Chapter 7

Assessment of Alternatives

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

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

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

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

7. ASSESSMENT OF ALTERNATIVES

Chapter 6, Project Description, presents the current optimised configuration proposed for the Project, one that has been developed in a collaborative, multi-disciplinary process through various concept, pre-feasibility and feasibility studies described in Section 2.2. It is the outcome of many years of detailed exploration and other investigations by the WGJV and previous exploration licence holders.

This chapter provides an overview of the alternatives and the assessment process used to define the Project configuration that is the basis of this EIS.

7.1. Stages in the Assessment of the Project

There are typically three stages in the assessment of a mining project (the 'pre-development' phase), and each stage is usually completed before proceeding to the next.

The three stages comprise the following:

- Concept or scoping stage: The scoping phase of a project, whereby a conceptual mine plan is outlined and potential production outputs and costs are estimated at a high level.
- Pre-feasibility stage: The preliminary assessment phase of a project, whereby more detailed exploration results help to delineate the orebody and proposed mining, processing and waste management methods are identified. Potential significant environmental, social and cultural heritage constraints are also described.
- Feasibility stage: The critical assessment phase of a project used to determine its viability, comprising a detailed mine plan including mining method, production rates, supporting infrastructure and budget forecast. Predicted environmental, social and cultural heritage risks and impacts and potential management measures to address these are also described.

The stages are undertaken in order to:

- Establish the viability of a proposed project
- Define the project in sufficient detail to provide a basis for a forward work plan for further investigations.

If the proposed mining project is found to be feasible, it may proceed to detailed front-end engineering design for all project infrastructure.

7.2. Development Concept

Typical of most resource projects, the development of the Project is subject to a range of constraints that will be influential on the WGJV's capacity to develop the Project successfully, and the extent to which Project stakeholders (local communities and regulators) support its development. These constraints include:

- Physical – The fixed location of the orebody, within a certain landscape and climate
- Environmental – The existing environmental values (e.g., plants, animals, plant communities and water bodies)
- Social – The characteristics, values, lifestyle, expectations and concerns of affected communities
- Cultural heritage – The cultural heritage of the communities that host the Project
- Economic – The Project must be commercially viable

The Project development concept contained in this EIS represents the current optimisation of engineering, economic, environmental and social considerations. Engineering design and other studies, including environmental studies, are continuing and there is potential that aspects of the proposed Project design, layout and timetable – including the alternatives described in this chapter – may change.

7.3. Alternatives Considered

A high-level overview of the alternatives considered for each Project component is provided in Table 7.1, with those subject to detailed consideration described further in the following sections.

Table 7.1: High level overview of alternatives considered

Aspect	Alternatives investigated
Mining method	• Open pit • Underground (sublevel caving, block caving, open stoping)
Ore extraction depth	• Various
Underground access	• Shaft (various locations) • Declines (various locations)
Underground mine layout	• Various decline and shaft designs, production level layouts and drawpoint designs
Tailings management method	• Tailings storage facility (sub-aerial or sub-aqueous deposition) • Dry stacking • Deep sea tailings placement (DSTP)
Terrestrial tailings storage location (45 in total)	• Markham Gap • Markham Farms • Lower Watut River floodplain • Bavaga • Additional regional locations
DSTP outfall location	• Various locations along the Huon Gulf coastline from Singaua (in the north) to Labumiti village (in the south)
Port Facilities Area location	• Various sites within the Lae Tidal Basin • Berth 6 (also known as the Tanker Berth) • Various sites subject to a purchase agreement with a private third party
Concentrate, fuel and terrestrial tailings pipeline alignments	• Various alignments
Concentrate filtrate discharge location	• Lae Tidal Basin • Markham River • 'The Point', located between Markham River and Lae Tidal Basin • Berth 6 (also known as the Tanker Berth)
Ore treatment	• Solvent extraction • Froth flotation • Cyanidation
Ore treatment location	• Mine Area • Lae
Product transport	• Truck • Pipeline
Ventilation	• Shaft or decline (various locations)

Aspect	Alternatives investigated
Site access	• Lower Watut River • Roads (various alignments including Demakwa Access and Wafi Access roads (from the Bululo Highway) and the Northern Access Road and Mine Access Road (from the Highlands Highway))
Power generation	• Third-party provider • Self-generation
Fuel for power generation	• Liquefied natural gas (LNG) • Liquefied petroleum gas (LPG) • Diesel • Intermediate fuel oil (IFO) • Heavy fuel oil (HFO)
Hard rock sources	• River gravels • Borrow pits • Hard rock quarry • Third-party supply
Accommodation facility	• Various locations

7.3.1. Assessment of Mineral Deposits

Drilling has identified four main deposits within Exploration Licences 440 and 1105 held by the WGJV:

- Wafi: a high sulphidation epithermal gold deposit
- Link Zone: a mineralised gold quartz vein array
- Golpu: a mineralised porphyry copper-gold deposit
- Nambonga: a mineralised porphyry copper-gold deposit

The Wafi and Link Zone deposits were the early focus for potential development. These deposits were discovered in the 1970s and, being located close to the ground surface, were proposed to be mined by open pit.

The Golpu deposit is the most advanced and economically significant of the deposits. Because of its mineralogy, size and grade, the Golpu deposit was quickly recognised as having the best combination of attributes to sustain the first commercial mining development, and is the subject of the current Project description outlined in this EIS (see Chapter 6, Project Description).

While not the subject of this EIS, there is potential for future development of the Wafi, Link Zone and Nambonga orebodies which will be the subject of future assessments by the WGJV. Should WGJV in future propose developing any of those other orebodies, it would be subject to separate approval under the *Environment Act 2000* by the Independent State of Papua New Guinea.

7.3.2. Mining Method

Large-scale open pit mining, sub-level cave operation and block-cave mining have all been considered as methods for mining the Golpu deposit.

7.3.2.1. Open Pit Mining

The concept study undertaken by the WGJV in 2009 considered large-scale open pit mining to access the Golpu deposit, however it was assessed not to be economically viable at that time due to a range of technical and cost considerations including:

- The significant depth of the Golpu deposit
- Extremely high pre-strip ratio to remove overburden
- The difficulty to safely store the large volume of potentially acid forming (PAF) waste rock produced, increasing the potential for acid and metalliferous drainage (AMD) and consequent environmental and social impacts unless managed appropriately.

7.3.2.2. Underground Mining

Investigations then shifted to consideration of underground mining to access the Golpu deposit.

Block cave underground mining was identified as the underground mining method more suited to the deposit, and has become the preferred mining method for the Project. Block caving is a low-cost, bulk mining method that minimises the mine footprint and is generally applied to large, near-vertical orebodies, such as Golpu. The extraction level is established at the bottom of the ore block to be mined and is used for the entire life of the block. The use of the block cave method will also avoid ore extraction from within the cap zone of the Golpu deposit, which is the zone of ore that contains high arsenic concentrations.

The use of the block cave underground mining method will reduce the surface footprint of the Project in comparison to open pit mining and large-scale sub-level cave underground mining, and significantly reduce the amount of waste rock generated by the Project.

7.3.3. Production Rate

Capital and operating costs are largely related to the rate of production. Studies have been undertaken to assess the Project viability at different production rates ranging from 3 to 20Mtpa.

Further optimisation of the commercial production rate was undertaken in the Feasibility Study Update (2018) as part of a wider scope of work. After considering multiple factors, including tailings management options, water supply volumes and power generation capacity, the Feasibility Study Update confirmed a viable Project business case based on a process plant design production rate of 16.84Mtpa.

The WGJV proposes mining the Golpu deposit via three block caves (BC 44, BC 42 and BC 40) in a multi-stage operation, for which the production rate will ramp up over the first five years of operations to achieve the process plant design production rate of 16.84Mtpa.

7.3.4. Tailings Management

The proposed mine is predicted to generate approximately 360 million tonnes (Mt) of tailings solids (dry weight basis) over the 28-year life from first production of the processing plant (excluding construction and closure phases). The characteristics of the tailings solids require that the tailings are managed in a low risk and environmentally secure manner that is also economically feasible.

Based on a desire to minimise impacts on the biophysical and social environment and cultural heritage and adopt the option with the lowest construction, operational, and post closure risks, WGJV has decided to adopt deep sea tailings placement (DSTP) as the preferred tailings management option for the Project.

The following section provides an assessment of the tailings management options that have been considered for the Project. To place tailings management alternatives in context, considerations for tailings management are discussed generally before the available methods for on-land and deep sea tailings management are described. Finally, the alternative conceptual designs that have been investigated for the Project are discussed, including the evaluation of their respective costs, risk profiles and possible environmental, social and cultural impacts. Together, this represents WGJV's basis for the selection of DSTP as the preferred tailings management option for the Project.

7.3.4.1. Considerations for Tailings Management

The selection of a tailings management solution requires careful consideration of a range of factors, as outlined in the following sub-sections.

7.3.4.1.1. Context

The production of tailings is a consequence of ore processing. Tailings management planning needs to be conducted over a life of mine timescale where the potential effects on the natural and social environment are considered in design, construction, operations and closure. In the post-closure period, the long-term fate of the tailings and the long-term maintenance of a tailings storage facility (TSF), if relevant, also requires consideration.

7.3.4.1.2. Characteristics of the Tailings

The Wafi Golpu tailings slurry will comprise mostly silt-sized fragments of mined ore after the economically recoverable metals and minerals have been removed, in a suspension of process water.

The ore contains sulphide minerals, most of which will be removed during ore processing but, depending on the rock types being processed, there will be periods when high levels of sulphide minerals such as pyrite will remain in the tailings. If reactive sulphide minerals in the tailings are exposed to both air and water, oxidation will occur which can lead to formation of acid and metalliferous drainage (AMD), high sulphate concentrations and elevated concentrations of dissolved metals.

It has been estimated (Beca, 2017) that ore processed from Years 1 to 10 will produce tailings that are non-acid forming (NAF); however, ore processed from Years 11 to 28 will produce tailings that are PAF.

