TOTAL
TOTAL E&P PNG LIMITED

PAPUA LNG PROJECT

UPSTREAM ENVIRONMENTAL IMPACT STATEMENT

VOLUME 1: MAIN REPORT

Chapter 5: Project Options and Analysis

TOTAL E&P PNG LIMITED

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5. Project Options and Analysis

5.1 Introduction

This chapter describes the commercial, facility siting, design, technology, construction and transportation alternatives considered for the Project. Avoiding and or minimizing social and environmental impacts has been integral when considering alternatives during the Project's conceptual and pre-Project design phases. Further optimization of the Project 'base case' design will continue through the Project's front-end engineering design (FEED) and detailed design phases.

5.1.1 Options Analysis Approach

Resource projects of this size and nature undergo assessment so that they are both viable physically, technically and commercially, and acceptable socially and environmentally. TEP PNG has rigorously and continuously assessed options at successive stages during the conceptual and pre-Project design phases and has adopted a risk-management approach through the hierarchical application of:

- Avoidance.
- Minimization.
- Rehabilitation or restoration.
- Offset or compensation.

Analysis of options and alternatives for the Project began in 2014, with a preliminary study that assessed gas and condensate commercialization and export options (Section 5.2). The next stages of assessment comprised a conceptual phase (April 2014 to July 2015) and a pre-Project phase (September 2015 to December 2018):

- The conceptual phase focused on selecting the optimum development concept based on a comprehensive screening of scenarios. This involved:
  - A screening study (April to September 2014), which assessed various options and locations for the key process and infrastructure components (e.g., liquefied natural gas (LNG) plant, central processing facility (CPF) and export pipeline corridor).
  - An additional screening study (October 2014 to February 2015) to reduce the number of scenarios.
  - A detailed conceptual phase (March to July 2015) to further compare the options from the screening studies and review potential social and environmental constraints (Section 5.3).
- The pre-Project phase considered pipeline alignment and gas transportation (Section 5.4), Project process and technological design such as acid gas management (Section 5.5), construction techniques (Section 5.6) and logistics routes (Section 5.7).

Finally, TEP PNG considered the no-project option (Section 5.8) in terms of avoiding adverse environmental and social impacts, and potential lost economic and social development opportunities for Papua New Guinea.

Stakeholder input (Chapter 6), baseline surveys (Chapters 7 to 10), technical studies and risk workshops helped filter options to arrive at the Project 'base case' design description presented in Chapter 4.

Alternatives to the base case were assessed for their potential to impact on environmental and social sensitivities and on their physical, technical and commercial feasibility. Different Project components were assessed using different methods. In this chapter, qualitative criteria aligned with International Finance Corporation requirements have been used to communicate the outcomes of these assessments in a cohesive format.

Table 5.1 outlines the main criteria that informed the alternatives analyses, and the tables that follow throughout the chapter provide a summary of how each has informed the assessment of multiple options.

Table 5.1 – Qualitative Criteria for Assessing Options

Ranking	Technical or Logistical Difficulty	Environmental Sensitivity	Social Sensitivity
High	Constructability (e.g., risk of flooding or landslides) geohazards, gas processing technology, gas transport parameters, logistical constraints, infrastructure requirements and commercial viability.	Potential impacts on sensitive species and ecosystems, topography, landforms and soils, and water resources.	Proximity to population centers, potential impacts on livelihoods and on access to resources and services, cultural heritage, community resilience, in-migration, and health and safety risks.
Medium			
Low			

5.1.2 Alternatives Considered

An overview of all the alternatives considered for each Project component is provided in Table 5.2 and those taken forward for assessment are described further in the following sections.

Table 5.2 – Summary of Alternatives Considered During the Conceptual and Pre-Project Phases

Item	Summary of Alternatives Considered
Commercialization and Export Options	
Gas commercialization	♦ Initial screening of 14 locations for the LNG plant location. ♦ Construct a greenfield plant or extend existing LNG facilities.
Gas and condensate export	♦ Use existing condensate export terminals at Kutubu. ♦ Construct a greenfield terminal closer to PRL-15. ♦ Use a single pipeline for gas and condensate. ♦ Barge condensate export down the Purari River. ♦ Export gas and condensate through onshore pipelines rather than a combination of onshore and offshore pipelines.
Location and Layout	
Central processing facility (CPF) location	♦ Six site locations initially screened. ♦ Two site locations assessed in detail.
Wellpads and gathering station layout and location	♦ Re-use existing wellpads and wells. ♦ Group wells on each wellpad. ♦ Collocate wellpads and gathering station.
Logistic facilities	♦ Develop a new logistics base. ♦ Upgrade and use Herd Base as the logistics base throughout the Project life. ♦ Upgrade and use Herd Base for early works, and develop and use a new logistics base for construction and operations.

Table 5.2 – Summary of Alternatives Considered During the Conceptual and Pre-Project Phases (cont'd)

Item	Summary of Alternatives Considered
Routing	
Gathering network (flowlines and trunklines) routing	♦ Initial screening of several alignment options for both flowlines and trunklines. ♦ Re-use existing tracks or roads. ♦ Optimize the pipeline trench through collocation of pipelines (e.g., production, water injection).
Onshore export pipeline routing	♦ Full onshore alignment from the CPF to Caution Bay. ♦ Purari River route from the CPF to Orokolo Bay. ♦ CPF to shore crossing route options. ♦ Several alignment options at the Orokolo Bay shore crossing. ♦ Alignment options for the Purari River crossing.
Offshore export pipeline routing	♦ Several alignment options from Orokolo Bay to Caution Bay.
Process and Technology	
Acid gas management	♦ Acid gas injection into the Antelope and/or Elk reservoirs. ♦ Acid gas incineration. ♦ SO_2 venting to the atmosphere. ♦ Solid sulfur landfill disposal. ♦ Conversion of sulfur in liquid form for injection with water.
Produced water management	♦ Use reed bed technology. ♦ Discharge to soils/irrigation after treatment. ♦ Use solar and/or mechanical evaporation. ♦ Dilution during upset conditions prior to discharge. ♦ Discharge to the sea at Orokolo or Caution Bay. ♦ Discharge to the Purari River. ♦ Reinjection into the Antelope reservoir.
Construction	
Aggregate sourcing and quarry locations	♦ Transport aggregates by road and barge from Port Moresby. ♦ Re-use materials from onsite excavations (e.g., for the CPF, roads). ♦ Establish/use quarries (various options).
Pipeline construction techniques (river crossings and shore crossing)	♦ Horizontal directional drilling (HDD). ♦ Micro-tunneling. ♦ Direct Pipe. ♦ Bridge. ♦ Open trenching.
Transport and Logistics	
Airfield design and location	♦ Upgrade the existing Purari airstrip to Code 2. ♦ Develop a new (Code 2) airstrip north of the Purari River. ♦ Develop a smaller new (Code 1) airstrip north of the Purari River and use the existing airstrip during construction.
Water transport routes	♦ Wame-Varoi River. ♦ Uriko-Ivo River. ♦ Purari River.

5.1.3 Consideration of Alternatives During the FEED Phase

Additional technological and process alternatives will be evaluated as part of the FEED phase in alignment with the hierarchy outlined in Section 5.1.1 and with good international industry practice.

5.2 Commercialization and Export Options

5.2.1 Gas Commercialization

During the early Project phases, screening studies to identify a recommended LNG plant location considered fourteen locations. Six were selected for further analysis, and environmental and social screening was undertaken on these sites (Table 5.3). This process progressed concurrently with a similar screening process for the CPF locations (Section 5.3.1).

Table 5.3 – LNG Plant Location Social and Environmental Screening Results

	Aspect	Caution Bay	Ala-Ala	Obu Plantation	Cape Possession	Oiapu	Cape Cupola
Social Assessment	Resettlement	Low	Med	High	High	Med	Low
	Land ownership	Low	High	Med	Low	Low	Med
	In-migration	Med	Med	Med	Med	Low	High
	Cultural heritage	High	High	Low	Low	Med	Low
	Livelihood	Low	Low	High	High	Low	Low
	Community resilience	Med	High	Med	High	Med	High
	Community sensitivity	Low	High	High	High	High	High
Environmental Assessment	Landform and soils	Low	Med	Low	High	Med	High
	Water resources	Med	Low	Low	Low	Med	Med
	Terrestrial biodiversity	Low	High	Low	Med	Low	High
	Marine environment	Med	Med	Med	Med	Med	Med
	Fisheries and shipping	Med	Med	Med	Med	Med	Med

Proposed sites at Ala-Ala, Obu Plantation, Cape Possession and Cape Cupola were assessed as having high-risk social sensitivities, which were likely to create or exacerbate community disputes and in-migration or require resettlement and economic restoration. Ala-Ala and Cape Cupola also have environmental sensitivities, including highly significant monsoonal forest at Ala-Ala and the potential for the presence of International Union for Conservation of Nature (IUCN)-listed species at Cape Cupola. Cape Possession would require significant capital investment to implement environmental and social mitigations and avoid adverse off-site impacts to the coastal and marine environment.

The location south of the existing PNG LNG Facilities at Caution Bay was assessed as having several medium environmental and social sensitivities, and high cultural heritage values that could be managed appropriately through standard construction practices and suitable community engagement.

