will depend on the effectiveness of control measures, and therefore the spatial extent of the impact, and sediment transport capacity of waterways (i.e., the habitat recovery timeframes).

Based upon these considerations, and the residual sedimentation impacts identified in Section 11.3.5.1, the expected magnitude of impact on aquatic biodiversity and residual impact significance for each waterway is shown in Table 11.38.

Table 11.38 – Significance of Sedimentation Impacts for PAOI Waterways

Waterway	Catchment	Sensitivity of Receptor	Construction Phase		Operations Phase	
			Magnitude of impact	Impact Significance	Magnitude of Impact	Impact Significance
Boa Creek	Era	Medium	Medium	Moderate	Low	Minor
Mena River	Era	Medium	Medium	Moderate	Low	Minor
Era River	Era	Medium	Minimal	Negligible	Minimal	Negligible
Hou Creek	Purari	Medium	Minimal	Negligible	Minimal	Negligible
Kuku Creek	Purari	Medium	Medium	Moderate	Low	Minor
Oyomo Creek	Purari	Medium	High	Moderate	Low	Minor
Purari River	Purari	Medium	Low	Minor	Low	Minor
Waterways along the export pipeline route	Purari	Low	Low	Minor	Low	Minor

11.5.5.2.2 Dredging

Any sediment plumes due to dredging at the new jetty in the Purari River are expected to be highly localized and restricted to the short period of dredging (i.e., weeks) due to the strong river flows and high sediment advection (see Section 11.3.5.1.3). Given the high ambient turbidity, the plume is expected to be difficult to visually detect more than 0.5 km downstream of the dredging site (i.e., will be highly localized); however, given that Oyomo Creek flows into the Purari River approximately 100 m downstream from the proposed jetty, plumes may potentially extend into this tributary during periods of reverse flow of the creek, should such flow conditions occur during the period of dredging. This could increase the sediment loads delivered to this system during high flows. The highly localized impacts to habitat and ecosystems due to dredging are; however, expected to be very low and undetectable with respect to natural variability. The magnitude of impact is therefore rated to be ***Minimal***.

The Purari River and Oyomo Creek are considered to have ***Medium*** sensitivity (see Section 11.5.5.2.1). This provides an overall impact significance rating of ***Negligible*** for both waterways.

11.5.5.3 Contamination of Waterways

11.5.5.3.1 Planned Wastewater Discharges

Hydrotest Water

As described in Section 11.5.5.2, the sensitivity of the Purari River for aquatic habitat and species is ***Medium***. Hydrotest water discharge locations and discharge rates, to either land or water, will be defined during FEED. Any discharges to surface waters will comply with designated water quality standards. Hydrotest water may contain a small amount of an oxygen scavenger, such as sodium bisulfite, to inhibit corrosion and a biocide to prevent bacteria developing. Any impacts from residual amounts of these chemical additives in the hydrotest water discharges to the Purari River would be localized with no detectable change in the composition or viability of ecosystem communities and populations. The expected magnitude of impact of such discharges is ***Low,*** providing an overall impact significance rating of ***Minor***.

Sewage Effluent

The discharge of treated sewage effluent is likely to have only highly localized (i.e., within 0.5 km of the discharge point) impacts on water quality in the Purari River. Discharged water quality will meet designated water quality standards, and the significant flow volumes in the Purari River are expected to rapidly dilute treated effluent. Any increase in nutrient levels at the discharge point is unlikely to cause detectable flow-on effects, particularly given that the high turbidity and fast flow of the Purari River limits the potential for algal blooms and hence effects due to eutrophication. The expected magnitude of impact is; therefore, ***Minimal***. Given the sensitivity of the Purari River for aquatic habitat and species is ***Medium***, the overall impact significance is assessed to be ***Negligible***.

Captured Stormwater and Produced Water

Hydrocarbon-contaminated stormwater and potentially produced water discharges from the CPF and wellpads, will contain only residual amounts of hydrocarbons following water treatment. High flow volumes in the Purari River are expected to rapidly disperse residual pollutants and; therefore, acute toxic impacts are not expected. Any impacts to habitat, ecosystem and species would be localized and only marginally detectable with respect to natural variability and therefore have a ***Low*** magnitude. The sensitivity of the Purari River to this impact is ***Medium***, providing an overall impact significance rating of ***Minor****.*

11.5.5.3.2 Discharge of Firefighting Foams

Using low-toxicity, biodegradable firefighting foams in contained areas at the CPF will reduce the risk of polluting waterways (see Section 11.4.4). The firefighting foams will be captured in the OD1 and OD2 open drain networks and directed to an observation basin, where degradation will occur, and the water will be tested for suitability for release prior to it being discharged into the Purari River. Such discharges will only occur following routine fire response training and equipment testing exercises. Impacts to habitat, the ecosystem and species from these controlled releases are expected to be localized and cause no measurable decline in species populations, and; therefore, are of ***Low*** magnitude. The sensitivity of habit, the ecosystem and species of the Purari River is ***Medium***, providing an overall significance rating of ***Minor***.

11.5.5.3.3 Accidental Hydrocarbon or Chemical Releases

Any fuel or chemical spills at the CPF and wellpads will be captured by the OD1 and OD2 open drain networks, treated and discharged to the Purari River. These discharges are planned discharges that are addressed in Section 11.5.5.3.1. For other areas of Project activities, potential releases to surface water would not be controlled to a known discharge location.

Incidental small spills and leaks from barge traffic, and fuel and chemical storages and transfers at the Logistics Base are considered to present the highest Project risk to the Purari River (see Section 11.4.5.3). Given the fast-flowing nature of the Purari River and that hydrocarbons float on the surface of water, a spill could potentially extend beyond 2 km; however, water quality deterioration from an accidental spill would only be for a short period given the high assimilative capacity of the river due to its large flows. Water quality would be expected to quickly recover to its previous condition prior to the spill (within hours). Given that most fauna of the Purari River are demersal (i.e., bottom-dwelling), their exposure to hydrocarbons in surface waters would be limited. An accidental spill would only be expected to cause a minor decline in a localized species population and would not threaten the viability of a subregional population. The magnitude of impact to aquatic biodiversity is; therefore, categorized to be ***Low***. Given the sensitivity of the

habit, ecosystem and species of the Purari River is ***Medium***, the overall impact significance rating is ***Minor***.

Other waterways in the PAOI have a sensitivity rating similar to or less than the Purari River and are considered less likely to be exposed to spills than the Purari River. Similar or lesser residual impacts to other waterways in the PAOI are; therefore, expected in the event of accidental hydrocarbon or chemical releases, depending on the quantity and nature of the spill, extent of remediation possible and the characteristics of the receiving waterbody.

11.5.5.4 Fauna Strike

Most fauna of the Purari River are demersal, fast-moving or present in low abundance, which reduces the risk of vessels striking them. Additionally, most Project vessels will be slow-moving barges, which are unlikely to strike aquatic fauna. Lower speeds will be implemented past aquatic fauna when observed in the water.

Dredging operations are unlikely to strike fauna. The dredger will be stationary most of the time, and it will only move at slow speeds. Fauna will be readily able to evade the dredge. The dredge arm will also move slowly, reducing the likelihood of strikes injuring or killing fauna. Noise and vibration generated by the dredge will also deter fauna from being present in the dredging area.

Based on the above, the magnitude of impact of fauna strike is assessed to be ***Minimal***. Given the sensitivity of aquatic species in the Purari River is ***Medium***, the overall impact significance rating is ***Negligible***.

11.5.5.5 Introduction and Spread of Aquatic Pest Species

11.5.5.5.1 Introduction of New Species to the PAOI

Waterways most likely to be affected are those near Project infrastructure, i.e., the upper reaches of Hou Creek, Boa Creek, Mena River, Kuku Creek and Oyomo Creek. These waterways and the Purari River provide good quality habitat for a wide range of invertebrate and fish species, including the threatened and endemic aquatic species identified as occurring or possibly present in the PAOI (see Section 11.5.1) and; therefore, have a ***Medium*** sensitivity.

The disturbed waterways along the export pipeline route are likely to have lower habitat values and are considered unlikely to support threatened or endemic species due to existing sedimentation impacts and have a ***Low*** sensitivity.

The Project is unlikely to be responsible for introducing new aquatic pest species into the PAOI with appropriate biosecurity measures, including a quarantine program for imported equipment and supplies. No measurable decline in a species population is expected due to new pest species, and the magnitude of impact is considered to be ***Minimal***.

The overall impact significance on habitat and species due to the introduction of new pest species is assessed to be ***Negligible*** for all streams in the PAOI.

11.5.5.5.2 Spread of Existing Pest Species

Implementing risk-based hygiene protocols will reduce the risk of aquatic weeds spreading in the PAOI; however, a risk of isolated outbreaks remains. Habitat condition and ecosystem viability may be reduced in the affected area over a medium duration; hence, the magnitude of impact is rated as ***Low***.

Waterways most likely to be affected due to existing weed species being spread are those near Project infrastructure, particularly around the Purari Airstrip where water hyacinth (*Eichhornia crassipes*) is known to be present.

Invasive fauna could colonize and proliferate in impounded and ponded waters and drainage depressions across the PAOI. Eradicating invasive fish is feasible when these areas are contained; however, eradication is difficult without impacts to non-target native species if invasive species spread to other waterways from these areas. Localized residual impacts to aquatic fauna populations (especially fish) may occur. The magnitude of impact is therefore categorized to be ***Low***.

The sensitivity of the various waterways in the PAOI is as described in Section 11.5.5.5.1.

Based on the sensitivity of the habitats and species, the overall impact significance for biodiversity is ***Minor*** for all streams in the PAOI.

11.5.6 Summary of Residual Impacts to Freshwater and Estuarine Biodiversity

Table 11.39 provides a summary of the assessment of residual impacts to freshwater and estuarine biodiversity, including in which Project phase and location these impacts are expected to occur. The table should be read in conjunction with the specific mitigation measures provided in Table 11.37.

All residual impacts are assessed to be ***Negligible*** to ***Minor***, except for impacts described below which are assessed to have a ***Moderate*** residual impact:

- Aquatic habitat degradation and declines in fauna populations in Oyomo Creek from direct fragmentation, habitat removal and increased suspended sediment and sedimentation levels due to CPF construction.
- Aquatic habitat degradation and declines in fauna populations in the Mena River, Kuku Creek and Boa Creek from increased suspended sediment and sedimentation levels due to pipeline laying and road construction.

Table 11.39 – Summary of Assessment of Residual Impact Significance for Freshwater and Estuarine Biodiversity

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Habitat disturbance and fragmentation	Earthworks and physical infrastructure.	Direct loss of aquatic habitat in Oyomo Creek catchment.	PRL-15	C, O	♦ EM001 ♦ EM024	Medium/Medium	Moderate
	Construction works and onshore pipeline construction – pipeline and road crossings of waterways.	Direct loss of aquatic habitat at stream crossings and blockage of fish passage leading to population declines.	PRL-15 Export pipeline route	C	♦ EM001 ♦ EM004 ♦ EM020 ♦ EM024	Medium/Low	Minor
	Construction of water supply dams on Hou and Boa creeks.	Direct loss of aquatic habitat in the footprints of extraction infrastructure in Hou and Boa creeks.	PRL-15	C	♦ EM001 ♦ EM020 ♦ EM021 ♦ EM024	Medium/Low	Minor
		Modification of aquatic habitat and fish movement in Hou and Boa creeks.	PRL-15	C		Medium/Low	Minor
	Dredging at the Logistics Base.	Direct loss of aquatic habitat in the dredging footprint in the Purari River.	River transport corridor	C, O	None	Medium/Low	Minor
Increased suspended sediment and sedimentation levels	Earthworks and spoil disposal.	Smothering of fauna and habitat from sediment generated by construction phase ground disturbance and changes in surface cover – Oyomo Creek.	PRL-15	C	♦ EM002 ♦ EM003 ♦ EM004 ♦ EM005 ♦ EM006 ♦ EM010 ♦ EM011 ♦ EM012 ♦ EM013	Medium/High	Moderate
		Smothering of fauna and habitat from sediment generated by construction phase ground disturbance and changes in surface cover – Mena River, Kuku Creek and Boa Creek.	PRL-15	C		Medium/Medium	Moderate

Table 11.39 – Summary of Assessment of Residual Impact Significance for Freshwater and Estuarine Biodiversity (cont'd)

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
Increased levels of suspended sediment and sedimentation (cont'd).	Earthworks and spoil disposal (cont'd).	Smothering of fauna and habitat from sediment generated by construction phase ground disturbance and changes in surface cover – Era River and Hou Creek.	PRL-15	C	See above	Medium/Minimal	Negligible
		Smothering of fauna and habitat from sediment generated by construction phase ground disturbance and changes in surface cover – Purari River.	PRL-15 Export pipeline route	C		Medium/Low	Minor
		Smothering of fauna and habitat from sediment generated by construction phase ground disturbance and changes in surface cover – waterways along export pipeline route.	Export pipeline route	C		Low/Low	Minor
		Smothering of fauna and habitat from sediment generated from roads during operations phase – Boa Creek, Mena River, Kuku Creek and Oyomo Creek.	PRL-15	O		Medium/Low	Minor
		Smothering of fauna and habitat from sediment generated from roads during operations phase – Hou Creek and Era River.	PRL-15	O		Medium/Minimal	Negligible

Table 11.39 – Summary of Assessment of Residual Impact Significance for Freshwater and Estuarine Biodiversity (cont'd)

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Increased suspended sediment and sedimentation levels (cont'd).	Earthworks and spoil disposal (cont'd).	Smothering of fauna and habitat from sediment generated from roads during operations phase – Purari River.	Export pipeline route	O	See above	Medium/Low	Minor
		Smothering of fauna and habitat from sediment generated from roads during operations phase – waterways along export pipeline route.	Export pipeline route	O		Low/Low	Minor
	Dredging at the Logistics Base.	Smothering of fauna and habitat from sediment generated from dredging – Purari River and Oyomo Creek.	River transport corridor	C, O	♦ EM037	Medium/Minimal	Negligible
Contamination of waterways.	Planned wastewater discharges.	Impacts on aquatic ecosystems and biota from discharge of hydrotest water – Purari River.	PRL-15	C	♦ EM008 ♦ EM015 ♦ EM016	Medium/Low	Minor
		Impacts on aquatic ecosystems and biota from discharge of treated sewage effluent – Purari River.	PRL-15	C, O		Medium/Minimal	Negligible

Table 11.39 – Summary of Assessment of Residual Impact Significance for Freshwater and Estuarine Biodiversity (cont'd)

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Contamination of waterways (cont'd).	Planned wastewater discharges (cont'd).	Impacts on aquatic ecosystems and biota from discharge of contaminated stormwater and produced water – Purari River.	PRL-15	O	See above	Medium/Low	Minor
		Impacts on aquatic ecosystems and biota from firefighting foams discharges during fire response training and equipment testing – Purari River.	PRL-15	O		Medium/Low	Minor
	Accidental hydrocarbon or chemical releases; use of hazardous materials.	Impacts on aquatic ecosystems and biota from hydrocarbon or chemical spill or leaks – Purari River and other PAOI waterways.	PRL-15 Export pipeline route River transport corridor	C, O	♦ EM017 ♦ EM018 ♦ EM019	Medium/Low	Minor
Fauna strike.	Logistics and transport (barging along waterways).	Vessel strike causing fauna injury or death.	River transport corridor	C, O	♦ EM022	Medium/Minimal	Negligible
Introduction and spread of aquatic pest species.	Logistics and transport; vegetation clearing.	Introduction of new pest species to the PAOI reducing habitat quality and outcompeting and preying on native aquatic biota.	PRL-15 River transport corridor	C, O	♦ EM023 ♦ EM028	Medium/Minimal	Negligible
			Export pipeline route	C, O		Low/Minimal	Negligible
		Spread of existing aquatic weeds reducing habitat quality for native aquatic biota.	PRL-15 River transport corridor	C, O		Medium/Low	Minor

Table 11.39 – Summary of Assessment of Residual Impact Significance for Freshwater and Estuarine Biodiversity (cont'd)

Impacting Process	Activity and Potential Impact		Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Introduction and spread of aquatic pest species (cont'd).	Logistics and transport; vegetation clearing (cont'd).	Spread of existing aquatic weeds reducing habitat quality for native aquatic biota (cont'd).	Export pipeline route	C, O	See above	Low/Low	Minor
		Spread of existing invasive fauna outcompeting and preying on native aquatic biota.	PRL-15 River transport corridor	C, O		Medium/Low	Minor
			Export pipeline route	C, O		Low/Low	Minor

C = Construction, O = Operations.

11.6 Terrestrial Biodiversity

11.6.1 Context

The information assessed in this section is based on the baseline characterization of terrestrial biodiversity (Part 6 of Volume 2 and summarized in Chapter 7) and the Project description (Chapter 4).

The Project is located in the Kikori-Purari biogeographic region which is a biologically diverse and endemically rich terrestrial region. It is divided into five ecological zones; the Middle Purari Hills, Southeast Hills, Delta Swamps and Plains, Mangroves and Southeast Coast; each of which supports a distinct assemblage of terrestrial flora and fauna. The study area is of very high conservation value due to its large size, remoteness, low human population and high degree of connectivity amongst a variety of intact and biodiversity-rich habitats that support numerous species of conservation significance (Chapter 7).

The study area qualifies as Tier 1 Critical Habitat under the International Finance Corporation's (IFC's) Performance Standard 6 (IFC, 2012a), due to the presence of three International Union for the Conservation of Nature (IUCN) Critically Endangered and nine Endangered terrestrial flora and fauna species, more than 100 terrestrial restricted-range species, the presence of threatened and unique ecosystems, and inclusion of part of the Crater Mountain Wildlife Management Area.

The area is covered almost entirely in natural vegetation (i.e., 98.9%, including regenerating logged forest), which is arranged into five broad vegetation groups: hill forest, alluvial forest, freshwater swamp vegetation, mangroves and littoral forest. Hill forest is widespread and covers nearly half the Middle Purari Hills and Southeast Hills ecological zones. Freshwater swamp vegetation and alluvial forest covers much of the Delta Swamps and Plains zone, and the Mangroves ecological zone occurs along the coast (Part 6 of Volume 2).

Nine types of focal sites[3] are recognized in the various ecosystems. Focal sites include caves, nesting sites, large trees and forest pools.

Ninety-two IUCN listed and nationally Protected species are known or likely to occur in the study area. These include three Critically Endangered species (*Diospyros lolinopsis, Guioa hospita* and Bulmer's fruit bat (*Aproteles bulmerae*)) and nine Endangered species (*Diospyros insularis*, *Pterocarpus indicus* and *Flindersia pimenteliana*, two tree kangaroo (*Dendrolagus*) species, giant bandicoot (*Peroryctes broadbenti*), far eastern curlew (*Numenius madagascariensis*), great knot (*Calidris tenuirostris*) and pig-nosed turtle (*Carettochelys insculpta*)). A further 65 species are scientifically undescribed, including 49 new-to-science species (i.e., 34 plants, two small nonvolant mammals, two reptiles, three frogs and eight odonates), and 119 species are restricted-range species.