Generally, the potential for oxidation of reactive sulphides in the tailings may be minimised by:

- Permanent underwater storage, or
- Encapsulation of PAF materials using a cover that effectively seals off the reactive sulphides in the tailings from both oxygen and water.

For on-land storage of tailings, this means engineered cover systems that must maintain their integrity in perpetuity. For DSTP, placing the tailings on the ocean floor minimises the potential for oxidation without the need to maintain a storage and treatment facility in perpetuity.

7.3.4.1.3. Earthquakes

Papua New Guinea is bounded by several major tectonic plates and is one of the most seismically active regions in the world (World Bank, 2008). There are two main sources of earthquakes that could occur in the vicinity of the Project Area:

- Crustal events that occur in areas away from plate contacts and have produced earthquakes up to magnitude 7.7 on the Richter scale (SRK, 2007)
- Subduction events that occur due to the subduction of the Pacific Plate at the interface between the Pacific Plate and the overriding Indo-Australian Plate, or in the intra-slab zones within the subducting Pacific Plate. These events have produced earthquakes up to magnitude 8.4 on the Richter scale (SRK, 2007)

Earthquakes are common along the Ramu-Markham Fault and the subduction zone of the New Britain Trench. Between 1900 and 2010 there have been 22 Magnitude 7.5+ earthquakes recorded in the New Guinea region[1], of which four (18%) have occurred in and around the New Britain Trench (see Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf).

There is a history of earthquake-induced landslides, tsunamis and related hazards in the Huon Peninsula region (as described by Buleka et al., 1999). Large earthquakes causing landslides in the mountainous catchments of the Markham, Butibum and Busu rivers have augmented the sediment loads carried by these rivers. Changes in river loads, and floods related to landslide dam breaches have caused damage to Lae and its roads and bridges, especially in the Butibum and Busu river floodplains.

The region’s high seismic risk increases the complexity and cost of engineering due to elevated earthquake loading for on-land tailings storage options as compared, say, to the goldfields of Western Australia. Any on-land tailings containment structure needs to be designed and engineered to be able to withstand the following design earthquakes and associated earthquake loading as outlined in the guidelines on tailings dams formulated by the Australian National Committee on Large Dams (ANCOLD, 2012):

- The Operating Basis Earthquake (OBE), for which dams should remain serviceable. The OBE is generally expected to cause limited damage/deformations that could be repaired without significantly disrupting operations. The recommended Annual Exceedance Probability (AEP) for design ranges from 1:50 to 1:1,000 determined from the dam failure consequence category, ranging from low to extreme (ANCOLD, 2012).
    - Note that for conventional seismic design analyses, the OBE is defined for a 475 year average earthquake return period (1:475) which relates to a probability of exceedance of 0.21% annually, 10% over 50 years and 19% over 100 years.
- The Maximum Design Earthquake (MDE), for which dam damage can be more extensive and may disrupt operations, but the structural integrity of the dam needs to be maintained and uncontrolled release of tailings/water should not occur. The recommended design AEP for design ranges from 1:100 to 1:10,000 determined from the dam failure consequence category, ranging from low to extreme (ANCOLD, 2012).
- The Maximum Credible Earthquake (MCE) is the maximum earthquake that could occur at a site as derived from a deterministic seismic analysis. Earthquake events with an AEP of 1:10,000 or greater approach the MCE. For dam closure stability assessments, the MCE should be used for design, but taking into account the expected long term properties of the tailings.

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[1] The region considered extends from 118°E to 168°E, and includes eastern Indonesian Archipelago, Irian Jaya, PNG mainland and islands, Solomon Islands and Vanuatu.

Even more stringent ‘design’ conditions to mitigate the effects of earthquakes may be appropriate if the downstream environmental and social consequences of potential impoundment failure would be severe.

7.3.4.1.4. Tsunamis

Any tailings management infrastructure located on or near the coast could be subject to the effects of tsunamis. Three tsunamis have been observed at Lae since 1906 with the largest occurring in 1972 and associated with a water level rise of 1.5m and slumping of the shoreline at Voco Point (see Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf). Elsewhere in the Huon Gulf, a Magnitude 8 earthquake at the western end of the New Britain Trench, which occurred in 1906, resulted in tsunami waves along the shoreline of the Huon Gulf and also the islands of Tami, Siassi and Umboi.

Slumping of submarine canyon walls or sliding of steep submarine slopes may also be the cause of mini-tsunamis observed in the region, and major submarine slope failure was considered to be the cause of several episodes of breakage of communication cables in the outer Huon Gulf, some 200km to the east of Lae (see Appendix M, Physical, Chemical and Biological Sedimentology of the Huon Gulf).

Tsunami and slope failure risk increases the complexity and cost of engineering for any tailings management solutions involving the placing the tailings on the ocean floor.

7.3.4.1.5. Landforms

The steep mountainous terrain that is typical of PNG is a result of mountains thrust up in a tectonic collision zone between the Indo-Australian and Pacific plates. Rapid weathering and high tropical rainfall have created deeply incised valleys that are subject to high rates of erosion and frequent valley-wall instability. Landslides are common and rivers and streams generally carry heavy sediment loads to the coast. Many streams have steep gradients and are actively ‘downcutting’ (i.e., deepening of the stream channel through hydraulic action) while others are aggrading and flow in braided river channels such as the lower Markham and Busu rivers.

On alluvial floodplains, such as along the Lower Watut and Markham rivers, it is important that tailings containment structures are sited to avoid the active meander belt of the river (i.e., where the river is actively migrating), especially where the containment structure is required to be maintained in perpetuity.

The topography of PNG imposes significant challenges of availability and sufficiency of capacity of suitable sites for any on-land tailings management solution. It also poses constraints to designing DSTP pipelines, where bathymetry must be considered.

7.3.4.1.6. Foundation Conditions

Although foundation conditions are highly site specific, a recurring theme in PNG is the disproportionate occurrence of rocks with weak strength or rocks that disintegrate (slake) on exposure. These, combined with deep tropical weathering and unconsolidated alluvial deposits, can lead to poor ground stability conditions.

Avoidance of liquefaction of the foundation materials under seismic loading (i.e., during an earthquake) is a critical consideration. Liquefaction is the potential for saturated or partially saturated soil losing strength and stiffness as a result of, for example, an earthquake, causing it to behave like a liquid.

Consideration of foundation conditions is applicable to both on-land and DSTP tailings management solutions (with regard to the stability and security of the pipeline infrastructure), but is of particular significance for the design of on-land tailings containment structures given the safety risks to downstream communities in the event of a catastrophic failure of the structure.

7.3.4.1.7. Water Management

Annual rainfall is high to very high in most parts of PNG. Average annual rainfall for the Mine Area is 2,836mm. Analysis of the data from all rainfall measuring sites indicates that average rainfall ranges from 2,059mm/year to 3,478mm/year. Annual evaporation is approximately 2,000mm (BECA, 2017). Therefore, the Mine Area has a substantial water surplus. This means that any tailings containment structure will have to be designed to manage the water surplus during construction, operations and in the post-closure period. Typical criteria for water handling is for a spillway on a tailings containment structure to be designed to safely pass a 1 in 1,000-year return period rainfall event during operations.

Another water management consideration (e.g., for dry stacking of tailings) is the number of rain-free days per month (Golder, 2017). At the Mine Area, the number of rain-free days vary from more than 14 per month in a dry year to more than 7 per month in a wet year (i.e., rainfall at 3,478mm/year).

For on-land storage of tailings, the presence of heavy rainfall is challenging for controlled earthworks to create impervious fill for TSF embankments as well as construction of a dry stack of tailings.

The potential effects of high rainfall conditions are of particular significance for the design of on-land tailings containment structures, particularly for the post-closure period.

Water management is not typically a constraint for DSTP operations.

7.3.4.1.8. Closure Planning

At the end of the life of mine, all tailings management infrastructure needs to be closed in an appropriate and planned way so that unnecessary infrastructure is removed and any structure containing tailings is left physically and chemically stable and in a state able to be maintained in perpetuity.

For infrastructure associated with DSTP, this is a relatively straightforward process of flushing the DSTP outfall pipelines to remove any residual tailings slurry, decommissioning and removing the mix/de-aeration tank and above-ground sections of the pipeline and sealing the ends of the underground pipeline to remain in situ.

For an on-land tailings containment structure, this normally means capping the tailings – or ensuring a water cover in perpetuity – to limit oxidation of reactive sulphides and render the structure resistant to erosion and to withstand a combination of rainfall, runoff, settlement and seismicity. A typical criterion for post-closure water handling on a TSF spillway is to safely pass the maximum probable precipitation event (i.e., typically a 1 in 10,000-year return period rainfall event).

7.3.4.1.9. Environmental, Social and Cultural Heritage Effects

While some disturbance is unavoidable during the management of tailings, WGJV’s primary objective is to avoid, minimise or reduce the effects of the preferred tailings management method on the natural, social and cultural heritage environment with a focus on preserving local peoples’ use of, access to and enjoyment of the environment. This includes consideration of water quality, land use (terrestrial or offshore), ecological values (e.g., gardens, plants, animals and plant communities, including marine ecology), community impacts and impacts to cultural heritage sites.

7.3.4.1.10. Access and Constructability

For TSFs located in remote areas of PNG, gaining access to the site usually involves constructing a road, pipeline and power easements, associated quarries, laydown areas and significant land clearance. These can be challenging if the site is located in rugged terrain with high rainfall. Associated issues can arise such as landslide generation, challenging water management, disposal of excess spoil, sourcing suitable construction materials and the downstream effects of construction activities.

While DSTP outfall sites can also be located in remote areas of PNG, their proximity to a coastline with favourable bathymetry means that gaining access to the DSTP site can be more straightforward. However, there may be challenges with access and constructability linking the mine site with the DSTP site if they are not close to each other.

