Chapter 8

Physical and Biological Environment Characterisation

DISCLAIMER

This disclaimer applies to and governs the disclosure and use of this Environmental Impact Statement ("EIS"), and by reading, using or relying on any part(s) of the EIS you accept this disclaimer in full.

This Environmental Impact Statement, including the Executive Summary, and all chapters of and attachments and appendices to it and all drawings, plans, models, designs, specifications, reports, photographs, surveys, calculations and other data and information in any format contained and/or referenced in it, is together with this disclaimer referred to as the "**EIS**".

Purpose of EIS

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**").

The Permit Application is to be lodged with the Conservation and Environment Protection Authority ("**CEPA**"), Independent State of Papua New Guinea.

Ownership and Copyright

The EIS is the sole property of the WGJV Participants, who reserve and assert all proprietary and copyright ©2018 interests.

Reliance and Use

The EIS is intended and will be made available to CEPA, for review by CEPA and other applicable agencies of the Government of the Independent State of Papua New Guinea ("**Authorised Agencies**"), for the purpose of considering and assessing the Permit Application in accordance with the Act ("**Authorised Purpose**"), and for no other purpose whatsoever.

The EIS shall not be used or relied upon for any purpose other than the Authorised Purpose, unless express written approval is given in advance by the WGJV Participants.

Except for the Authorised Purpose, the EIS, in whole or in part, must not be reproduced, unless express written approval is given in advance by the WGJV Participants.

This disclaimer must accompany every copy of the EIS.

The EIS is meant to be read as a whole, and any part of it should not be read or relied upon out of context.

Limits on investigation and information

The EIS is based in part on information not within the control of either the WGJV Participants or the Consultants. While the WGJV Participants and Consultants believe that the information contained in the EIS should be reliable under the conditions and subject to the limitations set forth in the EIS, they do not guarantee the accuracy of that information.

No Representations or Warranties

While the WGJV Participants, their Related Bodies Corporate and Consultants believe that the information (including any opinions, forecasts or projections) contained in the EIS should be reliable under the conditions and subject to the limitations set out therein, and provide such information in good faith, they make no warranty, guarantee or promise, express or implied, that any of the information will be correct, accurate, complete or up to date, nor that such information will remain unchanged after the date of issue of the EIS to CEPA, nor that any forecasts or projections will be realised. Actual outcomes may vary materially and adversely from projected outcomes.

The use of the EIS shall be at the user's sole risk absolutely and in all respects. Without limitation to the foregoing, and to the maximum extent permitted by applicable law, the WGJV Participants, their Related Bodies Corporate and Consultants:

- do not accept any responsibility, and disclaim all liability whatsoever, for any loss, cost, expense or damage (howsoever arising, including in contract, tort (including negligence) and for breach of statutory duty) that any person or entity may suffer or incur caused by or resulting from any use of or reliance on the EIS or the information contained therein, or any inaccuracies, misstatements, misrepresentations, errors or omissions in its content, or on any other document or information supplied by the WGJV Participants to any Authorised Agency at any time in connection with the Authorised Agency's review of the EIS; and
- expressly disclaim any liability for any consequential, special, contingent or penal damages whatsoever.

The basis of the Consultants' engagement is that the Consultants' liability, whether under the law of contract, tort, statute, equity or otherwise, is limited as set out in the terms of their engagement with the WGJV Participants and/or their related bodies corporate.

Disclosure for Authorised Purpose

The WGJV Participants acknowledge and agree that, for the Authorised Purpose, the EIS may be:

- copied, reproduced and reprinted;
- published or disclosed in whole or in part, including being made available to the general public in accordance with section 55 of the Act. All publications and disclosures are subject to this disclaimer.

Development of Project subject to Approvals, Further Studies and Market and Operating Conditions

Any future development of the Project is subject to further studies, completion of statutory processes, receipt of all necessary or desirable Papua New Guinea Government and WGJV Participant approvals, and market and operating conditions.

Engineering design and other studies are continuing and aspects of the proposed Project design and timetable may change.

NEWCREST MINING LIMITED DISCLAIMER

Newcrest Mining Limited ("**Newcrest**") is the ultimate holding company of Newcrest PNG 2 Limited and any reference below to "Newcrest" or the "Company" includes both Newcrest Mining Limited and Newcrest PNG 2 Limited.

Forward Looking Statements

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

Forward looking statements inherently involve known and unknown risks, uncertainties and other factors that may cause the Company's actual results, performance and achievements to differ materially from statements in this EIS. Relevant factors may include, but are not limited to, changes in commodity prices, foreign exchange fluctuations and general economic conditions, increased costs and demand for production inputs, the speculative nature of exploration and project development, including the risks of obtaining necessary licences and permits and diminishing quantities or grades of reserves, political and social risks, changes to the regulatory framework within which the Company operates or may in the future operate, environmental conditions including extreme weather conditions, recruitment and retention of personnel, industrial relations issues and litigation.

Forward looking statements are based on the Company's good faith assumptions as to the financial, market, regulatory and other relevant environments that will exist and affect the Company's business and operations in the future.

The Company does not give any assurance that the assumptions will prove to be correct. There may be other factors that could cause actual results or events not to be as anticipated, and many events are beyond the reasonable control of the Company. Readers are cautioned not to place undue reliance on forward looking statements. Forward looking statements in the EIS speak only at the date of issue. Except as required by applicable laws or regulations, the Company does not undertake any obligation to publicly update or revise any of the forward looking statements or to advise of any change in assumptions on which any such statement is based.

Non-IFRS Financial Information

Newcrest results are reported under International Financial Reporting Standards (IFRS) including EBIT and EBITDA. The EIS also includes non-IFRS information including Underlying profit (profit after tax before significant items attributable to owners of the parent company), All-In Sustaining Cost (determined in accordance with the World Gold Council Guidance Note on Non-GAAP Metrics released June 2013), AISC Margin (realised gold price less AISC per ounce sold (where expressed as USD), or realised gold price less AISC per ounce sold divided by realised gold price (where expressed as a %), Interest Coverage Ratio (EBITDA/Interest payable for the relevant period), Free cash flow (cash flow from operating activities less cash flow related to investing activities), EBITDA margin (EBITDA expressed as a percentage of revenue) and EBIT margin (EBIT expressed as a percentage of revenue). These measures are used internally by Management to assess the performance of the business and make decisions on the allocation of resources and are included in the EIS to provide greater understanding of the underlying performance of Newcrest's operations. The non-IFRS information has not been subject to audit or review by Newcrest's external auditor and should be used in addition to IFRS information.

Ore Reserves and Mineral Resources Reporting Requirements

As an Australian Company with securities listed on the Australian Securities Exchange (ASX), Newcrest is subject to Australian disclosure requirements and standards, including the requirements of the Corporations Act 2001 and the ASX. Investors should note that it is a requirement of the ASX listing rules that the reporting of Ore Reserves and Mineral Resources in Australia comply with the 2012 Edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (the JORC Code) and that Newcrest's Ore Reserve and Mineral Resource estimates comply with the JORC Code.

Competent Person's Statement

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

HARMONY GOLD MINING COMPANY LIMITED DISCLAIMER

Harmony Gold Mining Company Limited ("**Harmony**") is the ultimate holding company of Wafi Mining Limited and any reference below to "Harmony" or the "Company" includes both Harmony Gold Mining Company Limited and Wafi Mining Limited.

Forward Looking Statements

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

These forward-looking statements, including, among others, those relating to our future business prospects, revenues and income, wherever they may occur in this EIS and the exhibits to this EIS, are essentially estimates reflecting the best judgment of our senior management and involve a number of risks and uncertainties that could cause actual results to differ materially from those suggested by the forward-looking statements. As a consequence, these forward-looking statements should be considered in light of various important factors, including those set forth in these materials. Important factors that could cause actual results to differ materially from estimates or projections contained in the forward-looking statements include, without limitation: overall economic and business conditions in South Africa, Papua New Guinea, Australia and elsewhere, estimates of future earnings, and the sensitivity of earnings to the gold and other metals prices, estimates of future gold and other metals production and sales, estimates of future cash costs, estimates of future cash flows, and the sensitivity of cash flows to the gold and other metals prices, statements regarding future debt repayments, estimates of future capital expenditures, the success of our business strategy, development activities and other initiatives, estimates of reserves statements regarding future exploration results and the replacement of reserves, the ability to achieve anticipated efficiencies and other cost savings in connection with past and future acquisitions, fluctuations in the market price of gold, the occurrence of hazards associated with underground and surface gold mining, the occurrence of labour disruptions, power cost increases as well as power stoppages, fluctuations and usage constraints, supply chain shortages and increases in the prices of production imports, availability, terms and deployment of capital, changes in government regulation, particularly mining rights and environmental regulation, fluctuations in exchange rates, the adequacy of the Group's insurance coverage and socio-economic or political instability in South Africa and Papua New Guinea and other countries in which we operate.

For a more detailed discussion of such risks and other factors (such as availability of credit or other sources of financing), see the Company's latest Integrated Annual Report and Form 20-F which is on file with the Securities and Exchange Commission, as well as the Company's other Securities and Exchange Commission filings. The Company undertakes no obligation to update publicly or release any revisions to these forward-looking statements to reflect events or circumstances after the date of this EIS or to reflect the occurrence of unanticipated events, except as required by law.