Ninety-seven invasive alien plant species have been recorded in the study area, including seven 'Priority 1' weed species that have the potential to invade undisturbed natural habitats, i.e., Angelonia (*Angelonia angustifolia*), water hyacinth (*Eichhornia crassipes*), anglestem willow (*Ludwigia leptocarpa*), mile-a-minute vine (*Mikania micrantha*), bamboo daka (*Piper aduncum*), African tulip tree (*Spathodea campanulate*) and coconut palm (*Cocus nucifera*, a commercial cultivar). Among invasive alien fauna, four rodent species, feral pigs and dogs, the Eurasian tree sparrow (*Passer montanus*) and the cane toad (*Rhinella marina*) are all confirmed present.

3 Various localized terrain and habitat features upon which multiple species or multiple individuals of one or more species are ecologically dependent.

11.6.2 Discipline-specific Impact Assessment Method

11.6.2.1 Approach

General Approach

The impact assessment for terrestrial biodiversity follows the significance assessment method outlined in Chapter 3. The level of significance is derived from a combination of the value's sensitivity and the impact's magnitude.

This assessment adopts a high-level, combined approach in determining the overall residual significance of Project-related impacts. Individual impact processes are initially discussed separately, but in many cases the mechanisms of change are interrelated, and their effects are accumulative such that examining each factor in isolation can lead to a misleading assessment. Section 11.6.5 considers the significance of residual impacts as a combined function of all direct and indirect impact processes. The approach was developed by specialists based on expertise, experience and precedents from other peer reviewed impact assessments.

Assessing Impacts to Species Known Only from the Study Area

Potential impacts to species that are presently known only from the study area are assessed under the precautionary principle. A lack of basic information on distribution and abundance from which to infer rarity exists for many taxa, both globally and those known to occur in the study area. Most species presently known only from the study area are likely to occur more widely across the Gulf Province and country, and across a broader range of suitable habitat types. A precautionary approach is required until such records exist. This assessment conservatively considers that where species ecologies are incomplete, one or more may be restricted to the study area where they may be constrained by specific habitat requirements or be locally uncommon or rare.

Features Not Assessed in This Chapter

The following biodiversity values are not assessed in this chapter:

- Those species and ecosystems judged in Part 6 of Volume 2 to be ***Not Sensitive*** or to have ***Low Sensitivity***. The impact magnitude for each of these values is deemed to be ***Medium*** or lower, and the impact significance is therefore ***Negligible*** or ***Minor***.
- The IUCN Critically Endangered mangrove tree *Bruguiera hainesii* and the associated '*Bruguiera hainesii* zone' focal site, located at the eastern edge of the Mangroves ecological zone approximately 550 m north of Harevavo village. A recent genetic study has found this taxon to be a hybrid form and thus not a valid species (Ono et al., 2016). Hybrids are not assessed under the IUCN Red List of Threatened Species and it is not considered further here.
- Hill forest on limestone is a ***Very Sensitive*** terrestrial ecosystem restricted to areas outside of the PAOI and is not expected to be adversely impacted directly or indirectly by Project activities; it is therefore not assessed in this report.
- The Wi'i Creek cave which potentially harbors a colony of IUCN Critically Endangered Bulmer's fruit bat. This site will be avoided by the Project and induced, and indirect impacts are unlikely given its remoteness from villages. Thus, the Wi'i Creek cave will not be considered further.

- Impacts to freshwater ecosystems are considered in detail in Sections 11.3 to 11.5. This chapter will only assess impacts in relation to terrestrial flora and fauna that rely on these environments.
- The PRL-15 oxbow wetlands and other oxbow lakes will be avoided during construction and are not predicted to be impacted from Project generated noise disturbance and are not expected to be adversely affected by potential induced population influx associated with Project construction to nearby communities (i.e., Poroi 1, 2 and 3) that use the wetlands (see Section 13.1.7). Thus, impacts to oxbow lakes are not assessed further.
- Impacts to marine ecosystems are considered in detail in Chapter 12. This chapter will only assess impacts in relation to terrestrial flora and fauna.

11.6.2.2 Sensitivity

Biodiversity values (i.e., ecosystems, focal sites and species) present in the study area are assigned a sensitivity ranking in Part 6 of Volume 2, where the methods used to assign sensitivity and the features relevant to biodiversity values of conservation significance are described in detail. Briefly, the sensitivity of each biodiversity value is assessed according to its inherent value and sensitivity to change. These qualities are aligned with the key concepts of 'irreplaceability' and 'vulnerability' outlined in IFC Performance Standard 6 and related guidance note (IFC, 2012b). Relevant sensitivity attributes include:

- Intrinsic worth – including the value's importance to supporting sensitive species or communities, and conservation status as applied by governments and other authorities.
- Intactness – the degree to which the biodiversity value under consideration remains unchanged by anthropogenic impact processes.
- Replacement potential – a measure of the value's abundance and distribution within and beyond the study area and biogeographic region, incorporating the potential for a representative or equivalent example to be found to replace or buffer any losses.
- Resilience – a measure of the value's ability to withstand, buffer (ecosystems and focal sites) or adapt to (species) changing conditions without affecting its intrinsic worth (e.g., a habitat's potential to support species and communities) or other sensitivity attributes (e.g., a species' conservation status, abundance or rarity).

Each attribute is assessed independently for each biodiversity value. The sensitivity rating is assigned based on the average sensitivity of a biodiversity value's attributes and the professional judgement and experience of experts. Based on this, biodiversity values are assigned one of five sensitivity rankings: ***Minimal***, ***Low***, ***Medium***, ***High***, ***Very High***.

Tables 11.40 and 11.41 summarize the guideline criteria used to assign sensitivity to ecosystems, focal sites and species. Section 7.7 summarizes the sensitivity ranking of the biodiversity values present in the study area.

11.6.2.3 Impact Magnitude

The magnitude of impacts resulting from various Project activities is defined by the amount and type of change incurred by the biodiversity value. Aspects considered in quantifying and ranking impact magnitude include:

- Severity – a measure of the intensity of impact through the scale or degree of change from existing conditions due to the impact.
- Geographic extent – the spatial extent of the impact.

- Duration – the length of time during which the impact effects persist.

The overall impact magnitude ranking is assigned based on the average magnitude across all aspects with respect to a biodiversity value.

Table 11.42 provides the guideline criteria used to determine the magnitude of impacts. These have been developed specifically for the Project and draw partly on criteria used to assess impacts to biodiversity associated with the development of other petroleum projects in Papua New Guinea (e.g., CNS, 2009 and 2015) and have been refined to heighten their relevance to the current context.

When characterizing impacts to focal sites and common or widespread species, impacts to ecosystem values (i.e., habitats) are often used as a surrogate to inform the significance of impacts to the values the ecosystems support. In addition to taxa confirmed present in the study area, this assessment considers sensitive species that have not been recorded but that may occur based on current information regarding their distribution and habitat preferences (Part 6 of Volume 2). Methods used to assess impacts on additional potentially occurring species are the same as those applied to taxa confirmed to be present.

Table 11.40 – Terrestrial Biodiversity Sensitivity Criteria for Species

Sensitivity	Conservation-listed Species*	New-to-Science, Undescribed and Restricted-range Species**
Very High	♦ IUCN CR. ♦ IUCN non-CR species whose true conservation status is likely to be equivalent to IUCN CR at the national or global scale, according to expert opinion.	A rare to very rare species known only from the study area, with highly specialized habitat requirements and low dispersal potential (flora).
High	♦ IUCN VU and EN. ♦ IUCN non-Threatened (DD, NT, NE or LC) species whose true conservation status is likely to be equivalent to IUCN VU or EN at the national or global scale, according to expert opinion.	An uncommon to rare species known only from the study area, with specialized habitat requirements and low to moderate dispersal potential (flora).
Medium	♦ Protected under the Fauna Act. ♦ CITES Appendix I. ♦ IUCN NT. ♦ IUCN DD, NE or LC species whose true conservation status is likely to be equivalent to IUCN NT at the national or global scale, according to expert opinion.	An uncommon species, restricted-range or known only from the study area, with moderately specialized habitat requirements and moderate dispersal potential (flora).
Low	♦ CITES Appendix II. ♦ IUCN LC. ♦ IUCN DD or NE species considered to be common and/or widespread according to expert opinion.	A common species known from outside the study area, with low habitat specialization and high dispersal potential (flora).
Minimal	♦ Invasive species. ♦ Native species well adapted to habitat loss or degradation.	An undescribed species common or widespread beyond the study area that is not restricted range and is well adapted to habitat loss or degradation.

* IUCN = International Union for Conservation of Nature, CR = Critically Endangered, EN = Endangered, VU = Vulnerable, LC = Least Concern, NT = Not Threatened, DD = Data Deficient, NE = Not Evaluated.
** Adapted from a numeric score-based approach developed specifically for the Project and described in detail in Part 6 of Volume 2.

Table 11.41 – Terrestrial Biodiversity Sensitivity Criteria for Ecosystems and Focal Sites

Score	Intrinsic Worth	Intactness	Replacement Potential	Recovery Potential
Ecosystems				
Very High	A natural ecosystem or habitat that: ♦ Supports IUCN CR or other Extremely Sensitive species. ♦ Is critical to the survival of a species or ecological community. ♦ Is a Tier 1 IFC Critical Habitat.	An ecosystem that is unmodified by human activity. Its ecological functions and species composition are unmodified, and its wilderness values are recognized.	The ecosystem is unique or very rare locally and regionally.	Recolonization by or revegetation with native species to restore ecosystem structure and function is problematic, with success unlikely.
High	A natural ecosystem that: ♦ Supports a high or regionally important concentration of IUCN Threatened or other Very Sensitive species. ♦ Supports important populations of endemic, restricted-range, migratory or congregatory species. ♦ Supports a unique species community or a high proportion of habitat-specialist species in a small area. ♦ Is a protected area or classed as Tier 2 IFC Critical Habitat.	An ecosystem that is essentially unmodified by human activity and the primary ecological functions and species composition of which are intact. Its wilderness values are recognized.	An ecosystem that is rare locally and regionally or has a moderate number of regional equivalents that have been extensively degraded with limited connectivity to comparable environments outside the Project area.	Recolonization by or revegetation with native species to restore ecosystem structure and function requires significant intervention or is only successful in a minority of cases.
Medium	A natural ecosystem that supports viable communities of native species that are largely unaltered from the original composition. Conservation-listed species may be present.	An area of natural habitat where human activity has not significantly modified the area's primary ecological functions, species composition or forest structure.	An ecosystem that has a moderate number of local and regional equivalents, with some connectivity to comparable environments outside the Project area.	Recolonization by or revegetation with native species to restore ecosystem structure and function is slow or partially successful without intervention.
Low	An ecosystem that supports viable communities of some native species, but species communities are significantly altered from the original composition. Invasive species may be present.	Converted land that retains some native vegetation cover, or natural vegetation that has been extensively or heavily degraded by human activity.	An ecosystem that is common locally and regionally, with moderately high connectivity to comparable environments outside the Project area.	Recolonization by or revegetation with native species to restore ecosystem structure and function occurs and is expected to be successful in most cases without intervention.

Table 11.41 – Terrestrial Biodiversity Sensitivity Criteria for Ecosystems and Focal Sites (cont'd)

Score	Intrinsic Worth	Intactness	Replacement Potential	Recovery Potential
Ecosystems (cont'd)				
Minimal	An ecosystem that supports few or no native species or in which invasive species are prevalent.	Areas with little or no remnant vegetation or areas that are highly degraded.	An ecosystem that is common and widespread locally, regionally and nationally, with high connectivity to comparable environments outside the Project area.	Recolonization by or revegetation with native species to restore ecosystem structure and function occurs without intervention and is expected to be successful in all cases.
Focal sites				
Very High	A local landscape feature upon which one or more IUCN CR or other Extremely Sensitive species are ecologically dependent.	Unmodified and undisturbed by human activity and has evidence of recent and frequent use.	The feature has very limited local availability and is extremely difficult to replace or relocate.	The feature is fragile and is unlikely to recover from disturbance.
High	A local landscape feature upon which one or more IUCN Threatened or other Very Sensitive species are ecologically dependent.	Unmodified and undisturbed by human activity and has evidence of recent or regular use.	The feature has a restricted regional distribution and limited local availability. The feature is difficult to replace or relocate.	The feature is relatively fragile and may not recover from disturbance.
Medium	A local landscape feature upon which multiple species or multiple individuals of one or more species (excluding not sensitive species) are ecologically dependent.	Modified by human activity and/or subject to some disturbance but has evidence of use.	The feature is not common but is widespread locally and regionally. The feature can be replaced or relocated with moderate effort.	The feature is likely to recover from disturbance over a long time.
Low	A local landscape feature that multiple species or multiple individuals of one or more species will opportunistically use.	Largely modified by human activity; may be used opportunistically.	The feature is common and widespread locally and regionally. The feature can be replaced or relocated with minimum effort.	The feature is relatively robust and will recover from disturbance in a moderate time.
Minimal	A local landscape feature that is likely to only be used by a limited number of species or a limited number of individuals of one or more species that are not sensitive or low sensitivity.	Converted or highly modified by human activity; rarely used.	The feature is common and widespread locally, regionally and nationally. Numerous replacements exist within the territory or home range of the species.	The feature is robust and will recover from disturbance in a short time.

IUCN = International Union for the Conservation of Nature, CR = Critically Endangered.

Table 11.42 – Terrestrial Biodiversity Magnitude of Impact Criteria

Magnitude	Severity	Geographic Extent	Duration
Very high	♦ Ecosystems – impact very large with respect to natural variability; greatly reduces ecosystem function or viability in the affected area. ♦ Focal sites – feature lost or no longer ecologically functional. ♦ Species – very large decline that greatly reduces the viability of the population.	Impact very widespread; affects a very high proportion (approximately 15% or more) of the value's extent or distribution in the ecological zone or study area and potentially a high proportion of its regional occurrence.	Impact very long term (more than 25 years) or potentially permanent.
High	♦ Ecosystems – impact large with respect to natural variability; reduces ecosystem function or viability in the affected area. ♦ Focal sites – a large reduction in the feature's ecological function. ♦ Species – large decline that reduces the viability of the population.	Impact widespread; affects a high proportion (up to 15%) of the value's extent or distribution in the ecological zone or study area.	Impact long term (15 to 25 years).
Medium	♦ Ecosystems – moderate impact readily detectable with respect to natural variability; limited reduction in ecosystem function or viability in the affected area. ♦ Focal sites – a moderate reduction in the feature's ecological function. ♦ Species – moderate decline with limited reduction to the viability of the population.	Impact contained to 5% or less of the value's extent or distribution in the ecological zone or study area.	Impact medium term (5 to 15 years).
Low	♦ Ecosystems – low impact marginally detectable with respect to natural variability; unlikely to affect ecosystem function or viability. ♦ Focal sites – a minor reduction in the feature's ecological function. ♦ Species – minor decline that does not threaten the viability of the local population.	Impact restricted to 1% or less of a species distribution in the ecological zone or study area.	Impact temporary or short term (2 to 5 years).
Minimal	♦ Ecosystems – very low impact not detectable with respect to natural variability. ♦ Focal sites – no measurable effect on the feature's ecological function. ♦ Species – no measurable population decline.	A highly localized impact to a value restricted to the Project footprint.	Impact very short term (less than 1 to 2 years).

11.6.2.4 Impact Significance

The interaction between the sensitivity of a value and the magnitude of impact is combined to determine the level of significance of impacts arising from Project development (see Chapter 3). Table 11.43 presents the significance assessment matrix used to determine the significance of impacts to terrestrial biodiversity values.

Table 11.43 – Terrestrial Biodiversity Significance Assessment Matrix

Magnitude of Impact	Sensitivity of Value				
	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

11.6.3 Identification of Potential Impacts

Potential impacts to terrestrial 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]. The following embedded design controls will address potential impacts to terrestrial biodiversity:

- The Project will design its plant to meet the applicable emission standards and relevant ambient air quality criteria beyond the proposed facility boundary [ED002]
- All facilities and infrastructure will be constructed with surface-water drainage systems to reduce the potential for soil loss and degradation both on and off construction areas, and to limit soil erosion and discharge of sediment-laden water to local drainage lines and watercourses. Bridges and culverts will be designed to allow for high flow events following heavy rainfall and to replicate natural flow characteristics as far as practicable. The design is:
  - To account for local rainfall conditions and catchment size of works areas.
  - To allow avoiding unseasonal waterlogging
  - To allow for rainfall events with an ARI of at least two years for temporary roads and up to 20 to 50 years for long-term major haulage routes as far as practicable [ED014].
- All vehicles and machinery (including vessels and aircraft), plant and equipment will be regularly maintained to the manufacturer's specifications; defective items will be removed from service until they are repaired [ED019]
- The flares will be used only for safety flaring in alignment with the TOTAL no routine flaring policy [ED023].
- During the first years of production when it is not possible to dispose of acid gas by injection, a sulfur recovery unit will be installed and operated at the CPF to remove sulfur-containing compounds from the acid gas after it has passed through a thermal oxidizer [ED024].
- Once the Elk reservoir has been depleted, acid gas removed from the raw gas using the AGRU will be disposed of by injecting it into the reservoir [ED025].

- The sulfur recovery unit will remain on standby, ready to operate at short notice so that acid gas can be treated if acid gas injection is not possible [ED026].
- Fixed or mobile equipment will be used and / or located in consideration of people and other sensitive receptors [ED030].
- Minimize noise from mechanical plant, as far as practicable [ED031].
- The Project will design its plant and undertake activities to comply with the applicable noise criteria [ED032].

11.6.3.1 Overview

This section describes the impact processes that may affect terrestrial biodiversity values due to Project development. They are grouped into the following categories:

- Habitat loss and fragmentation, including loss of important features and impacts from barrier effects.
- Habitat degradation, including impacts from edge effects, erosion and movement of soil and spoil, sedimentation and contamination of waterways, reduction in air quality, fire, deforestation and acid rain.
- Natural regeneration failure following vegetation clearing.
- Loss of individuals and populations.
- Mortality or injury to fauna, including vehicle strike and impacts from trenching.
- Disturbance to fauna and focal breeding and roosting sites, for example, through noise and light emissions.
- Introduction and spread of invasive alien species, including weeds, pathogens and pests.
- Indirect impacts from social and commercial aspects, including increased hunting, exploitation of forest resources and clearing of land for housing and gardens.