7.3.4.2. Alternative Tailings Management Methods

A number of tailings management options have been considered during the extensive studies undertaken in relation to the Project:

- On-land storage of tailings:
    - Purpose-built TSF with either sub-aerial[2] or sub-aqueous[3] tailings deposition
    - Dry-stacking of tailings
- Deep sea tailings placement (DSTP)

7.3.4.2.1. On-land Storage of Tailings – General Requirements

For on-land tailings storage (either using a TSF or dry-stacking) for the Project, the following would be required:

- Alienation of land from its existing use for the storage area, for access (roads and pipeline easements), plus quarry or borrow areas for the construction materials and cover material required for closure. The alienation of land from its existing use would be permanent for the storage area.
- Construction of an impoundment structure where the tailings solids can be stored.
- Sub-aerial deposition of tailings during the first ten years of operations when the tailings are NAF and then sub-aqueous tailings deposition when PAF tailings are produced. Maintenance of a water cover over the tailings would be required continuously for the last 18 years of mine life (and potentially in closure depending on capping method). This requires a more complex water retaining impoundment.
- Management of excess water from the storage would be required for the duration of the operating life of the storage facility, and, if suitable, excess water would be discharged to the natural drainage. If water quality is unsuitable for discharge, then treatment would be required prior to discharge. This requirement may extend beyond operations and closure.
- Seepage management would be required during operations with a pump back system or, if required, a treatment plant with disposal of treated effluent to the natural drainage (and potentially indefinitely thereafter).
- Ultimate closure of the facility, including a design cover to encapsulate the reactive sulphides contained in PAF tailings. The surface and any containment embankments would need to be left in a condition that is safe, resistant to erosion and be able to

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[2] Exposed to the atmosphere to promote drying on rain-free days (for NAF tailings only)

[3] Underwater discharge (for PAF tailings)

withstand the effects of extreme rainfall, flood events and earthquakes. Water management would be critical and a closure spillway capable of handling the probably maximum precipitation would be required to be maintained in perpetuity. Seepage may require treatment for a long period beyond closure.

The Hidden Valley Mine is currently the only large mine operating in PNG using on-land tailings storage. Other much smaller gold mines in PNG have operated with on-land tailings storage but most have ceased operations.

Two methods of on-land tailings disposal were not considered for the Project. These were:

- Riverine disposal of tailings: while mines at Ok Tedi, Porgera and Tolukuma use this method, it was not considered due to the potential environmental and social impacts on downstream communities.
- Underground tailings disposal (e.g., paste backfilling) was not considered, as this approach is not feasible for a total tailings stream storage and in block cave mines there is no safe space for any storage above the extraction levels.

The detailed assessments undertaken of different on-land tailings management options are discussed in Section 7.3.4.3 below.

7.3.4.2.2. Deep Sea Tailings Placement (DSTP) – General Requirements

Another option considered for tailings management was DSTP. For DSTP, the following would be required:

- Alienation of land from existing use for the pipeline corridor and coastal facilities (access road, terrestrial tailings pipeline easement to the coast, power supply and DSTP outfall facilities).
- Construction of a choke station and mix/de-aeration tank within approximately 100m of the shoreline.
- Construction of seawater intake and outfall pipelines extending into the ocean to a suitable distance/depth. These would require trenching from the mix/de-aeration tank and a shore crossing with localised shoreline and nearshore effects during construction.
- The passive pre-discharge dilution of the tailings with seawater prior to discharge from the outfall.
- Suitable geophysical and oceanographic conditions that mean that:
  - Once discharged, the tailings slurry would form a coherent density current as it descends the submarine slope below the outfall.
  - Oceanic water would be entrained by the density current making it progressively more dilute as it continues downslope.
  - Some of the tailings (fine solids and liquor) would separate from the descending density current and form very dilute subsurface plumes at different depths in the oceanic water column which would then be transported by oceanic currents and further diluted.
  - The remaining tailings (solids and liquor) would continue as a density current down the submarine slope all the way to the bottom of the canyon and the tailings solids would settle and be mixed with natural sediments.
- At closure, the mixed deposits of tailings and natural sediments are expected to be periodically eroded, re-transported and re-deposited further downslope by the episodic but frequent mass movements and associated turbidity current events. Over time, the

mixed deposits of tailings and natural sediments would eventually be buried by natural sediments.

Deep sea tailings placement is presently used at six mines in four countries. Papua New Guinea has three existing active DSTP operations (Lihir gold mine, Simberi gold mine, Ramu nickel and cobalt mine), one permitted (Woodlark gold project) and one closed (Misima gold mine).

Further details of DSTP, including those mines at which DSTP is in use, are discussed in Section 7.3.4.5 below.

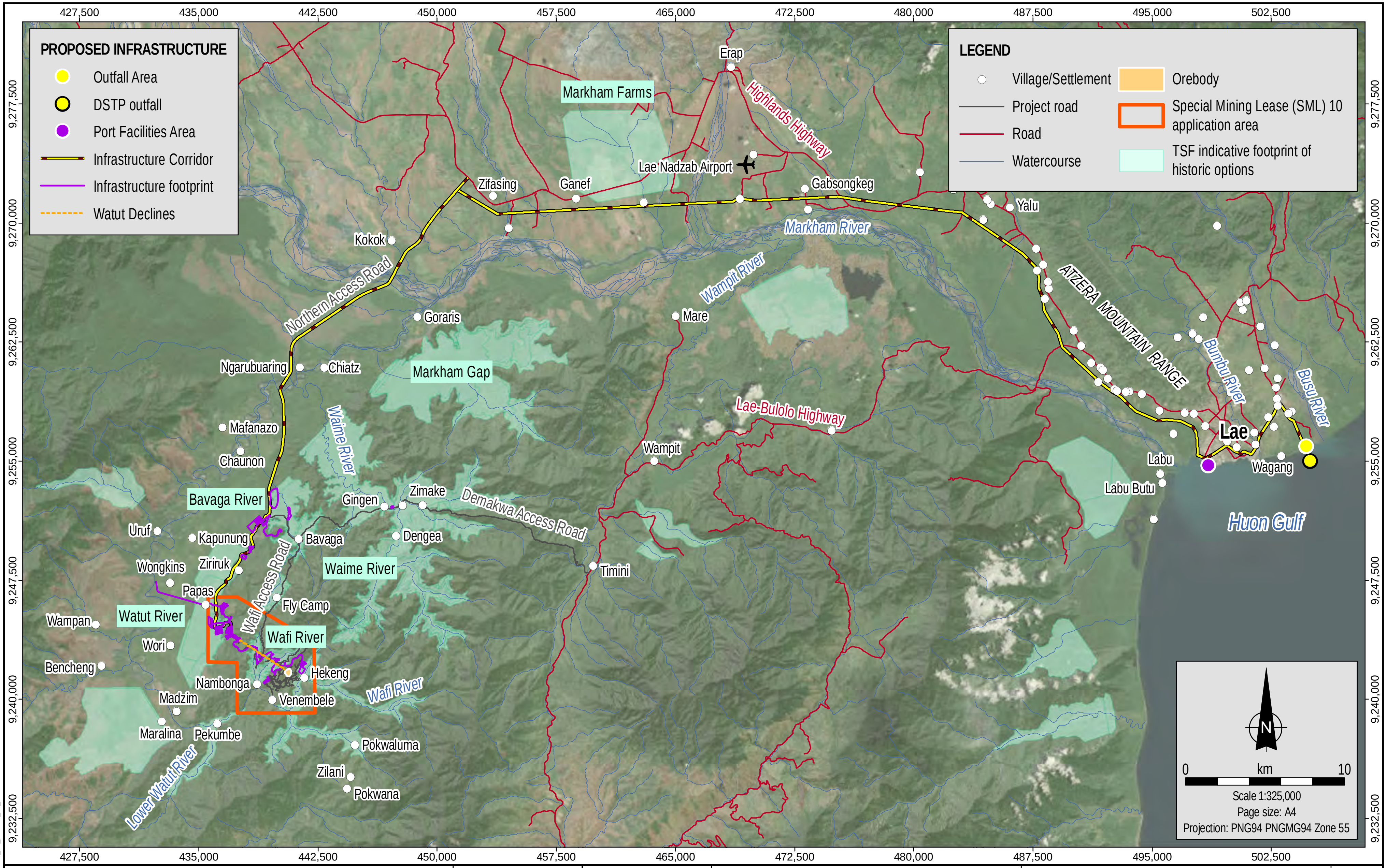
7.3.4.3. On-land Tailings Storage using a Tailings Storage Facility

The consideration of potential sites for a terrestrial TSF has evolved over time as the volume of anticipated life of mine (LOM) tailings requiring permanent storage has fluctuated in parallel with changes to the production rate.

Between 1993 and 2017, 45 terrestrial TSF site options have been assessed for their viability to support a terrestrial TSF for the Project (Figure 7.1) (KCB, 2017; WGJV, 2014 and 2015). Of these, sites within the principal locations of Markham Gap, Markham Farms and the Bavaga River valley were investigated at a pre-feasibility study level, while sites within the Bavaga River valley and the Lower Watut River valley were investigated at a feasibility study level.

The considerations in assessing potential TSF sites at these locations included:

- Safety considerations in relation to seismicity, high rainfall and geotechnical stability and potential impacts to the environment and host communities.
- Topography, catchment area and required storage volume over the proposed LOM, i.e., the capacity to accommodate LOM tailings and potential additional storage capacity requirements for any mine extensions.
- Environmental considerations of the tailings management footprint, including potential impact on biodiversity or other environmental values.
- Social and cultural heritage considerations of the tailings management footprint, including the effect on people’s subsistence and livelihoods.
- Capital, operating cost and closure costs (including the cost of post-closure management and monitoring in perpetuity).
- Distance from the Watut Process Plant.
- Legacy considerations at mine closure, including any residual risks that may need to be actively managed such as water quality and safety/stability considerations.



Source:
TSF options from Coffey (extracted from KCB document).
SML and orebody from WGJV.
Villages, infrastructure and project roads from WGJV and Coffey.
Roads and watercourses from NSO.
Imagery from ArcGIS Online (capture date unknown).