Competent Person's Statement

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

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

8. PHYSICAL AND BIOLOGICAL ENVIRONMENT CHARACTERISATION

This chapter describes the existing physical and biological environments of the Project Area and its surrounds. The physical environment comprises the geology, landforms, soils and hydrogeology (groundwater) of the Project Area; and the ambient noise and air environments. The biological environment comprises the terrestrial plants, animals, vegetation communities and habitats that contribute to its structure and diversity. The freshwater aquatic ecology is described in Chapter 9, Freshwater Environment Characterisation. The marine environment is described in Chapter 10, Nearshore Marine Environment Characterisation and Chapter 11, Offshore Marine Environment Characterisation.

8.1. Location and Climate

Located in the southwestern Pacific Ocean, Papua New Guinea (PNG) occupies the eastern half of the island of New Guinea and is bordered by Indonesia to the west, with Australia and the Solomon Islands located to the south and east, respectively. Papua New Guinea's closest northern neighbours are the small islands of Micronesia, over 1,000 kilometres (km) to the north. The Project Area is located approximately 300km north-northwest of Port Moresby, and the Mine Area is 65km southwest of Lae, within the foothills of the Watut River catchment.

The northeastern coast of PNG experiences two distinct seasons; a southeast monsoon, from mid-May to October, and a northwest monsoon, from mid-November to the end of March, with intervening periods of light, variable winds.

The Coastal Area, located between the Markham and Busu rivers near the Port of Lae, experiences trade winds during the southeast monsoon, which are moderate, typically around 4 metres per second (m/s) and annual rainfall of between 3,900 to 4,500 millimetres (mm) (Embassy of Papua New Guinea to the Americas, 2004) with rainfall peaking between May and August.

From December to April, the major influence on weather at the Coastal Area is the northwest monsoon (originating in Asia) and warming sea temperatures of the Southern Hemisphere. During this period, the two combine over the Coral Sea to form occasional cyclones (Appendix A, Air Quality and Greenhouse Gas Impact Assessment).

Further inland, the Mine Area has an average annual rainfall of 2,836mm. The Mine Area is also characterised by low wind speeds, high humidity and warm temperatures (average maximum of 28 degrees Celsius (°C) and average minimum of 21°C).

8.2. Geology, Topography and Soils

8.2.1. Geology

8.2.1.1. Regional Geology

Papua New Guinea is bounded by several major tectonic plates. Papua New Guinea is situated on the northeastern margin of the Indo-Australian Plate, which is undergoing oblique convergence with the Pacific, North Bismarck, South Bismarck and Solomon and Caroline plates.

The Project Area occurs within the eastern margin of the Aure Trough, which is comprised predominately of sediments deposited by fast flowing, sediment-laden water. The alluvial material is primarily of volcanic origin. The structural geology in the Project Area results from compressional stress and strain and deformation of the original formations due to the

Project Area's location near the collision line of the Indo-Australian and Pacific tectonic plates. The Geological Survey of Papua New Guinea (Geoscience Australia, 2002) describes the rocks underlying most of the Project Area as Jurassic to Cretaceous (formed 180 million to 100 million years ago) in age.

The main geologic units in the Project area are displayed in Figure 8.1 and described below.

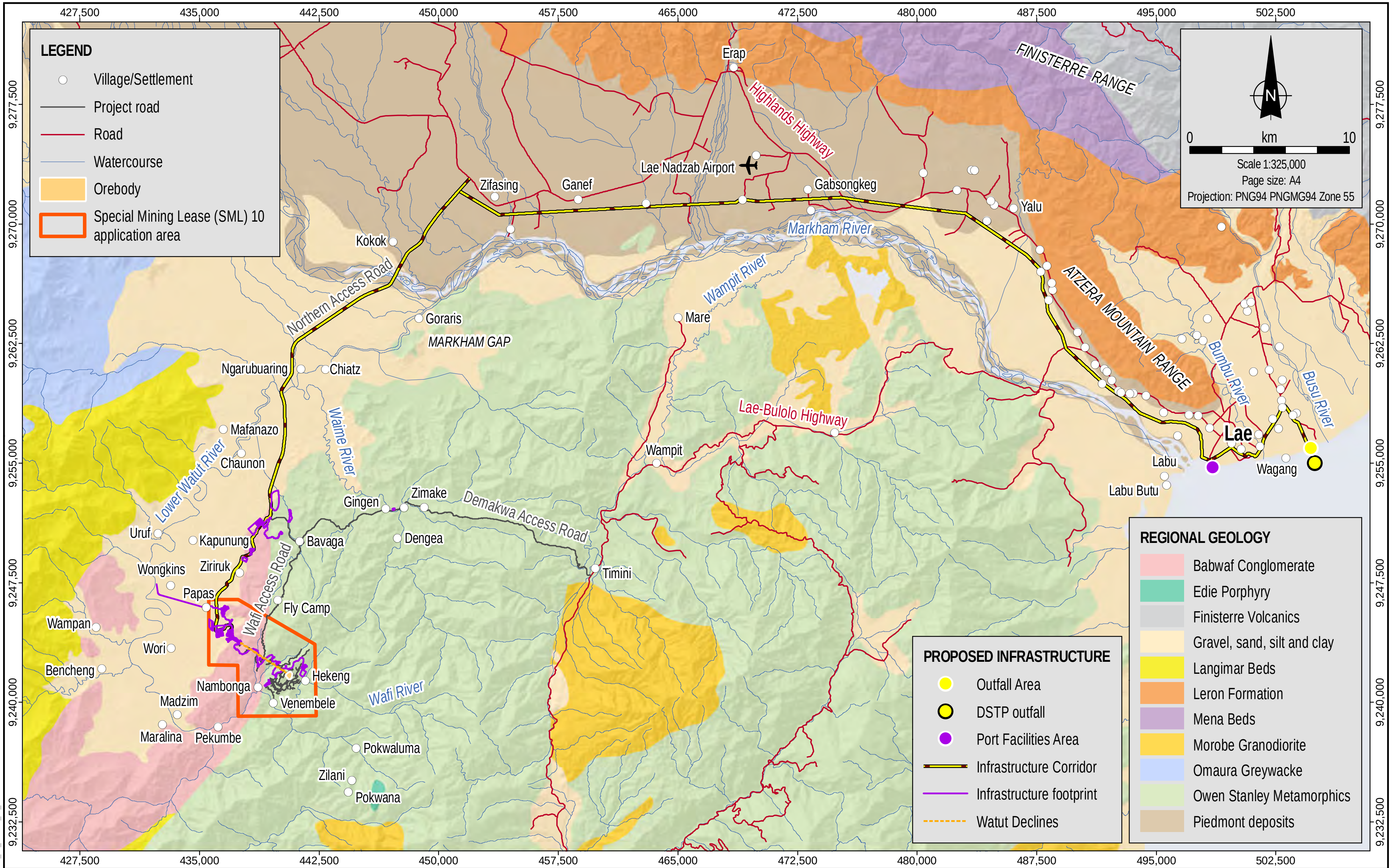
The predominant rock unit is the Cretaceous-aged Owen Stanley Metamorphics. The Owen Stanley Metamorphics comprise weakly metamorphosed rocks that were strongly deformed by the Papuan Orogeny (mountain belt formation) during the Palaeocene era, 60 to 30 million years ago. The Owen Stanley Metamorphics are frequently expressed on the surface as rugged mountainous terrain with deeply dissected valleys and high cliffs.

The Langimar Beds lie unconformably over the Owen Stanley Metamorphics south and west of the Mine Area and show little sign of deformation in the Project Area. These Middle Miocene (10 million to 5 million years ago) lithologies include volcanics, volcano-lithic pebble and cobble conglomerate with lenses of silty sandstone. The sediments become finer-grained towards the south of the Mine Area, and are predominantly silty mudstone and siltstone with sandstone and conglomerate. Langimar Beds thicknesses of up to 3,000 metres (m) are recorded in the region.

The Langimar Beds are unconformably overlain by the Pliocene (5 million to 3 million years ago) Babwaf Conglomerate. This stratigraphic unit generally comprises massive brown to grey pebble and cobble conglomerate and subordinate coarse, sandstone, siltstone and volcanics. The Babwaf Conglomerate formations have thicknesses in excess of 1,300m.

The Golpu Porphyry copper-gold orebody consists of multiple, diorite porphyries (i.e., volcanic rocks with coarse crystals within a finer grained matrix) bearing hornblende (an amphibolite mineral), intruded into host sediments of the Owen Stanley Metamorphics (see Appendix E, Mine Material Geochemistry). The orebody originates from volatile magma that ascended through the Earth's crust, and is approximately 800m by 400m, extending from 200 metres below ground level (mbgl) to more than 2,000mbgl. Within the Golpu deposit are a porphyry core, a high sulphidation hydrothermal system surrounding the core and a mixed zone where these two systems combine. The porphyry system is mineralised with gold, copper, silver and molybdenum. In the outer hydrothermal zone of the orebody, gold is associated with pyrite and chalcopyrite. Arsenic and sulphur are enriched within the high sulphidation hydrothermal system.

The wide floodplains and valleys in the Project Area are blanketed by Holocene-aged (approximately 2.5 million years ago) alluvial and swamp deposits (identified as 'gravel, sand, silt and clay' on Figure 8.1). These unconsolidated gravel, sand and silt materials have filled river valleys, floodplains and lagoons where fluvial erosion has shaped the landscape (KCB, 2013).



Source:
Geology, 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).

coffey
A TETRA TECH COMPANY

Date: 13.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.01_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Project Area geology

Figure No: 8.1

MXD Reference: 0520DD_10_GIS007_v0_6

8.2.1.2. Geochemistry

Geochemical investigations have been undertaken to characterise the rock types within the Mine Area (refer to Chapter 6, Project Description, Section 6.7, Waste Rock Management) with a view to:

- Understand the orebody.
- Plan for the ongoing management of potentially acid forming (PAF) rock types.
- Understand waste water management during mining (particularly with respect to acid and metalliferous drainage (AMD) within the block caves).
- Understand water management after closure (particularly with respect to AMD within the block cave and subsidence zone).
- Determine the suitability of the waste rock as:
  - Construction material.
  - An acid neutralising resource.
  - A substrate for vegetation.
  - A waste rock dump cover.