The various processes may impact biodiversity values directly or indirectly, where:

- Direct impacts occur due to planned Project activities, e.g., removing forest habitat to develop infrastructure during the Project construction phase.
- Indirect impacts would not have occurred without Project development but do not directly result from planned Project activities. They include:
  - Impacts due to the actions of Project personnel but that arise unintentionally and where the impact does not directly involve materials required for Project development, e.g., accidental fires caused by Project workers outside of authorized Project activities.
  - Impacts mediated by non-Project personnel, e.g., increased hunting or habitat loss due to changes in the population size or the subsistence activity patterns of local residents or changes in land use by third-party commercial developments.

11.6.3.2 Habitat Loss and Fragmentation

Habitat Loss

Habitat loss is the primary cause of global biodiversity loss (Pimm and Raven, 2000) and is recognized as a major cause of population decline for most IUCN Red Listed New Guinean flora and fauna (e.g., Leary et al., 2016; Wooley et al., 2016). The immediate consequence of

vegetation clearing for the Project is the loss of vegetation, habitat and associated terrestrial biodiversity. Factors influencing the magnitude of the impact of habitat loss include:

- The amount and type of habitat lost.
- The extent and distribution of remnant areas of similar (or better quality) habitat.
- The duration of loss and the extent to which regeneration occurs.

Associated impacts for fauna resident in development footprints is discussed in Section 11.6.3.5. Additional loss of suitable habitat from habitat degradation processes may exacerbate the impacts of habitat loss to some biodiversity values (Section 11.6.3.3).

Loss of Focal Features

Focal features, such as large trees which provide roosting, breeding, nesting, mating and food resources, are assumed to be uniformly distributed in forest ecosystems. Proportional ecosystem losses provide a useful surrogate measure to predict the loss of these features.

Numerous plant species are important to fauna, as specialist food items, and keystone food plants support a broad diversity of taxa. These species may be lost or degraded by construction and operations activities. Loss of these species may affect local populations of sensitive fauna that rely on them. In terms of conservation significant fauna present in the Project area, specialist food plants include:

- Figs (*Ficus* spp.) are widely regarded as a keystone food resource in tropical forests (Lambert & Marshall, 1991; Mackay et al., 2018) and are a prominent dietary component of sensitive bird species such as Blyth's hornbill (*Rhyticeros plicatus*), manucode birds-of-paradise (*Manucodia* and *Phonygammus* spp.), and Pesquet's parrot (*Psittrichas fulgidus*).
- Vines of the family Aristolochiaceae are the sole food source for the larvae of birdwing butterflies (*Ornithoptera* spp.), including the southern tailed birdwing (*O. meridionalis*), which feeds exclusively on the vine *Pararistolochia meridionaliana*; the paradise birdwing (*O. paradisea*), which consumes a select variety of *Pararistolochia* and *Aristolochia* food plants; and the Goliath birdwing (*O. goliath*), which feeds on the vines *A. goliathiana* and *A. crassinervia*.

Other focal features that may be lost or damaged by Project development include breeding and roosting sites, such as caves and rocky outcrops, nest mounds, nesting, lekking or roosting trees and nesting banks. Section 11.6.3.6 discusses impacts to fauna from the loss of these features.

Social drivers of change, including additional clearance by local residents (Section 11.6.3.8) may exacerbate loss or degradation of these features.

Loss of Watercourse and Wetland Habitats

Project construction will cause the loss of some small-scale watercourses, wetland habitat and hill forest pools important to the ecology of some terrestrial taxa. Large watercourses are avoided where possible but some streams in the CPF footprint will be permanently diverted and some hill forest pools will be lost to infrastructure development.

Terrestrial species dependent on these features include various frogs (e.g., *Hylarana* spp., *Litoria* spp.) and odonates (most taxa) that require forest streams and pools to reproduce, stream bank specialist flora, and microhylid frogs that may be specialist inhabitants of streamside vegetation in hill forest (*Cophixalus* sp. 3, *Oreophryne* sp. 2). Most of these species occur widely in suitable habitat and declines in their populations from the loss of these habitats and associated resources are considered to be low. Species most at risk include two new-to-science species known from

only a few individuals recorded at one or two locations; the stream bank specialist herb *Begonia* sp. 5 in the CPF footprint, and the damselfly *Teinobasis* sp. 1 recorded at a single forest pool alongside the road leading northwest from the ANT-10 wellpad.

Barrier Effects

Barrier effects occur when connectivity is lost between habitat areas thus restricting the movement of a broad range of species, limiting their access to resources and reducing their potential for survival. Roads, large forest gaps and linear clearings act as effective barriers for many mammals, forest birds, reptiles and amphibians (Laurance et al., 2004; Andrew et al., 2015; van der Ree et al., 2015). Barrier effects are typically avoided where connectivity is retained. Roads and clearings created for the Project are unlikely to effectively fragment populations and are unlikely to affect the movement or population viability of conservation significant fauna given that most species are highly vagile or known to cross anthropogenic clearings, and that forest cover throughout the PAOI will remain.

11.6.3.3 Habitat Degradation

Edge Effects

Edge effects occur when clearing vegetation changes the condition of adjacent remnant habitats. They include (Murcia, 1995):

- Abiotic effects from increased exposure of the forest edge to sun and wind, leading to changes in forest microclimate that include lighter, hotter and drier conditions.
- Direct biological effects, including changes in the presence and abundance of various species in direct response to the change in physical conditions.
- Indirect biological effects from changes in species interactions, for example, predation, competition, herbivory and seed dispersal.

Edge environments are more susceptible to desiccation and burning, and trees located in edge habitats are at a higher risk of mortality from wind throw. Edge habitats provide a suitable environment for invasive alien species to establish and may provide corridors for such species to expand their range and impacts (see Section 11.6.3.7). Local species may be outcompeted in edge habitats for space and resources leading to the loss of individuals and changes in the character and functioning of the ecosystem.

Edge effects will impact most on forest interior specialist species that are adapted to dark, humid microclimates or shaded streamside habitats, for example, some riparian plants, microhylid frogs, understory-dwelling bird species and damselflies. Where forest streams are exposed to increased sunlight, water temperature may increase, reducing the long-term breeding success of frog species requiring cool waters (e.g., Welsh & Ollivier, 1998).

Clearing for the Project will directly impact adjacent forest habitat through the creation of edge habitats and their associated effects. Few studies have investigated the influence of edge effects in New Guinean forests. Recent work in lower montane limestone forests in a high rainfall zone of Papua New Guinea have found no strong evidence for an influence of edge effects on the distribution and abundance of frogs, bats or terrestrial birds and mammals (Richards 2017; Woxvold and Legra, unpublished data). Studies in other tropical regions have shown that different components of edge effects may penetrate different distances into the forest (Laurance and Bierregaard 1997; Laurance et al. 2000, 2004). In Amazonian forests, some birds may stay 50 m away from the forest edge, microclimatic changes may be detectable at 100 m, and increased tree mortality and open-habitat invertebrates may penetrate at least 300 m. In fragmented

rainforests of north Queensland, edge effects can impact forest structure 200 m into the forest and may be detectable up to 500 m from the edge. Mammal communities in degraded edge habitats typically include fewer species than the original forest and have different community structures (Asquith and Mejia-Chang 2005). Based on this information, this assessment, precautionarily assumes edge effects penetrate 100 m into vegetation surrounding linear infrastructure and facility sites that are less than 150 m wide. For clearings more than 150 m wide, edge effects are assumed to penetrate 150 m into surrounding habitats.

Edge effects may be locally intensified by other factors, such as Project-related erosion and soil or the spread of invasive alien species. Additional clearance by local residents for housing and subsistence activities may also increase the extent of edge effects (Section 11.6.3.8).

Erosion and Movement of Soil and Spoil in Terrestrial Environments

Substrates in the PAOI, including in both hill and alluvial terrain, are highly erodible. Rock falls, landslides, flows and gullying are common geohazards, and transported sediments will also exhibit poor stability. Across much of PRL-15, the soft mudstones and siltstones of the Orubadi Beds are particularly unstable.

Ground disturbance at Project facilities and infrastructure sites located on unstable substrates, particularly during construction where vegetation clearing and earthwork activities occur, may lead to erosion and smothering of vegetation and related habitats adjacent to infrastructure footprints located in areas with poor soil stability. Soil and spoil exposure, disturbance and stockpiling may lead to erosion and the uncontrolled transfer of soil into adjacent terrestrial habitats, degrading vegetation, killing flora and potentially causing habitat loss beyond the Project footprint. Regeneration may also be inhibited due to the reduced availability of essential topsoil and the changed soil conditions for germination.

Impacts could be highest for new-to-science species known from only a few localities near the Project footprint that are precautionarily presumed to be rare. Species most at risk include the *Begonia* sp. 5 population at the edge of the CPF footprint, the riparian plant *Medinilla* sp. 1 near ANT-10, *Archidendron* sp. 1 and any unidentified *Syzgium* sp. 1 near high activity construction areas and spoil dump areas near the CPF, the IUCN Endangered timber tree *Diospyros insularis* near the Logistics Base, and *Pseuduvaria* sp. 1, *Ficus* sp. 1, *Discocalyx* sp. 1, *Syzygium* sp. 4 and the IUCN Critically Endangered timber tree *Diospyros lolinopsis* in the proposed export pipeline corridor.

Among fauna, Scheepmaker's crowned pigeon (*Goura scheepmakeri*) has a restricted distribution in its hill zone habitat, preferring the narrow strips of gentle terrain in valley floors. Uncontrolled soil deposition typically accumulates in these areas, which may result in localized losses of suitable habitat and the potential decline in IUCN Vulnerable Scheepmaker's crowned pigeon populations.

The potential impacts from soil erosion may be exacerbated when local residents clear additional forest (Section 11.6.3.8) exposing and destabilizing topsoil. The effects; however, would be localized to areas near villages.

Sedimentation of Waterways and Changes to Hydrology

Construction of Project facilities, roads and pipeline ROWs may increase sediment loads and modify hydrological patterns in some waterways. In acute cases, large influxes in sediment loads and damming or drainage of various habitats for constructing causeways and roads can alter flood regimes. Forests adapted to dry-land conditions die if flooded for even short periods.

Swamp forests and woodlands, which are adapted to permanent or periodic flooding episodes, may die if the flooding and drying dynamics change.

Impacts would be most prevalent in hill terrain and where roads and pipelines cross watercourses. Construction of the CPF is expected to increase sediment loads in the upper portions of the Oyomo Creek system and dredging of the Logistics Base may increase sediment loads in the Purari River system. Turbid plumes from dredging could extend down river into Oyomo Creek during periods of high flow in the Purari River (see Section 11.3.). Runoff from spoil disposal sites, if not engineered correctly, may also affect adjacent watercourses such as Boa Creek and Kuku Creek in hilly terrain, and Oyomo Creek tributaries on the alluvial plain near the CPF.

Terrestrial flora and fauna potentially impacted include plants growing in riparian, swamp or other environments sensitive to changes in sedimentation (including mangroves) and animals dependent on clean and clear watercourses as a source of food or for reproduction. Sediment deposition may smother stream microhabitats, such as interstitial spaces among rocks, and alter streamside vegetation. This may reduce the abundance and diversity of aquatic resources, cause the loss of some species and cause other species to relocate to tributaries with better water quality.

Influxes in sediment load and changes in hydrology may cause population declines of amphibians and odonates (Ashton et al., 2006; Luke et al., 2017), which require cool, clear forest streams to breed and complete early life stages. Other taxa, including those that hunt in clear watercourses, such as kingfishers, Salvadori's teal (*Salvadorina waigiuensis*), forest bittern (*Zonerodius heliosylus*) and the semi-aquatic new-to-science rodent *Hydromys* sp. 1, may also experience declines if their foraging ability is impeded. Crocodiles (New Guinea freshwater crocodile (*Crocodylus novaeguineae*) and estuarine crocodile (*C. porosus*)) and freshwater turtles (pig-nosed turtle (*Carettochelys insculpta*) and striped New Guinea soft-shelled turtle (*Pelochelys bibroni*)) occupying the already turbid larger watercourses of the lower Purari River system will not be greatly impacted. In contrast, a significant increase in sediment loads to Oyomo Creek (see Section 11.3.5) may impact nesting behavior and reduce nesting success of IUCN Threatened freshwater turtle species if the morphology of nest banks is considerably altered (see Section 11.6.3.6).

Altered hydrological regimes may exacerbate influxes in sediment loads. Sections 11.3 to 11.5 considers impacts to freshwater ecosystems in detail.

The potential impacts of sedimentation and hydrological change may be intensified where local residents clear additional vegetation, thereby increasing the potential for erosion and runoff (Section 11.6.3.8). These impacts are expected to be greatest for waterbodies near existing communities and, to a lesser degree, along infrastructure routes such as the export pipeline access road.

Contamination of Terrestrial and Aquatic Environments

The construction, operation and decommissioning of Project facilities and infrastructure, including wells, roads and pipelines, will require the use, production and management of hazardous and non-hazardous substances and waste streams. Accidental contamination may degrade habitat and reduce species health.Section 13.6 discusses potential impacts to human health from the contamination of terrestrial and aquatic environments.

Contamination can also alter the structure and floristics of riverine vegetation by encouraging alien plant species that are suited to the altered water chemistry to establish (Richardson et al., 2007) and displace native species.

Contamination of terrestrial and aquatic habitats may impact any species. Biodiversity values most likely to be directly and indirectly impacted in the Project area include watercourses and wetlands, associated riparian habitats, and the flora and fauna that rely on these environments. Terrestrial flora and fauna likely to be impacted include plants growing in riparian or swamp environments (including mangroves); frogs requiring water for reproduction; and turtles, crocodiles, waterbirds, odonates, and forest birds and mammals that specialize in eating aquatic fauna. The most likely species to be directly impacted are rare new-to-science streambank specialist flora that occur close to planned infrastructure footprints, such as *Begonia* sp. 5, *Syzygium* sp. 1, *Medinilla* sp. 1 and *Glochidion* sp. 1.

The potential for ecosystem contamination may be elevated due to Project-induced population growth, which could be associated with an increase in the use of potential contaminants, e.g., fuels and oils for outboard motors and generators.

Reduction in Air Quality

Project development may reduce air quality due to gaseous and particulate emissions, including dust. Air quality impacts associated with gaseous emissions from Project activities comply with adopted Project criteria (Part 2 and 5 of Volume 3). As such, the greatest potential impacts to terrestrial biodiversity from air quality will likely occur from fugitive dust. Potential sources include earthworks, transporting spoil, quarrying, vehicle and equipment movement on unsealed roads, and wind erosion of exposed surfaces, e.g., soil stockpiles or disposal areas.

Dust may coat plant leaves, hindering or preventing photosynthesis and respiration, and allowing the penetration of phytotoxic gaseous pollutants. This causes decreased plant productivity and visible injury symptoms or mortality. Most forms of vegetation are affected; although, lichens and mosses are among the most susceptible (Farmer, 1993). Rain generally washes dust off vegetation; although, repeat events of dust deposition, such as those that occur along roads or near spoil disposal sites and quarries, may have long-term effects on the health and survival of individuals which may lead to changes in the structure and composition of local vegetation communities. Excessive dust circulating during dry periods may temporarily displace local fauna, and dust coating vegetation may displace invertebrates that are a food source for a variety of vertebrate fauna.

Species most likely to be affected are new-to-science flora, precautionarily presumed to be rare, that occur close to planned infrastructure footprints, such as *Begonia* sp. 5, *Archidendron* sp. 1 and *Syzygium* sp. 1 in the CPF area, *Syzygium* sp. 4 along the proposed export corridor and *Medinilla* sp. 1, and *Glochidion* sp. 1 located in the gas field. Overall, impacts will be localized to the degradation buffer outlined for edge effects and temporary given the high rainfall, low wind speeds (Part 19 of Volume 2) and dense vegetation in the area. Impacts will be higher during dry years and during construction.

Unplanned and Uncontrolled Fire

Under exceptional circumstances, Project activities may directly cause fires through sparks from machinery and equipment, from vehicles, from workers smoking and from accidental leaks of flammable gases from facilities and pipelines if ignited.

The likelihood of wildfire, including frequency and severity may be exacerbated by desiccated or weed infested forest edges which increases their flammability and provides a starting point for more extensive forest fires.

Once established, a wildfire has the capacity to degrade or destroy extensive areas of natural habitat well beyond its ignition source. Animals that fail to escape its path will be lost, and limited resources such as fruiting trees and trees with nesting hollows may be damaged or destroyed.

The potential for fire is greatest during dry years when even normally wet forests can burn. Major fires during the 1997 to 1998 El Niño event resulted in the loss of large areas of forest in Papua New Guinea[4] (Haberle et al., 2001; Johns et al., 2007; Bryan & Shearman, 2015). Recent climate modelling suggests that the rate of occurrence of 'extreme' El Niño events, such as those that occurred in 1982 to 1983 and 1997 to 1998, may double in frequency during this century (to one in every 10 years) due to climate change (Cai et al., 2014).

There is minimal evidence of previous major local fire events and such events are likely limited by the high monthly rainfall experienced by most of the Project area during most years.

Deforestation and Habitat Degradation from Logging

Commercial forestry is the largest industrial land use activity to have operated in the Project area. Approximately 1,300 km^2 of forest have been logged; and a further 3,370 km^2 of unlogged, commercially viable hill and alluvial forest remains. Most of the remaining commercially viable forest (66.9%) occurs in the Baimuru Blk 3 concession in the northern half of the Project area. Most of the primary hill and alluvial forest present in PRL-15 is included under the Baimuru Blk 3 concession.

Commercial developments may indirectly contribute to the degradation of forest environments where they influence the amount or pattern of industrial logging activity; however, Project development will not affect commercial logging. Commercial logging is expected to continue at the same rate and to move north of the Purari River, as the Baimuru Blk 3 concession is developed, including into areas of hill and alluvial forest in PRL-15. This would have occurred regardless of Project development and there is no evidence to suggest that Project activities will influence the rate or pattern of deforestation across the Project area. Chapter 17 provides discussion on the predicted cumulative impact of future logging activities.

Acid Rain

The reservoir contains sulfur, which could produce acid rain if not appropriately recovered. Acid rain occurs when sulfur dioxide and nitrogen oxides emitted into the atmosphere react with water, oxygen and other chemicals to form sulfuric and nitric acids. These then mix with water and other materials before falling to the ground. Acid rain can become a regional problem when winds carry sulfur dioxide or nitrogen oxides beyond the local source.

Ecological impacts of acid rain include:

- Acidification of aquatic environments, with associated declines in fauna health or animal mortality.
- Interference with soil chemistry and processes from acid-induced leaching of beneficial cations, interfering with plants abilities to absorb nutrients and potentially causing long-term damage to or mortality of floristic communities (Likens et al., 1996). As such impacts on soil chemistry is generally considered the most pervasive effect of acid rain on terrestrial environments.