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Tailings storage facility locations historically assessed

Figure No:
7.1

MXD Reference: 0520DD_10_GIS033_v0_6

Four sites passed the initial engineering conceptual study (i.e., storage capacity, cost efficiency and proximity) requirements and were subjected to a more rigorous assessment. Overall, the most important factors arising from studying the various potential TSF sites were:

- The required storage volumes of between 140Mt and 1,000Mt of tailings would result in a large disturbance footprint of between approximately 420ha and 3,375ha over areas which can have high environmental, social and cultural value, and/or would require the displacement of communities and their livelihoods.
- The Project Area has high seismicity and complex geology, including active faulting, which could at some sites result in liquefiable soils. Complex engineering design would be required to partly mitigate such factors, and this complex design would carry high risk and high cost in both construction and ongoing operation.
- The Project Area has high rainfall of over 2,000mm per year and large water catchment areas, which would require significant and costly water management treatment solutions to keep the structure safe and minimise environmental and social impacts to downriver communities. These solutions would need to remain effective in perpetuity. Any structure would contain very large amounts of water with commensurate risks to downstream communities in the event of its catastrophic failure.
- Due to terrain and geotechnical complexity, multiple storage sites and types of tailings management would be required for the LOM solution (currently, 360Mt). Generally, it is more difficult to manage multiple storage sites and types of tailings management than a single storage site and type.
- The mining operation would be exposed to significant closure and rehabilitation risk associated with ensuring the long term stability and safety of the tailings storage structure, and these would remain high in perpetuity due to the geotechnical, climatic, environmental and social setting of the Project.

The significant constraints associated with the four potential terrestrial TSF sites which passed the initial engineering conceptual study requirements are summarised in Table 7.2 and discussed at a high level in the following sub-sections.

Table 7.2: Significant constraints for the four key TSF locations assessed

Location	Significant Constraints Identified
Markham Gap (assessed in 2012 Pre-Feasibility Study and follow-up studies in 2017)	• Low geotechnical stability • Difficult to manage surface water due to large upstream catchment • Important ecological habitat with corresponding very high ecological values • Very high cultural heritage values
Markham Farms (assessed in 2012 Pre-Feasibility Study)	• Low geotechnical stability due to deep alluvial material below proposed embankment • Susceptible to flooding due to floodplain location in Markham River valley • Long distance (40km) from Mine Area
Bavaga River valley (assessed in 2014 Pre-Feasibility Optimisation Study and 2015 Feasibility Study; and follow-up studies in 2017)	• Low geotechnical stability • Several major fault structures in vicinity • Insufficient capacity for LOM tailings production • Villages impacted, particularly Bavaga village • Loss of cultural heritage sites

Location	Significant Constraints Identified
Lower Watut River valley (assessed in 2015 Feasibility Study)	• Susceptible to liquefaction • Insufficient capacity for LOM tailings production • Large footprint in area of high land and water resource use • Loss of high biodiversity ecological habitat (Large to Medium Crowned Forest) • Loss of significant cultural heritage sites

7.3.4.3.1. Markham Gap

Markham Gap was investigated by the WGJV in the 2012 Pre-Feasibility Study when LOM tailings production was anticipated to be 1,000Mt. Markham Gap is located approximately 20km north-northwest from the Mine Area, in a low-lying valley with the Lower Watut River Valley to the west (see Figure 7.1).

Sites at this location would have sufficient storage capacity for the current anticipated LOM tailings of approximately 360Mt and the surrounding steep topography was favourable (thereby requiring less engineered structures to contain the tailings). Cost estimates indicate that a TSF at Markham Gap would have the lowest overall cost of any tailings management option of less than 0.5 USD/tonne of tailings stored. However, the Markham Gap was considered significantly constrained for the following reasons:

- The high permeability soils (up to 20m thick) and poorly consolidated sediments result in low geotechnical stability that would necessitate significant engineering to ensure the stability of a future TSF structure, with consequent safety and cost implications.
- The large surface water catchment upstream of the site, which would result in large volumes of inflow into the TSF and the need to provide long-term maintenance of a spillway capable of safely passing the maximum probable precipitation event (i.e., typically a 1 in 10,000-year return period rainfall event) post closure.
- Ecological studies identified the Markham Gap area as being highly important for terrestrial biodiversity, supporting a complex and diverse mosaic of little-disturbed and functionally integrated habitats that may be unique in the region (Booyong Forest Science, 2011; Woxvold, 2012).
- Stakeholder engagement and selective field surveys (Hitchcock, 2012) also identified numerous tangible and intangible cultural heritage sites associated with the Markham Gap TSF location.

7.3.4.3.2. Markham Farms

Markham Farms was investigated by the WGJV in the 2012 Pre-Feasibility Study when LOM tailings production was anticipated to be 1,000Mt. It is located approximately 40km north-northwest of the Mine Area on the Markham River floodplain (see Figure 7.1).

As with the Markham Gap, sites at this location would have sufficient storage capacity for the current anticipated LOM tailings of approximately 360Mt. The estimated costs of transporting tailings, construction and maintenance of the TSF embankments were higher than for the Markham Gap, but lower than other options considered, being between 0.5 to 1.5 USD/tonne of tailings stored.

The underlying strata on the alluvial floodplains of the Markham River, is, however, likely to be subject to a high seismic risk (i.e., liquefaction). This would require significant engineering to ensure the stability of a TSF and its consequent long term safety to the population living downstream on the Markham River (and the city of Lae). The risk to the long-term stability of a TSF at this location and the safety risk due to geotechnical failure were key reasons the site was considered significantly constrained.

7.3.4.3.3. Bavaga River Valley

This location was initially considered in the 2014 Pre-Feasibility Optimisation Study, and progressed to consideration in the 2015 Feasibility Study, when LOM tailings production was anticipated to be 140Mt. It is located approximately 10km north of the Mine Area (see Figure 7.1).

The natural topography of the Bavaga River valley means that tailings confinement would be achieved through the construction of an embankment within the valley, with the potential for it to be constructed in multiple stages in line with the production schedule. The studies undertaken sought to determine the optimal embankment height considering the storage capacity required to either accommodate the LOM tailings at the time, or to accommodate a proportion of the LOM tailings as one of several TSFs. No individual site within the Bavaga River valley would have sufficient capacity for the currently anticipated LOM tailings of approximately 360Mt. Further, the majority of TSF site options investigated in the Bavaga River valley would result in significant social and cultural heritage impacts to the nearby Bavaga village.

Cost estimates demonstrated that a TSF in the Bavaga River valley would have a comparatively high overall cost for tailings management greater than 3.5 USD/tonne of stored tailings.

Geotechnical studies revealed that the depth of sediments in the Bavaga River valley, which are typically of low strength, reached 15m below the surface in the valley and decreased to less than 2m below the surface closer to the valley edges. This would result in additional engineering and maintenance requirements to increase the stability of embankments. It was also found that Bavaga River sites are susceptible to liquefaction, which poses a significant risk to the long-term stability of a TSF at this location. Further to this, a study undertaken at this location indicated that several major fault structures are present which lead to significant seismic risk and potential TSF failure (Advisian, 2017a).

The lack of storage capacity, social impacts, and elevated risks to long-term stability at these sites, were key reasons this location was considered significantly constrained.

7.3.4.3.4. Lower Watut River Valley

With the identification of significant constraints on the Bavaga River valley location during the preparation of the 2015 Feasibility Study, consideration turned to the Lower Watut River floodplain in the 2015 Feasibility Study. The required capacity at the time of the study was estimated at 146Mt of tailings. The proposed location was on the eastern edge of the Lower Watut River floodplain immediately west of the proposed location of the Watut Process Plant (see Figure 7.1).

An additional geotechnical investigation was undertaken on the proposed Watut TSF site in 2016 to complete the site-wide assessment of ground conditions. This investigation identified interbedded layers of coarse-grained and fine-grained alluvium at various depths ranging between 20mbgl and 80mbgl. A liquefaction assessment undertaken for the site identified that the coarse-grained alluvium is likely to liquefy in the event of an earthquake, which could destabilise a TSF embankment.

A subsequent assessment of the Watut TSF identified that the site would require high-cost ground improvement works to address the liquefaction risk. It also identified that, considering liquefaction risk based on earthquake design criteria specified by ANCOLD (2012), the maximum safe embankment height would reduce the capacity to less than

146Mt (Advisian, 2017c). Cost estimates demonstrated that a TSF in the Lower Watut River Valley would have a comparatively high overall cost for tailings management greater than 3.5 USD/tonne of tailings stored.

Locating the TSF on the Lower Watut River floodplain would also result in ecological, social and cultural heritage impacts. Ecological impacts would result as a consequence of clearing high value biodiversity habitat (namely the Large to Medium Crowned Forest). Social impacts would occur due to the loss of land and water resources and potentially would require the resettlement of the village of Papas. Cultural heritage impacts would occur due to the presence of oral tradition and archaeological sites within the proposed TSF footprint.

Based on the risks relating to the geotechnical conditions and long term stability and the safety and cost implications to address them, the environmental, social and cultural heritage impacts, and higher costs per tonne of tailings stored, the Watut TSF location was considered significantly constrained.

7.3.4.4. On-land Tailings Storage using Dry Stacking of Tailings

Dry stacking of tailings was also considered as an option for tailings management. Dry stacking is a form of on-land tailings storage involving thickening and filtering of the tailings to a slurry density of 80% to 90% solids by weight. The de-watered tailings are then transported by conveyor or truck and placed, spread and compacted to form an unsaturated, dense and stable tailings ‘stack’, hence the terminology dry stacked tailings. It is commonly used for mines in arid environments, where water is scarce and evaporation is high.

The dry-stacking method uses a combination of dewatering, stockpiling and compaction of tailings to minimise – but not eliminate – potential AMD.