In general, the host rock types are enriched[1] with molybdenum, arsenic, sulphur, cadmium, lead, antimony, selenium, thallium and zinc when compared with rock from outside the block caves and predicted subsidence zone.

A weathered layer of non-acid forming (NAF) rock overlies the orebody and host rock which is potentially acid forming (PAF). The layer varies in thickness across Mt Golpu. Excavation of the declines and ventilation shafts will disturb both NAF and PAF rock, with approximately 75% of rock within the Watut Declines and nearly 95% of rock within the Nambonga Decline expected to be PAF. The majority of the ore to be recovered from the block cave is expected to be PAF. The block cave subsidence material is expected to comprise NAF and PAF, with the ultimate ratios depending on the final development of the block cave and subsidence pattern.

8.2.1.3. Seismicity

Papua New Guinea is bounded by several major tectonic plates and is one of the most seismically active regions in the world (Stanaway, 2008). The Project Area is seismically active, and historical evidence suggests the region has experienced a number of earthquakes in excess of magnitude 7 (Geoscience Australia, 2015).

To the north of the Owen Stanley Ranges, tectonic plate movements thrust the leading edge of Indo-Australian Plate over the Pacific Plate, leading to rotation and compression of the rock formations in the Project Area. There are two potential sources of earthquakes in the Project Area:

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

---

[1] The listed elements were found to have Geochemical Abundance Index values of three or more (Appendix E, Mine Material Geochemistry), which represents 12 to 24 times the median value and is generally considered to be significantly enriched (INAP, 2018).

A regional seismic assessment undertaken by SRK (2007) estimated peak ground acceleration (PGA) for events with 475 years return period, the operating basis earthquake for the Project Area, and 10,000 years return period, the maximum credible earthquake for the Project Area. Peak ground acceleration is a measure of earthquake acceleration (g) on the ground. Unlike the Richter scale, it is not a measure of the total energy (magnitude) of an earthquake, but rather of how hard the earth shakes in a given geographic area (i.e., the intensity). Peak ground acceleration is measured by instruments such as accelerographs. Examples of different ranges of acceleration include:

- 0.001g – Perceptible by people.
- 0.02g – Causes people to lose their balance.
- 0.50g – Buildings can survive if the duration is short, and if the building mass and configuration has enough damping (i.e., can disperse the energy sufficiently).

Results of the seismic assessment indicated the following:

- The PGA for the operating basis earthquake is 0.34g
- The PGA for the maximum credible earthquake is 0.43g

In the Mine Area, major structural faults strike roughly north-south and dip to the east at about 40° to 45°. The frequency that these faults occur increases to the east of the Golpu orebody. Other near-vertical faults occur in the Golpu deposit.

The tectonic setting of the Huon Peninsula and Huon Gulf means that earthquakes are common in the Coastal Area. The Indo-Australian Plate and Pacific Plate, or more specifically the Solomon and Bismarck sub-plates, are currently active. The movement of these plates causes regional uplift or subsidence as evidenced by historic earthquake activity. Due to the relatively unstable nature of the seabed in the Huon Gulf (steep, muddy slopes) and the seismic activity, seafloor slumping or slope failures may occur and may, in turn, trigger tsunamis. A historical paper by Everingham (1973) identified submarine landslide events in the coastal area near the Port of Lae in 1932, 1969, 1971 and August 1972, when tsunami waves over two metres high and lasting for several minutes occurred coincident with submarine landslides. Seismicity within the Huon Gulf is discussed further in Chapter 10, Nearshore Marine Environment Characterisation.

8.2.2. Topography

Situated on the northern side of the main dividing range of PNG, the landscape of the Project Area consists of three major terrain units, as described in Table 8.1.

Table 8.1: Major terrain units within the Project Area

Terrain Units	Description
Mountainous terrain with deeply incised valleys	This terrain comprises ridgelines, peaks and deeply incised valleys. The steep slopes cause rapid runoff in the river and creek catchments. Mountain ridges run approximately northeast to southwest driven by drainage lines which are likely geologically controlled as preferential erosion zones. Where logging has not occurred most mountains are densely forested (Coffey, 2013). To the northeast of the Mine Area, Watut Mountain is the highest peak at 1,000 metres above sea level (mASL).
Broad, alluvial valleys of mature rivers	The Watut and Markham rivers are large-scale, mature rivers and their valleys are characterised by a meandering channel within a depositional floodplain. They have high sediment loads under average flow conditions. In times of higher rainfall or extreme events, flows extend across the low-gradient floodplain and when returning to normal flow, may scour new channels. As a result of the large cross-sectional area, these river valleys are capable of expansive flooding.

Terrain Units	Description
Poorly drained areas	The Markham Gap is an example of a low-gradient, poorly-drained area adjacent to the Markham River valley. The source of water is likely a combination of rainfall and surface water, punctuated by inflow during flood events of the Markham River.

The terrain units described in Table 8.1 are evident in the slope analysis presented in Figure 8.2 which has been compiled from data in the Papua New Guinea Resource Inventory Survey (PNGRIS) (University of PNG Remote Sensing Centre, 2008). The landforms associated with these terrain units are shown in Figure 8.3.

The Mine Area is situated approximately 55km west of the Huon Gulf, with a maximum elevation at Mt Golpu of approximately 760mASL. Mt Golpu is the high point of a north-south trending ridgeline rising 565m from the Wafi River.

The flanks of Mt Golpu drop steeply to the Wafi River to the east and Nambonga Creek to the west, with overall slope gradients of around 17 degrees (º) to 27º, respectively. Slopes are incised with first-order ephemeral creeks oriented approximately 90° to the Mt Golpu ridgeline. The creeks feed Nambonga Creek and Wafi River.

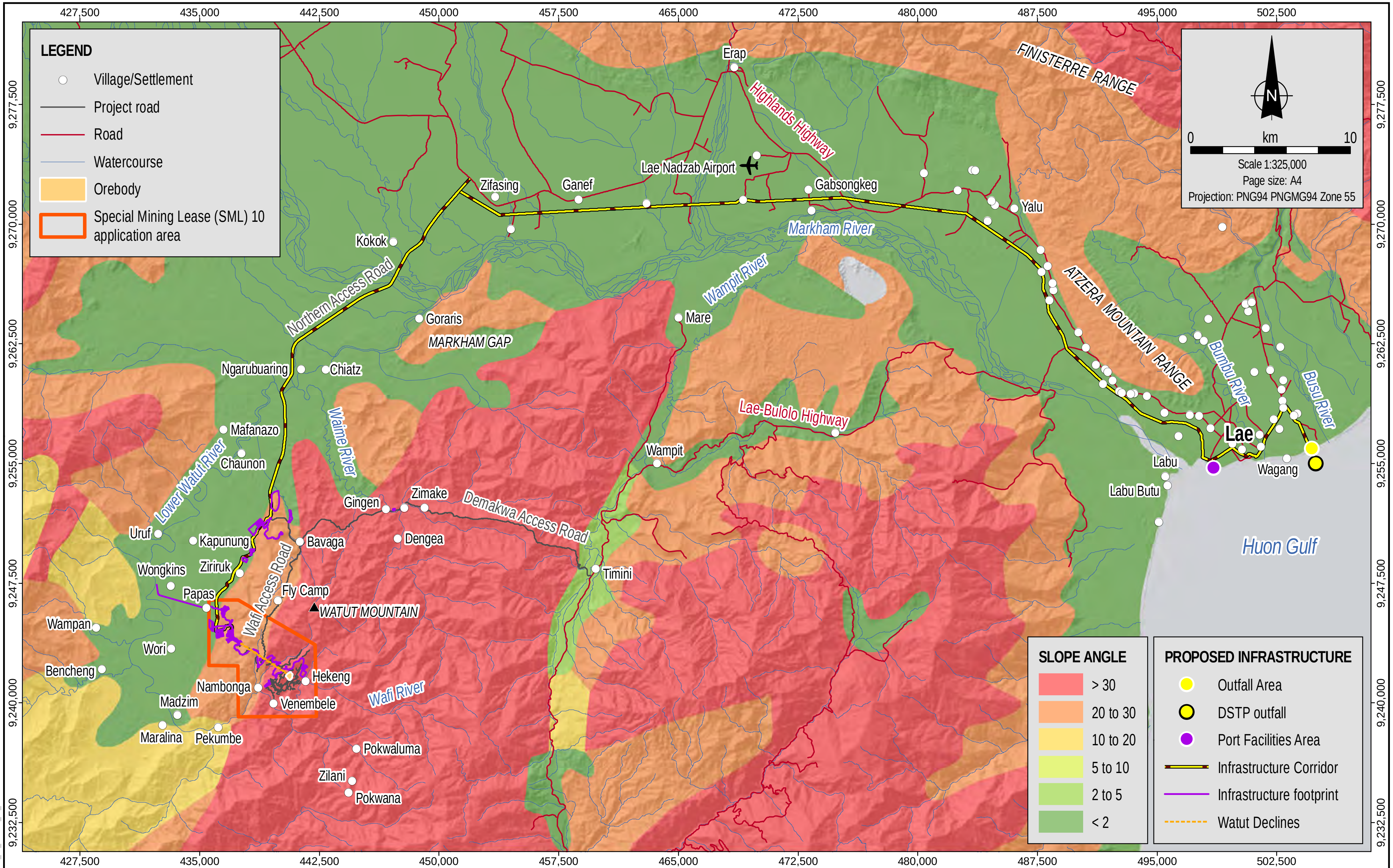
Mountainous terrain with fault-controlled valleys dominates the landscape at the surface of the orebody, ventilation shaft and along the Demakwa Access Road. The proposed portal terrace, Watut Process Plant, explosive magazine, Migiki Borrow Pit and Link Road are located within the foothills of the mountains with moderate slopes of 20° to 30°.