4 Comparable losses were recorded for multiple other drought events. Much of the lowland rain forest in New Guinea burned during the droughts of 1877–1878, 1888, 1891, 1902, 1914–1915, 1940–1942, 1982–1983, and more recently in 1991 (Johns et al., 2007; Bryan & Shearman, 2015).

- Visible injury to leaves reducing photosynthetic and respiratory capacity which may in turn reduce their resilience to other environmental stressors, e.g., drought, and alter habitats.

The Project's acid gas recovery strategy is estimated to capture up to 95% of sulfur emissions and will largely negate the potential for acid rain. In the unlikely event of acid rain, direct impacts will be restricted to areas immediately surrounding the CPF and will mostly likely occur during early stages of the operational phase prior to the injection of acid gas to the Elk reservoir.

11.6.3.4 Natural Regeneration Failure

The ability of cleared areas to naturally regenerate from existing seed or parent stock, in some cases following preparatory activities and surface stabilization is compromised by factors affecting:

- Topsoil availability and condition, including the intensity of construction-related disturbance, erosion and soil compaction.
- The sensitivity of the vegetation type and associated soil disturbance.
- The level of weed infestation.

Natural regeneration is most successful when the topsoil is intact, as it contains the best physical, chemical and biological properties to promote plant growth, including a high-density soil seed bank of mostly pioneer species that are adapted to colonize disturbed sites.

Natural regeneration may be compromised on the steep slopes and unstable landforms of the Middle Purari Hills and Southeast Hills ecological zones where critical topsoil may be lost, exposing mudstone/siltstone bedrock, which provides an inhospitable substrate for natural regeneration. Mudstone bedrock typically remains bare or partly colonized by invasive grass species, such as *Paspalum conjugatum.* Sensitive vegetation types in which natural constraints to regeneration are highest include:

- Littoral forest (including scrub components) which has thin topsoil that is difficult to salvage and easily eroded.
- *Pandanus*-dominated swamp woodland which is highly sensitive to soil disturbances, changes to the natural drainage and the availability of raised mound regeneration microsites.
- Mangrove which is sensitive to sediment erosion and associated modified tidal flows.

Natural regeneration failure may also occur where excess spoil is deposited, as spoil can be an unsuitable substrate for regeneration if not appropriately managed. Under such conditions, spoil sites may become weed hotspots.

11.6.3.5 Loss of Individuals and Populations

For most taxa, the proportion of suitable habitat lost through vegetation clearing and degradation provides a suitable surrogate measure for estimating local population decline (Hardner et al., 2015). Exceptions, however, include species that depend on microhabitats or other local landscape features that are not uniformly distributed in ecosystems and locally rare species that occur at very few sites. For these species, habitat loss may have a disproportionately high impact on the loss of individuals and populations.

Section 11.6.3.8 addresses the potential loss of individuals and populations as a result of induced hunting from population influx. Any increase in the loss of individuals and populations from an increase in hunting represents an additional loss to those described in this section.

Loss of Fauna

Fauna resident in Project infrastructure footprints have limited capacity to vacate developing sites and to survive in surrounding areas of habitat, since:

- Most non-volant mammals, reptiles and amphibians are likely to seek shelter in situ during habitat clearance.
- Larger and more agile species may be able to move into surrounding areas (e.g., birds, bats, wallabies), but many such species are territorial, and displaced individuals are likely to encounter existing populations of the same species. In such situations, within-species territorial interactions are likely to favor resident animals and cause poor survivorship of immigrant individuals (Burns, 2005).

For wider-ranging, non-territorial species, vegetation clearing causes the loss of foraging, sheltering and breeding habitat, and the loss of high value local landscape features, such as large trees that provide important nesting, breeding, roosting and food resources. This may ultimately cause local population declines.

Highly and ***Very Highly*** sensitive species most vulnerable include the giant bandicoot, Scheepmaker's crowned pigeon, starry owlet-nightjar (*Aegotheles tatei*), Goodfellow's tree kangaroo (*Dendrolagus goodfellowi*), ifola (*D. notatus*), eastern long-beaked echidna (*Zaglossus bartoni*), Salvadori's teal, striated lorikeet (*Charmosyna multistriata*) and banded yellow robin (*Poecilodryas placens*) and some odonate taxa.

Vehicle Strike and Boat Strike

Vehicle strike is a major cause of mortality for some terrestrial species, particularly those that interact frequently with roads (Marsh & Jaeger, 2015). Project traffic on roads and waterways may directly kill or injure susceptible terrestrial fauna such as echidnas, dasyurids, wallabies, bandicoots, cassowaries, crowned pigeons, a suite of small vertebrate fauna and some non-volant arboreal species that may be forced to the ground to cross roads. In waterways, the IUCN Threatened pig-nosed turtle and striped New Guinea soft-shelled turtle may collide with boats.

Fauna Falling in Project Excavations

Fauna may fall into Project excavations including quarries and pipeline trenches where they may be trapped, injured, killed or unable to escape and so may perish. Potentially affected species include reptiles, frogs, non-volant mammals and cassowaries.

Loss of Flora

The loss of plant taxa is anticipated to be proportional to the loss of suitable habitat (Hardner et al., 2015). Exceptions to this include:

- Species occurring in hill or alluvial forest whose actual habitat requirements may restrict them to areas near the ‘hill-foot’ boundary, in well-drained alluvial forest environments or at the base of the foothills near the alluvial plain.
- Rare plants known in the study area from only a few individuals recorded at one or two locations in or near planned infrastructure footprints. They include:
  - Near the proposed CPF and Logistics Base: *Begonia* sp. 5, *Syzygium* sp. 1, *Archidendron* sp. 1, and *Diospyros insularis*.
  - Along the proposed export pipeline corridor: *Pseuduvaria* sp. 1, *Ficus* sp. 1, *Discocalyx* sp. 1, *Syzygium* sp. 4, and *Diospyros lolinopsis*.

– Along the proposed new and upgraded road routes and flowlines near ANT-10: *Teinobasis* sp. 1 and *Medinilla* sp. 1.

11.6.3.6 Disturbance to Fauna and Disturbance to Feeding, Breeding, Nesting and Roosting Sites

Disturbance to Fauna from Noise, Vibration and Light

Project construction, operation and decommissioning may cause noise, localized vibration and light pollution that may disturb local fauna.

The operation of vehicles, equipment and machinery, vegetation clearing, and excavation will produce noise and vibrations, and dredging and construction of the new quay at the Logistics Base will generate underwater noise. Noise and vibration disturbances may displace taxa that communicate acoustically, including birds, bats and frogs (Parris, 2015). Underwater noise may upset the behavior of and displace crocodiles and freshwater turtles; although, potential consequences to these species will be low (see Section 12.4.5).

Some facilities, e.g., the CPF and accommodation area, will be artificially lit at night. Increases in light levels due to artificial lighting may extend the activity time of diurnal animals, disorient some nocturnal animals, and attract others, making them more susceptible to predation or bringing them in to feed (Longcore & Rich, 2004; Gaston et al., 2013). Fast-flying bats congregate at lights where they benefit from the higher density of insect prey, but slow-flying bats avoid lights. This benefit-differential among taxa may affect local community structures by favoring the survival of populations that respond positively to anthropogenic influences.

Noise, vibration and light disturbance to fauna will be localized to near Project infrastructure footprints, and potential impacts to terrestrial and underwater species are generally low or very low.

Sections 15.3 and 12.4 provide a detailed assessment of the potential impacts of above ground and underwater noise.

Disturbance to Focal Breeding, Roosting, Nesting and Feeding Sites

Project activities, such as vegetation clearing and earthworks, may destroy or damage focal breeding, roosting, nesting or feeding sites that provide important habitat for a variety of fauna. Impacts may occur:

- During Project construction.
- As part of regular planned operational activities.
- If Project personnel disturb fauna at key sites as part of unauthorized activities.
- If Project induced population growth influences disturbance-related activity by local residents at these sites.

Caves and Rock Shelters

Damage to caves or rock shelters may be incurred directly from blasting or earthworks activities during construction.

Caves and other rock shelters provide important habitat for some congregatory species, including the IUCN Critically Endangered Bulmer's fruit bat and a variety of other bats and swiftlets (Chapter 7 and Part 6 of Volume 2). Physical damage to caves may cause the loss of colonies, and hunting and human disturbance may cause mortality, especially during the breeding season (Martin et al., 2000; Cardiff et al., 2009). Few caves and rock shelters are known from the study

area and noise or other disturbance from nearby construction activities is not expected to impact these features.

Threatened Freshwater Turtle and Crocodile Nesting Sites

Damage or disturbance to crocodile and freshwater turtle nesting sites can reduce breeding success. Trampling nests and changes to the topography of nest banks can make habitual sites less suitable for nesting (Moll & Moll, 2004; Georges et al., 2008a), and increased river traffic may alter behaviors and damage nests through erosion of sand banks.

River traffic from the Purari River mouth to the logistics base will increase directly from the Project's transportation needs and indirectly by the Project potentially increasing the local population size, increasing household incomes and improving access to outboard motors and fuel.

Pig-nosed turtle nesting sites occur along the banks of the main river channels and tributaries (see Part 6 of Volume 2). Another nesting site occurs at the junction of Oyomo Creek and the Purari River 100 m downstream from the proposed Logistics Base jetty which will receive regular boat traffic and where dredging may be undertaken during the life of the Project.

Pig-nosed turtles nest on exposed sand or mud banks during the dry season (September-January, though may extend to February; Georges et al. 2008a) when the water level is at its lowest. Preferred nesting beaches are of low relief and nests are typically placed less than 1 m above the water line (Georges et al. 2008b). During this period, nesting banks and nests will be sensitive to increased levels of boat wash if these reach levels where erosion of nesting banks exposes nests, or if the wash floods nests. Egg clutches that are inundated for more than a brief period do not survive (Georges et al. 2008a).

Although sedimentation and other structural changes to the river bank are naturally affected by seasonal flooding events, substantial changes in the morphology of nesting banks due to increased sediment accumulation from boat-generated wash and dredging during the nesting season may potentially reduce their suitability for nesting. Other banks upstream of the Project or along downstream tributaries may provide suitable alternative nest sites; although nest-site fidelity is not well-understood.

Migratory Shorebird, Resident Marine Coastal Bird and Freshwater Wetland Bird Feeding, Breeding and Roosting Sites

Disturbance is a recognized threat to shorebirds, coastal birds and wetland birds worldwide (Kirby et al. 1993; Rogers et al. 2006; Rosa et al. 2006). Migratory, coastal and wetland birds are most susceptible to disturbance while congregating at low tide to feed, at high tide roost sites and during the breeding season. Disturbance from river traffic, construction work and Project workers can raise shorebird energy expenditure by restricting access to foraging areas and reducing food intake and enhancing predation risk (Fitzpatrick & Bouchez, 1998; Peters & Otis, 2007). Shorebirds are particularly vulnerable to disturbance as they have high energy demands (Finn, 2007).

Barge traffic is predicted to be audible to some villages along the transport route (see Chapter 15) and will therefore also have the potential to disturb these birds along the 65 km shorefront of the lower Purari delta in the Mangrove ecological zone and nearby wetland habitats, particularly along the tidal wetlands and extensive mud and sand bars that flank the distributary outlets (see Part 6 of Volume 2), during September to May.

Megapode Nest Mounds, Large Trees with Nesting Birds and Birds-of-paradise Display Trees

Damage or disturbance, e.g., from noise, vibration and edge effects, from Project activities to megapode nest mounds or to large trees with nests of Pesquet's parrot, hornbills or raptors may cause nest failure and cause birds to abandon habitual nesting sites. Similar disturbance to birds-of-paradise display sites, notably those of the Raggiana bird-of-paradise (*Paradisaea raggiana*), may interrupt reproductive behaviors. Sustained disturbance may cause birds to abandon a habitual display site and relocate, potentially missing a critical period in the annual breeding cycle. Consecutive missed breeding cycles may cause a decline in the local population.

11.6.3.7 Introduction and Spread of Invasive Alien Species and Pathogens

The Project may directly introduce new or contribute to the spread of existing invasive alien species when importing and transporting personnel, materials, equipment or machinery. The risk of introduction and spread of alien species from Project activities will be greatest during peak mobilization periods of equipment and personnel during construction. Potential impacts from invasive or alien species may intensify as populations become more firmly established during subsequent Project phases and are likely to persist beyond decommissioning.

Invasive alien species may predate upon, compete with, or displace native taxa and may introduce novel pathogens that have the potential to cause material declines in populations for local native flora and fauna. Areas of environmental disturbance provide optimal establishment sites for most weeds and pests (Sakai et al., 2001). Weeds, alien rodents, cane toads, snails and ants are all readily transported unwittingly over large distances with freight and building materials or with any other items that have been stored in areas with open access. Baseline studies show, except for feral pigs, that alien species are largely absent from intact natural environments in the Project area, including extensive areas of relatively remote and little-disturbed forest present in PRL-15 (Volume 2, Part 6). Once established, eradicating invasive species can be challenging depending on the ecology of the species, labor and time intensive, and may cause unexpected changes to other ecosystem components (Zavaleta et al., 2001).

Weeds, pests and diseases can permanently alter ecosystems, which makes introducing or spreading invasive alien species one of the most important impact processes to manage to sustain the long-term ecological health of the Project area.

The potential for introducing and spreading invasive alien species may be intensified through induced population growth, which may drive increased clearing, natural habitat disturbance and the creation of suitable habitat for weed establishment, and through increased human traffic along roads and ROWs, which will increase the potential to spread invasive alien species.

Weeds

Most weed species persist only in disturbed environments and cannot invade undisturbed forest or other intact native vegetation types where native species outcompete them. Weeds of highest concern include Priority 1[5] species with the potential to invade natural habitats (Section 7.7.6.6).

Potential impacts include the loss of biodiversity from natural habitats and the failure of native vegetation to regenerate on rehabilitation sites. Construction activities can create large areas of disturbance that provide ideal sites for weed species to establish, especially sites where complete vegetation removal has exposed topsoil or where topsoil is stockpiled.

5 Priority 1 species are species which can persist in unmodified native ecosystems, have the potential to cause ecosystem degradation by displacing native species or negatively impact on regeneration or rehabilitation measures.

Priority 1 weed species present in the study area with the potential to degrade terrestrial environments include:

- Bamboo daka readily outcompetes native flora and can invade both disturbed and primary forest. It can replace native vegetation with single species stands in extreme cases, reduce floral species diversity and degrade ecosystem diversity by simplifying vegetation structure. It typically establishes in forest gaps, on landslides, on freshly deposited sediments along watercourses, and along forest edges and road margins. It can persist in the soil seedbank for many years and can regenerate in response to a variety of natural or anthropogenic disturbance events. It is common along disturbed road margins and is present around Project facilities, including Herd Base, Wabo Camp and the Purari Airstrip.
- Mile-a-minute vine is a major threat to disturbed freshwater swamp vegetation and forested sites that are subject to prolonged inundation, causing forest dieback. Under favorable conditions, it smothers small to medium trees. In the Project area, it is known from along roads, the Purari Airstrip, undisturbed swamp grassland and coastal villages.
- African tulip tree can invade disturbed forest environments where it can become a dominant canopy tree species and persist for decades (Bito, 2007). In the Project area, it was recorded only near Muro Mission.
- Angelonia was planted as an ornamental at Herd Base by a previous operator and has been introduced to and has subsequently spread widely across some Project wellpads.
- Coconut palm is a commercial cultivar that has established in undisturbed mangroves in Orokolo Bay where it degrades the mangrove forest structure.

Infrastructure development, particularly roads, which provide disturbance suitable corridors for weed spread, establishment and growth, has facilitated weed invasion and establishment across the Project area.

Section 11.5.5.5 assesses potential weed impacts on riverine and wetland environments.

Rodents

Alien rodents, particularly *Rattus* species, are a potentially serious threat. The Pacific rat (*Rattus exulans*) and black rat (*R. rattus*) are patchily widespread in anthropogenic habitats in the Project area (Chapter 7). Neither is particularly invasive of natural habitats in New Guinea; although the black rat is capable of establishing in a variety of contexts, including areas with disturbed and weedy vegetation, and around human habitation. Interactions between alien rodents and native species are most likely to occur in degraded habitats such as forest edges where they may predate native fauna and transfer novel pathogens to native mammals. Black rats are known to be reservoirs and vectors for at least 60 zoonotic diseases (Weber, 1982); their introduction to other ecosystems has led to the native species decline or extinction from the spread of diseases (Ganzhorn, 2003; Wyatt et al., 2008). ***Very Sensitive*** native rodents, such as *Hydromys* sp. 1, *Pseudohydromys* sp. 1 and *Xeromys myoides*, are likely to be vulnerable to black rat expansion in the Project area.

Other Mammals

Local residents throughout the PAOI keep dogs (*Canis familiaris*) as pets, and residents in the area report that feral populations roam in PRL-15 north of the Purari River and towards the coast near Muro Mission where they may predate on native fauna. Domestic cats (*Felis catus*) are not well suited to feral existence in New Guinean rainforest environments. No evidence of feral cat populations was reported during baseline surveys (Part 6 of Volume 2); although, domestic cats

may predate native species where they interact in villages. Dog and cat-induced population declines in native species are likely to be very localized to these areas.

Cane Toads

The cane toad is widespread but patchily distributed in anthropogenic habitats across the study area. It is not well suited to rainforest habitats but spreads rapidly through open and disturbed areas; they disperse well with human transport (e.g., boats, vehicles, crates and other containers) and can move along roads, including those through forest, to colonize new areas. Once established, they are almost impossible to eradicate (Australian Government, 2010). Cane toads produce a powerful toxin that is fatal to some individuals when consumed; it is present in the eggs, larvae and adults. Lizards, snakes, crocodiles, dasyurid marsupials and omnivorous bandicoots that prey on frogs are particularly susceptible to poisoning particularly where they overlap with cane toads in open or forest-edge environments (Shine, 2010). They are implicated in major population declines of multiple taxa in Australia, and Woolley et al. (2016) identified toads as a potential threat to the survival of quolls in New Guinea.

Invertebrates

A severe infestation of the giant East African snail (*Lissachatina fulica*) is present in the Southeast Coast ecological zone south of the Muro River. It is one of the world's largest and most damaging land snail pests. It can cause extensive destruction and loss of vegetation, is a vector of plant pathogens and can compete intensely with native species. Local residents to the Muro River indicated that it recently spread to the area and that the Muro River is acting as a barrier to dispersal into areas to the north. There is a serious risk that it will pass this barrier and spread north into the Southeast Hills and Delta Swamps and Plains ecological zones. It moves readily with agricultural products, equipment, cargo and plant or soil matter. Should pipeline construction require a temporary bridge crossing at the Muro River, it would facilitate its spread, and there is also the potential for it to move into areas north of the Purari River. It is predominantly an agricultural pest but was observed during baseline studies to be common in alluvial forest where it may eat native vegetation. It targets smaller plants but may include saplings of large tree species. If Project activities introduced the snail to new ecological zones, the snail could cause widespread damage to vegetation, particularly seedlings, and alter vegetation communities. It would be most common in forest edges and forest degraded by logging or other relevant processes. Rare plant species in these environments may be lost or their health reduced.