As a result of the screening study, the recommended site for the LNG plant was south of the existing PNG LNG Facilities at Caution Bay. Once Caution Bay was selected as the preferred site, two concepts were considered for its development:

- Construction of a greenfield standalone plant.
- Integration with the existing PNG LNG Facilities.

TEP PNG and ExxonMobil began discussing adding gas processing facilities at the existing PNG LNG Facilities in 2017. Integrating the Papua LNG Project downstream LNG facilities with the existing PNG LNG Facilities is the preferred option, subject to a suitable commercial arrangement. Additional trains will use the spare capacity of the existing utility, storage and loading facilities, and existing common facilities can be expanded as needed to meet additional requirements of the expanded facility (Figure 5.1).

This EIS does not address the downstream LNG plant; however, the plant design influences the design of upstream Project components, and it has therefore been included in this report for context.

5.2.2 Condensate Export

The Project team considered several options for exporting the condensate of the Elk-Antelope reservoirs during the preliminary study (see Section 5.1.1). This involved assessing the feasibility of using one of the two existing locations for condensate export (i.e., the Kumul terminal or the PNG LNG Facilities) or of developing a new condensate export terminal closer to PRL-15.

In particular, the option to use the Kumul terminal, which already exports oil produced from operated fields, was considered. This option was rejected due to additional operational complexity and the need for an additional 100 km of offshore pipeline to the terminal, which would increase the Project footprint.

Barging condensate on the Purari River was also considered, but discarded because of the pollution risk and to avoid the potential adverse impacts of high boat traffic on communities. A comparison of these options confirmed that the preferred option was to pipe the condensate to the existing PNG LNG Facilities at Caution Bay.

5.2.3 Gas and Condensate Export Optimization

Optimizing gas and condensate export pipelines into one multiphase (i.e., gas and condensate) pipeline was evaluated. The two-pipeline option was chosen based on the following operational and environmental benefits:

- Less vegetation clearing required at the CPF departure when gas and condensate are separated. Gas and condensate are less volatile when exported in separate pipelines. The reduced volatility requires a smaller exclusion zone around the pipelines, which requires less vegetation clearing.
- The absence or the reduction of compression requirements when condensate is separated from gas before transport, generating fewer greenhouse gas emissions.
- The possibility to operate at lower flowrates than those allowed by multiphase transportation.
- Laying the two pipelines in parallel, which does not affect significantly the construction ROW width, as the two pipelines can be laid in the same trench.

EXPANSION POTENTIAL AT THE PNG LNG FACILITIES AT CAUTION BAY

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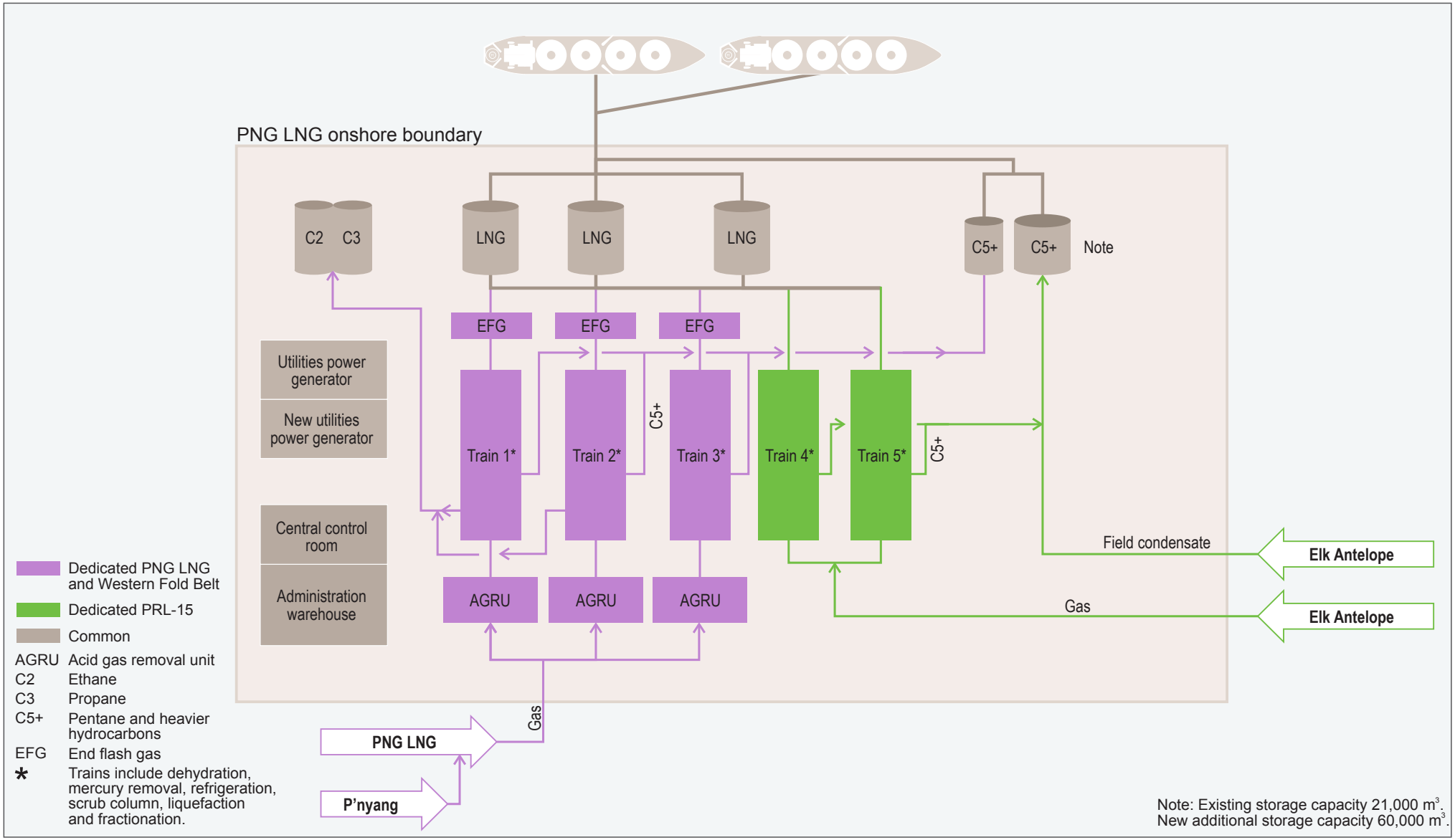
FIGURE 5.1



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5.3 Location and Layout Alternatives

Assessment of alternatives for facility locations and layouts aimed to minimize the number and size of facilities, while ensuring that they were in the optimal location for Project operations and had considered environmental and social constraints.

5.3.1 Central Processing Facility

Several locations were considered for the CPF during the conceptual phase of Project development, including sites near the wellpads (i.e., E1-A, F1 and F2), near Herd Base (i.e., P1 and P2) and near the Purari River (Figure 5.2). These locations were evaluated based on the requirement for clearing and fill material, and the potential need to build or upgrade roads to allow heavy equipment access, especially during construction.

Sites CPF-F2, CPF-P1 and CPF-I3 were identified as having high environmental, landform and water sensitivities, respectively at the conclusion of the screening study. Sites CPF-F1 and CPF-P2 showed medium risk for all three sensitivities, and CPF-E1 showed medium risk for soils and landform and for biodiversity and conservation, and low risk for water resources.

The access road must be able to accommodate large trucks carrying loads greater than 1,000 tonnes as the CPF site will contain large pieces of prebuilt equipment. An investigation of the roads connecting the nearest unloading point on the Purari River to the potential CPF locations F1, F2 and E1 found that these roads would require significant upgrades to meet the Project needs during construction, and this was seen as a major factor against selecting these sites. A CPF location near the Purari River (i.e., P1 or P2) was chosen; therefore, to avoid the additional cost, potential delays to the Project schedule, and adverse impacts from road improvements or extensive changes and potential navigation risks to Hou Creek.

Table 5.4 summarizes the assessment criteria for each site.

Table 5.4 – CPF Alternatives Analysis Summary

Criteria	CPF Site					
	F1	F2	P1	P2	I3	E1
Technical or logistical difficulty	High	High	Med	Med	High	High
Environmental sensitivity	Med	High	High	Med	High	Med
Social sensitivity	Low	Low	Low	Low	Low	Low

During the pre-Project phase, geophysical surveys and civil engineering studies confirmed the suitability of site P2 over P1, as P1 showed a higher risk of flooding and associated operational and environmental impacts. In the P2 area, the exact CPF location was defined more specifically to minimize the site preparation requirements. Two subsites, P2C and P2A, were assessed.

Table 5.5 highlights the attributes of the two sites that were assessed in detail to select P2C as the final proposed CPF location.