Further west of these areas, the broad Lower Watut River floodplain is characterised by a more gentle topography. The landforms of these areas comprise back swamps and meandering floodplains. Landforms associated with back swamps and meandering floodplains typically have slopes of less than 2°.

The Infrastructure Corridor between the Mine Area and Markham River traverses a range of landforms, including hills, meandering floodplains and back swamps. Near Zifasing, the Infrastructure Corridor departs from the Northern Access Road, and runs along an existing powerline corridor in the Markham River valley to the Coastal Area. The predominant landform traversed is the recent alluvial fans with little dissection. This landform is largely of fluvial origin and consists of predominantly stratified older sediments of unsorted gravel, boulders and finer-grained sediments. The landform is above the present flood level, generally unweathered, and subject to channelling and slope collapse.

8.2.3. Soils

Soils in the Project Area largely reflect the landforms (see Figure 8.3). Information describing the soils across the Project Area is derived from the PNGRIS dataset.



MXD Reference: 0520DD_10_GIS008_v0_7

Source:
Slope degree data from PNGRIS.
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).

coffey A TETRA TECH COMPANY

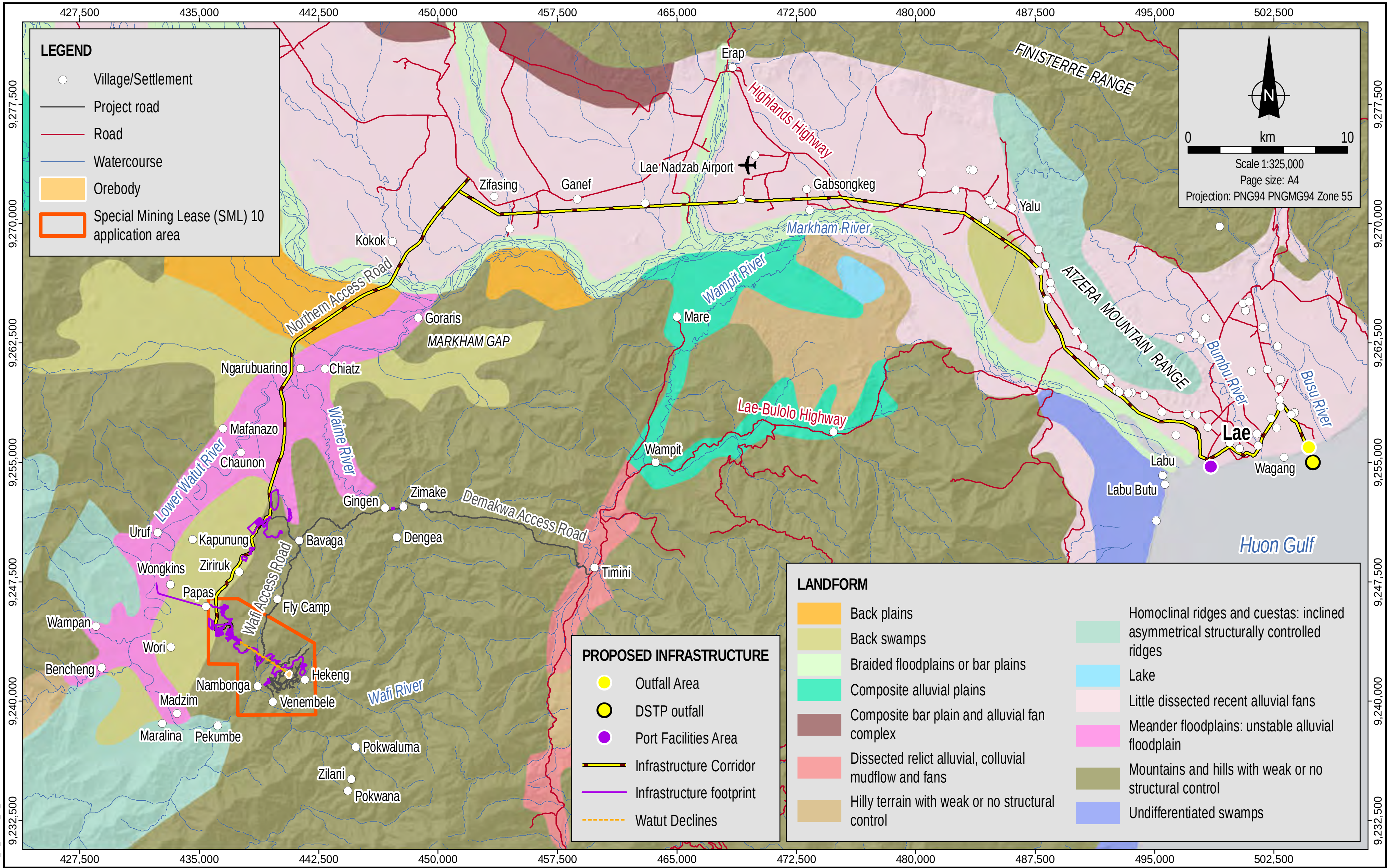
Date: 13.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.02_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Project Area slope

Figure No: 8.2



Source:
Landform data from PNGRIS.
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).

coffey
A TETRA TECH COMPANY

Date: 13.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.03_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Project Area landform

Figure No: 8.3

Soils across the Project Area comprise five main geological units. Visual inspection and physical/chemical analysis of soils in the Mine Area provides further detail of the soil classifications used in PNGRIS. The geological units and their particular properties based on investigations in the Mine Area are:

- Alluvium – These soils are loose sediments made up of a variety of materials and vary both vertically and horizontally in the soil profile. Alluvium soils within the Mine Area display high plasticity and are non-dispersive.
- Colluvium – These soils are formed as eroded material is transported down gradient and is the dominant soil layer on the valley slopes. Colluvium soils within the Mine Area display moderate to high plasticity and are non-dispersive.
- Residual – These soils originate from weathered Langimar Bed metasediment and conglomerate rock types and are likely to show more variability than alluvium, colluvium and slopewash soils. Residual soils within the Mine Area are non-dispersive.
- Slopewash – These soils are formed and distributed in a manner similar to that of colluvium soils but are more coarsely grained. Slopewash soils within the Mine Area display high plasticity and are non-dispersive.
- Topsoils – These soils are generally dark brown and occur in the uppermost layer. Topsoils within the Mine Area are non-dispersive.

Figure 8.4 shows the soil types associated with the geological units in the Project Area, as described below.

Areas of mountainous terrain with deeply incised valleys in the Project Area are predominantly comprised of eutropept and troporthent soils. These are slightly to moderately weathered, undifferentiated, and mostly shallow soils. Troporthent soils also occur in the Atzera Mountain Range.

The broad, alluvial valleys of mature rivers largely contain ustorthents, haplustolls, and fluvaquents along with smaller areas of hydraquents and hapludolls. These range from relatively well-drained ustorthents, which occur along most of the Northern Access Road, to the deeper, weakly acid to alkaline haplustolls and hapludolls that are subject to seasonal moisture stress, which occur along the eastern part of the proposed Northern Access Road and most of the Infrastructure Corridor south of Yalu. Poorly drained soils along approximately the first 10km of the Northern Access Road consist of hydraquents, soils that are permanently saturated, soft underfoot and mainly fine textured.