Alien ant species pose a threat to local fauna. The yellow crazy ant (*Anoplolepis gracilipes*) and the little fire ant (*Wasmannia auropunctata*) are potentially the most destructive. Although they were not detected in the study area during baseline studies, both species are established in New Guinea and their introduction from the transport of equipment and materials from outside the Project area presents a potential threat. The yellow crazy ant is listed among the world's 100 worst invasive species; it has invaded and degraded native ecosystems in numerous islands across the Pacific and Indian oceans. Both species may occur locally in open or highly degraded habitats; while they do occupy some drier natural forest environments, they are not known to infest intact wet rainforest habitats (ISSG, 2019). Yellow crazy ants prey on or interfere in the reproduction of a variety of arthropods, reptiles, birds and mammals on the forest floor and canopy. High densities have the potential to devastate native keystone species, causing a rapid alteration of ecosystem processes (ISSG, 2019). Ants are readily transported unintentionally over large distances with freight and building materials, or with any other items that have been stored in areas with open access. Incursions are most likely to occur where such items are received or stored. Preventing the introduction of invasive ants, and the introduction of other new invasive species is required to successfully manage potential Project impacts.

11.6.3.8 Impacts to Terrestrial Biodiversity from Induced Changes to the Livelihoods and Subsistence Activity Patterns and from Population Influx

Terrestrial biodiversity values may be impacted from induced changes in social conditions and subsequent changes to economic and livelihood activities beyond the control of the Project. In some instances, this may exacerbate impacts discussed in Sections 11.6.3.2 to 11.6.3.7. Most people living in the PAOI live a subsistence-based lifestyle. They rely heavily on local natural resources to grow food and meet household nutritional requirements, to provide building materials and medicines, to transport materials (e.g., canoe trees) and as a source of income (Chapter 9).

Project-induced changes in population size and associated changes in livelihoods and subsistence activities may reduce local biodiversity values. In-migration is expected to be greatest during construction around the Pawaian villages in PRL-15 (e.g., Wabo, Ura and Wabo Station) due to the perceived potential for economic opportunities from employment and access to Project financial benefits but is also expected to occur, albeit to a lesser degree, in villages towards the coast and at Orokolo Bay. Population influx is expected to be otherwise low across the PAOI (Chapter 13); thus, potential declines in species populations, except for hunting-sensitive fauna, and habitat degradation will be commensurate with this.

Multiple factors influence the degree to which local residents use local biodiversity values including household incomes, accessibility to natural resources (e.g., forest areas), accessibility to markets, and the availability of alternative sources of supply (e.g., building materials and processed foods) (Chapter 13).

Project development may induce:

- An increase in the sale of natural resources, garden produce and cash crops from a boost to the local cash economy, including increases of household incomes.
- Improved access to natural resources and to the markets at which those resources can be sold.
- Opportunities to supplement subsistence-based food sources with processed foods from an increase in the range and availability of processed foods.
- An increase in the availability of imported building materials, such as roofing iron.

The relationships between these factors are complex, and the overall impacts are difficult to predict, e.g., an increase in the average household income and in access to supplementary food sources, and a reduction in the time available to locally resident Project workers for subsistence activities (Section 13.4), may reduce the overall reliance on natural resources in many resident households and reduce pressures on terrestrial biodiversity. In contrast, an increase in the availability of processed foods may reduce the time required to grow foods for household consumption and release time for harvesting natural resources that may be sold or traded. Moreover, an increase in the availability of commodities such as fuel, outboard motors, vehicles and firearms, may increase the harvesting rate of some plants and animals that fetch a high price in local or regional markets.

For this assessment, the following are considered likely:

- Increased hunting.
- Increased forest resource use.
- Increased land clearing for dwellings and gardens.

Change in the Level of Hunting

Hunting is a major contributor to the rarity and decline of larger animals in Papua New Guinea (Papua New Guinea Department of Conservation, 2014). Large areas of forest remain intact across much of Papua New Guinea, as such, hunting pressure (rather than forest loss) is listed as a major threat contributing to the conservation status of almost all IUCN Threatened non-volant vertebrates considered in the assessment. Hunting-sensitive species of conservation significance include long-beaked echidnas, tree kangaroos, wallabies, giant bandicoot, Bulmer's fruit bat, southern cassowary (*Casuarius casuarius*), Scheepmaker's crowned pigeon, Papuan eagle (*Harpyopsis novaeguineae*), Pesquet's parrot, Blyth's hornbill, freshwater turtles, and multiple other large parrots, pigeons, birds-of-paradise, raptors and possums (e.g., George, 1978; Kocher Schmid, 1993; King and Nijboer, 1994; Flannery, 1995). Hunting has reduced the populations of many of these taxa already, and many are now rare or no longer occur near villages.

Hunting becomes a more serious ecological threat when it is commercialized to serve a wider demand for meat or *bilas* (traditional decoration) in addition to subsistence purposes. Where regular access to a market is available, the speed at which target species are depleted is greatly increased (Purcell et al., 2014; Brewer et al., 2012).

Baseline levels of hunting pressure vary among species. While most large fauna are scarce near settled areas, grey dorcopsis (*Dorcopsis luctuosa*), giant bandicoot, long-beaked echidnas, tree kangaroos, southern cassowary, Blyth's hornbill, Pesquet's parrot, palm cockatoo (*Probosciger aterrimus*) and both crocodile species remain locally widespread and common in suitable habitat. In contrast, annual harvesting of pig-nosed turtle and striped New Guinea soft-shelled turtle adults and eggs, along the banks of the Purari River and its tributaries is likely unsustainable (Eisemberg et al., 2011; 2015). Scheepmaker's crowned pigeon is vulnerable to hunting pressure in its preferred primary alluvial forest habitat and remains common only in remote areas.

Hunting patterns and the importance of wildlife to local communities are described in detailed in Part 18 of Volume 2. Additional information on the hunting of particular species is provided in Part 6 of Volume 2 (including Annexes 2, 4 and 5).

Hunting pressure on local wildlife may increase from the following factors:

- Induced access to local forest environments, which were previously inaccessible or only accessible from walking tracks, from new Project roads, pipeline ROWs and facilities. This will increase foot traffic along these routes and subsequently increased wildlife encounters. The access road along the proposed export pipeline corridor will be open to public use and may permit non-Project vehicles into new forest areas.
- Induced regional access, causing readier access to potential markets for local wildlife products. A boost to the local cash-based economy, enabling fuel and outboard motors to be purchased, and the construction of the export pipeline access road will facilitate this access.
- Induced population growth increasing local wildlife exploitation.
- Induced change in the subsistence activity patterns of local residents including an increase in access to firearms.
- Increased demand for bush meat from Project staff and contractors, and from a larger local population. Customary land use rights and access to hunting grounds is exclusively vested in clans and may help moderate an increase in hunting activity driven by population influx or temporary contractors.

The loss of biodiversity from increases in hunting activity may occur during all Project stages and may continue after Project decommissioning.

Changes to Forest Resource Use

Resource harvesting is likely to increase with local population growth and improved vehicle access along the export pipeline maintenance track. The expected increase in wealth may also induce a requirement for local timber for construction (Section 13.4) and a modest improvement in housing and living conditions.

At-risk species include mangrove trees near the densely settled Orokolo Bay, which are harvested for firewood, and uncommon or rare timber trees growing along major waterways and, to a lesser degree, the proposed export pipeline corridor. Loss of individuals and associated harvesting damage will likely be localized to in-migration hot spots and is predicted to be minimal for most taxa and relevant ecosystems.

Unplanned impacts may arise if an induced increase in community wealth influences the harvesting activity of local residents, e.g., by increasing the number of small-scale sawmills.

Increased Clearing of Land for Dwellings and Gardens

Additional forest may be cleared for conversion to garden and housing to accommodate induced growth in local communities. The extent of these losses cannot be accurately predicted but are expected to be negligible relative to the available forest cover and localized to villages and, to a lesser degree, along infrastructure routes.

11.6.4 Proposed Mitigation and Management Measures

Table 11.44 describes mitigation and management measures to further reduce impacts to terrestrial biodiversity.

In addition to the measures presented in Table 11.44, additional measures relevant to mitigating and managing impacts to terrestrial biodiversity are outlined in Chapters 13, 15 and 16 and Sections 11.1, 11.3, 11.4 and 11.5. For example:

- Measures relevant to managing population influx, wealth inequality and other social factors that may indirectly reduce local biodiversity values (Chapters 13 and 16).
- Measures relevant to managing erosion, uncontrolled soil and spoil movement, waterway sedimentation and changes to hydrology (Sections 11.1, 11.3 and 11.5).
- Measures directed at minimizing river bank scour from boat wash (Section 11.3).
- Measures relevant to managing potential impacts from hazardous and non-hazardous materials (Sections 11.2, 11.4, 11.5 and 12.2).
- Measures relevant to managing potential impacts from air emissions and acid rain (Sections 15.1 and 15.5).
- Measures relevant to managing potential impacts from light and noise (Sections 13.8, 15.3 and 15.4).

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans

Potential Impact	Mitigation Strategy	Relevant Management Plan
Habitat Loss and Fragmentation		
Habitat loss	♦ All sites proposed for development as part of the Project will be subject to a preconstruction survey to clearly identify acid sulfate soils, sensitive sites and habitats, e.g. roosting, breeding, nesting and threatened species sites, priority ecosystem services, archaeological sites, burial sites, sites of religious importance to be subject to specific mitigation measures [EM001]. ♦ Maintain a minimum practical distance from sensitive features to minimize potential degradation and disturbance. Buffer distances shall be ecologically relevant, considering: – Sensitive habitats, i.e. primary alluvial forest, mangroves, riparian vegetation along forest streams. – Habitats that provides focal breeding, roosting or feeding sites for sensitive fauna, e.g. caves, rock shelters, rock outcrops, large trees with hollows, large trees with nests, bird-of-paradise display trees, forest pools, large fig trees (Ficus spp.) and vines of the family Aristolochiaceae. – Sites that support populations of IUCN Threatened or rare and localized plant species [EM024].	Biodiversity Action Plan
Forest dieback from flooding	No additional mitigation measures are proposed.	NA
Habitat Degradation		
Forest degradation and destruction	♦ Progressively clear vegetation and rehabilitate cleared areas as soon as practicable to minimize the time cleared areas are exposed; and allow fauna to move away from areas to be cleared, where practicable [EM002]. ♦ Minimize damage to habitat surrounding planned footprints by safely felling trees into planned footprints or into less environmentally sensitive natural spaces between standing trees [EM025]. ♦ Actively or passively rehabilitating bare sites as soon as possible to promote a stable self-sustaining landscape, e.g.: – Allow forest edges to naturally regenerate or create appropriate conditions to facilitate natural regeneration, e.g. rip the substrate, replace topsoil, apply mulch – Rehabilitate Pandanus habitats, e.g. recreate mounds, re-instate the intertidal surface between Pandanus mounds – Rip compact surfaces across the slope, as appropriate, to facilitate revegetation and minimize erosion. – Spread stockpiled topsoil, organic matter and cleared vegetation over the rehabilitation area to promote natural regeneration.	Biodiversity Action Plan; Site Restoration and Rehabilitation Plan

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Habitat Degradation (cont'd)		
Forest degradation and destruction (cont'd)	– Use native vegetation to revegetate sites when active rehabilitation measures are required. [EM029]. ♦ Implement dust control, where required [EM041].	See above
Unplanned, uncontrolled fire	♦ 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]. ♦ Avoid burning cleared vegetation, wherever practicable [EM026]. ♦ Project personnel, workers, contractors or third-party operators, while engaged in Project activities, will be prohibited: – To light and use fire except for specific work requirements controlled under the 'Hot Works' permit procedure and in designated smoking areas. – To hunt, fish, collect or disturb forest or wildlife resources. – To possess hunting or fishing equipment, including firearms, bow and arrows, spears, rubber guns, slingshots and other hunting tools. – To keep pets or to purchase, acquire or possess any wildlife or wildlife products [EM027] ♦ All Project personnel, workers, contractors and third-party 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].	Biodiversity Action Plan; Emergency Response Plan
Contamination and degradation of wetland habitat	♦ Water from trenches will be discharged in accordance with applicable water quality standards with erosion and sediment controls where relevant [EM011].	Biodiversity Action Plan; Water Management Plan

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Habitat Degradation (cont'd)		
Contamination and degradation of wetland habitat (cont'd)	♦ Maintain buffer zones between permanent surface water and project infrastructure, except to carry out works associated with the construction of watercourse crossing or where facilities are proposed to be located within that buffer [EM012]. ♦ Dispose of excess spoil material from Project earthworks in designated spoil disposal sites [EM030]. ♦ Minimize erosion and sediment runoff (see Sections 11.2.4, 11.3.4, 11.5.4).	See above
Natural Regeneration Failure		
Natural regeneration failure	♦ Progressively clear vegetation and rehabilitate cleared areas as soon as practicable to minimize the time cleared areas are exposed; and allow fauna to move away from areas to be cleared, where practicable [EM002]. ♦ Cut trees where practicable to retain the rootstock and maintain soil stability [EM003]. ♦ Stabilize spoil stockpiles and areas of ground disturbance as soon as practicable after initial disturbance using, e.g., mulched vegetation, aggregates and soil binders [EM005]. ♦ Backfill trenches as soon as practicable after disturbance, using material originally excavated from the trench as much as possible. The backfilled trenches should not exceed the preconstruction levels after the material has settled [EM009]. ♦ 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]. ♦ Actively or passively rehabilitating bare sites as soon as possible to promote a stable self-sustaining landscape. e.g.: – Allow forest edges to naturally regenerate or create appropriate conditions to facilitate natural regeneration, e.g. rip the substrate, replace topsoil, apply mulch – Rehabilitate Pandanus habitats, e.g. recreate mounds, re-instate the intertidal surface between Pandanus mounds – Rip compact surfaces across the slope, as appropriate, to facilitate revegetation and minimize erosion.	Invasive Species, Pests and Pathogen Management Plan; Site Restoration and Rehabilitation Plan

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Natural Regeneration Failure (cont'd)		
Natural regeneration failure (cont'd)	– Spread stockpiled topsoil, organic matter and cleared vegetation over the rehabilitation area to promote natural regeneration. – Use native vegetation to revegetate sites when active rehabilitation measures are required [EM029]. ♦ Dispose of excess spoil material from Project earthworks in designated spoil disposal sites [EM030].	See above
Weed establishment in rehabilitation areas	♦ 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].	Invasive Species, Pests and Pathogen Management Plan
Loss of Individuals and Populations		
Loss of individuals or populations of forest flora and fauna from Project activities and hunting by Project workers	♦ All sites proposed for development as part of the Project will be subject to a preconstruction survey to clearly identify acid sulfate soils, sensitive sites and habitats, e.g., roosting, breeding, nesting and threatened species sites, priority ecosystem services, archaeological sites, burial sites, sites of religious importance to be subject to specific mitigation measures [EM001]. ♦ Progressively clear vegetation and rehabilitate cleared areas as soon as practicable to minimize the time cleared areas are exposed; and allow fauna to move away from areas to be cleared, where practicable [EM002]. ♦ Project personnel, workers, contractors or third-party operators, while engaged in Project activities, will be prohibited: – to light and use fire except for specific work requirements controlled under the 'Hot Works' permit procedure and in designated smoking areas. – to hunt, fish, collect or disturb forest or wildlife resources. – to possess hunting or fishing equipment, including firearms, bow and arrows, spears, rubber guns, slingshots and other hunting tools. – to keep pets or to purchase, acquire or possess any wildlife or wildlife products [EM027].	Biodiversity Action Plan; Traffic and Transport Management Plan; Air Emissions and Greenhouse Gas Management Plan

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Loss of Individuals and Populations (cont'd)		
Loss of individuals or populations of forest flora and fauna from Project activities and hunting by Project workers (cont'd)	♦ All Project personnel, workers, contractors and third-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]. ♦ Use a suitably trained fauna handler to relocate fauna, where practicable, before vegetation clearing [EM031]. ♦ When a significant impact remains on IUCN Threatened species or rare and localized plant species, translocation and propagation shall be considered when ecologically feasible [EM032]. ♦ Develop Traffic and Transport Management controls that include: – Posting speed limits on Project roads via posted speed limit signs. – Requiring vehicles to keep to posted speed limits – Keeping vehicles and mobile machinery to marked trafficable areas and work sites [EM033]. ♦ Implement dust control, where required [EM041]. ♦ See mitigations for Habitat Loss and Fragmentation, Impacts to Terrestrial Biodiversity from Induced Changes to the Livelihoods and Subsistence Activity Patterns and from Population Influx.	See above
Reduction in the viability of populations of forest flora and fauna	♦ See mitigations for Habitat Loss and Fragmentation and Habitat Degradation.	Biodiversity Action Plan
Loss of specialist feeding plants	♦ All sites proposed for development as part of the Project will be subject to a preconstruction survey to clearly identify acid sulfate soils, sensitive sites and habitats, e.g., roosting, breeding, nesting and threatened species sites, priority ecosystem services, archaeological sites, burial sites, sites of religious importance to be subject to specific mitigation measures [EM001]. ♦ Maintain a minimum practical distance from sensitive features to minimize potential degradation and disturbance. Buffer distances shall be ecologically relevant, considering: – Sensitive habitats, i.e. primary alluvial forest, mangroves, riparian vegetation along forest streams.	Biodiversity Action Plan