POTENTIAL CPF LOCATIONS

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FIGURE 5.2

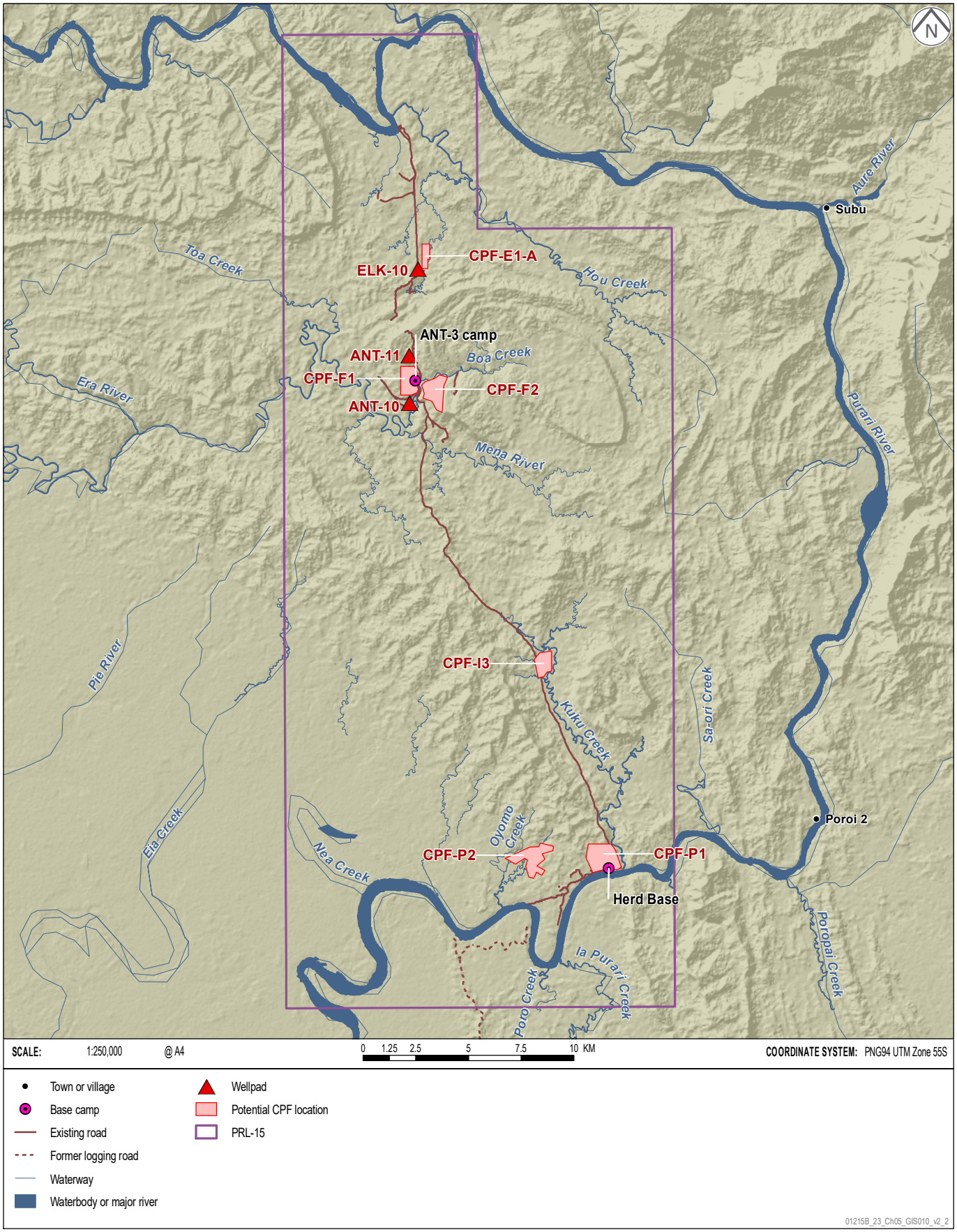

Table 5.5 – Key Attributes in Determining the Final CPF Location

Attribute	P2C	P2A
Physical		
Vegetation	Hill forest.	Hill forest.
Population centers	None (closest is Poroi 1).	None (closest is Poroi 1).
Soil type	Rocky, suitable base for process equipment foundations.	Gravel/conglomerate at depths, overlaid with softer clays.
Drainage	Lower risk of flooding due to being built into the foothills.	Higher risk of flooding from the nearby creeks.
Technical and Design		
Geohazards	Harder soils, less risk of seismic movement. Less exposed to landslides.	Softer clay soils, higher risk of seismic movement.
Site preparation	Does not require deep soil improvement but requires more excavations.	Deep soil improvement required. An additional eight months' preparation time required.
Access and logistics	Access from the Purari River. Can reuse excavated material as backfilling material.	Access from the Purari River. Large quantities of aggregates would need to be imported for site preparation.

5.3.2 Wellpads and Gathering Station

Up to eight wellpads were identified to develop the reservoir at the end of the conceptual phase. As appraisal drilling took place during the pre-Project phase, the data showed that optimizing the number of wellpads was possible. Consequently, the Antelope production wells have been grouped on a single wellpad, reducing the disturbance footprint from pads and interconnecting pipelines.

Reusing two appraisal wellpads is planned for the new production (ELK-10, formerly Elk-1) and water injection (ANT-11, formerly ANT-1) wells, so that only the Antelope production wellpad (ANT-10) will be new. Grouping wells and reusing existing wellpads has significantly reduced the overall wellpad disturbance footprint.

A separate gathering station, where the gas will be collected from the wellpads, was also assumed at the beginning of the pre-Project phase; however, with the improved reservoir knowledge enabling the single wellpad for Antelope, it was decided to locate the gathering station at the Antelope production wellpad, thus further reducing the overall footprint and minimizing vegetation clearing and ground disturbance.

5.3.3 Logistics Facilities

Herd Base is an existing logistics base in PRL-15 and was used during appraisal drilling. The Kuku Ridge separates it from the CPF location, and access between the two would require the existing track, which has several steep sections, to be upgraded. These steep sections would require extensive grading, leveling, and realignment to meet the heavy haul requirements of the CPF equipment (e.g., up to 1,000 tonnes and large modules) and to support the large traffic volume likely during CPF construction.

Herd Base is also physically constrained in its expansion capacity beyond its existing footprint to meet the projected construction personnel requirements and is at risk of inundation at the quay level.

The following three options were assessed for their capacity to meet the construction and operations logistics needs because of these limitations:

- Option 1 – develop a new logistics base of approximately 20 ha on the northern bank of the Purari River, approximately 5 km downstream from Herd Base, and construct an approximate 2.6-km, flat, heavy transport road to the CPF.
- Option 2 – upgrade and expand the existing facilities at Herd Base (to be used as a logistics base for the duration of the Project) and construct an approximate 5-km, steeper, heavy transport road to the CPF.
- Option 3 – upgrade and use Herd Base for early works with the construction of a 'light-duty' road, using the existing track, to support initial mobilization and the development drilling campaign, then develop a smaller, approximate 7-ha, new logistics base and a 2.6-km heavy haul road to the CPF at a later stage.

These options were developed based on the logistics sequences of early works, Project construction and Project operation. Options 1 and 2 have approximately the same total footprint, as the heavy haul road requires more earthworks and the heavy haul and light-duty roads from Herd Base would need to be longer than one heavy haul road from a new logistics base.

Option 3 has been selected as the preferred option because it enables early mobilization of personnel and equipment to begin the construction of Project infrastructure, which better meets the Project timeline (Table 5.6).

Table 5.6 – Logistics Base Alternatives Analysis Summary

Criteria	Option 1	Option 2	Option 3
Technical or logistical difficulty	High	High	Med
Environmental sensitivity	Med	Med	Med
Social sensitivity	Low	Low	Low

5.4 Routing Alternatives

This section outlines the processes followed to determine the preferred routes for each section of the Project pipelines, including the gathering network, and onshore and offshore export pipeline routes.

5.4.1 The Gathering Network

The gathering network comprises two 22-inch trunklines connecting the Antelope production wellpad (ANT-10) to the CPF and a 14-inch flowline connecting the Elk production wellpad (ELK-10) to the CPF.

5.4.1.1 Elk Production Flowline

Three alignments were assessed for the Elk production flowline routing; the western, central and eastern routes (Figure 5.3 and Table 5.7).