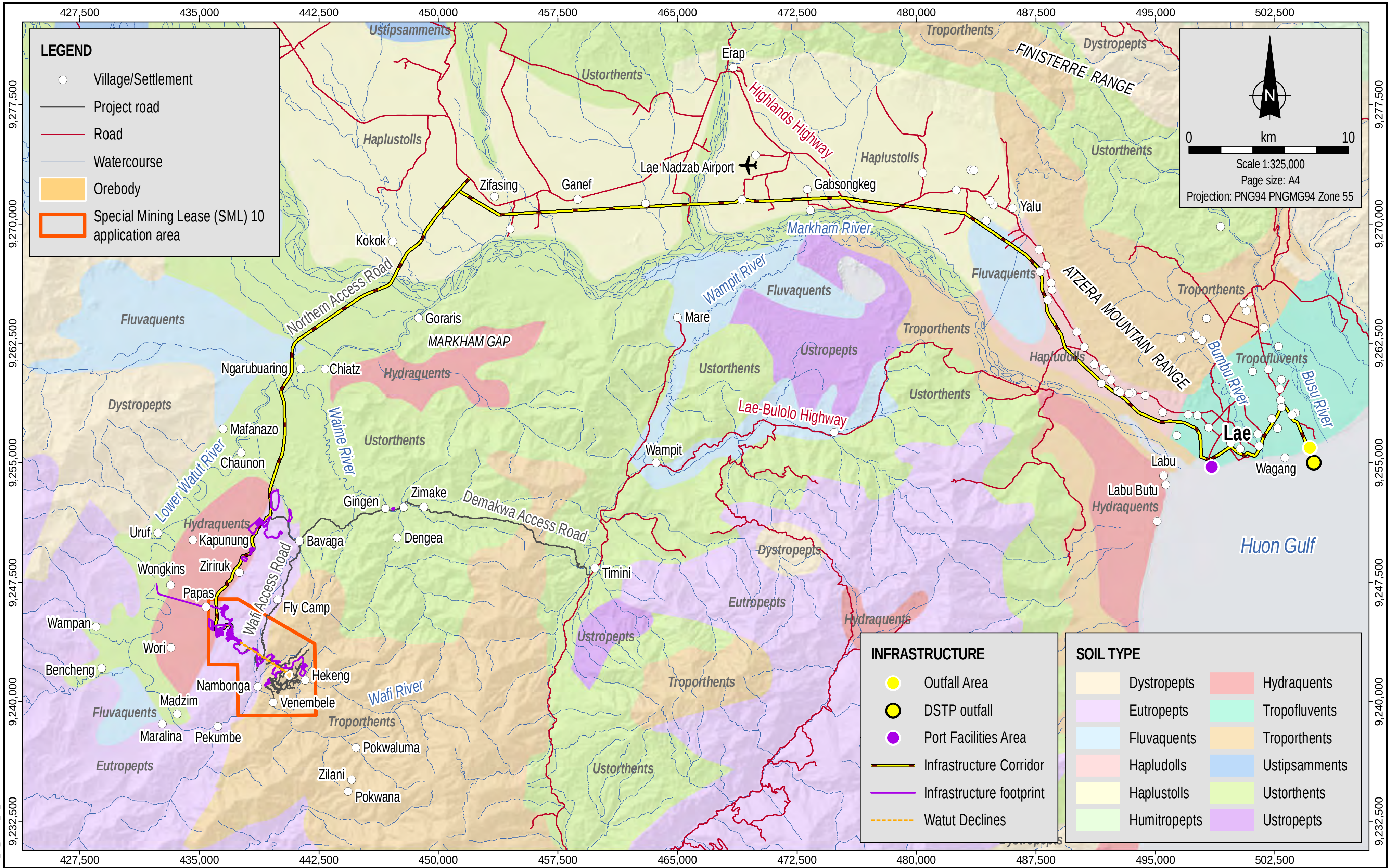
Around Lae, tropofluvent soils dominate. These soils typically occur in the lower reaches of valleys where gradients are low and are comprised of alluvial sediments deposited by large rivers. These soils are generally well drained in the upper 50cm.

8.2.3.1. Soil Geochemistry

The potential enrichment of metals was assessed based on assay results for selected samples obtained during the KCB (2013) assessment. A Geochemical Abundance Index (GAI) of zero indicates an element that is present at a concentration similar to, or less than, the median crustal abundance while a GAI of six indicates approximately a 100-fold or greater concentration above median abundance.

Consistent with the enrichment expected of a mineralised zone, the GAI levels for the soils at the surface above the orebody showed elevated levels of arsenic, lead, antimony, selenium and zinc, compared to the crustal abundance (KCB, 2013).

Soil samples from the portal terrace footprint also showed elevated levels of zinc and selenium. Zinc was significantly enriched at all sample locations tested.



Source:
Soil types data from PNGRIS.
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).

coffey
A TETRA TECH COMPANY

Date: 13.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.04_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Project Area soil types

Figure No: 8.4

MXD Reference: 0520DD_10_GIS010_v0_6

A shake flask extraction was undertaken for a selection of soil samples taken during the KCB (2013) investigation. The results for those analyses identified several significantly enriched metals (arsenic, lead, antimony, selenium and zinc) and are summarised below. The results provide an indication of the readily soluble constituents, expressed as the mass of each measured element per unit mass of sample tested.

The ‘mine’ soil sampling area encompasses the existing Wafi Exploration Camp and proposed ventilation shaft. The ‘Watut’ soil sampling area encompasses the proposed explosive magazine, portal terrace, process plant terrace and Fere Accommodation Facility.

The results for shake flask extraction on soil samples within the infrastructure areas of interest indicate the following water-soluble concentrations of metals and metalloids:

- Antimony is below detection limits.
- Arsenic is above detection limits within the mine and Watut sampling areas ranging from 0.003 to 0.051mg/kg.
- Lead is above detection limits within the mine sampling area ranging from 0.006 to 0.045mg/kg.
- Selenium is above detection limits within the mine sampling area ranging from 0.006 to 0.045mg/kg.
- Zinc is above detection limits within the mine and Watut sampling areas ranging from 0.003 to 10.5mg/kg.

The shake flask leachate pH was indicated to be between 2.7 (mine sampling area) and 8.7 (Watut sampling area).

8.2.3.2. Acid Sulphate Soils

Acid sulphate soils (ASS) and potential acid sulphate soils (PASS) are naturally occurring soils, sediments or organic substrates formed under waterlogged conditions. These soils contain iron sulphide minerals (predominantly as pyrite) or their oxidation products. In an undisturbed state below the water table, ASS are benign. However, if the soils are drained or exposed to air (e.g., by lowering the water table), the sulphides can react with oxygen to form sulphuric acid.

Acid sulphate soils and PASS are found in low-lying coastal areas, estuaries, lakes and swamps, generally below or just above the high-tide level. These materials appear as soft black, dark grey or green, with visibly high organic content.

Acid sulphate soils and PASS may occur within the vicinity of the Port Facilities Area and Outfall Area where the soils are known to have high sulphide content. These soils may also occur in other low-lying areas and floodplains of the Lower Watut River and Markham River. Infrastructure such as the concentrate, terrestrial tailings and fuel pipelines, concentrate filtration plant and Outfall System are located in these areas.

Site-specific soil assessments will be carried out for ASS and PASS as part of the geotechnical investigation of the construction contractor package of works.

8.3. Groundwater

This section describes the baseline hydrogeological setting of the Mine Area.

Key documents that inform the understanding of the baseline conditions include:

- Advisian, 2016. Watut tailings storage facility hydrogeological report. Ref: 201310-13317-532-1068-FS-REP-0003. 16 September 2016.
- WSP, 2016. Golpu Stage 1: Evaluation of mine inflows – Modelling of inflows to Golpu underground using Seep/W. 28 November 2016. Ref: 56072TM07v0.

Additional geotechnical and hydrogeological studies are currently underway and will inform detailed mine design and groundwater management during mining and on closure of the mine.

8.3.1. Hydrogeological Units

The hydrostratigraphy of the Mine Area has been conceptualised based on the deposit geology, weathering, fracturing, alteration and hydraulic conductivities as determined from drill hole packer testing and test pumping.

The hydrogeological units identified in the Mine Area include:

- Alluvium and colluvium
- Bedrock (comprised of bedrock or metasediments, partially weathered bedrock and weathered bedrock)

These units are described in detail in the following subsections.

8.3.1.1. Alluvium and Colluvium

The Lower Watut River valley hosts a relatively thick sequence of alluvium between 40 and 80m thick in the central, active zone of the river valley. It reduces to approximately 30m thickness on the floodplain margins. The highly permeable alluvium has two distinct alluvial aquifers associated with the shallow and deep gravel deposits that are separated by a clay aquitard. The alluvial aquifers are associated with the existing and palaeo channels of the Lower Watut River and its predecessors. The alluvium is expected to have some hydraulic connection with the underlying bedrock.

Colluvial layers exist on the flank of Mt Golpu. They are characterised by a mixture of clay, silt, sand and gravel (WSP, 2016). This material is expected to be unsaturated and is not considered an aquifer; however, its presence is thought to play an important role in the control of recharge and runoff to underlying units.

8.3.1.2. Bedrock

8.3.1.2.1. Weathered Bedrock

The geology of the mountain and foothill area is characterised by different zones of outcropping bedrock including the Babwaf Conglomerate, Langimar Beds and Owen Stanley Metamorphics units. A weathering profile has developed across the Mine Area with varying degrees of alteration and weathering observed across the different bedrock lithologies. The limit of the weathered zone depth is highly irregular varying between 20 and 150mbgl (WSP, 2016 and Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine).

A productive aquifer exists within the shallow weathered and partially weathered metasediments associated with the breakdown of the rock mass. These materials were originally clastic with iron cementing that tends to become increasingly friable with development of goethite and limonite replacement.

A typical geological description for the weathered bedrock unit[2] is that it is weak and completely oxidised, with rubbly texture, and is also argillic, commonly fault-sheared and fractured with extensive clay infill. Weathering occurs across the different metasediment lithotypes however the observed effects depend on the original mineralogy.

Hydraulic conductivity ranges widely from 0.9 to 2.6×10^{-5} metres per day (m/day). Original materials that were more clayey, with a tendency to decompose with residual weathering products such as clays and kaolinite have typically led to the lower hydraulic conductivity conditions. Similarly, clay infill of fracture zones may result in a reduction in hydraulic conductivity, predominantly in the fully weathered strata.

The unit presents a porosity of 10 to 30% (WSP, 2016), with the drainable water being less than 5% of the rock volume (see Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine).

8.3.1.2.2. Partially Weathered Bedrock

The partially weathered bedrock is a transition unit between the overlying weathered bedrock and underlying fresh metasediments. The unit is characterised by a rubbly texture, with less clay content and consequently more integrity than the weathered material. Depth to the unit varies between 10 and 300mbgl, however is typically around 50mbgl (WSP, 2016).

Hydraulic conductivity is similar to the overlying weathered bedrock with highly variable values ranging from 1×10^{-6} to 1×10^{-3}m/day. The two units are conceptualised to generally act as a single aquifer unit with depth being the main parameter determining hydraulic conductivity.

In borehole WR520, wireline data shows a porosity in the range of 5 to 20% and the water volume is primarily composed of water in the unsaturated zone above the water table (WSP, 2016). Porosity is expected to decrease with depth to less than 10% (WSP, 2016).