Several studies into dry stacking of tailings have been undertaken for the Project. Two of those (Golder, 2017 and Advisian, 2017b) concluded:

- There would be operating risks (such as liquefaction or AMD) associated with the high annual rainfall and high seismicity.
- There is no known precedent of sites where dry stacking of tailings has been implemented in a wet tropical environment such as the Project Area, which increases the level of engineering and financial risk to WGJV if it was to be implemented for the Project.
- Dry stacking of tailings is a 24 hour per day operation requiring dedicated machinery operators and a higher level of supervision (than for a conventional TSF) for the placement of the tailings in the stack to mitigate against the risk of failure due to the development of a high phreatic surface and earthquake induced seismicity.
- Dry stacking would not reduce the long-term risk of storing a large volume of PAF tailings in perpetuity to a level of risk acceptable to the WGJV.
- Dry stacking would not avoid the environmental, social and cultural heritage impacts (dependent upon the chosen site) associated with the TSF options described above.

Cost estimates in Advisian (2017b) showed that dry stacking of tailings would have a comparatively high overall cost for tailings management greater than 3.5 USD/tonne of tailings stored.

The assessment of dry stacking of tailings concluded that, for the Project, the risks of dry-stacking are essentially the same as for a conventional terrestrial TSF.

7.3.4.5. Deep Sea Tailings Placement – Proposed Option

Deep sea tailings placement involves the discharge of a tailings slurry from a pipeline into the sea at a location where deep oceanic water occurs close to shore and a steep and continuous slope occurs between the outfall terminus and the deep ocean floor. The option of DSTP was considered for the Project due to the availability of deep water in the Huon Gulf, located some 100km to the east of the Mine Area that could potentially accommodate the placement on the ocean floor of the current anticipated LOM tailings of approximately 360Mt.

Figure 7.2 shows the locations of worldwide mines with either shallow water marine placement or DSTP. The first mine to use DSTP in PNG was the now-closed Misima gold mine that operated from 1989 to 2004. The Simberi gold mine, Lihir gold mine and Ramu nickel and cobalt mine are operating mines in PNG using DSTP; the Woodlark Island Gold Project is approved to use DSTP but has not yet commenced construction.

As described in Chapter 6, Project Description, evaluation of the DSTP option considered the Draft General Guidelines for DSTP in PNG (SAMS, 2010) to assess the suitability of the Huon Gulf as a potential DSTP site. In addition, the DSTP option was examined by assessment against the following best practice criteria for DSTP:

- Selecting an outfall site on a sufficiently steep seafloor slope such that the tailings solids will not accumulate and plug the outfall pipe and where the seafloor slope continues into deep water.
- Selecting a discharge depth that is deep enough (based on at least a year's measurements) to be below:
    - The base of the biologically productive near-surface layer known as the euphotic zone where light penetration from the surface allows photosynthesis to take place.
    - The deepest measured surface mixed layer (the uppermost part of the ocean water column that is kept well mixed by the turbulent action of wind and waves).
    - The base of upwelling (if any).
- Providing adequate de-aeration of the tailings slurry prior to discharge to avoid tailings being transported to the surface by air bubbles.
- Ensuring that the tailings slurry has a higher density than the receiving ocean water so that a density current will form and flow down the sloping seafloor driven by gravity.

7.3.4.5.1. DSTP Outfall Site Selection

Studies documenting the feasibility of DSTP as a tailings management option for the Project have been undertaken by various specialists at concept, pre-feasibility and feasibility study level since 2012.

Deep sea tailings placement was considered as a potentially viable option in the Huon Gulf given that:

- The coastal margins of the Huon Gulf slope steeply to depths of 300m within 10km and to depths of 2,000m within 30km from shore.
- A submarine canyon runs eastwards through the Huon Gulf commencing near the Markham River mouth. Called the Markham Canyon, it slopes continuously downwards before joining the New Britain Trench, which reaches depths of over 9,000m.

Previous concept studies (IHAconsult, 2012 and 2015) identified four potential DSTP outfall sites in the Huon Gulf as shown on Figure 7.3 (Options A to D).

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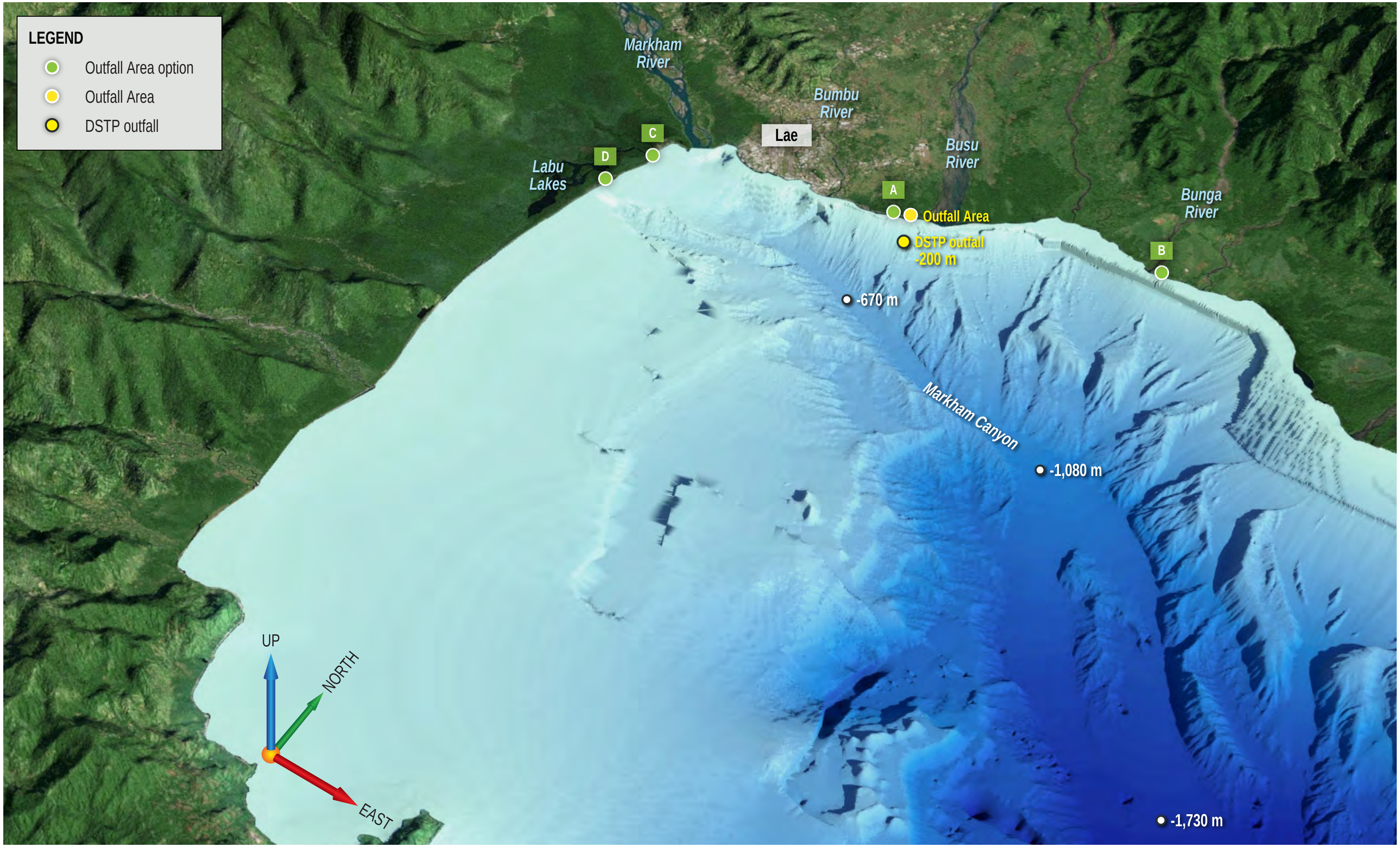
Wafi-Golpu Project

Worldwide mines with either shallow water marine placement or DSTP

Figure No:
7.2

INDD Reference: 0520DD_10_GRA109.indd_3



Note:
3D perspective view generated by Coffey in 3ds Max. 2x vertical exaggeration.

Source:
Bathymetry and infrastructure from WGJV.
Satellite imagery from ArcGIS online (currency unknown).

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Date: 30.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F07.03_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

DSTP site options

Figure No: 7.3

INDD Reference: 0520DD_10_GRA047.indd_5

Based on the geotechnical information available at the time the studies were undertaken, two options (Options B and C) were determined to be less favourable due to potential geohazards and were not considered further.

In 2016, a multi-disciplinary assessment of the remaining two sites, Outfalls A and D, was undertaken. This assessment took into account physical, environmental and social considerations and constraints relating to each option for the DSTP outfall site and subsea pipeline route, shore crossing and terrestrial DSTP pipeline route (Coffey, 2016). The Outfall A site is located approximately 3km east of Lae and 1km west of the Busu River mouth and the Outfall D site is located approximately 3km southwest of the mouth of the Markham River, as shown in Figure 7.3.

Site selection criteria to assess the constraints of the DSTP components for Option A and Option D were developed by a multidisciplinary team and included application of the Draft General Guidelines for DSTP in PNG (SAMS, 2010). The assessment concluded that Outfall A was preferable based on physical, environmental, social and cultural heritage perspectives:

- DSTP outfall and DSTP outfall pipelines:
  - Outfall A had an appropriately steep seafloor gradient.
  - Outfall A had no obvious indications of seafloor instability at the outfall depth.
  - Outfall D had a shallower gradient and required a significantly longer (6km-long) outfall pipeline to reach the same outfall depth.
  - At Outfall D, the seabed appeared to be in a fluidised or near-fluidised state which is considered suboptimal for pipeline construction.
  - Outfall D is located within a currently designated commercial shipping exclusion zone.
- Shore crossing:
  - The shore crossing area at Outfall A features a large flat area and road access suitable for conducting construction activities and with extensive anthropogenic disturbance resulting in degraded secondary growth forests and non-vegetated (and urban) areas.
  - Outfall D is more remote, not accessible by road and has higher environmental sensitivity being located adjacent to the Labu Lakes and traversing nesting habitat for the critically endangered west Pacific leatherback turtle (see Chapter 10, Nearshore Marine Environment Characterisation).

Oceanographic and engineering investigations are ongoing to refine the Outfall location.

7.3.4.5.2. Outfall Area Facilities Site Selection

Following the selection of the DSTP outfall location described above, factors considered for the placement of the Outfall Area included: the mix tank/de-aeration facilities, proximity to the DSTP outfall, stability of the shoreline, potential for flooding, as well as potential impacts to environmental, social and cultural heritage aspects.