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Loss of Individuals and Populations (cont'd)		
Loss of specialist feeding plants (cont'd)	– Habitats that provides focal breeding, roosting or feeding sites for sensitive fauna, e.g. caves, rock shelters, rock outcrops, large trees with hollows, large trees with nests, bird-of-paradise display trees, forest pools, large fig trees (Ficus spp.) and vines of the family Aristolochiaceae. – Sites that support populations of IUCN Threatened or rare and localized plant species [EM024].	See above
Reduction in adult populations of IUCN Threatened freshwater turtles	♦ Implement lower speeds past aquatic fauna when observed in the water [EM022]. ♦ Maintain a minimum practical distance from sensitive features to minimize potential degradation and disturbance. Buffer distances shall be ecologically relevant, considering: – Sensitive habitats, i.e. primary alluvial forest, mangroves, riparian vegetation along forest streams. – Habitats that provides focal breeding, roosting or feeding sites for sensitive fauna, e.g. caves, rock shelters, rock outcrops, large trees with hollows, large trees with nests, bird-of-paradise display trees, forest pools, large fig trees (Ficus spp.) and vines of the family Aristolochiaceae. – Sites that support populations of IUCN Threatened or rare and localized plant species [EM024]. ♦ See mitigations for loss of individuals and populations of forest flora and fauna from Project activities and hunting by Project workers under the Loss of Individuals and Populations.	Biodiversity Action Plan; Traffic and Transport Management Plan
New-to-science plants with one of few known populations in or near Project footprints and regionally rare IUCN Threatened timber trees: Loss of only known plant individual (*Syzygium* sp. 1 and 4) or one or more of few known individuals	♦ See mitigations for Habitat Loss and Fragmentation and Habitat Degradation. ♦ When a significant impact remains on IUCN Threatened species or rare and localized plant species, translocation and propagation shall be considered when ecologically feasible [EM032]. ♦ Minimize in-stream and stream bank disturbance during high rainfall [EM013].	Biodiversity Action Plan
Injury to or mortality of forest fauna from vehicle strike and being trapped in trenches	♦ Backfill trenches as soon as practicable after disturbance, using material originally excavated from the trench as much as possible. The backfilled trenches should not exceed the preconstruction levels after the material has settled [EM009]. ♦ Develop traffic and transport management controls that include: – Posting speed limits on Project roads via posted speed limit signs. – Requiring vehicles to keep to posted speed limits.	Biodiversity Action Plan; Traffic and Transport Management Plan

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Loss of Individuals and Populations (cont'd)		
Injury to or mortality of forest fauna from vehicle strike and being trapped in trenches (cont'd)	– Keeping vehicles and mobile machinery to marked trafficable areas and work sites [EM033]. ♦ Install ramps, e.g. unexcavated or backfilled earth plugs, in the pipeline trench at regular intervals and at other high-risk locations to permit fauna to exit [EM034]. ♦ Visually inspect open trenches and excavations in the morning and evening and use a suitably trained fauna handler to remove trapped wildlife, where practicable [EM035].	Biodiversity Action Plan; Traffic and Transport Management Plan
Disturbance to Fauna at Feeding, Breeding, Nesting and Roosting Sites		
Damage to or loss of IUCN Threatened freshwater turtle river bank and crocodile nest sites and nest failure	♦ Maintain a minimum practical distance from sensitive features to minimize potential degradation and disturbance. Buffer distances shall be ecologically relevant, considering: – Sensitive habitats, i.e., primary alluvial forest, mangroves, riparian vegetation along forest streams. – Habitats that provides focal breeding, roosting or feeding sites for sensitive fauna, e.g., caves, rock shelters, rock outcrops, large trees with hollows, large trees with nests, bird-of-paradise display trees,, forest pools, large fig trees (Ficus spp.) and vines of the family Aristolochiaceae. – Sites that support populations of IUCN Threatened or rare and localized plant species [EM024]. ♦ Develop traffic and transport management controls that include: – Posting speed limits on Project roads via posted speed limit signs. – Requiring vehicles to keep to posted speed limits – Keeping vehicles and mobile machinery to marked trafficable areas and work sites [EM033]. ♦ Implement low speed limits through areas sensitive to vessel wash impacts [EM014]. ♦ See mitigations for the loss of individuals and populations of forest flora and fauna from Project activities and hunting by Project workers under the Loss of Individuals and Populations.	Biodiversity Action Plan; Traffic and Transport Management Plan
Loss of tree-hollow or cave roosting bats from loss of breeding or roosting sites	♦ Limit construction work, where practicable, to daytime hours [EM046]. ♦ See mitigations for Habitat Loss and Fragmentation.	Biodiversity Action Plan

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Disturbance to Fauna at Feeding, Breeding, Nesting and Roosting Sites (cont'd)		
Loss of individual migratory shorebirds, resident marine coastal birds and freshwater wetland birds and disturbance to feeding or roosting congregations and breeding sites	♦ 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
Loss of congregatory bats and birds and disturbance to feeding or roosting congregations and breeding sites	♦ Maintain a minimum practical distance from sensitive features to minimize potential degradation and disturbance. Buffer distances shall be ecologically relevant, considering: – Sensitive habitats, i.e. primary alluvial forest, mangroves, riparian vegetation along forest streams. – Habitats that provides focal breeding, roosting or feeding sites for sensitive fauna, e.g. caves, rock shelters, rock outcrops, large trees with hollows, large trees with nests, bird-of-paradise display trees, forest pools, large fig trees (Ficus spp.) and vines of the family Aristolochiaceae. – Sites that support populations of IUCN Threatened or rare and localized plant species [EM024]. ♦ Project personnel, workers, contractors or third-party operators, while engaged in Project activities, will be prohibited: – to light and use fire except for specific work requirements controlled under the 'Hot Works' permit procedure and in designated smoking areas. – to hunt, fish, collect or disturb forest or wildlife resources. – to possess hunting or fishing equipment, including firearms, bow and arrows, spears, rubber guns, slingshots and other hunting tools. – to keep pets or to purchase, acquire or possess any wildlife or wildlife products [EM027]. ♦ All Project personnel, workers, contractors and third-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].	Biodiversity Action Plan

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Disturbance to Fauna at Feeding, Breeding, Nesting and Roosting Sites (cont'd)		
Loss of congregatory bats and birds and disturbance to feeding or roosting congregations and breeding sites	♦ Avoid directly lighting areas at night and minimize fixed night lighting for safe operations, e.g., direct lighting away from the Purari Airstrip House, and the surrounding forest [EM047]. ♦ Limit construction work, where practicable, to daytime hours [EM046].	Biodiversity Action Plan
Introduction and Spread of Invasive Alien Species and Pathogens		
Introduction and spread of invasive alien pests, weeds 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].	Invasive Species, Pests and Pathogen Management Plan
Weed invasion and rapid establishment in rehabilitation areas leading to poor or failed regeneration of native forest vegetation	♦ 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]. ♦ Actively or passively rehabilitating bare sites as soon as possible to promote a stable self-sustaining landscape, e.g.: – Allow forest edges to naturally regenerate or create appropriate conditions to facilitate natural regeneration, e.g., rip the substrate, replace topsoil, apply mulch – Rehabilitate Pandanus habitats, e.g., recreate mounds, re-instate the intertidal surface between Pandanus mounds – Rip compact surfaces across the slope, as appropriate, to facilitate revegetation and minimize erosion. – Spread stockpiled topsoil, organic matter and cleared vegetation over the rehabilitation area to promote natural regeneration. – Use native vegetation to revegetate sites when active rehabilitation measures are required [EM029].	Invasive Species, Pests and Pathogen Management Plan; Site Restoration and Rehabilitation Plan

Table 11.44 – Terrestrial Biodiversity Mitigation Strategies and Management Plans (cont'd)

Potential Impact	Mitigation Strategy	Relevant Management Plan
Introduction and Spread of Invasive Alien Species and Pathogens (cont'd)		
Weed invasion and rapid establishment in rehabilitation areas leading to poor or failed regeneration of native forest vegetation	♦ Where possible, separate and stockpile cleared topsoil (with the inherent seed bank and any coarse woody debris) to use for future rehabilitation [EM036].	Invasive Species, Pests and Pathogen Management Plan; Site Restoration and Rehabilitation Plan
Impacts to Terrestrial Biodiversity from Induced Changes to the Livelihoods and Subsistence Activity Patterns and from Population Influx		
Increased hunting, forest resource use and land clearing for gardens and dwellings	♦ See Chapter 13 for management of in-migration to mitigate increased hunting pressure, forest resource use and land clearing for gardens and dwellings from population growth.	Biodiversity Action Plan; Project-induced In-migration Management Plan

NA: Not applicable.

11.6.5 Residual Impact Assessment

The following section provides the assessment of residual impacts to terrestrial biodiversity subject to the embedded design controls in Section 11.6.3 and the successful implementation of the proposed mitigation and management measures in Section 11.6.4. 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.

This assessment adopts a high-level approach to determine the overall residual significance of Project-related impacts. Although Section 11.6.3 identified and discussed individual impact processes separately, the mechanisms of change are inter-related, and their effects are accumulative such that examining each factor in isolation can lead to a misleading assessment. Thus, in this section the significance of residual impacts is considered as a combined function of all impact processes on a value.

11.6.5.1 Sensitivity of Terrestrial Biodiversity

The sensitivity of terrestrial biodiversity values discussed are characterized in this section. Part 6 of Volume 2 identifies species and ecosystem sensitivities. Those identified as ***Not Sensitive*** or ***Low Sensitivity*** (see Section 7.7.8.1), and which are rated as having ***Low*** or ***Minimal*** sensitivity based on Tables 11.40 and 11.41, are not addressed, as impacts for each of these values are deemed to be ***Medium*** or lower, and the residual impact significance rating is therefore ***Negligible*** or ***Minor***. This section focuses on values ranked ***Medium*** sensitivity (or as ***Moderately Sensitive*** as in Chapter 7) or higher which, depending on the magnitude of the impact, are predicted to result in a ***Moderate*** or greater residual impact significance.

Terrestrial Ecosystems and Protected Areas

Terrestrial ecosystem-scale values considered in this assessment are major vegetation types and protected areas.

The sensitivities of major vegetation types in the Project area are:

- ***Medium*** – primary hill forest, logged alluvial forest, riverine seral forest, swamp forest, swamp woodland and low freshwater swamp vegetation.
- ***High*** – Hill forest on limestone, primary alluvial forest and Mangrove.

The sensitivity of the Crater Mountain Wildlife Management Area is considered to be ***High*** based on its protected area status and overlaps with the northern extremities of PRL-15 (11.9 km^2). No Project facilities are present or are planned to be developed in the Wildlife Management Area and thus any impacts to this site could be induced, e.g., associated with population influx at Wabo (see Sections 11.6.3.8 and 13.1.7).

No ecosystems have a sensitivity of ***Very High***.

Most ***Medium*** sensitivity ecosystems are locally widespread. Primary hill forest covers approximately 80% of PRL-15 and most of the rest of the Middle Purari Hills ecological zone. Logged alluvial forest, swamp forest, swamp woodland and low freshwater swamp vegetation occur in all parts of the onshore Project area.

Focal Sites and Features

Focal sites and features of highest conservation significance include ***Very High*** sensitivity IUCN Threatened freshwater turtle nesting sites and crocodile nesting sites which occur along the

Purari river and tributaries. The sensitivity of cave systems is considered ***Very High*** although none were identified during baseline surveys.

The loss or degradation of these sites may disproportionately affect the activities or survivability of multiple individuals in a local population, and in some cases jeopardize the viability of local populations that use these sites.

In contrast, ***Medium*** sensitivity focal sites and features are relatively widespread in suitable ecosystems and their value to fauna is thus more localized. Features with ***Medium*** sensitivity include rock shelters (other than caves), large trees, large fig trees and hill forest pools.

Watercourses and Wetlands

Watercourses and wetland habitats in the study area provide essential resources and habitat to terrestrial taxa. These habitats are considered to have ***Medium*** sensitivity as they provide key resources to a variety of fauna, including breeding, nesting and feeding resources and they support habitat-specialist flora.

Most are in their original condition. Open canopy watercourses occur in all parts of the onshore Project area, and forest streams are widespread in hill forest and in well-drained alluvial forest at the interior rim of the Delta Swamps and Plains.

Species

Ninety-two IUCN listed and nationally Protected species have been recorded in the study area or may occur based on current knowledge of distribution and habitat preferences. Two IUCN Critically Endangered species (***High*** sensitivity) are confirmed present; the timber tree *Diospyros lolinopsis* in primary alluvial forest in the export pipeline corridor and Bulmer's fruit bat known from remains collected from immediately outside of the Project area. The IUCN Critically Endangered plant *Guioa hospita* has not been recorded but may occur in the study area.

High sensitivity conservation listed taxa recorded within the study area include:

- Eight IUCN Endangered species – the timber trees *Diospyros insularis*, *Pterocarpus indicus* and *Flindersia pimenteliana*, two tree kangaroo (*Dendrolagus*) species, giant bandicoot, far eastern curlew and pig-nosed turtle.
- Thirteen IUCN Vulnerable species.
- The IUCN Data Deficient starry owlet-nightjar.

Forty-nine new-to-science species were discovered for the first time during Project surveys; 34 plants, two small non-volant mammals, two reptiles, three frogs and eight odonates. Based on habitat associations and recorded distribution and abundance, one new-to-science species is ranked as ***Very High*** sensitivity; the terrestrial herb *Begonia* sp. 5, currently known only from a few individuals at two sites in and near the proposed CPF area. Another 26 new-to-science and undescribed species are ranked as ***Very High*** sensitivity.

At least 119 restricted-range species (area of occurrence less than 50,000 km^2) have been recorded or may occur in the study area, 94 of which are ranked ***Medium*** sensitivity or higher. Thirteen of these species are also conservation listed and fifty-five species are new-to-science or undescribed. Ten additional species not in these categories are ranked as ***High*** sensitivity; six plants known only from the type material collected previously from the study area, and four habitat-specialist damselflies known from outside the study area but only in neighboring regions.

Thirty-seven conservation listed, restricted-range or scientifically undescribed species are determined to have ***Low*** sensitivity (six plants, two non-volant mammals, four bats, two birds, eight reptiles,12 frogs and three damselflies).

11.6.5.2 Terrestrial Ecosystems, Protected Areas, Focal Sites and the Study Area Landscape

Terrestrial Ecosystems

The Project's construction phase will involve vegetation clearing from planned infrastructure footprint areas and will cause the loss of natural habitat. Most footprints will remain clear of vegetation for the life of the Project, but some areas will be allowed to naturally regenerate after construction.

Table 11.45 summarizes the areal extent of natural vegetation that will be lost or degraded within affected ecosystems due to clearing for the Project. The following approaches and assumptions were used to calculate affected areas:

- Degradational effects, e.g., edge effects, were precautionarily assumed to penetrate 100 m into vegetation surrounding linear infrastructure and facility sites that are less than 150 m wide, and 150 m into habitats surrounding facility clearings that are more than 150 m wide.
- Areas of vegetation previously cleared from proposed footprints and degradational buffers were identified from satellite imagery (2016) and were deducted from the areas of natural vegetation predicted to be lost or degraded due to Project development. These areas are shown for each ecosystem in Table 11.45.
- Areas mapped as natural vegetation from the Project footprint are assumed to support complete cover of natural vegetation despite the presence of small-scale disturbances in some sites.
- Predictions of vegetation loss were calculated based on the Project description presented in Chapter 4. Changes to this description are unlikely to significantly alter the predicted outcomes (less than 0.5%) or the assessment of impacts to ecosystems or the species they support, given the proportional magnitude of the remaining ecosystem areas.

Construction activities will take place predominantly in hill forest (594.8 ha of primary and logged forest to be cleared), alluvial forest (237.4 ha of primary and logged forest to be cleared) and swamp forest (65.1 ha cleared) (Table 11.45). Proportional impacts will be highest for logged alluvial forest, with 0.43% of this ecosystem lost and a further 1.74% potentially subject to edge effects and other Project-related degradational processes described in Section 11.6.3.3. Less than 0.75% of the study area's primary hill forest will be lost (less than 0.19%) or degraded (0.54%) and less than 0.5% of high value primary alluvial forest will be lost (0.13%) or degraded (0.32%). Approximately 0.38% of swamp forest will be lost or degraded. Other terrestrial ecosystems will either not be directly affected or will have less than 10 ha cleared. For all terrestrial ecosystems, the magnitude of direct impacts from vegetation clearing and associated edge effects will therefore be ***Minimal*** or ***Low***.

The magnitude of other impact processes is more difficult to quantify. The most widespread potential impacts are associated with increased levels of hunting potentially affecting faunal community composition, increased fire risk during dry years, and the establishment and spread of invasive species. There is a higher potential impact from processes such as wildfire and the spread of invasive species in already degraded logged forest environments. The potential magnitude of these impacts will be limited by a combination of environmental, social and Project controls.

Table 11.45 –Terrestrial Ecosystems Cleared and Degraded by Project Construction*

Ecosystem**	Sensitivity	Ecosystem Area (ha)	Footprint				Degradation Buffer				Total Affected Area
			Total Area (ha) †	Existing Clearance (ha)	Project Clearance (ha)	% Cleared by the Project	Total Area (ha)	Existing Clearance (ha)	Project Degradation (ha)	% Degraded by the Project	
Primary hill forest (H)	Medium	250,983	555	67	488	0.19	1,405	39	1,366	0.54	1,854
Logged hill forest (H)	Low	89,996	21	2	20	0.02	120	2	118	0.13	138
Primary alluvial forest (P)	High	85,001	107	0	107	0.13	271	<1	271	0.32	378
Logged alluvial forest (P)	Medium	30,340	156	25	131	0.43	532	5	527	1.74	658
Riverine seral forest (Fri)	Medium	853	0	0	0	0.00	0	0	0	0.00	0
Swamp forest (Fsw)	Medium	111,460	65	<1	65	0.06	358	2	356	0.32	421
Swamp woodland (Wsw)	Medium	60,286	8	0	8	0.01	45	<1	45	0.07	53
Low freshwater swamp vegetation (Hsw, Gsw, Gri)	Medium	7,497	1	0	1	<0.01	7	0	7	0.09	8
Mangrove (M)	High	60,363	<1	0	<1	<0.01	1	0	1	0.00	2
Littoral forest (B)	Low	178	0	0	0	0.00	0	0	0	0.00	0

*The areas calculated do not consider regeneration of some areas.
** The descriptive terms presented here are accompanied by their PNG Forest Inventory Mapping System (FIMS) code. They appear without the FIMS code in the text.
†The total footprint area varies from the Project disturbance footprint presented in Table 4.15 due to the exclusion of non-vegetated areas (i.e., dams), alignment of the various geospatial layers and refinements in the Project design subsequent to the calculations of habitat loss and degradation.

The magnitude of residual impacts to terrestrial ecosystems, both in terms of individual mechanisms of change and their aggregated effects, will be ***Low*** or ***Minimal*** in all cases provided the mitigation measures outlined in Section 11.6.4, are successfully implemented.

The resulting impact significance will be ***Negligible*** or ***Minor*** for most ecosystems, though with a ***Moderate*** residual impact to ***High*** sensitivity primary alluvial forest.

Protected Areas

No vegetation will be cleared for Project development from the Crater Mountain Wildlife Management Area. Population influx in Pawaian villages such as Wabo (see Section 11.6.3.8) may generate induced impacts such as hunting and localized small-scale vegetation clearing for dwellings and gardens, but they are not anticipated to have any significant impact on the Wildlife Management Area or biodiversity therein. The overall impact magnitude to this ***High*** sensitivity protected area will be ***Minimal*** resulting in a ***Minor*** residual impact significance.