8.3.1.2.3. Bedrock or Metasediments

The fresh bedrock unit, also referred to as metasediments (including intermediate and strong alteration), comprises unweathered sediments, metasediments and intrusives often with pervasive fracturing at relatively shallow depths or in association with structural features.

Fracturing generally reduces with depth in the fresh bedrock. Geological logging has identified infilled micro-fractures and a general reduction in the level of brecciation, pervasive fracturing and weak zones with depth.

The intrusive rocks comprise the porphyry intrusions (Golpu, Golpu West, Hornblende (Livana) and Diorite Porphyries) and the diatreme, and include the units that will be mined and subject to the primary stresses associated with block caving.

The bedrock geology sequences of the Babwaf Conglomerate, Langimar Beds and Owen Stanley Metamorphics units are characterised by generally low primary hydraulic

[2] The term 'oxide aquifer' was developed and has been used by the Project since early exploration drilling in the 1990s to describe a variety of rock types that are variably weathered and comprise zones of moderate to high alteration. The oxidised and partially oxidised zones are indefinite in terms of specific layering and depth, and are identified as being heterogeneous with variable hydraulic conductivity. The preferred term is 'weathered bedrock unit' to refer to the shallow oxidised strata.

conductivity and low storage capacity, with groundwater movement and storage mostly attributable to networks of fractures. The groundwater resource potential is generally low and these units are not considered to be aquifers given their limited potential for productive yield (SKM, 2011).

Hydraulic tests in the Mine Area have focused primarily on these metasediments due to the potential for groundwater inflows to the proposed declines and block caves. Results indicate a strong correlation of reducing hydraulic conductivity with depth, reducing to 2.1 x 10^{-4}m/day at the depth of the extraction zone (900m). Nuclear magnetic resonance results support the assumption that groundwater movement through the deep and fresh metasediments is likely to be negligible due to very low permeability and effective porosity (WSP, 2016).

8.3.1.3. Faulting

Significant faults exist across the Mine Area with several fault zones that intersect the Golpu Porphyry. A series of thrust faults dipping 60° to the east, collectively referred to as a 'thrust fault package', has resulted in the deterioration of the rock competence (resistance of the rock to deformation). In addition, increased weathering occurs in a zone around the individual faults often extending approximately 20m either side.

Groundwater flow in the fault systems is complex due to the variable fault orientation and cross-cutting geometry, in addition to the potential for faults to either act as barriers or conduits to flow (or both). Faults acting as conduits can provide preferential pathways for recharge. The fault zones exhibit a wide range of hydraulic properties from 2.0 x 10^{-5} to 5.0 x 10^{-2} m/day (see Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine).

The primary faults are shown in Figure 8.5 and described below:

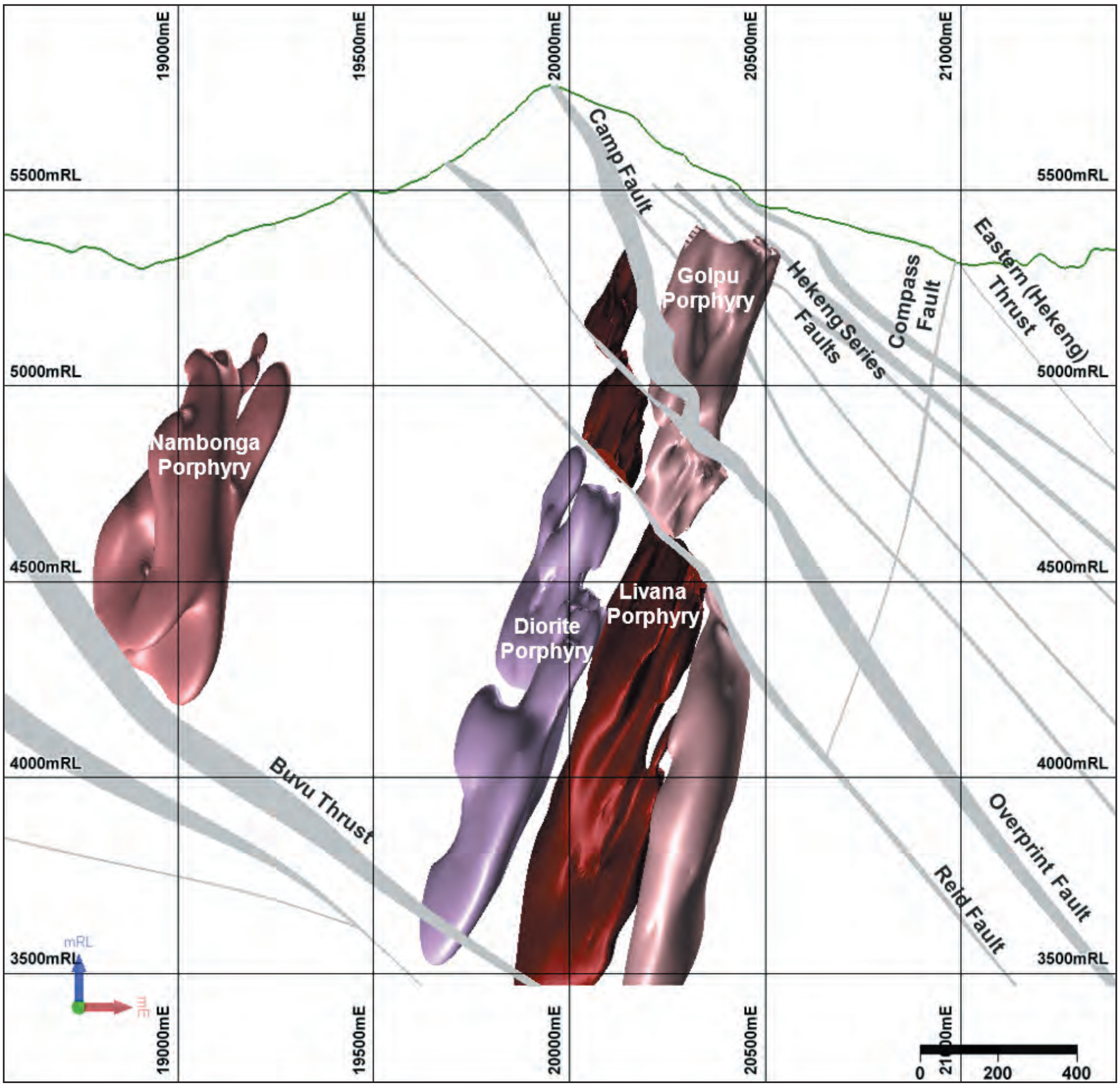
- Buvu Thrust – A sub-horizontal thrust which forms a 50m wide zone of fractured, sheared and gouged material.
- Reid, Overprint and Hekeng series faults – A series of thrust faults that result in strata displacement (whether this leads to barrier boundary effects is unclear).
- Compass and Camp faults – These sub-vertical faults cut across the 'thrust fault package' and are considered significant as they may provide a conduit for water transmission through the connected fault systems and into the final mine subsidence zone.

Given the very low hydraulic conductivity of the metasediments, the fractured zones form features with higher potential to convey water. This is particularly relevant for the development of the mine because faults that cross-cut the mine workings may potentially result in significant inflows.