The initial outfall location selected (Outfall A) was subsequently identified to be located within the boundary of the Hungkwanpup cultural heritage site (see Chapter 13, Cultural Heritage Characterisation). Further site assessment was undertaken (Tetra Tech, 2017), and the location of the Outfall Area was moved approximately 200m east to avoid the cultural heritage site area, including a 100m buffer for additional protection of the cultural heritage site, with no corresponding reduction in suitability of the location for pipeline construction or tailings discharge.

7.3.4.6. Comparison of Tailings Management Options and Selection of a Preferred Option

Table 7.3 provides a high-level comparison between the on-land tailings storage options (including TSF and dry stacking tailings) and DSTP option considered for the Project across a total of nine factors and shows that there are substantial differences between on-land tailings storage and DSTP.

Table 7.3 Comparison between the on-land tailings management and DSTP options

Factor	On-land TSF Option	DSTP Option
Land alienation	Major (roads, pipelines, TSF footprint)	Minor (road and pipeline only)
Risk of catastrophic failure of stored tailings	Possible	No
Protection of storage structure from long-term erosion (i.e., requiring long-term management)	Required	Not required
Risk of pipeline rupture	Possible	Possible
Risk of damage from tsunami (i.e., causing temporary disruption to tailings storage)	No	Possible
Discharges to the environment:		
• During operations	Required	Required
• Post-closure (i.e., requiring long-term management)	Required	Not required
Shallow marine impacts	None	None other than short-term localised effects during subsea pipe construction
Deep-ocean marine impacts	None	Expected low to moderate residual impacts
Maintenance in perpetuity	Required	Not required

A more in-depth comparison was then made between the four potential TSF sites investigated in detail, dry stacking of tailings and the DSTP option across the following key parameters:

- Level of investigation undertaken
- Engineering constraints (storage volume potential and geotechnical stability)
- Environmental, social and cultural heritage constraints (direct terrestrial ecological impact; effects on land and water resources used by local people; direct cultural heritage impact; and post-closure monitoring and management)
- Other considerations including cost (capital, operating and closure) and cost per tonne of tailing stored

This comparison is presented in the matrix in Figure 7.4.

Generally, the more green infill in the circle, the greater the amount of investigation, the lower the level of risk, severity of consequence or level of constraint and the lower the cost. Conversely, the less green infill of the circle, the lower the amount of investigation, the higher the level of risk, severity of consequence or level of constraint and the higher the cost.

Key parameters		On-land options					DSTP
		Markham Gap TSF	Markham Farms TSF	Bavaga River TSF	Lower Watut TSF	Dry-stacking*	
Level of investigation	○ Not investigated ◔ Preliminary ◑ Conceptual ◕ Pre-Feasibility ● Feasibility	◕	◕	●	●	◑	●
Engineering constraints							
Storage volume potential	○ 0 to 90Mt ◔ 90 to 180Mt ◑ 180 to 270Mt ◕ 270 to 360Mt ● Greater than 360Mt	●	●	◔	◔	◕	●
Geotechnical stability Relates to the terrestrial component of each option (i.e., the terrestrial tailings pipeline for DSTP)	○ Fault structures ◔ Deep poorly consolidated sediment (e.g., greater than 10mbgl) ◑ Shallow poorly consolidated sediment (e.g., less than 10mbgl) ◕ Competent soils ● Competent rock	◔	◔	○	◔	◑	◑
Environmental and social constraints							
Direct terrestrial ecological impact*	○ Greater than 1,000ha ◔ 500 to 1,000ha ◑ 100 to 500ha ◕ Less than 100ha ● None	○	○	◑	◔	◌	◕
Direct cultural heritage impact*	○ Destruction of numerous sites ◔ Destruction of some sites ◑ Minor disturbance to numerous sites ◕ Minor disturbance to some sites ● No disturbance to cultural heritage sites	○	◕	○	◔	◌	●
Direct social impact*	○ Relocation required ◔ Extensive land alienation ◑ Moderate land alienation ◕ Small land alienation ● No land alienation	◕	◑	○	○	◌	●
Effects on coastal resources used by local people	○ Widespread ◔ Moderate ◑ Minor ◕ Highly localised ● None	●	●	●	●	●	◕
Post-closure monitoring and management	○ Erosion control and water management in perpetuity ◔ Erosion control and water management for unknown period ◑ Erosion control and water management for a known period ◕ Post closure monitoring only ● Nothing required	○	○	○	◔	◔	◕
Other considerations							
Cost (capital, operational and closure)	○ Greater than USD 1,200m ◔ USD 900 to 1,200m ◑ USD 600 to 900m ◕ USD 300 to 600m ● Less than USD 300m	●	◔	◑	◑	○	◑
Cost per tonne	○ Greater than 3.5 USD/tonne ◔ 2.5 to 3.5 USD/tonne ◑ 1.5 to 2.5 USD/tonne ◕ 0.5 to 1.5 USD/tonne ● Less than 0.5 USD/tonne	●	◕	○	○	○	◑

◌ * Footprint related impacts are dependent upon the location of the site selected. For example, using dry stacking at Markham Gap would be equal to or greater than the impact of a TSF at the same location.

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Comparison of tailings management options

Figure No: 7.4

While the costs include capital, operating and closure costs (noting they were assessed at different times to different levels of engineering by different parties), they do not include an estimate of post closure monitoring and maintenance, the latter of which could require substantial cost outlays for those options requiring long term ongoing water treatment and/or maintenance. Despite this limitation, examination of the cost per tonne of tailings stored shows that:

- The TSF options range from the highest to the lowest cost
- Dry stacking of tailings is a high cost option
- DSTP is an intermediate cost option, with a higher upfront capital expenditure but lower LOM capital expenditure

Costs were therefore only one factor considered in the selection of tailings management option. Figure 7.4 shows that of all the options considered, generally, it is the DSTP option that has the lowest level of risk, severity of consequence or level of constraint, particularly relating to the post-closure phase.

While risks and uncertainties exist with each option, the WGJV has assessed each of the above options against the key parameters and their ratings. The WGJV has also considered the detailed assessments of the environmental, social and cultural heritage impacts and potential risks to human health associated with DSTP described in chapters 14 to 20 of this EIS. The DSTP studies to date have confirmed that:

- The Outfall Area is a highly suitable environment for DSTP
- The tailings are expected to mix and co-deposit with a significant, naturally occurring loading of riverine sediments from the Markham, Busu and other rivers that are also conveyed via the Markham Canyon into the Huon Gulf.
- The pelagic, deep-slope and sea floor receiving environment has a very low biodiversity as a result of the riverine sediment transport, deposition and regular mass movements (underwater landslides).
- Risks to human health from consuming fish caught in the Huon Gulf beyond baseline conditions are not expected from the use of DSTP.
- The natural riverine sediments are expected to also bury the co-deposited tailings at closure and promote benthic recovery to pre-mine conditions.

In light of the above, and the factors considered in relation to the outcomes from the study of 45 sites for terrestrial tailings storage (particularly relating to the long-term stability and safety of such a structure), the WGJV has decided to adopt DSTP as the preferred tailings management option for the project.

7.3.5. Infrastructure Corridor

The Infrastructure Corridor is proposed to comprise the following:

- Mine Access Road commencing at the Watut Process Plant and ending at the junction with the proposed Northern Access Road
- Northern Access Road connecting the Mine Area to the Highlands Highway
- Concentrate pipeline, terrestrial tailings pipeline and fuel pipeline connecting the Mine Area to the Coastal Area

7.3.5.1. Road Access Route

The Mine Area is currently accessible via the existing Wafi Access Road and Demakwa Access Road, which connect to the Lae-Bulolo Highway to the east (Figure 7.5). These unsealed roads traverse mountainous terrain.

Alternative routes were investigated for Mine Area access during operations. The broad Lower Watut River valley, which runs north from the Mine Area to the Highlands Highway and features flat to gently undulating terrain, was identified as a preferred road access corridor.

Natural features posed various levels of constraint in selecting the new road access route through the Lower Watut River valley. The southern end of the route, closest to the Mine Area, is constrained by geography, the location of the orebody, and the proposed location of future infrastructure (e.g., process plant terrace, Watut Declines Portal Terrace). This is the route of the Mine Access Road.