INFIELD FLOWLINE SHOWING THE PREFERRED WESTERN ROUTE

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FIGURE 5.3

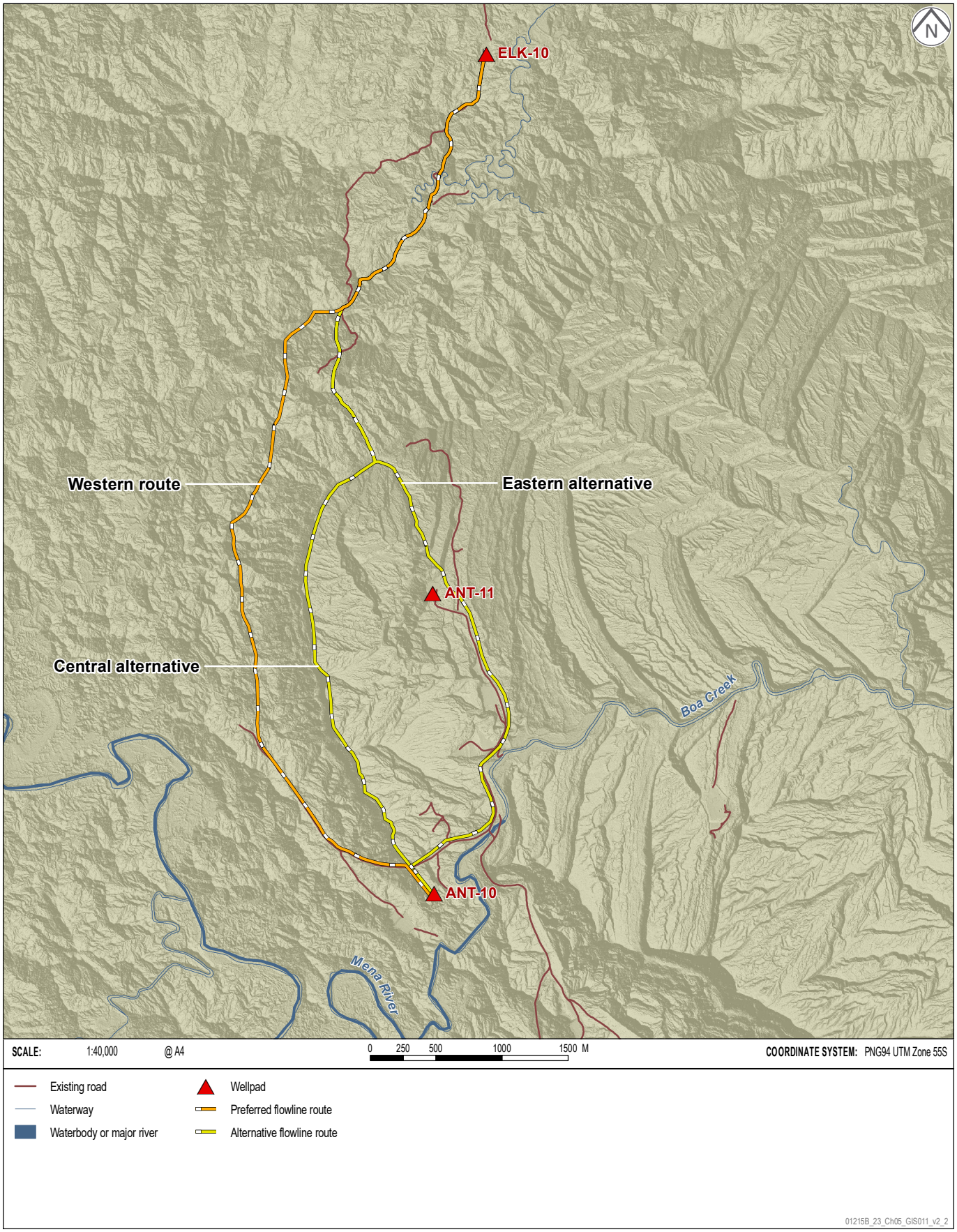

Table 5.7 – Flowline Routing Alternatives Analysis Summary

Criteria	Western	Central	Eastern
Technical or logistical difficulty	Med	High	High
Environmental sensitivity	Med	Med	Low
Social sensitivity	Low	Low	Low

During initial investigations, the central route was the preferred option from a pipe-laying and integrity perspective; however, studies noted that constructing and maintaining the service track in this area would present a challenge because it follows a narrow and eroding ridge. The eastern route, which follows an existing track and therefore would require less clearing, was discarded as a viable option as it crosses more varied terrain than the central route, including active planar landslides. Consequently, the western route became the preferred 'base case' option.

The western route connecting ELK-10 to ANT-5 via Elk-4 is the longest option, but it crosses the fewest geohazard zones and follows a relatively homogeneous terrace and slope setting. Building an access road close to the pipeline ROW is feasible.

A specialist pipeline construction contractor will further optimize the infield routing prior to finalizing the alignment.

5.4.1.2 Trunklines

Trunkline routing considered several constraints, including swampy areas, fault crossings and landslides, river crossings, slopes, environmentally sensitive forest areas, soil conditions, the availability of aggregates and accessibility for construction.

Table 5.8 and Figure 5.4 show the five route options considered.

Table 5.8 – Trunkline Routing Alternatives Analysis Summary

Criteria	Western	Western New	Alternative 1 Options A-E	Alternative 2	Central
Technical or logistical difficulty	High	High	High	High	Med
Environmental sensitivity	High	High	Med	Low	Low
Social sensitivity	Med	Med	Low	Low	Low

As a result of the analyses, the central route was selected as the preferred option. The main reasons for this choice were:

- The alignment minimizes the length to limit pressure drops, enabling a free-flow CPF design.
- Combining the access road and the pipeline ROW reduces the vegetation clearing and earth disturbance footprint.
- Construction and maintenance will be easier due to the pipeline ROW running parallel to the road.
- The environmentally sensitive alluvial forest south of the Kuku Ridge was avoided.

TRUNKLINE ROUTE OPTIONS INVESTIGATED DURING THE PRE-PROJECT DESIGN PHASE

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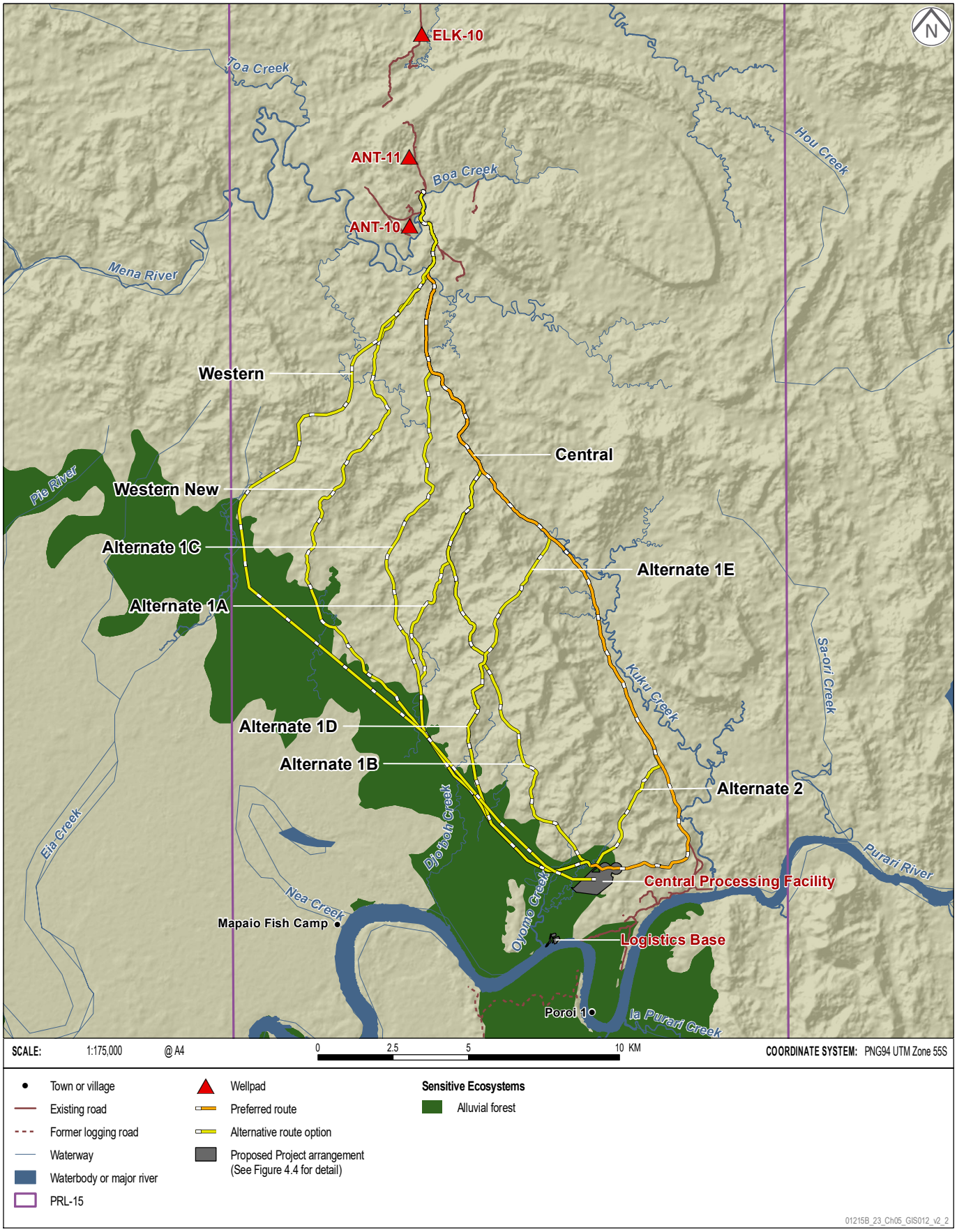
FIGURE 5.4



- The Pie River catchment, which is remote, relatively untouched by development and identified as a high priority for avoidance due to the upstream terrestrial biodiversity baseline study (Part 6 of Volume 2) and the possibility of increasing the number of affected communities downstream of pipeline works, was avoided.

Optimizing the pipeline trench design allowed co-location of the four pipelines (i.e., three production and one water injection) south of ANT-10 and the electric and fiber optics cables in only two trenches, decreasing the width of the pipeline ROW.

As the Project develops, the proposed routing will be refined, as additional data is collected, and final alignment and preconstruction surveys are undertaken.

5.4.2 Onshore Export Pipelines

The main export pipeline system will consist of separate gas and condensate pipelines connecting the CPF to the downstream LNG plant. Two early scenarios considered and discarded due to environmental, social, logistical and safety constraints were:

- An onshore route only – this scenario considered a fully onshore export pipeline alignment from the CPF to the LNG plant near Port Moresby. This option was found to have the following disadvantages:
  - Many coastal areas are swampy and would present severe logistical challenges.
  - Many rivers drain Gulf Province and would need to be crossed.
  - More land would need to be acquired and more adverse community impacts would occur.
- A Purari River route – this scenario was an adaptation of the onshore route above and considered laying the pipelines in the Purari River. In this case, the disadvantages were:
  - The water level in the Purari River is prone to seasonal variations, which could destabilize the pipelines.
  - Accidents may occur due to boat anchors and fishermen's nets damaging the pipelines or others' property.