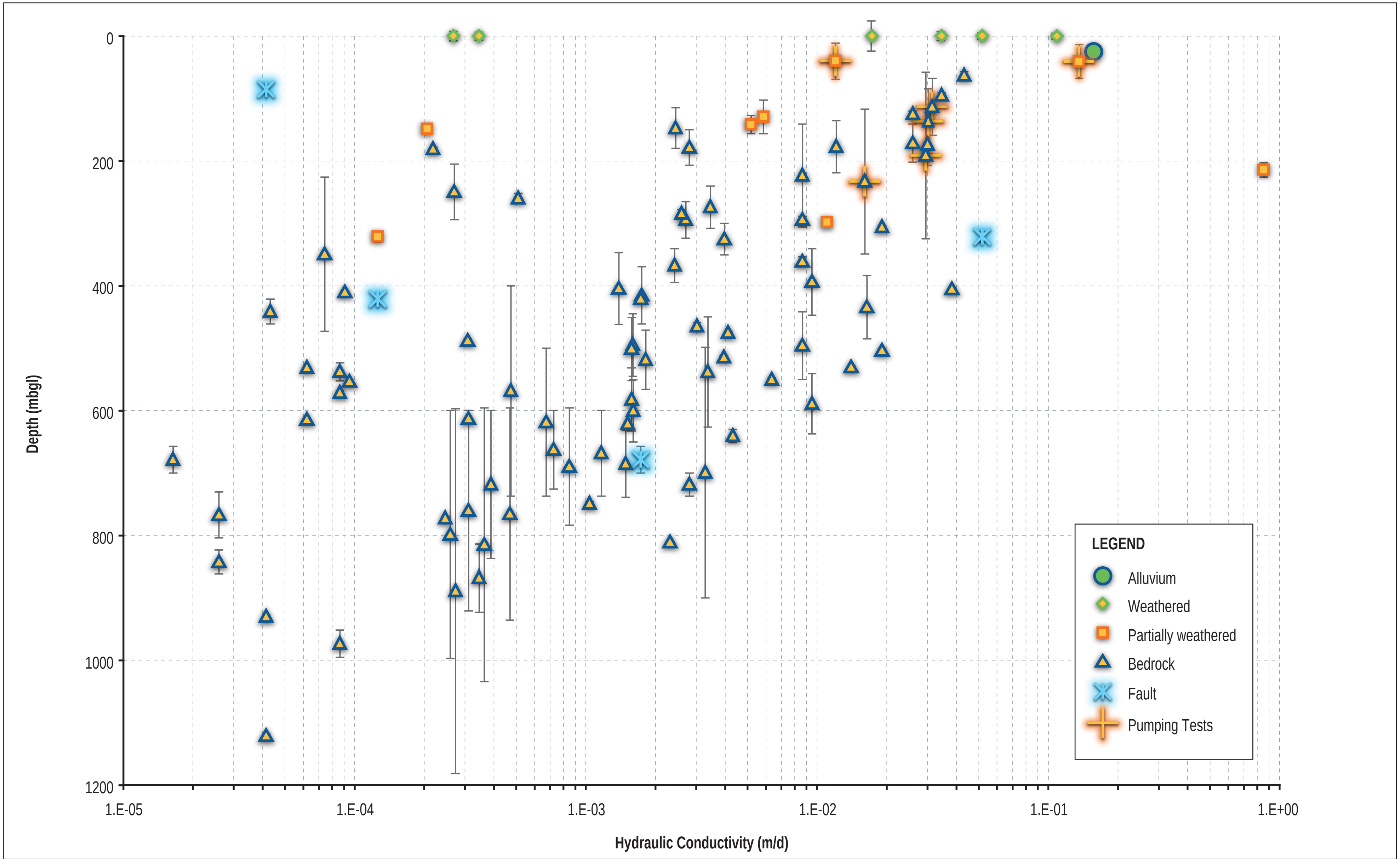
8.3.2. Hydraulic Properties

A total of 105 hydraulic tests have been undertaken across the Mine Area between 2005 and 2017 to provide estimates of hydraulic conductivity and storativity[3] at different depths and for different lithologies. Hydraulic tests have included airlift, packer and pumping tests. There are limited numbers of hydraulic conductivity measurements from all strata except for the zone of intermediate alteration. The results are summarised in Table 8.2 and Figure 8.6.

[3] The storativity of a confined aquifer (or aquitard) is defined as the volume of water released from storage per unit surface area of the aquifer or aquitard per unit decline in hydraulic head.



coffey A TETRA TECH COMPANY	Date: 29.03.2018 Project: 754-ENAUABTF100520DD File Name: 0520DD_10_F08.05_GRA	WAFI-GOLPU JOINT VENTURE Wafi-Golpu Project	Geological cross-section through the mine showing faults and major geology units	Figure No: 8.5



Source:
WGJV: 532-1005-EN-REP-0004-1.11, Figure11.2
Note:
Markers represent the hydraulic conductivity at the mid-point of the test interval.
Error bar annotations show the length of the test interval.

coffey
A TETRA TECH COMPANY

Date: 21.03.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.06_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Hydrogeological unit hydraulic conductivity variability

Figure No: 8.6

Analysis of the packer test data indicates a depth-dependence of hydraulic conductivity in the Mine Area. The raw data suggests an exponential decrease in hydraulic conductivity with an increase in depth (see Figure 8.6). Highest hydraulic conductivity values are measured in the alluvium on the Lower Watut River floodplain (geometric mean of 0.2m/day). The weathered and partially weathered bedrock units have the same geometric mean hydraulic conductivity (0.008m/day) and are both highly heterogeneous with hydraulic conductivity ranging over four orders of magnitude.

The hydraulic conductivity for the unweathered bedrock ranges over four orders of magnitude with a general logarithmic trend of reducing hydraulic conductivity with depth associated with improved lithological competency and reduced fracture density and connectivity.

Table 8.2: Summary of measured and calibrated hydraulic conductivity and storativity for hydrogeological units

Hydrogeological unit	Hydrogeological zone	Approx. depth range (mbgl)	Hydraulic conductivity (m/day)				Storativity (-)
			Min	Max	Geomean	No. of measurements	
Alluvium		0 - 50	3.46×10^{-2}	4.32×10^{-1}	1.57×10^{-1}	3	-
Bedrock	Weathered bedrock	20 - 100	2.68×10^{-4}	1.09×10^{-1}	8.23×10^{-3}	6	-
	Partially weathered bedrock	10 - 300	1.26×10^{-4}	8.54×10^{-1}	7.68×10^{-3}	8	3.30×10^{-2}
	Bedrock (intermediate alteration)	60 - 900	8.64×10^{-6}	4.32×10^{-2}	1.89×10^{-3}	69	6.32×10^{-4}
	Bedrock (strongly altered)	500 - >1200	2.00×10^{-5}	3.28×10^{-3}	1.73×10^{-4}	13	-
	Fault zones	variable	1.64×10^{-5}	5.18×10^{-2}	6.56×10^{-4}	6	-

Source: WSP (2016).

Six tests have been conducted in fault zones, with hydraulic conductivities ranging over three orders of magnitude. The Hekeng 3 (0.05m/day) fault has relatively high permeability suggesting that it is, at least in part, capable of transmitting groundwater. The Hekeng and Buvu Thrust faults have relatively low permeabilities (0.0001m/day and 0.00002m/day respectively) indicating they may (at least in part) be acting as barriers to groundwater flow. The Reid fault shows high variability in parameters across different drill holes, highlighting the variability in the properties of regional faults. Considerable uncertainty remains regarding the hydraulic properties of the major faults in the Mine Area. The faults may host a large amount of water and produce peaks of inflows in the future underground works, however it is unlikely that the faults will provide a continuous pathway for water from the surface to depths greater than 400m. The conductivity of these faults and how they affect groundwater flow in the Mine Area will be the subject of ongoing investigation.

Hydraulic test results indicate that the andesite intrusions typically act as flow barriers partially confining the units beneath. Micro-scale differences (i.e., higher matrix cementation or increased distribution of fines) within the formation may lead to discrete areas of lower permeability.

8.3.3. Groundwater Recharge

The tropical climate of the Mine Area is characterised by high rainfall averaging approximately 2,836 millimetres per year (mm/yr). Groundwater recharge is a direct function of rainfall infiltration with some variation to local groundwater recharge rates expected as a result of differences in altitude, soil cover and slope.

Direct recharge to the weathered bedrock occurs where more permeable zones exist and topography allows infiltration. The presence of high permeability colluvium is also expected to be an important influence on local rainfall recharge rates to the underlying weathered bedrock. These factors are expected to lead to an irregular distribution of recharge zones across the Project Area.

A component of recharge will enter the fresh bedrock primarily via transmissive fracture networks connected to the overlying weathered or partially weathered strata or alluvium. River valleys coincident with faults therefore have the potential for significant recharge if the fault acts as a conduit to groundwater flow.

The alluvium within the nearby river valleys is in hydraulic connection with the local rivers and creeks. The alluvial aquifer is expected to receive seasonal rainfall recharge and direct recharge from surface water during high flow periods. Baseflow analysis of river flow gauges in the Mine Area indicates recharge to the alluvial aquifer is in the range of 8 to 24% (WSP, 2016).

A groundwater recharge rate for PNG of 457mm/yr was estimated based on Aquastat data from the Food and Agriculture Organisation of the United Nations (Food and Agriculture Organisation of the UN, 2014). This equates to 16% of annual rainfall which compares well with the local recharge estimates based on stream gauging data in the area.

The recharge rates are estimated to vary according to the slope of the surface, ranging from 10mm/yr for the steepest slopes in the higher regions of the Project Area to 637mm/yr for the Lower Watut River floodplain and its tributary rivers and their floodplains. Anecdotal evidence indicates that rapid rises in artesian groundwater levels are evident in artesian wells on the eastern flank of Mt Golpu within hours of significant rainfall events. This supports the assessment of the relatively high recharge rates calculated from river flow levels.

Given the occurrence of rainfall throughout the year, recharge to the groundwater system should occur over the entire year.

8.3.4. Groundwater Levels and Flow Direction

8.3.4.1. Lower Watut River Floodplain Alluvium

Three boreholes were installed in the Lower Watut River valley alluvial sediments to the west of the Fere Accommodation Facility. Groundwater levels were shallow, ranging from 1.2 to 1.9mbgl in 2007 (SRK, 2007). A further 13 boreholes were installed across a wider area of the floodplain during 2016 as part of a hydrogeological investigation of a potential tailings storage facility site (Advisian, 2016). Depth to groundwater ranged from 0.28m above ground level (i.e., artesian conditions), to 2.54mbgl. Groundwater level fluctuations have been observed to range between 0.2 and 1m.

A northerly groundwater flow direction was interpreted for both the shallow and deep sand and gravel horizons of the alluvial aquifer based on the 2016 piezometric data (Advisian, 2016). Groundwater flow directions in the vicinity of Lower Watut River indicate there is some recharge from the Lower Watut River to the alluvial aquifer (Advisian, 2016). Runoff from the mountains and hills to the east is also expected to recharge the alluvial aquifer following rain (Advisian, 2016).

An upward vertical hydraulic gradient between the two horizons was observed across the majority of Lower Watut River floodplain indicating confinement of the deep horizon by the intervening clay layer (Advisian, 2016).

8.3.4.2. Bedrock Overlying the Twin Declines

Twenty one vibrating wire piezometers (VWP) were installed at 13 locations along the length of the declines' 2011 proposed alignment. The data remains relevant to the current proposed alignment of the declines. Sensors were installed at depths of between 20 and 978mbgl through the weathered profile and into underlying fresh bedrock.

Shallow VWPs installed in the weathered and partially weathered bedrock (within approximately 150mbgl) indicate that groundwater levels largely reflect the topography (Figure 8.7), with a degree of recharge from the surface though the weathered strata. A generally downward hydraulic gradient is indicated across these boreholes although locally artesian conditions have been recorded in some shallow VWPs.

Given the spatial distribution of the monitoring points, regional piezometric level contouring has not been established. Along the decline alignment and subsidence zone, groundwater levels generally mimic topographic relief. This indicates that recharge to the weathered bedrock occurs over the length of the decline alignment.