Focal Sites

Caves and other rock shelters may harbor breeding or roosting colonies of congregatory bat or bird species. The main potential threat to these features, should they be identified, will arise from the direct impacts from the Project to these sites. Their avoidance, where practicable, of any caves and rock shelters following preconstruction surveys, and the prevention of hunting and disturbance of focal sites by the Project workers will reduce the impact magnitude to ***Minimal***. This will result in a ***Negligible*** residual impact significance to ***Medium*** sensitivity sites (rock shelters) and a ***Minor*** residual impact significance for ***High*** sensitivity cave sites.

Large trees, large fig trees and forest pools are of ***Medium*** sensitivity and assumed to be uniformly distributed in forest ecosystems. Proportional ecosystem losses are a useful surrogate measure for assessing potential impacts to these features. As with impacts to forest ecosystems, residual impacts to these features will be ***Low*** resulting in a ***Minor*** impact significance.

Impacts to freshwater turtle and crocodile nesting sites are considered in Section 11.6.5.3, ‘Hunting-sensitive Fauna’ and ‘Other Sensitive Fauna’, respectively.

11.6.5.3 Species

Forest-dwelling Species

Most species assessed occupy forest environments, occur widely in ecosystems with suitable forest habitat and are not targeted by hunters. In such cases, proportional losses of the ecosystems that species occupy provide a suitable surrogate measure for local population decline (Hardner et al., 2015). Most species are assessed in this manner.

Separate assessments are made for species that depend on microhabitats or other local landscape features that are not uniformly distributed in forest ecosystems, or locally rare species that occur at very few sites. These sites may support locally, regionally or internationally significant concentrations of particularly rare species. Rare species face a heightened risk when populations are located near proposed footprints. Hunting-sensitive fauna are also assessed separately.

Species Widespread in Forest Ecosystems

For species occupying hill forest, mangroves or freshwater swamp environments, suitable habitat is widespread and extends unbroken into adjacent regions. Most forest-dwelling taxa were recorded at multiple sites during Project field surveys and are expected to occur in multiple ecological zones. When species known from just one site do not display special habitat

requirements, they are assumed to occur more widely in local ecosystems. Some rare plants are precautionarily considered an exception until further information regarding their distribution and status becomes available.

Hill forest is the most widespread ecosystem in the study area. Primary hill forest occurs throughout most of the Middle Purari Hills ecological zone, while logged hill forest occurs extensively throughout the Southeast Hills ecological zone. Less than 0.75% of primary hill forest will be lost (less than 0.19%) or degraded (0.54%), resulting in a ***Low*** impact magnitude to flora and fauna relying on primary habitats and occurring predominantly in the Middle Purari Hills ecological zone.

Proportional impacts are lower in the Southeast Hills where logging has already degraded much of the habitat. The magnitude of impacts to hill forest species occupying this ecological zone and species that are tolerant of habitat disturbance will be ***Minimal***.

Residual impacts to species preferring alluvial forest will be ***Low*** as combined losses of primary and logged alluvial forest from clearing and degradational processes will be less than 0.6%. Similarly, the overall magnitude of impacts to species occupying the foothill zone, including well-drained alluvial forest and adjacent low elevation foothills, will be ***Low*** given the extensive area of suitable and remote habitat remaining nearby.

For all widespread or common plant species potentially present but not recorded during Project surveys, potential impacts are predicted to be ***Minimal*** in magnitude. Residual impacts are also ***Minimal*** for species occupying hill forest in the northern margins of the study area beyond the PAOI, including the ***Medium*** sensitivity striated lorikeet and banded yellow robin.

The residual impact significance for most taxa is ***Minor*** or ***Negligible***. A ***Moderate*** residual impact significance is predicted for ***High*** sensitivity species that will incur an impact magnitude of ***Low***. This is applicable to the primary forest plants *Bulbophyllum* sp. 1 and *Oberonia* sp. 1 present only in the Middle Purari Hills ecological zone or adjacent well-drained alluvial terrain at the northern rim of the Delta Swamps and Plains, including

Species Dependent on Forest Streams, Forest Pools and Riparian Habitats

A variety of species depend on forest streams, forest pools, stream banks or other riparian habitats. These features have a more restricted availability than intervening forest habitat but for this assessment they are assumed to be relatively uniformly distributed across the hill forest landscape and in well-drained alluvial forest along the inland rim of the Delta Swamps and Plains ecological zone.

Infrastructure footprints are designed to avoid large watercourses, but larger sites do overlap some stream sections. The southern part of the CPF footprint area overlies more than 1.6 km of a 5 to 10 m wide Oyomo Creek tributary. Streams in the proposed CPF footprint will be permanently diverted around the CPF, modifying 124.5 ha of the 2,250 ha (<6%) Oyomo Creek catchment. Permanent stream diversions are assessed as a loss of watercourse habitat.

Proportional losses of forest streams and pools are precautionarily considered to be slightly higher than those calculated for forest environments given the disposal of excess spoil in forested valleys and low-lying areas in alluvial terrain. The overall losses; however, are predicted to be well below 1 to 2% and the magnitude of impacts to the dependent species are again predicted to be ***Low*** in magnitude. The magnitude of impacts to mobile odonates found in open and disturbed environments (forest or garden clearings) will be ***Minimal***.

The residual impact significance for ***Medium*** sensitivity taxa is ***Minor*** or ***Negligible***. The residual impact significance to ***High*** sensitivity species dependent on forest streams, pools or riparian habitats is ***Moderate***. The following taxa have received a ***Moderate*** residual impact significance:

- *Cophixalus* sp. 3 – a new-to-science microhylid frog that is a specialist inhabitant of moist stream banks; it is locally widespread but was not recorded during relevant surveys conducted in adjacent catchments.
- *Oreophryne* sp. 2 – a new-to-science microhylid frog that is known from a single specimen along a stream bank near the ANT-3 base.
- Six damselfly species requiring cool clear forest streams – *Argiolestes tuberculiferus*, *Pyrrhargiolestes angulatus*, *Nososticta Smilodon*, *Rhyacocnemis* sp. 1, *Drepanosticta taurulus*, *Palaeosynthemis* sp. 1.
- Two new-to-science damselfly species recorded only at forest pools at single sites in PRL-15 – *Teinobasis* sp. 1 and *Nososticta* sp. 1.

Rare Plants with One of a Few Known Populations Near the Project Footprint

Among the most at-risk species are those rare flora and fauna with one of a few known individuals or populations recorded in or near proposed the Project footprint. A balanced but precautionary approach is taken in considering the potential impacts to these species. The potential for transplanting or propagating individuals is considered where some individuals may be lost. The residual significance of impacts may be reduced below the levels presented here if additional individuals or populations are discovered away from the Project footprint. The success of these efforts are, however, difficult to predict and cannot be presumed.

New-to-science Plants

Thirty-four plant species discovered during the Project surveys are currently known only from the PAOI. They are locally rare or are habitat-specialist plants that are known from only a few individuals recorded at one or two locations in or near the Project footprint.

The terrestrial herb *Begonia* sp. 5 is known from only five specimens in two isolated populations growing on permanently moist, shaded stream banks in foothill and well-drained alluvial forest; one along the northwest edge of the CPF footprint, the other approximately 650 m to the northwest. The CPF population may be lost without translocation or a large shift in the edge of the CPF footprint with a significant buffer. Translocation may be a viable mitigation for this ***Very High*** sensitivity species, but the impact magnitude will remain ***Medium*** given the extensive developments planned for the only known area of occurrence. This results in a ***Major*** residual impact significance.

Similar threats face *Syzygium* sp. 1 and *Archidendron* sp. 1, respectively known from just one and three specimens located in or near the CPF footprint. Translocation is challenging for these larger woody species; although propagation is readily achieved for other species of *Syzygium* (cuttings) and *Archidendron* (seeds). Additional specimens may be located during preconstruction surveys. A ***Medium*** impact magnitude to these ***High*** sensitivity species will result in a ***Moderate*** residual impact significance.

Syzygium sp. 4 is known from a single specimen located in the middle of the export pipeline route ROW. Avoiding this individual, including the preservation of a suitable habitat buffer or propagation, would limit the impact magnitude to ***Medium***, however due to the lack of certainty of avoidance and the viability of alternative mitigation (i.e., propagation), the impact magnitude is

assumed to be ***High***, for this ***High*** sensitivity species resulting in a ***Major*** residual impact significance.

Pseuduvaria sp. 1 is known from the proposed pipeline corridor and examples outside the Project area. Some plants may be avoided or transplanted to limit the direct losses. The magnitude of potential impacts to this ***High*** sensitivity species will be ***Low***, resulting in a ***Moderate*** residual impact significance. Propagation, if feasible, may be considered to replace lost individuals.

Regionally Rare IUCN Threatened Plants

Approximately 300 m east of the proposed Logistics Base footprint is the only known mainland New Guinea occurrence of the ***High*** sensitivity IUCN Endangered timber tree *Diospyros insularis*. The single known specimen will not be cleared during construction and is unlikely to be damaged by edge effects, as it stands less than 150 m from a larger natural clearing (i.e., the Purari River). Successfully avoiding the tree would reduce the impact to ***Low*** magnitude, resulting in a ***Moderate*** residual impact significance. Propagation, if feasible, may be considered to increase the population.

A population of the IUCN Critically Endangered timber tree *Diospyros lolinopsis* occurs in primary alluvial forest in the middle of the proposed export pipeline route. This is the only known site for this species in New Guinea's southern watershed. The potential loss of multiple clustered individuals for the proposed export corridor or impact to potentially remaining nearby stands from degradational processes, will lead to a ***High*** magnitude impact to this ***Very High*** sensitivity species resulting in a ***Major*** residual impact significance. Propagation, if feasible, may be considered to increase the population and reduce the impact magnitude.

Hunting-sensitive Fauna

For species that hunters specifically target, any increase in hunting activity due to Project-induced population influx represents an impact additional to that incurred from other mechanisms of change. The assessment of hunting-sensitive fauna considers the aggregate impact of both impacts as a direct impact of the Project and those incurred from indirect interactions with the Project, including induced impacts of population growth.

The residual impact significance for population influx is assessed as ***Minor*** for coastal regions and ***Moderate*** for villages in PRL-15. Hunting due to population influx is expected to be localized to forests surrounding villages and along access routes and is not expected to penetrate remote forest areas.

Species that are often captured but remain locally common, such as bandicoots (*Echymipera* sp.) and mound-building birds (Megapodiidae), or that may be inadvertently captured by dogs or snares, e.g., dasyurid marsupials, are not considered to be hunting-sensitive; they are assessed as widespread forest species.

The following sections discuss species currently targeted by hunters including a variety of IUCN Threatened and Near Threatened bird and mammal species, and the potential residual impacts to their populations should any potential hunting increase not be managed.

Terrestrial Species Present in the Project Area

A variety of mid-size to large-bodied birds and mammals that are specifically targeted by hunters occupy forest environments in the Project area:

- The grey *Dorcopsis*, southern cassowary, Papuan eagle and Pesquet's parrot occupy hill forest and alluvial forest in most ecological zones.

- Scheepmaker's crowned pigeon prefers primary forest on alluvial terrain, on the Delta Swamps and Plains and along watercourses in the Middle Purari Hills and Southeast Hills.
- The lowland tree kangaroo is present at low densities in hill forest in the Middle Purari Hills ecological zone, including in PRL-15.
- The giant bandicoot is provisionally considered present in alluvial and low elevation hill forest along the southern half of export pipeline corridor.

The impact magnitude for widespread and mobile species that are known to be common in the PAOI, such as the grey *Dorcopsis*, or for which there is no evidence of intensive hunting in the study area, for example Papuan eagle and Pesquet's parrot will be ***Minimal***. The residual impact significance to these ***High*** sensitivity species will be ***Minor***.

For species with low population densities, the loss of just a few individuals may have a disproportionate impact on their local population. Impacts to these species, although rarely encountered, will be ***Low***, resulting in a ***Minor*** residual impact significance to the ***Medium*** sensitivity southern cassowary and a ***Moderate*** impact significance to the ***High*** sensitivity lowland tree kangaroo, giant bandicoot and Scheepmaker's crowned pigeon.

Freshwater Turtles

Induced hunting presents the greatest potential threat to the ***High*** sensitivity pig-nosed turtle and striped New Guinea soft-shelled turtle. An increase in harvesting rates is possible given:

- A potential increase in non-landowners passing freely along major watercourses with nesting sites that are not constrained by the restricted access that protects other terrestrial species.
- A potential increase in local resident boat traffic. Most exploitation of pig-nosed turtles in Papua New Guinea occurs at the local level and is largely limited by the cost of fuel for outboard motors (Eisemberg et al., 2015).
- A potential increase in demand for eggs and adult turtles as a result of population growth.
- Improved accessibility to sales points.

Harvesting rates are already likely unsustainable (Eisemberg et al., 2011; 2015) and any increase in hunting pressure is precautionarily considered to threaten the viability of the local population.

Damage to nesting banks by boat-wash and dredging represents an additional, and potentially serious, impact to pig-nosed turtles. During the high-water season, the flows of the river conceal the nesting banks exposing them to potential damage from sedimentation and hydrological changes. Should the high-water season correspond with periods of high sediment load multiple nesting sites along the banks of main river channels and tributaries could be damaged, although controlling Project traffic would reduce the magnitude of impacts.

Impacts to the pig-nosed turtle nesting site at the Oyomo Creek outlet will be harder to mitigate, though the continued use of a nesting site at the mouth of Kuku Creek adjacent to the Herd Base facility indicates that the Oyomo Creek site may remain functional.

Nest sites of the striped New Guinea soft-shelled turtle are less susceptible to damage as they do not nest along the main Purari River channels, although they still may be exposed to the impacts of erosion from increased local boat traffic in tributaries from the Project and residents.

Other relevant impacts from loss of watercourses and wetlands, sedimentation of waterways, underwater noise and boat strike are considered to be less threatening.

The overall Project-related impact to the IUCN Threatened freshwater turtles is ***Low*** in magnitude, resulting in a ***Moderate*** residual impact significance for these ***High*** sensitivity species

Species Occupying Northern Margins of the Study Area

Hunting-sensitive fauna species restricted to primary hill forest in the Middle Purari Hills ecological zone include ***High*** sensitivity species such as the eastern long-beaked echidna, Goodfellow's tree kangaroo, ifola, dusky pademelon (*Thylogale brunii*), Salvadori's teal and the ***Very High*** sensitivity congregatory cave-roosting Bulmer's fruit bat. These species occur outside of Project areas and are remote from the nearest Pawaian villages in most cases. Direct impacts are unlikely; potential impacts are associated with induced population influx in the northern Pawaian village areas predominantly at Wabo and Ura; although, local residents reported that these species were not commonly captured. The magnitude of impacts to these species will be ***Minimal***, resulting in ***Minor*** residual impact significance.

Other Sensitive Fauna

Migratory and Congregatory Shorebirds

Nine Threatened and Near Threatened migratory shorebird species may seasonally visit the 65 km shorefront and the greater coastal region where they congregate at low tide to feed on exposed sand and mudflats, and at high tide to roost in nearby dryland habitats. Degradation and contamination of wetland habitats, disturbance from temporary noise and an increase in people, and increased hunting present the main potential impacts. These impacts will be temporary in most instances and are readily mitigated. Residual impacts to all species will be ***Minimal***, resulting in a ***Negligible*** or ***Minor*** residual impact significance to these ***High*** and ***Medium*** sensitive species.

Resident Marine Coastal Birds

Resident marine coastal birds include the Near Threatened beach stone-curlew (*Esacus magnirostris*) and nationally Protected eastern osprey (*Pandion cristatus*). These ***Medium*** sensitivity non-congregatory species are highly mobile and are uncommon. They are most susceptible to damage to or loss of breeding sites. As with migratory shorebirds the magnitude of impacts will be ***Minimal***, resulting in a ***Negligible*** residual impact significance.

Freshwater Wetland Birds

Three nationally Protected egret species (i.e., the great egret (*Ardea alba*), intermediate egret (*Egretta intermedia*) and little egret (*E. garzetta*)) occupy freshwater wetlands and the margins of larger watercourses across the study area. The Project footprint and degradation buffer largely avoids these locations; therefore, the impact magnitude of Project development will be ***Minimal*** resulting in a ***Negligible*** residual impact significance to these ***Medium*** sensitivity species.

Crocodiles

Hunting pressure to crocodiles is low and both species remain locally widespread and common in suitable habitat. Potential impacts from induced hunting, underwater noise, damage to nests, and contamination to the two locally occurring ***Medium*** sensitivity crocodile species will be ***Low*** in magnitude resulting in a ***Minor*** residual impact significance.

11.6.6 Summary of Residual Impacts to Terrestrial Biodiversity

Table 11.46 provides a summary of the assessment of residual impacts to terrestrial 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 11.45.

The significance of all residual impacts is assessed to be ***Negligible*** to ***Minor***, except for ***Very High*** and ***High*** sensitivity species where the impact magnitude remains ***Medium*** or greater.

A ***Major*** residual impact significance has been determined for:

- *Begonia* sp. 5 – a ***Very High*** sensitivity new-to-science plant known from only five specimens in two isolated populations growing on permanently moist, shaded stream banks in foothill and well-drained alluvial forest; one along the northwest edge of the CPF footprint, the other approximately 650 m northwest.
- *Diospyros lolinopsis* and *Syzygium* sp. 4 – ***High*** sensitivity trees located in the proposed export pipeline corridor.

The following ***High*** sensitivity values have been assessed to have a ***Moderate*** residual impact significance:

- Primary alluvial forest – a locally and regionally restricted forest type that supports distinct flora and fauna communities.
- Lowland tree kangaroo, giant bandicoot and Scheepmaker's crowned pigeon – Hunting-sensitive fauna found in alluvial and hill forests.
- Pig-nosed turtle and striped New Guinea soft-shelled turtle – IUCN threatened freshwater turtles found in the Purari River and its tributaries.
- *Bulbophyllum* sp. 1 and *Oberonia* sp. 1 – Primary forest plants present only in the Middle Purari Hills ecological zone and adjacent well-drained alluvial terrain.
- *Archidendron* sp. 1, *Syzygium* sp. 1 and *Diospyros insularis* – new-to-science trees known from proposed CPF and Logistics Base.
- *Pseuduvaria* sp. 1 – a new-to-science tree located in the proposed export pipeline corridor.
- *Cophixalus* sp. 3 and *Oreophryne* sp. 2 –new-to-science microhylid frogs that are habitat specialists of moist stream banks.
- *Argiolestes tuberculiferus*, *Pyrrhargiolestes angulatus, Teinobasis* sp. 1, *Nososticta smilodon, Nososticta* sp. 1, *Rhyacocnemis* sp. 1, *Drepanosticta taurulus* and *Palaeosynthemis* sp. 1 – new-to-science or rare damselfly species requiring cool clear forest streams.