After discarding the fully onshore options, the Project considered laying the pipelines from the CPF to the Gulf of Papua coast, where they would connect to offshore pipelines. This approach would minimize the clearing footprint, the social implications and the engineering challenges of onshore routing.

Assessing these options began with identifying a western alignment to Orokolo Bay and a central alignment crossing the Vailala River and up to the Bluff coastline (Figure 5.5), which were ranked for social and environmental sensitivities, pipeline constructability and environmental (e.g., flooding, geophysical) constraints. This study determined that the western alignment to Orokolo Bay was preferred, as it had a lesser risk of landslides and had a significantly shorter onshore section (i.e., 60 km compared to 94 km) and thus was more commercially advantageous and generating less onshore footprint.

While the northern part of the western alignment largely followed an existing logging trail to minimize the disturbance footprint, the coastline south of the alignment has villages, marshes (including mangroves) and cultural sites, resulting in a risk of increased adverse impact on communities and the environment if a suboptimal crossing location was chosen.

ONSHORE EXPORT PIPELINE OPTIONS

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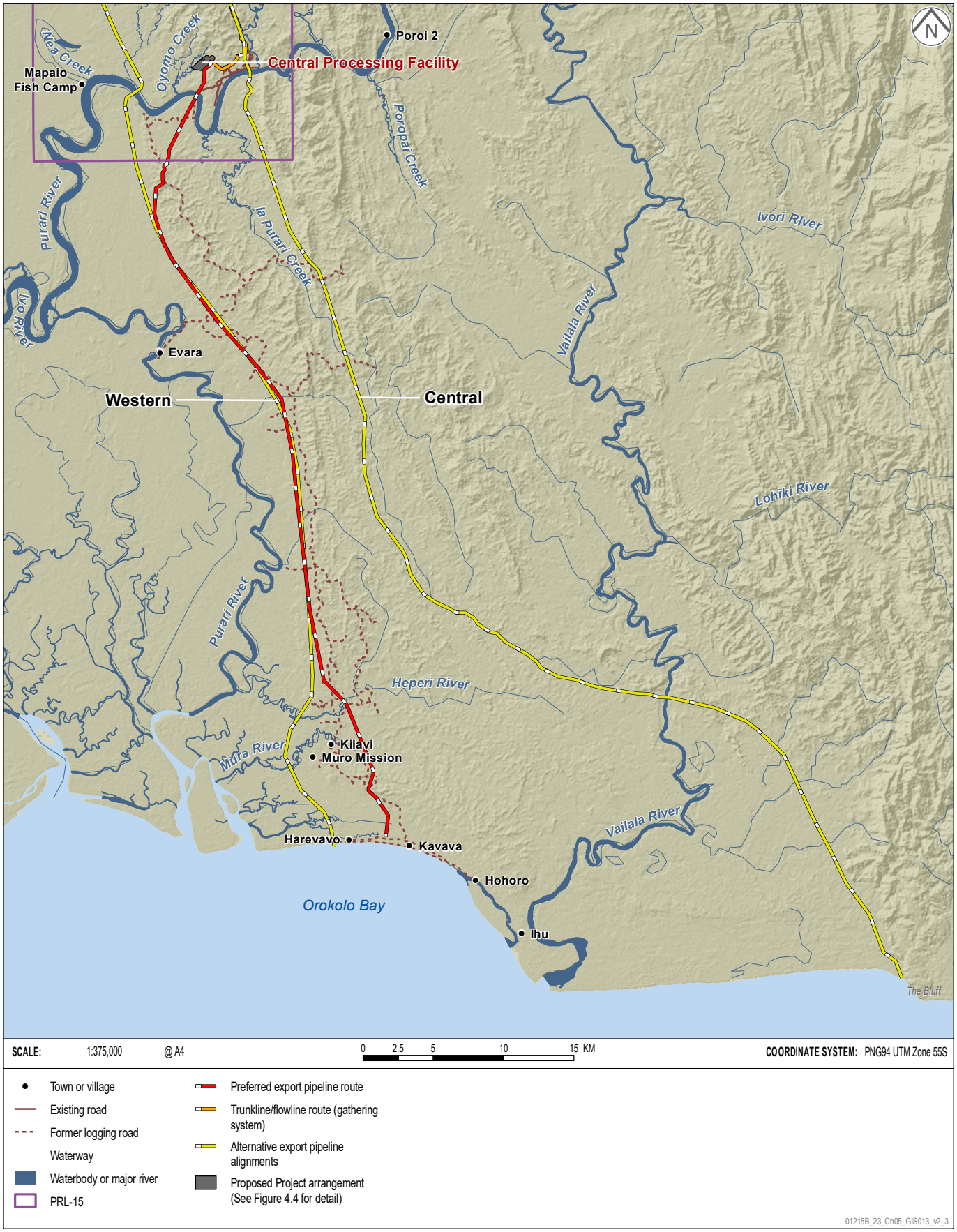
FIGURE 5.5



An early buffer forming a corridor was applied around the western alignment to support the assessment of social and environmental sensitivities. Constraints mapping was undertaken to optimize the corridor in the southern section from the village of Kilave to the coast at Orokolo Bay where the corridor was narrowed further. This refined export pipeline corridor, extending from approximately 2 km west of the village of Harevava in the west of Orokolo Bay to the village of Hororo in the east was the area mapped and characterized during the environmental and social baseline surveys (see Chapters 7 to 10).

Several potential alignments in this corridor were ranked according to their environmental and social sensitivity to determine the most appropriate shore crossing location for the pipelines. The Project team used this ranking to inform the final alignment recommendation. Figure 5.6 and Table 7.10 show the five route options considered. It shows that corridor E crosses sensitive herbaceous swamps and mangrove areas, and corridors A, B, C and D intersect with cultural sites and populated areas.

This assessment concluded that corridor B, passing between the villages of Iuku and Mareke, was the most suitable alignment. Environmental and social sensitivities are still present in corridor B, but this corridor is likely to cause the fewest potential adverse social, cultural and environmental impacts, provided cultural sites can be avoided (Table 5.9).

Table 5.9 – Onshore Export Pipeline Shore Crossing Alternatives Analysis Summary

Criteria	A	B	C	D	E
Technical or logistical difficulty	Low	Low	Low	Med	Low
Environmental sensitivity	High	Low	Low	Low	High
Social sensitivity	Med	Med	High	Med	Med

A narrower export pipeline corridor and proposed export pipeline route were defined based upon this preferred alignment, after further Project development and refinement. These form the 'base case' in the Project description (see Chapter 4). The proposed routing is expected to be adjusted slightly within the export pipeline corridor during the FEED phase to include all the findings from geophysical and geotechnical pipeline surveys. Thereafter, any further adjustments made, in response to unknown environmental and social sensitivities that are identified during the Detailed Design phase and preconstruction surveys, will be to avoid any localized sensitivities.

5.4.3 Offshore Export Pipelines

The offshore export pipelines route extends for approximately 260 km from Orokolo Bay to the PNG LNG Facilities in Caution Bay. Route selection for the offshore pipelines was informed by the following criteria:

- Selecting an appropriate site for the LNG facilities.
- Identifying the shore crossing in Orokolo Bay and Caution Bay.
- Remaining at least 5 km from shore to avoid interference with customary land and community livelihood activities.
- Optimizing the pipeline length to be as short as practicable.
- Maintaining a minimum distance of 100 m between the PNG LNG Gas Pipeline and the Project pipelines.