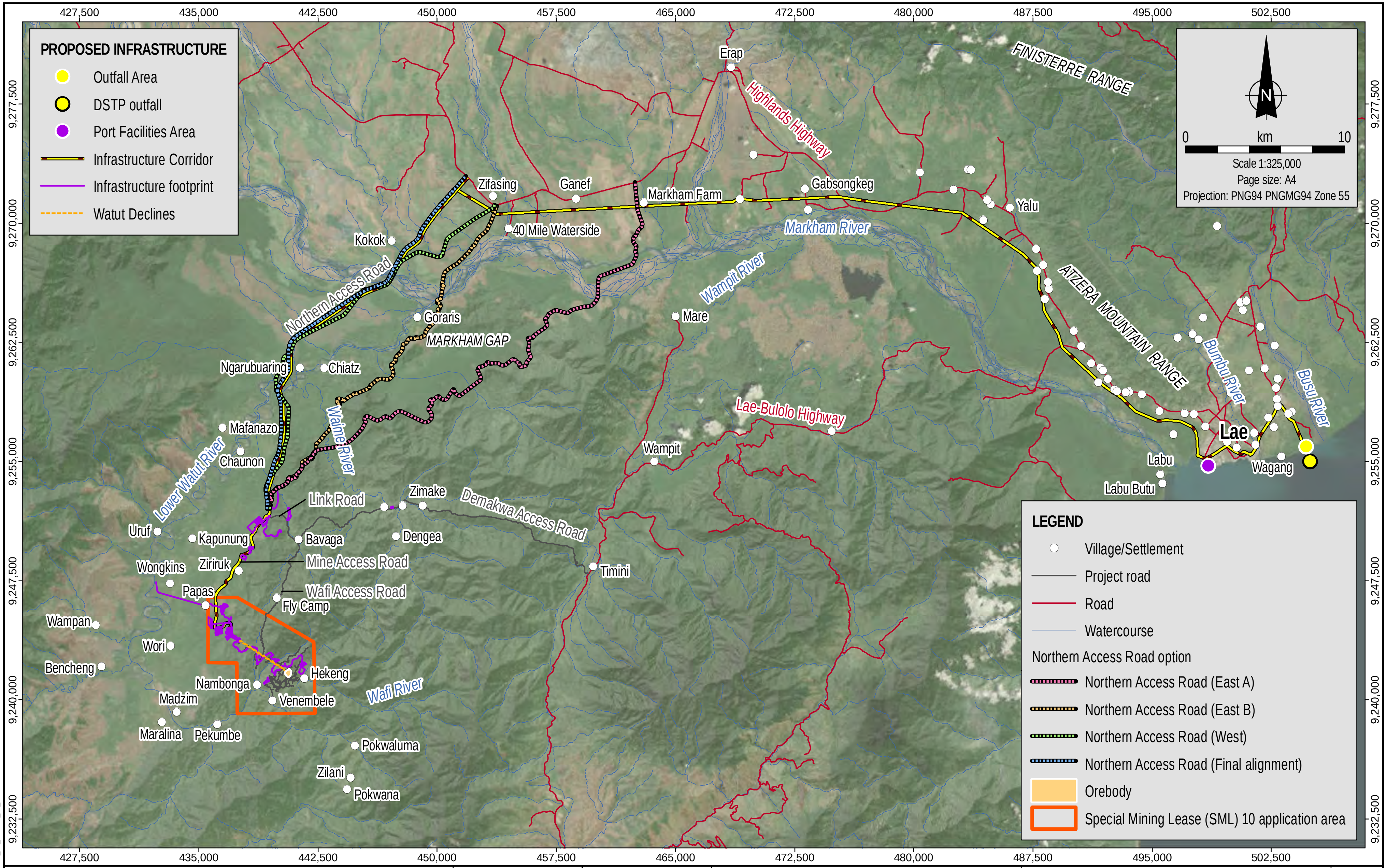
There was greater scope for consideration of alternative routes for the Northern Access Road between the Link Road intersection north to the Highlands Highway within the Lower Watut River valley. Three routes were considered (see Figure 7.5):

- West: crossing the Markham River upstream of the confluence with Lower Watut River and connecting to the Highlands Highway at Zifasing.
- East B: crossing the Markham River downstream of the confluence with the Lower Watut River and connecting to the Highlands Highway at Zifasing.
- East A: crossing the Markham River further downstream than the East A alignment and connecting to the Highlands Highway east of Ganef.

A number of significant constraints for the two eastern alignments were identified. Both eastern alignments would involve wide crossings of the Markham River and significant sections traversing steep and mountainous terrain. Both alignments would result in disturbance to the sensitive Large to Medium Crowned Forest, which provides habitat for the Critically Endangered plant, *Diospyros lolinopsis* (Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River). The East A alignment would also involve construction works in the Markham Gap area that contains numerous cultural heritage sites. On this basis, neither of the eastern alignments were considered further.

The western alignment avoids significant constraints. The route will be easier to construct from an engineering perspective, as it will traverse flatter landscapes and will cross the Watut and Markham rivers separately upstream of their confluence. It will also avoid critical habitat and significant cultural heritage sites. On this basis, the Northern Access Road (West) alignment was selected as the preferred route to connect the Mine Access Road to the Highlands Highway.

Further refinement of the original Northern Access Road (West) option to avoid a significant cultural heritage site (Fansun Sacred Hill) and to optimise the route to the Highlands Highway and co-locate the concentrate, terrestrial tailings and fuel pipelines in the same corridor gave rise to the current Northern Access Road route, which joins the Highlands Highway west of Zifasing as shown in Figure 7.5.



MXD Reference: 0520DD_10_GIS027_v0_11

Source:
NAR options, SML and orebody from WGJV.
Villages, infrastructure and project roads from WGJV and Coffey.
Roads and watercourses from NSO.
Imagery from ArcGIS Online (capture date unknown).

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Northern Access Road options

Figure No:
7.5

7.3.5.2. Concentrate, Fuel and Terrestrial Tailings Pipeline Route

7.3.5.2.1. Rationale

The most direct route is the starting point for all linear infrastructure route selection, as it is the shortest, and based on standard unit cost, the least cost assuming favourable conditions. However, practical constraints mean that realignment is usually necessary, with consequent increases to the route length and cost of construction. The route with the least overall length and cost that addresses the constraints is preferred.

The straight line between the Mine Area (start of pipelines) and Port Facilities Area and Outfall Area (ends of pipelines) traverses steep mountainous terrain. The mountainous terrain poses a strategic constraint on route selection considering the technical specifications of the pipelines which require gentle grades.

The gently undulating terrain of the Lower Watut River valley and the Lower Markham River valley offer viable routes that are less hazardous, less costly to construct and maintain, and that meet the technical specifications of the pipelines.

The Port Facilities Area and Outfall Area are located southwest and northeast of the Atzera Mountain Range respectively. The range poses similar constraints with the Lower Markham River valley to the west and Bumbu River valley to the east offering less constrained opportunities for pipeline routes.

Lae is situated between the southern end of the Atzera Mountain Range and the coast and is a constraint on pipeline route selection between the Port Facilities Area and the Outfall Area. Existing corridors (for example, roads) are potential opportunities for routes as they are relatively less constrained than adjacent residential, commercial, industrial and government land. Elsewhere, existing corridors offer opportunities for co-location reducing overall disturbance and impacts, provided the uses are not incompatible.

The route options identified and evaluated in selecting the proposed route for the pipelines are described in the following section.

7.3.5.2.2. Route Selection

The most favourable corridor for the pipelines in the Lower Watut River valley is the Northern Access Road, the new road to be constructed from the Mine Area to the Highlands Highway near Zifasing village. The road has a gentle grade. Co-location of the concentrate, fuel and terrestrial tailings pipelines with the road reduces the overall area of disturbance required to construct the pipelines, as well as providing all weather access for operation and maintenance purposes.

The existing Ramu to Lae 132 kV transmission line crosses the proposed alignment of the Northern Access Road between the Markham River and Highlands Highway. The transmission line and highway offer opportunities for co-location of infrastructure. Routes along the Highlands Highway are problematic due to encroaching development, maintenance activities along the road and the substantial cost of constructing pipelines in a road reserve over long lengths. The transmission line is less constrained and was adopted as the preferred route for the pipelines from the Northern Access Road to near Yalu village where the transmission line crosses the Highlands Highway.

The Bumbu River valley east of the Atzera Mountain Range offers more direct routes to the Outfall Area for the terrestrial tailings pipeline, whereas the Lower Markham River valley offers direct routes for the concentrate and fuel pipelines to the Port Facilities Area. Routes to the Outfall Area via the Bumbu River valley require a crossing of the northern end of the Atzera Mountain Range. The routes identified and assessed using constraints analysis based on engineering, environment, social and cultural heritage criteria are shown in Figure 7.6. The route selection was informed by consultation with Lae Local Level Government and Morobe Provincial Government.

Two routes were identified as the most favourable, a terrestrial tailings pipeline route (Route D6) across the Atzera Mountain Range and down the Bumbu River valley to the Outfall Area and a route (Route C3) between the Highlands Highway and Markham River to the Port Facilities Area for the concentrate and fuel pipelines. These routes would minimise impacts on intact forest, settler and urban communities, businesses and government infrastructure.

A geohazard and constructability assessment of these routes by an experienced pipeline construction contractor concluded that substantial construction and operation savings could be made, and environmental and social impacts reduced, by locating the pipelines in a single corridor from near Yalu village to the Port Facilities Area from which the terrestrial tailings pipeline would traverse Lae to the Outfall Area.

The WGJV acted on this recommendation and investigated routes from the Port Facilities Area to the Outfall Area. Several routes were investigated through Lae with the most favourable routes avoiding impacts on the heavily congested and highly constrained road network through Eriku and Omili, primarily Bumbu Road. Route C3 was refined and a new route (Route D8) identified. Subsequent refinement of Route D8 to further reduce impacts on the road network and adjacent businesses and properties resulted in the preferred route for the pipelines being:

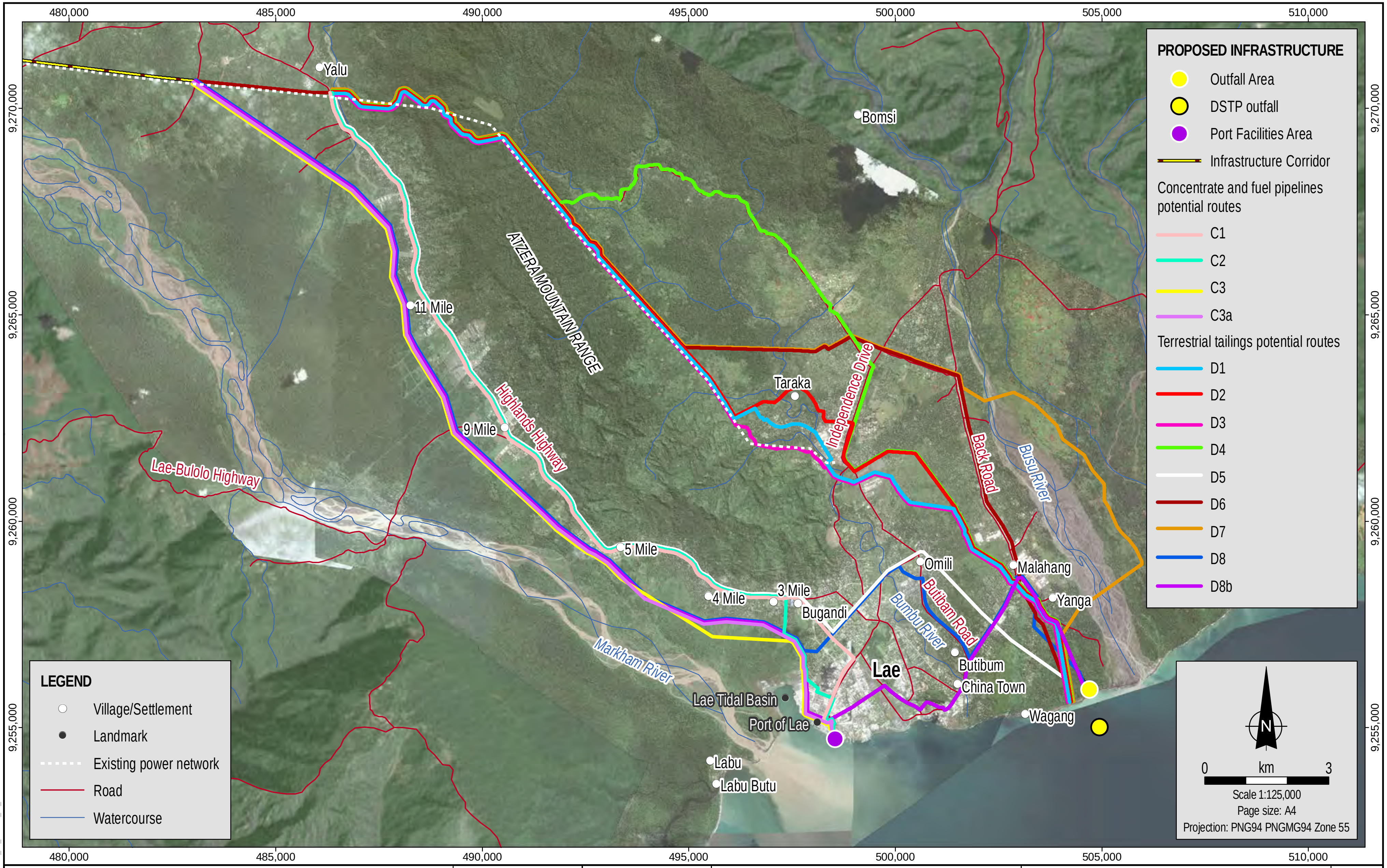
- Route C3a between Yalu and the Port Facilities Area in Lae for the terrestrial tailings, concentrate and fuel pipelines
- Route D8b between the Port Facilities Area and the Outfall Area for the terrestrial tailings pipeline

Route D8b includes refinement of Route D6 in the vicinity of Wagang village to address the revised location of the Outfall Area which was moved east to avoid disturbance to the Hungkwanpup cultural heritage site described in Section 7.3.4.3.2.

A number of route options shown in Figure 7.6 would have terminated at the outfall area under investigation at that time (to the west of the current Outfall Area), however this location was dismissed as an option because of the likely disturbance to the Hungkwanpup cultural heritage site described in Section 7.3.4.5.2.

Route C3a/D8b was identified as the preferred option because it:

- Maintains the three pipelines within a single corridor to the Port Facilities Area, thereby minimising the area of physical disturbance associated with two corridors and subsequent environmental, social and cultural heritage impacts
- Reduces impacts on Lae city development plans by following existing roads and future road easements
- Reduces construction activities in residential areas and along already heavily-congested roads by directing the pipeline through industrial areas
- Reduces geotechnical risk and loss of native forest that would be associated with crossing the Atzera Mountain Range and the headwaters of the Bumbu River



MXD Reference: 0520DD_10_GIS023_v0_5

Source:
Alternative routes, villages/settlements, landmarks and infrastructure from WGJV and Coffey.
Roads and watercourses from NSO.
Imagery from ArcGIS Online (capture date unknown) and WGJV (capture date 2016).

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Infrastructure Corridor route options east of Yalu

Figure No:
7.6

Subsequent to the WGJV's selection of this route option, in December 2017 the Customary Land Division of the Morobe Province Department of Lands and Physical Planning completed its Preliminary Land Investigation Study Report – DSTP and Concentrate Pipeline Proposed Route (Department of Land and Physical Planning, 2017). Following its process of landownership investigations and consultation along the route, the Morobe Provincial Government proposed slight amendments to the route in order to further minimise impacts to existing land use (particularly that of state leaseholders located between 9 Mile and the Port of Lae) and to avoid areas of disputed land ownership near the Port of Lae. The preferred Infrastructure Corridor route (Figure 7.6) reflects the C3a/D8b route incorporating the recommendations of the Morobe Provincial Government Land Investigation Report team.

7.3.6. Power Supply

A number of bulk power supply options to supply ongoing site operations have been investigated during the design of the Project. Given the underground mining operations envisaged and the need to ensure on-going ventilation and pumping, a critical consideration is the capacity to supply the amount of electricity required on a reliable, constant basis.

Accordingly, an on-site, dedicated power generation facility was investigated with different options for fuel, generation technology and location considered.

Initially, five fuel types were assessed:

- Intermediate fuel oil (IFO)-180 – shortlisted for further consideration
- Liquefied petroleum gas (LPG) – shortlisted for further consideration
- IFO-380 – not considered further due to difficulty to handle safely
- Diesel – not considered further for operations due to high cost of fuel, but considered for use during construction
- Liquefied natural gas – not considered further due to high cost of fuel and infrastructure.

Three options for power generation technology were assessed:

- Open cycle gas turbines – not considered further due to inefficient generation capability and consequent large quantity of fuel required.
- Combined cycle gas turbines – not considered further due to high capital and maintenance costs.
- Reciprocating engines, each with a capacity between 6 and 10MW – assessed as the most viable option.

Reciprocating engines in a dedicated Project power station could operate on either of the two shortlisted fuel types (IFO-180 and LPG). Both on- and off-site locations for a power generation facility were assessed including:

- On-site: Located within the Mine Area, with IFO-180 or LPG supplied via an 87km pipeline within the Infrastructure Corridor, and transmission lines to supply power approximately 6.5km from the power generation facility site to the Watut Process Plant.
- Off-site: Located at the Port of Lae, with IFO-180 or LPG supplied directly from ships via a short pipeline (nominally 1km) and transmission lines to deliver electricity to the Watut Process Plant.

The off-site options presented a higher risk of disruption to power supply compared to the on-site options, primarily due to the length of transmission lines. Of the shortlisted fuel types, IFO-180 was assessed to be the more cost efficient for the volume of power required.

On this basis, the preferred method of power generation for the Project is reciprocating engines at a power generation facility located within the Mine Area and powered by IFO-180 fuel. Diesel generators will be used to provide power during construction of the Project and as an emergency backup.

WGJV will continue to assess the viability of other power supply sources from third parties as development of the Project progresses.

7.4. References

Advisian. 2017a. Wafi-Golpu Project: Bavaga TSF Option D – Findings from seismological study and geological mapping exercise. January. Advisian trading as Worley Parsons Services Pty Ltd.

Advisian. 2017b. Wafi-Golpu Project: Bavaga Tailings storage facility Option D Phase 1 assessment report. February, Advisian trading as Worley Parsons Services Pty Ltd.

Advisian. 2017c. Wafi-Golpu Project Watut TSF Engineering Study TSF Raise 1 and 2, February. Advisian trading as Worley Parsons Services Pty Ltd.

ANCOLD. 2012. Guidelines on Tailing Dams - Planning, Design, Construction, Operation and Closure. Report prepared by The Australian National Committee on Large Dams Incorporated. May 2012.

Beca. 2017. Dry Stack Tailings Disposal - Fatal Flaws Assessment. Report prepared by Beca Pty Ltd for Wafi-Golpu Joint Venture. October 2017.

Booyong Forest Science. 2011. Terrestrial Flora Survey for the Markham Gap Basin Tailings Storage Facility for the WGJV Golpu Project. January 2011.

Coffey. 2016. Site Selection Assessment for the Deep Sea Tailings Placement Project. November. Report prepared by Coffey Services Australia Pty Ltd for Wafi-Golpu Joint Venture.

Golder. 2017. Dry Tailings Disposal Options – Desk Top Study. Report prepared by Golder Associates for Wafi-Golpu Joint Venture. July 2017.

Hitchcock, G. 2012. Cultural heritage report on the Golpu Project tailings storage facility (Markham Gap basin), Morobe Province, Papua New Guinea, March.

IHAconsult. 2012. Wafi-Golpu Project Pre-Feasibility DSTP Investigations. October, Report prepared by Ian Hargreaves and Associates for Morobe Mining Joint Venture.

IHAconsult. 2015. DSTP Scoping Study Concept and Location, Environmental, Community and Social, Engineering, and Permitting and International Considerations. October, Report prepared by Ian Hargreaves and Associates for Wafi-Golpu Joint Venture.

INAP. 2009. Global Acid Rock Drainage Guide. Prepared by International Network for Acid Prevention. Access from http://www.gardguide.com/

KCB. 2017. Wafi Golpu Project TSF Options Reassessment. January. Prepared by Klohn Crippen Berger for Wafi Golpu Joint Venture.

SAMS. 2010. Draft General Guidelines and Criteria for mining operations in Papua New Guinea (PNG) involving Deep Sea Tailings Placement (DSTP). Prepared by Scottish Association of Marine Science Research Services Limited.

SRK. 2007. Wafi-Golpu Seismic Hazard Analysis. Report prepared by SRK Consulting (Australasia) Pty Ltd. Sydney, Australia.

Tetra Tech. 2017. Overview of potential routes for the DSTP pipeline with the mix/de-aeration tank location outside of the sacred area. July. Memo prepared by Tetra Tech for Wafi-Golpu Joint Venture.

WGJV. 2014. Pre-Feasibility Optimisation Study. Prepared by Wafi-Golpu Joint Venture.

WGJV. 2015. Golpu Stage 1 project TSF Options Study Report, December. Prepared by Wafi-Golpu Joint Venture.

World Bank, 2008. Pacific Catastrophe Risk Financing Initiative.

Woxvold, I.A. 2012. Terrestrial Fauna Study of the northern Wafi-Golpu Project Area and Markham Gap Basin: Faunal Communities, Tailings Storage Facility Impacts and Recommendations. March 2012.