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Ecosystems							
Primary hill forest	Earthworks; vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operations; discharge of surface runoff; waste generation, storage and disposal	Habitat loss and fragmentation; habitat degradation; fire; introduction and spread of invasive alien species	PRL-15; export pipeline route	C, O, D	♦ EM001 ♦ EM002 ♦ EM003 ♦ EM004 ♦ EM005 ♦ EM011 ♦ EM012 ♦ EM018 ♦ EM041 ♦ EM078 ♦ EM018 ♦ EM024 ♦ EM025 ♦ EM026 ♦ EM027 ♦ EM028 ♦ EM029 ♦ EM030 ♦ EM036	Medium/Low	Minor
Primary alluvial forest			PRL-15; export pipeline route			High/Low	Moderate
Logged alluvial forest			PRL-15; export pipeline route			Medium/Low	Minor
Swamp forest; swamp woodland; low freshwater swamp vegetation			Export pipeline route			Medium/Low	Minor
Mangrove						High/Minimal	Minor
Riverine seral forest	Logistics and transport; Project employment and procurement	Habitat degradation; induced forest resource use and land clearing	River transport corridor			Medium/Minimal	Negligible
Protected Areas							
Crater Mountain Wildlife Management Area	Project employment and procurement	Induced hunting, forest resource use and land clearing	Pawaian villages (outside of Project areas)	C, O, D	See above	High/Minimal	Minor

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Focal Sites							
Caves	Quarries; earthworks	Habitat loss and fragmentation; loss of individuals and populations; disturbance, damage or destruction of feeding breeding nesting and roosting sites	PRL-15	C	♦ EM001 ♦ EM027 ♦ EM028	Very High/Minimal	Minor
Rock shelters						Medium/Minimal	Negligible
Large trees	Vegetation clearing	Habitat loss and fragmentation; loss of individuals and populations; loss of focal features	PRL-15, export pipeline route	C	♦ EM001 ♦ EM018 ♦ EM024 ♦ EM025 ♦ EM026 ♦ EM027 ♦ EM028 ♦ EM041	Medium/Low	Minor
Large fig trees							
Hill forest pools							
Forest Species: Primary Hill Forest Plants							
Bulbophyllum sp. 1	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operations; discharge of surface runoff	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire	PRL-15; export pipeline route	C, O, D	♦ EM001 ♦ EM002 ♦ EM004 ♦ EM013 ♦ EM018 ♦ EM023 ♦ EM024 ♦ EM025 ♦ EM026 ♦ EM027 ♦ EM028	High/Low	Moderate
Orophaea sp. 1; Begonia sp. 1; Ixora sp. 2; Maschalodesme sp. 1						Medium/Low	Minor

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Forest Species: Primary Hill Forest Plants (cont'd)							
Orophaea sp. 1; Begonia sp. 1; Ixora sp. 2; Maschalodesme sp. 1 (cont'd)	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operations; discharge of surface runoff	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire	PRL-15; export pipeline route	C, O, D	♦ EM030 ♦ EM031 ♦ EM033 ♦ EM041	Medium/Low	Minor
Begonia sp. 3; *B.* sp. 4; Genus 1 sp. 2; *Marsdenia venusta; Koompassia grandiflora; Myristica brachypoda; Syzygium sp. 3*						High/Minimal	Minor
Cyrtandra sp. 1; *C.* sp. 2; *Syzygium* sp. 2; *Ixora* sp. 1; *I.* sp. 3; *Psychotria diplococca* var. *tauriensis;* Genus 1 sp. 1; Genus 1 sp. 3						Medium/Minimal	Negligible
Forest Species: Disturbance Tolerant Hill Forest Plants							
Cyathocalyx lucidus; Mammea grandifolia; Ceratopetalum succirubrum; Archidendron forbesii; Intsia bijuga; Pterocarpus indicus; Flindersia pimenteliana; Guioa hospita	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire	PRL-15; export pipeline route	C, O, D	See above	High/Minimal	Minor

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Forest Species: Disturbance Tolerant Hill Forest Plants (cont'd)							
Pseuduvaria filipes; Cycas scratchleyana; Aglaia euryanthera; A. rimosa Myristica globose; Helicia amplifolia; H. latifolia; Flindersia amboinensis; F. schottiana	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation.	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire	PRL-15; export pipeline route	C, O, D	See above	Medium/Minimal	Negligible
Forest Species: Foothill Forest Plants							
Livistona sp. 1; *Cordyline minutiflora*; *Cyrtandra* sp. 3; *Barringtonia* sp. 1	Vegetation clearing operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation.	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire	PRL-15; export pipeline route	C, O, D	See above	Medium/Low	Minor
Forest Species: Primary Alluvial and Swamp Forest Plants							
Barringtonia sp. 2; *Psychotria purariensis*	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation.	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire	PRL-15; export pipeline route	C, O, D	See above	Medium/Low	Minor
Oberonia sp. 1						High/Low	Moderate

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Forest Species: Primary Alluvial and Swamp Forest Plants (cont'd)							
Syzygium sp. 5	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation.	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire.	PRL-15; export pipeline route	C, O, D	See above	High/Minimal	Minor
Species not recorded during Project surveys but known from nearby: *Cyrtandra externata; Ixora whitei*						High/Minimal	Minor
Avicennia rumphiana; *Bulbophyllum* sp. 2; *Glochidion delticola*; *Psychotria heterophylla*	Logistics and transport; Project employment and procurement	Loss of individuals; contamination of wetland habitat; habitat degradation; induced forest exploitation	River transport corridor	C, O, D	See above	High/Minimal	Minor
Forest Species: Hill Forest Fauna							
Goliath birdwing; paradise birdwing	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; construction works	Loss of habitat; loss of specialist feeding plants; invasive alien species; fire	PRL-15	C, O, D	♦ EM001 ♦ EM002 ♦ EM023 ♦ EM024 ♦ EM027 ♦ EM028 ♦ EM041	High/Low	Minor
Southern tailed birdwing			PAOI			Medium/Minimal	Negligible
Papuan free-tailed bat (*Otomops papuensis*); Papuan sheath-tailed bat (*Saccolaimus mixtus*)	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport;	Loss of individuals; damage or disturbance to breeding and roosting sites; fire; habitat loss and degradation; induced hunting	PRL-15; export pipeline route	C, O, D	♦ EM001 ♦ EM002 ♦ EM027 ♦ EM028 ♦ EM031	Medium/Minimal	Negligible

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Forest Species: Hill Forest Fauna (cont'd)							
Papuan free-tailed bat (*Otomops papuensis*); Papuan sheath-tailed bat (*Saccolaimus mixtus*) (cont'd)	quarries; Project employment and procurement	Loss of individuals; damage or disturbance to breeding and roosting sites; fire; habitat loss and degradation; induced hunting (cont'd)	PRL-15; export pipeline route	C, O, D	♦ EM046 ♦ EM047	Medium/Minimal	Negligible
New Guinea quoll (*Dasyurus albopunctatus*); Woolley's three-striped dasyure (*Myoictis leucura*)	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; Project employment and procurement	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire; induced hunting	PRL-15	C, O, D	♦ EM001 ♦ EM002 ♦ EM009 ♦ EM027 ♦ EM028 ♦ EM031 ♦ EM033 ♦ EM034 ♦ EM035 ♦ EM046 ♦ EM047	Medium/Low	Minor
Echymipera rufescens subsp.; Gurney's eagle (*Aquila gurneyi*); Doria's goshawk (*Megatriorchis doriae*); Blyth's hornbill; palm cockatoo; glossy-mantled manucode (*Manucodia ater*); crinkle-collared manucode (*M. chalybatus*); trumpet manucode (*Phonygammus keraudrenii*); magnificent riflebird (*Ptiloris magnificus*); magnificent bird-of-paradise (*Diphyllodes magnificus*)			PRL-15; export pipeline route			Medium/Minimal	Negligible

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Forest Species: Hill Forest Fauna (cont'd)							
King bird-of-paradise (*Cicinnurus regius*); Raggiana bird-of-paradise; yellow-eyed starling (*Aplonis mystacea*)	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; Project employment and procurement	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire; induced hunting	PRL-15; export pipeline route	C, O, D	See above	Medium/Minimal	Negligible
Gehyra sp. 1			Export pipeline route		♦ EM001 ♦ EM002 ♦ EM009 ♦ EM023 ♦ EM027 ♦ EM028 ♦ EM031 ♦ EM033 ♦ EM034 ♦ EM035 ♦ EM046 ♦ EM047	High/Minimal	Minor
Austrochaperina sp. 1; *Choerophryne crucifer*			PRL-15			Medium/Low	Minor
Callulops marmoratus; Cophixalus sp. 2*; Copiula* sp. 1*; Oreophryne* sp. 1;			PRL-15; export pipeline route			Medium/Minimal	Negligible

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Forest Species: Fauna - Alluvial and Foothill Forest							
Starry owlet-nightjar; *Stegonotus* sp. 1	Vegetation clearing operation of fixed and mobile plant and equipment; logistics and transport; construction works; Project employment and procurement	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire; induced hunting	PRL-15; export pipeline route	C, O, D	♦ EM001 ♦ EM002 ♦ EM009 ♦ EM027 ♦ EM028 ♦ EM031 ♦ EM033 ♦ EM034 ♦ EM035 ♦ EM046 ♦ EM047	High/Minimal	Minor
Oriomo bandicoot (*Echymipera oriomo*)						Medium/Low	Minor
Forest Species: Fauna Occupying Northern Margins of the Study Area							
Hydromys sp. 1; *Pseudohydromys* sp. 1	Logistics and transport; Project employment and procurement	Minor loss of habitat quality; zoonotic disease from invasive alien rodents	PAOI	C, O, D	♦ EM001 ♦ EM002 ♦ EM009 ♦ EM023 ♦ EM027 ♦ EM028 ♦ EM031 ♦ EM033 ♦ EM034 ♦ EM035 ♦ EM046 ♦ EM047	High/Minimal	Minor
Striated lorikeet; banded yellow robin						Medium/Minimal	Negligible

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Forest species: Fauna Dependent on Forest Streams, Forest Pools and Adjacent Riparian Habitats							
Cophixalus sp. 3; *Oreophryne* sp. 2; *Argiolestes tuberculiferus*; *Pyrrhargiolestes angulatus*; *Teinobasis* sp. 1; *Nososticta smilodon*; *N.* sp. 1; *Rhyacocnemis* sp. 1; *Drepanosticta taurulus*; *Palaeosynthemis* sp. 1	Vegetation clearing operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation	Loss of individuals or populations; degradation of remaining habitat; weed infestation; fire	PRL-15; export pipeline route	C, O, D	♦ EM001 ♦ EM002 ♦ EM004 ♦ EM009 ♦ EM018 ♦ EM023 ♦ EM027 ♦ EM028 ♦ EM031 ♦ EM033 ♦ EM034 ♦ EM035 ♦ EM046 ♦ EM047	High/Low	Moderate
Forest bittern; *Litoria exophthalmia*; *L. sauroni*; *L.* sp. 1; *Hylarana* sp. 1; *H.* sp. 2; *Metagrion trigonale*; *M.* sp. 1; *Teinobasis buwaldai*; *T. debeauxi*; *Selysioneura rhaphia*;						Medium/Low	Minor
Indolestes linsleyi; *Bironides ypsilon*; *Diplacina cyrene*; *Idiocnemis patriciae*; *Idiocnemis* sp. 1; *Nososticta chrismulleri*; *N. paraconifera; N. truncata*						Medium/Low	Minor

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Forest species: Fauna Dependent on Forest Streams, Forest Pools and Adjacent Riparian Habitats (cont'd)							
Odonates present in open and disturbed habitats: *Agyrtacantha* sp. 1; *Papuagrion* sp. 1					See above	Medium/Minimal	Negligible
Forest Species: Mangrove, Freshwater Swamp Forest and Alluvial Forest Fauna							
False water rat (*Xeromys myoides*)	Vegetation clearing operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation; waste generation storage and disposal; Project employment and procurement	Loss of individuals and habitat; contamination of wetland forest habitat; habitat degradation	All Project areas	C, O, D	See above	High/Minimal	Minor
Blue-black kingfisher (*Todirhamphus nigrocyaneus*); twelve-wired bird-of-paradise (*Seleucidis melanoleucus*)						Medium/Minimal	Negligible
New-to-science Plants with One of Few Known Populations in or near the Project Footprint							
Begonia sp. 5	Vegetation clearing operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation;	Loss of one of two known populations; degradation of remaining habitat; weed infestation; fire; threat to population viability	CPF	C, O, D	♦ EM001 ♦ EM013 ♦ EM018 ♦ EM024 ♦ EM025 ♦ EM026 ♦ EM027 ♦ EM028	Very High/Medium	Major
Archidendron sp. 1; *Syzygium* sp. 1		Loss of only known individual or one or more of few known individuals; degradation of remaining habitat; weed				High/Medium	Moderate

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
New-to-science Plants with One of Few Known Populations in or near the Project Footprint (cont'd)							
Archidendron sp. 1; *Syzygium* sp. 1 (cont'd)	waste generation storage and disposal; spoil disposal	infestation; fire; threat to population viability			♦ EM032 ♦ EM041	High/Medium	Moderate
Syzygium sp. 4	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation	Loss of only known individual or one or more of few known individuals; degradation of remaining habitat; weed infestation; fire	Export pipeline route	C, O, D	See above	High/High	Major
Pseuduvaria sp. 1						High/Low	Moderate
Ficus sp. 1; *Discocalyx* sp. 1						Medium/Low	Minor
Begonia sp. 2; *Medinilla* sp. 1; *Glochidion* sp. 1; *Lasianthus* sp. 1	Vegetation clearing; earthworks; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; construction works; pipeline operation; spoil disposal	Loss of individuals from among few known populations; degradation of remaining habitat; contamination of watercourses and associated riparian habitat; weed infestation; fire	Wellpads	C, O, D		High/Minimal	Minor
Regionally Rare IUCN Threatened Timber Trees							
Diospyros insularis	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; pipeline operation; spoil disposal	Loss of individuals from single known regional population; degradation of remaining habitat; weed infestation; fire	Logistics Base, CPF	C, O, D	See above	High/Low	Moderate

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Regionally Rare IUCN Threatened Timber Trees (cont'd)							
Diospyros lolinopsis	Vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport; onshore pipeline construction; pipeline operation		Export pipeline route	C, O, D	See above	Very High/High	Major
Hunting-sensitive Fauna in the Project Area							
Lowland tree kangaroo; giant bandicoot; Scheepmaker's crowned pigeon	Project employment and procurement; vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire; induced hunting	PRL-15, export pipeline route	C, O, D	♦ EM002 ♦ EM004 ♦ EM009 ♦ EM024 ♦ EM027 ♦ EM028 ♦ EM031 ♦ EM033	High/Low	Moderate
Pesquet's parrot; Papuan eagle; grey dorcopsis						High/Minimal	Minor
Hunting-sensitive Fauna Occupying Northern Margins of the Study Area							
Pesquet's parrot; Papuan eagle; grey dorcopsis (cont'd)	Project employment and procurement; vegetation clearing; operation of fixed and mobile plant and equipment; logistics and transport	Loss of individuals and habitat; degradation of remaining habitat; weed infestation; fire; induced hunting	PRL-15, export pipeline route	C, O, D	♦ EM034 ♦ EM035 ♦ EM046 ♦ EM047	Medium/Low	Minor
Southern cassowary							

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Hunting-sensitive Fauna Occupying Northern Margins of the Study Area (cont'd)							
Pig-nosed turtle; striped New Guinea soft-shelled turtle	Project employment and procurement; dredging at Logistics Base; logistics and transport	Adult population reduction; nest failure; damage to or loss of river bank nest sites; induced hunting	PRL-15, river transport corridor	C, O, D	♦ EM001 ♦ EM004 ♦ EM013 ♦ EM014 ♦ EM022 ♦ EM024 ♦ EM027 ♦ EM028 ♦ EM031	High/Low	Moderate
Bulmer's fruit bat	Project employment and procurement	Loss of individuals from one of few regional colonies; induced hunting	PAOI	C, O, D	♦ EM001 ♦ EM004 ♦ EM009 ♦ EM024 ♦ EM027 ♦ EM028 ♦ EM031 ♦ EM033 ♦ EM034 ♦ EM035 ♦ EM046 ♦ EM047	Very High/Minimal	Moderate
Eastern long-beaked echidna; Goodfellow's tree kangaroo; ifola; dusky pademelon	Project employment and procurement	Loss of individuals; induced hunting				High/Minimal	Minor

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Migratory and Congregatory Shorebirds							
Far eastern curlew; great knot	Logistics and transport; Project employment and procurement	Loss of individuals; disturbance to feeding or roosting congregations impacting on energy reserves required for migration; induced hunting	River transport corridor	C, O, D	♦ EM019 ♦ EM027 ♦ EM028 ♦ EM046 ♦ EM047	High/Minimal	Minor
Asian dowitcher (*Limnodromus semipalmatus*); black-tailed godwit (*Limosa limosa*); bar-tailed godwit (*L. lapponica*); grey-tailed tattler (*Tringa brevipes*); red knot (*Calidris canutus*); red-necked stint (*C.ruficollis*); curlew sandpiper (*C. ferruginea*)						Medium/Minimal	Negligible
Resident Marine Coastal Birds							
Eastern osprey; beach stone-curlew	Logistics and transport; Project employment and procurement	Loss of individuals; disturbance to breeding sites; induced hunting	River transport corridor	C, O, D	See above	Medium/Minimal	Negligible
Freshwater Wetland Birds							
Great egret; intermediate egret; little egret	Logistics and transport; operation of fixed and mobile plant and equipment; construction works; Project employment and procurement	Disturbance at feeding or roosting sites; contamination of watercourses and associated riparian habitat; induced hunting	PRL-15; river transport corridor	C, O, D	See above	Medium/Minimal	Negligible

Table 11.46 – Summary of Assessment of Residual Impact Significance to Terrestrial Biodiversity (cont'd)

Key Sensitivity	Main Activity	Potential Impact	Location of Activity	Project Phase	Mitigation and Management	Residual Assessment	
						Sensitivity/ Magnitude	Significance
Crocodiles							
New Guinea freshwater crocodile; estuarine crocodile	Project employment and procurement; logistics and transport; waste generation storage and disposal	Loss of individuals; nest failure; damage to or loss of nest sites; induced hunting	PRL-15; river transport corridor	C, O, D	♦ EM014 ♦ EM022 ♦ EM023 ♦ EM024 ♦ EM027 ♦ EM028	Medium/Low	Minor

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

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