EXPORT PIPELINE CORRIDOR ORKOLO BAY SHORE CROSSING ALTERNATIVES

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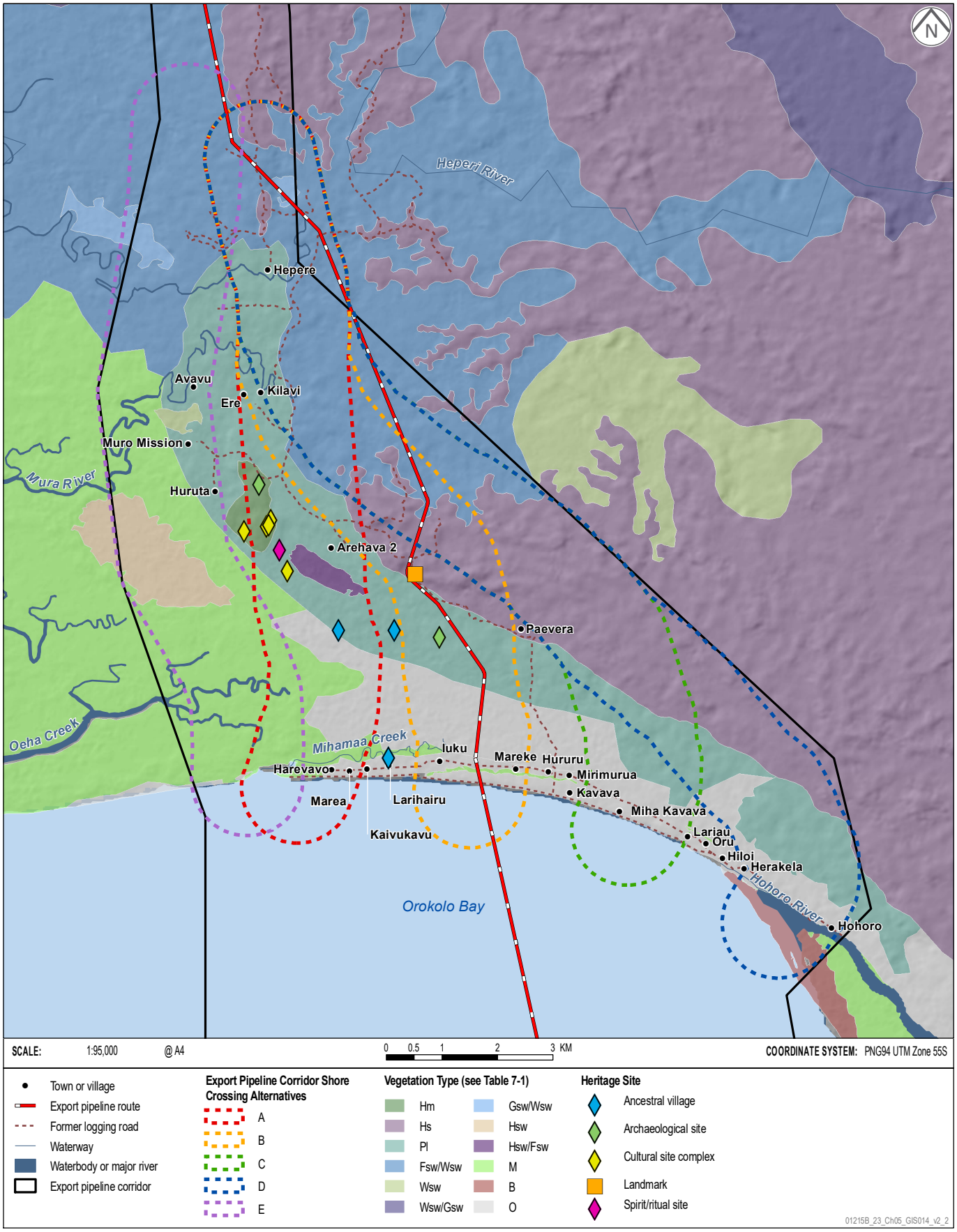
FIGURE 5.6



- Maintaining the crossing angle of the existing PNG LNG Gas Pipeline at between 60° and 90°.
- Minimizing the pipeline depth as much as practicable.

Seven route options were studied in 2017 to assess how well they met these design criteria. This analysis initially preferred option 7, assessed alongside option 2, because it was the shortest route and remained in shallower water until it crossed the PNG LNG Gas Pipeline.

An additional analysis was then performed using marine geophysical survey data collected for the PNG LNG Gas Pipeline, which highlighted that the option 7 corridor showed several seabed surface disturbances (i.e., depressions or pockmarks) and soil variations, which needed to be avoided to prevent free spans of the laid pipeline.

Option 2 was finally selected as it minimized pipeline length, avoided geohazards and used the existing PNG LNG pipeline corridor as much as possible (Table 5.10).

Table 5.10 – Offshore Export Pipeline Alternatives Analysis Summary

Criteria	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Technical or logistical difficulty	Med	Low	Med	Med	Med	Med	Med
Environmental sensitivity	Low	Low	Low	Low	Low	Low	Low
Social sensitivity	Low	Low	Low	Low	Low	Low	Low

Further surveys during FEED will be undertaken to refine the Caution Bay shore crossing in particular to avoid the sensitive marine and coastal environments in this area as much as practicable.

5.5 Process and Technology Alternatives

5.5.1 Acid Gas Management

The gas produced from the Elk-Antelope reservoirs contains native carbon dioxide (CO_2) and hydrogen sulfide (H_2S) and is referred to as acid gas. It must be removed prior to liquefaction to achieve the technical and commercial specification of less than 45 ppm for CO_2 and less than 3 ppm for H_2S.

5.5.1.1 Acid-gas Removal and Management

A commonly used technology to remove acid gas is to route it to an acid gas removal unit (AGRU) where it passes through amine, which absorbs the H_2S and CO_2. Several options were and are still being assessed that variously consider acid gas removal, e.g., incineration and injection:

- Full Incineration: The acid gas is treated with a thermal oxidizer and vented to the atmosphere.
- Partial Reinjection: Incineration, followed by acid gas reinjection into the reservoir after approximately 4 years.

In the case of full incineration, the entire flow of effluent gases from the AGRU is routed to the thermal oxidizer for combustion without sulfur removal causing full venting of acid gases for the life of the Project.

Carbon dioxide and H_2S injection back into the reservoir can be considered where technologically feasible in a cost-effective manner. The capacity of the reservoirs to accept injected CO_2 and H_2S was studied during the pre-Project phase. It was found that, although acid gas could potentially be injected into the Antelope reservoir from the beginning of gas production, injected acid gases are expected to rise to the surface with hydrocarbon gases after a few years, thereby potentially significantly increasing the CO_2 and H_2S content of the produced raw gas. This would then force the installation of a much larger amine unit and other design changes, and increase the power requirements for both gas production and reinjection. This option has been rejected, as this would significantly increasing the need for fuel gas and consequently the release of flue gas in the atmosphere.

The injection study showed that, after approximately four years of Elk reservoir depletion, sufficient capacity would be available for CO_2 and H_2S injection. The subsurface studies showed that the Elk reservoir appears to be independent from the Antelope reservoir, so the likelihood of CO_2 and H_2S circulation into the Antelope reservoir during ongoing production seems low. The actual separate behavior of both reservoirs will have to be assessed during the first years of production.

The outcome of the preliminary acid gas management assessment highlighted the relative differences between potential acid gas management concepts with respect to CO_2 as the primary greenhouse gas (Table 5.11), rather than in association with H_2S/SO_2, which have different management requirements; this is discussed further in Section 5.5.1.2. In any case, most of the SO_2 will be removed to minimize any adverse impacts of SO_2 emissions on sensitive receptors near the Project.

Table 5.11 – Indicative GHG Emissions Over the Project Lifetime

Concept	CO_2 (kt)
Full incineration	30
Partial reinjection	16

The partial reinjection concept has been further developed in the EIS to address GHG requirements; however, all concepts are being investigated further as a better understanding of the following Project characteristics and requirements is gained during FEED:

- Reservoir characteristics.
- More detailed project design considerations.
- The cost implications of each concept.
- Ongoing technological advances.
- Potential environmental benefits.
- Production constraints.

5.5.1.2 Sulfur Removal and Treatment

Options that would allow acid gas to be safely discharged to the atmosphere in case of acid gas incineration have and are still being investigated. Acid gas would go from the AGRU through a thermal oxidizer to convert sulfur compounds including H_2S into SO_2.

The main options assessed to manage the SO_2 are:

- Venting SO_2 to the atmosphere.
- Solid sulfur disposal in a landfill.

- Converting SO_2 to liquid effluent (flue gas desulfurization) for injection with produced water.

The results are summarized in Table 5.12.

Table 5.12 – Sulfur Removal and Treatment Alternatives Analysis Summary

Criteria	Venting SO_2 to the Atmosphere	Solid Sulfur in a Landfill	Conversion of SO_2 to a Liquid Effluent for Injection
Technical or logistical difficulty	Low	High	High
Environmental sensitivity	Assessment Ongoing	Med	Low
Social sensitivity	Med*	Low*	Low

* While direct impacts on communities are likely to be medium or low (respectively) for these scenarios, any potential adverse impacts to vegetation, due to sulfur emissions, could raise stakeholder concerns from both Project-affected communities and the wider public.

Sulfur dioxide venting to the atmosphere would reduce the CPF complexity and footprint and would avoid constructing a solid sulfur landfill and vegetation clearing. No solid sulfur handling would be required; however, venting SO_2 is likely to raise community concern due to the pungent odor, and has potential adverse health and environmental effects (e.g., acid rain).

Producing and disposing of solid sulfur presents several challenges, including:

- The operational complexities associated with a remote location.
- The low sulfur content of the acid gas (e.g., when compared to acid gases from a refinery) did not allow a technology to be selected that would produce marketable solid sulfur.
- No market for low-quality sulfur was known in Papua New Guinea.
- The absence of a suitable existing landfill for solid sulfur in Papua New Guinea.
- Solid sulfur, if sent for disposal elsewhere would require loading and transporting by barge up to seven tonnes per day. This would lead to additional combustion impacts associated with the transport of solid sulfur.

The overall approach of venting or sulfur recovery and landfill construction was also compared to an option of flue gas desulfurization, consisting of converting SO_2 to a liquid effluent. This option minimizes the need to vent SO_2, as the flue gas desulfurization liquid effluent can be injected with the produced water into the Antelope reservoir at ANT-11. It also reduces potential land disturbance and removes any adverse environmental impacts associated with the solid sulfur landfill. The SO_2 conversion into a liquid effluent via desulfurization, followed by reinjection with produced water, has been further developed in the EIS to address air quality requirements.

5.5.2 Produced Water Management

While the reservoirs are not expected to produce a large volume of water during production (i.e., produced water), the process of treating acid gas at the CPF will create a small volume of sulfur- and hydrocarbon-contaminated process water. The feasibility of injecting this water, and the treatment required for both injection and discharge of both produced and process water was evaluated. The study examined the following options:

- Option 1 – Reed bed (natural infrastructure) technology is considered to have an insufficient level of maturity, has not been proved by TOTAL and has a perceived lack of benefit compared with conventional biological treatment.
- Option 2 – Discharge on soils or irrigation is only recommended for very low water flow rates and when there is no river or sea nearby for disposal.

- Option 3 – Solar or mechanical evaporation is unlikely to be feasible in the Papua New Guinea context, given the rainfall rate is much higher than the evaporation rate. Further, a huge surface area of approximately 600 m by 300 m at the CPF or 500 m by 300 m at the LNG plant would be required to install evaporation ponds, resulting in greater vegetation clearing.
- Option 4 – Dilution during upset conditions involves the use of open drain water to dilute treated produced water prior to discharge during upset conditions. TEP PNG considers this option to be unacceptable even during degraded mode operations.
- Option 5 – Discharge to the sea would require additional pipelines to be installed and a costly water treatment plant to be installed so that discharged water can meet water quality specifications.
- Option 6 – Discharge to the Purari River would require a costly water treatment plant to be installed so that discharged water can meet water quality specifications.
- Option 7 – Full reinjection minimizes the potential negative effects on the receiving environment and the Project-affected communities that use it for fishing, drinking water and transportation.

Table 5.13 summarizes the analysis undertaken.

Table 5.13 – Produced Water Management Alternatives Analysis Summary

Criteria	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Technical or logistical difficulty	High	Med	High	Low	Med	High	Med
Environmental sensitivity	Low	Med	High	High	Med	High	Low
Social sensitivity	Low	Low	Med	High	Med	High	Low

Injection of all produced and process water, i.e., Option 7, was therefore adopted as the preferred option for normal operations. The Project proposes to reuse an appraisal-phase pad for water injection and collocating the water injection pipeline in the same trench as the trunkline (Section 5.4.1.2) pipeline for much of its length.

5.6 Construction Alternatives

5.6.1 Quarries

Constructing the upstream facilities will require a large volume of aggregate to provide a firm foundation for process equipment. Locations and layouts for these facilities have been chosen in part to minimize the need for aggregate by reusing excavated material and placing heavy equipment on naturally firmer areas.

Suitable quarry locations were sought near the CPF to limit the import of aggregate by river from outside the Project area. In identifying quarries, preference was given to existing quarries to reduce disturbance. Quarry locations (see Figure 4.11) were identified through several detailed geotechnical earthworks studies that estimated cut and fill volumes for the roads, wellpads, CPF, Purari airstrip extension and the Logistics Base; by analyzing material composition; and by considering environmental and social sensitivities.

Thirteen quarry locations (i.e., seven inside and six outside of PRL-15) were screened. Four quarries inside PRL-15 (see Figure 4.11) may be developed to supply construction backfill

material for the Project because of their reliability, accessibility, material suitability and lesser environmental sensitivities. The remaining rocky material will be sourced from off-site quarries described in Section 4.8.4.3 after further assessment of aggregate requirements and an analysis of environmental and social constraints during FEED.

5.6.2 River Crossings and Shore Crossings

Constructing the export pipelines will require crossing the Purari River and several small streams. Several different options for constructing the Purari River crossing were studied during the pre-Project phase, including horizontal directional drilling (HDD), micro-tunneling, direct piping and a bridge (Table 5.14).

Table 5.14 – Purari River Crossing Construction Alternatives Analysis Summary

Criteria	HDD	Micro-tunneling	Direct Pipe	Bridge
Technical or logistical difficulty	Med	Med	High	Med
Environmental sensitivity	Med	Med	Med	Low
Social sensitivity	Low	Low	Low	High

HDD was selected as the preferred technology for the Purari River crossing due to its lower cost and its significant successful track record compared to micro-tunneling.

Three routes across the Purari River were evaluated for their suitability for HDD construction (Figure 5.7). The eastern and western routes were discounted due to a low-lying, muddy entry platform required for the eastern route and the longer length of HDD required for both. The central route was chosen as the preferred route because of the gravel material available on the hills above the Purari River, which will provide a good platform with adequate drainage for construction, and because it is the shortest route.

HDD, micro-tunneling, direct pipe and open trench construction methods were assessed for the Orokolo Bay shore crossing. The Project team determined that no strong drivers for underground techniques existed, as the pipelines cross the coastline between two villages.

The open trench construction method is; the overall preferred option for Orokolo Bay shore crossing, due to technical and cost advantages (Table 5.15), despite its higher social sensitivity. With an open trench, local communities may experience temporary access restrictions, and increased exposure during the construction works; which are further assessed in Chapter 13.

Table 5.15 – Pipeline Shore Crossing Approach Construction Alternatives Analysis Summary

Criteria	HDD	Micro-tunneling	Direct Pipe	Open Trench
Technical or logistical difficulty	Med	Med	High	Low
Environmental sensitivity	Low	Low	Low	Low
Social sensitivity	Med	Med	Med	High

The Papua LNG downstream EIS shall address the Caution Bay shore-crossing construction methods.

PURARI RIVER CROSSING ALTERNATIVES

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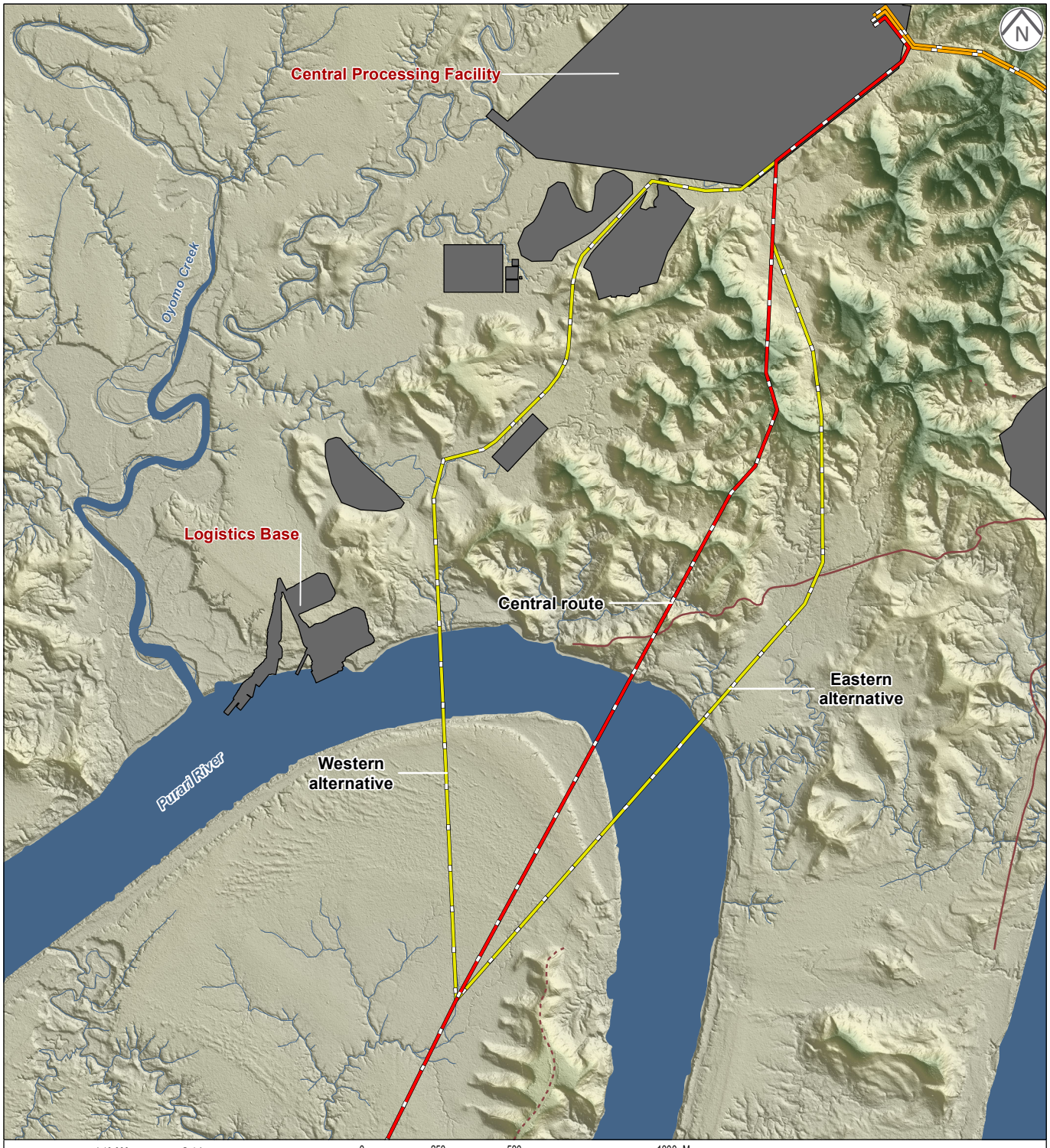
FIGURE 5.7



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- Existing road
- Former logging road
- Waterway
- Waterbody or major river
- Preferred export pipeline route
- Trunkline/flowline route
- Alternative export pipeline route
- Proposed Project arrangement (See Figure 4.4 for detail)

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5.7 Transportation and Logistics Options

5.7.1 Air Transport

Air transport of personnel will be an important component of Project logistics due to the remoteness of PRL-15, particularly during the construction phase when peak personnel requirements are estimated to be up to 6,000.

Air transport was determined to be the most feasible option for personnel transport. Consideration was given to fast crew boats, which can make the trip from Port Moresby in 1 to 2 days; however, this was deemed impracticable due to the large number of personnel required during the construction phase. Road access from Port Moresby is currently impossible and 100 to 150 km sections of road from Kerema would have to be built, which would be very costly, have significant environmental and social impact both in construction and operations, and still result in long transportation times and associated risks of accidents.

The existing airfield in PRL-15 is also currently too small to land the larger aircraft required to meet the personnel transfer demand during the construction period.

The following three options for personnel transport during construction were subsequently assessed:

- Option 1 – Develop a new 1,800-m Code 2 airstrip located on the same side of the Purari River as the CPF, new logistics base and accommodation.
- Option 2 – Use and expand the existing airstrip on the southern side of the Purari River to Code 2. This option requires upgrading the existing ramp to allow personnel to be transported across the river to the new logistics base. It would allow emergency landings of Code 3 aircraft.
- Option 3 – Design and build a new smaller Code 1 airstrip north of the Purari River while also upgrading the existing Code 1 airstrip south of the river, which would be used only during the construction phase.

TEP PNG undertook a qualitative analysis of these options, which considered:

- Technological hazards – landslide and flood risks, and soil quality.
- Human exposure – impacts on nearby communities, the risk to personnel associated with the river crossing and the access to medical evacuation.
- Logistics transport – the ease and comfort for personnel, and the access in case of unplanned or emergency events at site.
- Operational complexity – the operations of aviators for landing and takeoff operations, the access for maintenance and fueling, and the constraints associated with two airstrips operating simultaneously.
- Construction hazards – earthworks required, the access to the temporary construction camps and construction areas, construction permissions and the access to expand areas if required.
- Environmental and social impacts – of affecting new areas, on communities during the construction and also of continuously using the river, especially during the peak of the construction phase.

Results are summarized in Table 5.16, and the new and existing airstrip layouts, overlain with vegetation types are shown in Figure 5.8.

NEW AND EXISTING AIRSTRIP LAYOUT COMPARISON

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FIGURE 5.8

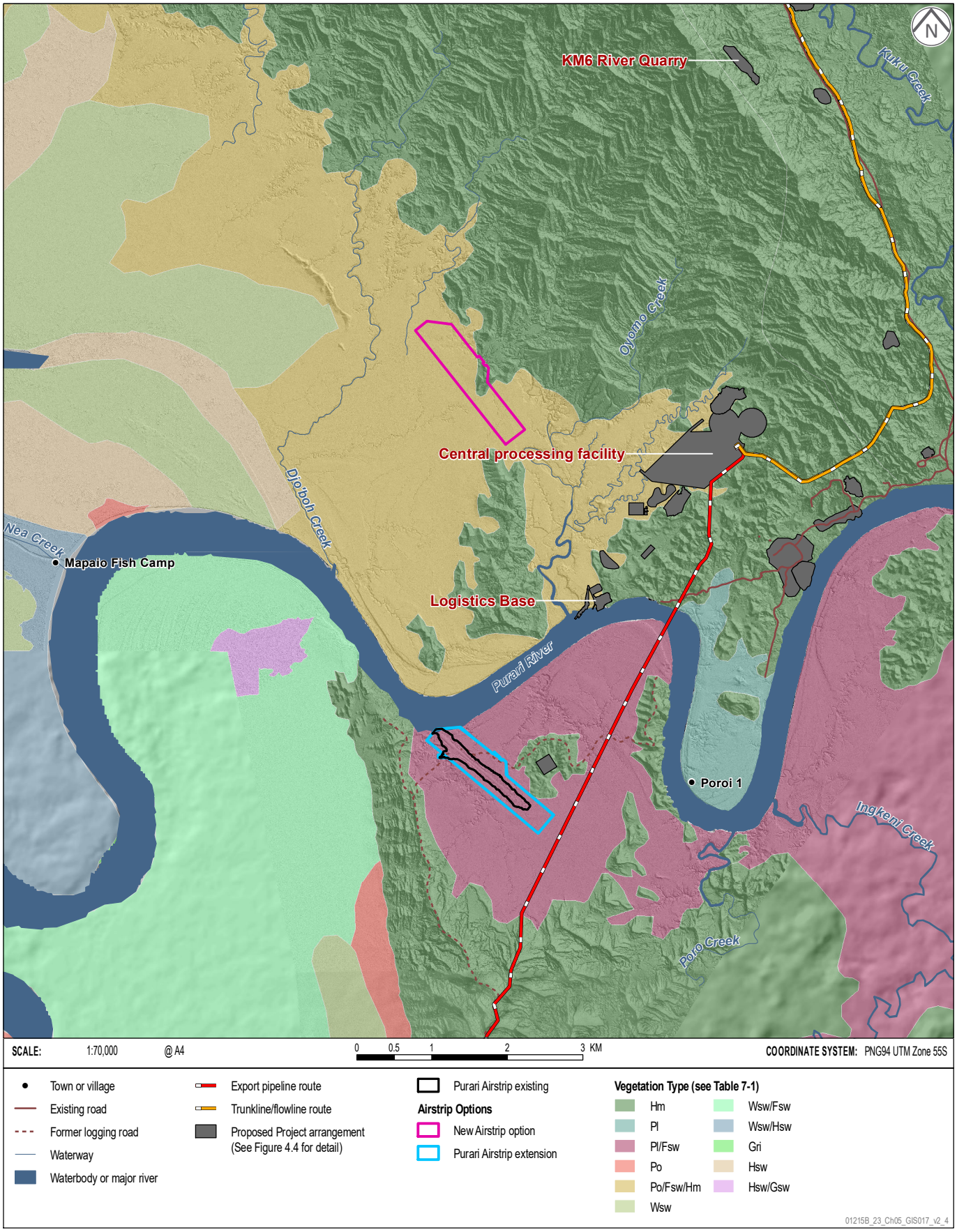

Table 5.16 – Airstrip Alternatives Analysis Summary

Criteria	Option 1 (New)	Option 2 (Existing)	Option 3 (Combination)
Technical or logistical difficulty	Med	High	High
Environmental sensitivity	High	Med	High
Social sensitivity	Med	Med	Med

Option 3 was discarded because of its limitations (e.g., emergency evacuation and transportation of materials).

Option 1 of a new airstrip north of the Purari River was the preferred option to negate the need for personnel transfers across the river; however, it carried significant adverse environmental and social impacts, e.g., the need to clear a large area of vegetation, and its closeness to the environmentally sensitive PRL-15 oxbow wetlands.

Option 2, involving the upgrade of the existing airstrip to Code 2 (see Section 4.8.7), is the preferred option because of its lower capital costs and reduced environmental footprint (Figure 5.8). The Purari Airstrip House is the nearest receptor and Poroi 1 is the nearest village to the existing Purari Airstrip. Potential impacts associated with noise and air quality are discussed and assessed in Chapter 15.

5.7.2 Water Transport

Equipment and construction materials will be stored at either the Motukea supply base or the Avenell Engineering Systems (AES) supply base 3 km away. Materials and equipment will be barged across the Gulf of Papua and up the Purari River to PRL-15 from either of these bases.

The Purari River finishes in a complex delta with many arms, and there are several entry points from the sea. An analysis of river transport routes was undertaken to assess the best option for transporting equipment from the Motukea or AES base to the logistics base.

Three branches were assessed for navigability and their capacity to support high-draught barges: the Purari River (eastern branch), the Urika-Ivo River (central branch) and the Wame-Varoi River (western branch) (see Figure 4.15).

Water level variability is a key issue with water transport on the Purari River and its delta rivers. Water levels can change very quickly and are not seasonally predictable.

The analysis initially recommended the Ivo as the most navigable route for river transport, but the preferred route is via the Aiele Passage and the lower Purari River. Local vessel masters currently use this route, which has a river mouth crossing that is considered easier than the Ivo river mouth crossing. The Urika-Ivo River is; therefore, considered as a secondary transport route to be used when the lower Purari River is not navigable, and the Wame-Varoi is unlikely to be used for Project transport.

5.8 No-Project Option

The direct alternative to developing this Project is for it not to proceed. If the Project failed to go forward, no adverse environmental or social impacts associated with Project development in Papua New Guinea would occur, as no construction or operational activities would take place; however, this needs to be balanced against the fact that no beneficial impacts associated with the Project would occur. Should the Project not proceed, the following benefits would not be realized:

- Up to an estimated 6000 jobs during peak construction.

- Direct benefits to national and provincial governments, and legally recognized landowners through equity, royalty and development levy benefits.
- A direct contribution of up to 5% of the exported gas to Papua New Guinean electrical power generation.
- National business development opportunities through supply of equipment and materials required for construction and operations.
- Socio-economic development of communities in the Project area.

The no-Project option also means that any adverse impacts associated with the Project, as outlined in Chapters 11 to 18, would not occur.