Some seasonal variation is also observed in boreholes WR496 and WR460, which monitor the weathered bedrock. For the other monitoring points located in the partially weathered bedrock or the metasediments, groundwater levels are stable over the year.

Artesian conditions are observed in exploration holes at the mid-slope of Mt Golpu, predominantly on the eastern side. Where exploration boreholes intersect the thrust faults, artesian conditions are often observed. The artesian conditions are indicative of the faults acting as conduits for groundwater flow and being hydraulically connected to the recharge areas.

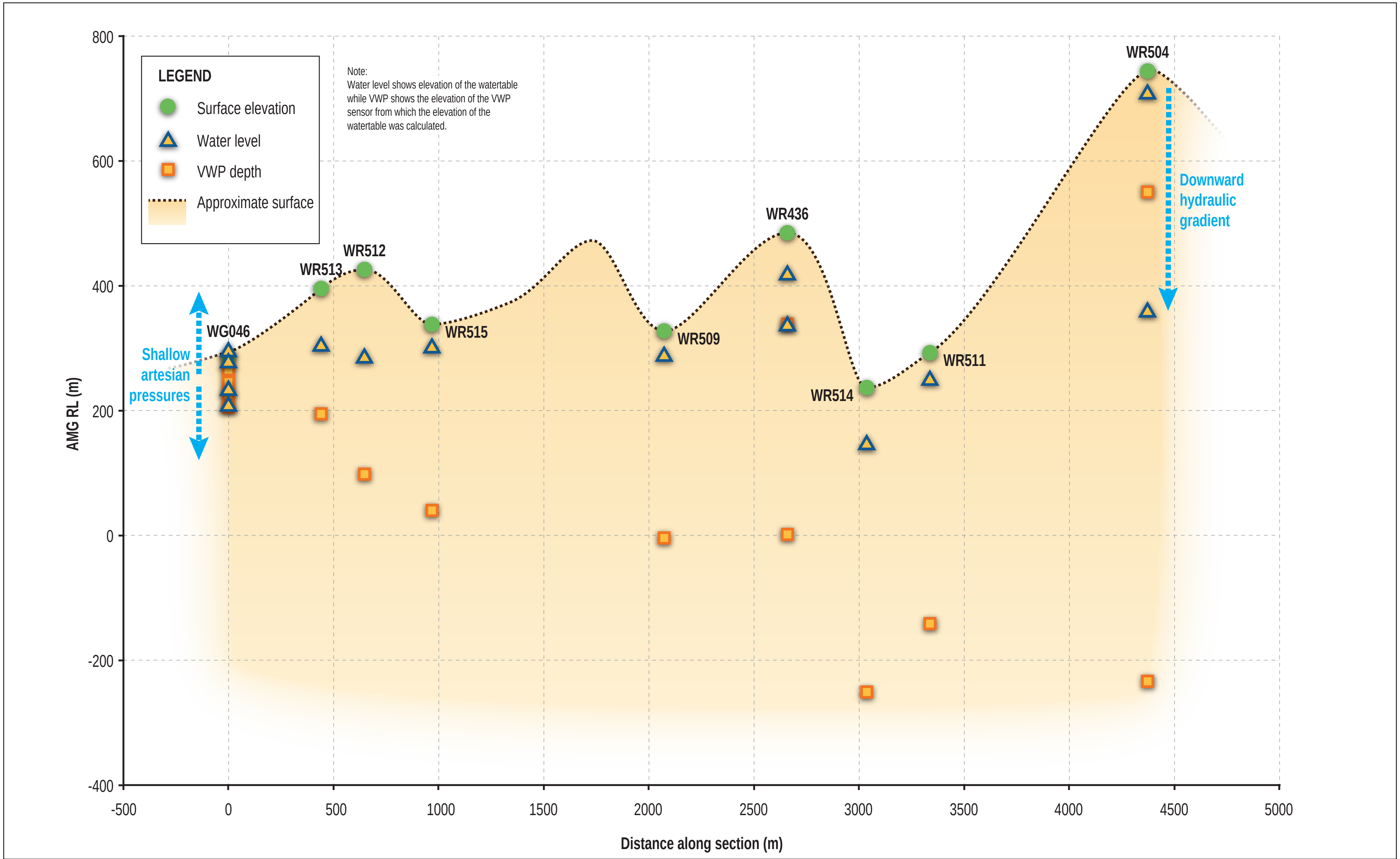
Artesian conditions were also identified at one location close to the portal (WG046) associated with the shallow weathered bedrock.

8.3.4.3. Orebody

Thirteen groundwater monitoring bores have been installed in the primary ore zone. The monitoring bores were generally installed to a total depth of 200mbgl (with the exception of WR496, which was installed to a depth of 156mbgl) and target the weathered/partially weathered bedrock sequence.

Monthly records of groundwater levels are available for most monitoring bores between June 2013 and August 2017. Temporal changes in groundwater levels and daily rainfall data are presented in Figure 8.8 and Figure 8.9. One significant variation in recorded water level for WR491 is interpreted to be a function of well construction rather than natural fluctuation.

Seasonal fluctuations have been observed at some monitoring bores including WR491, WR478, WR496 and WR460 (see Figure 8.9). At other monitoring bores, often associated with sites that show little or muted response to seasonal recharge (e.g., WR500, WR498, WR494 and WR474), a declining trend in groundwater level over time is evident. Ongoing monitoring will provide additional information as to the potential causes of the apparent declining trends.



Source:
WGJV: 532-1005-EN-REP-0004-1.11, Figure11.3

coffey
A TETRA TECH COMPANY

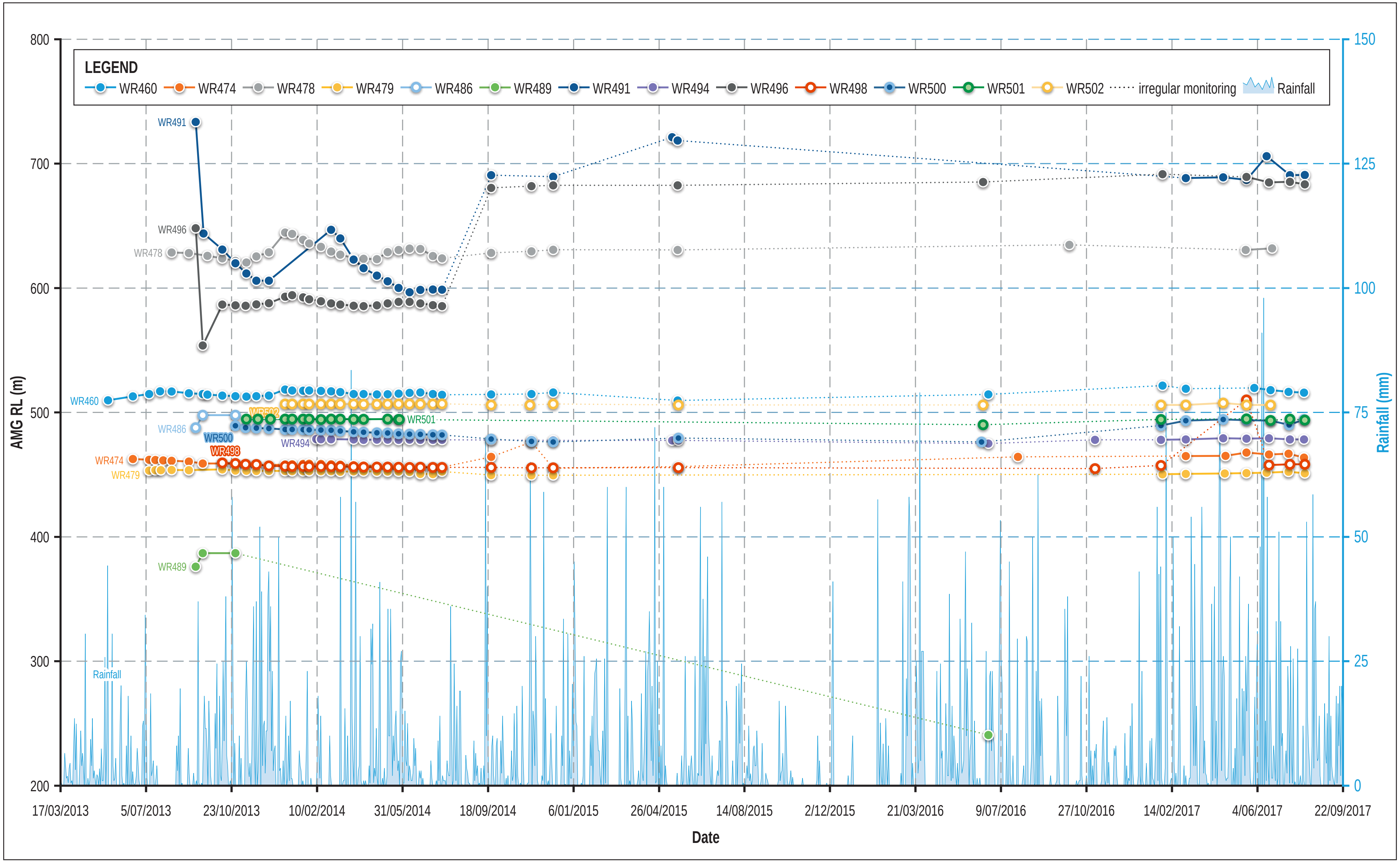
Date: 21.03.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.07_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Pore pressure measurements for VWPs along the declines

Figure No: 8.7



INDD Reference: 0520DD_10_GRA022.indd_4

Source:
WGJV 4.12.2017

coffey
A TETRA TECH COMPANY

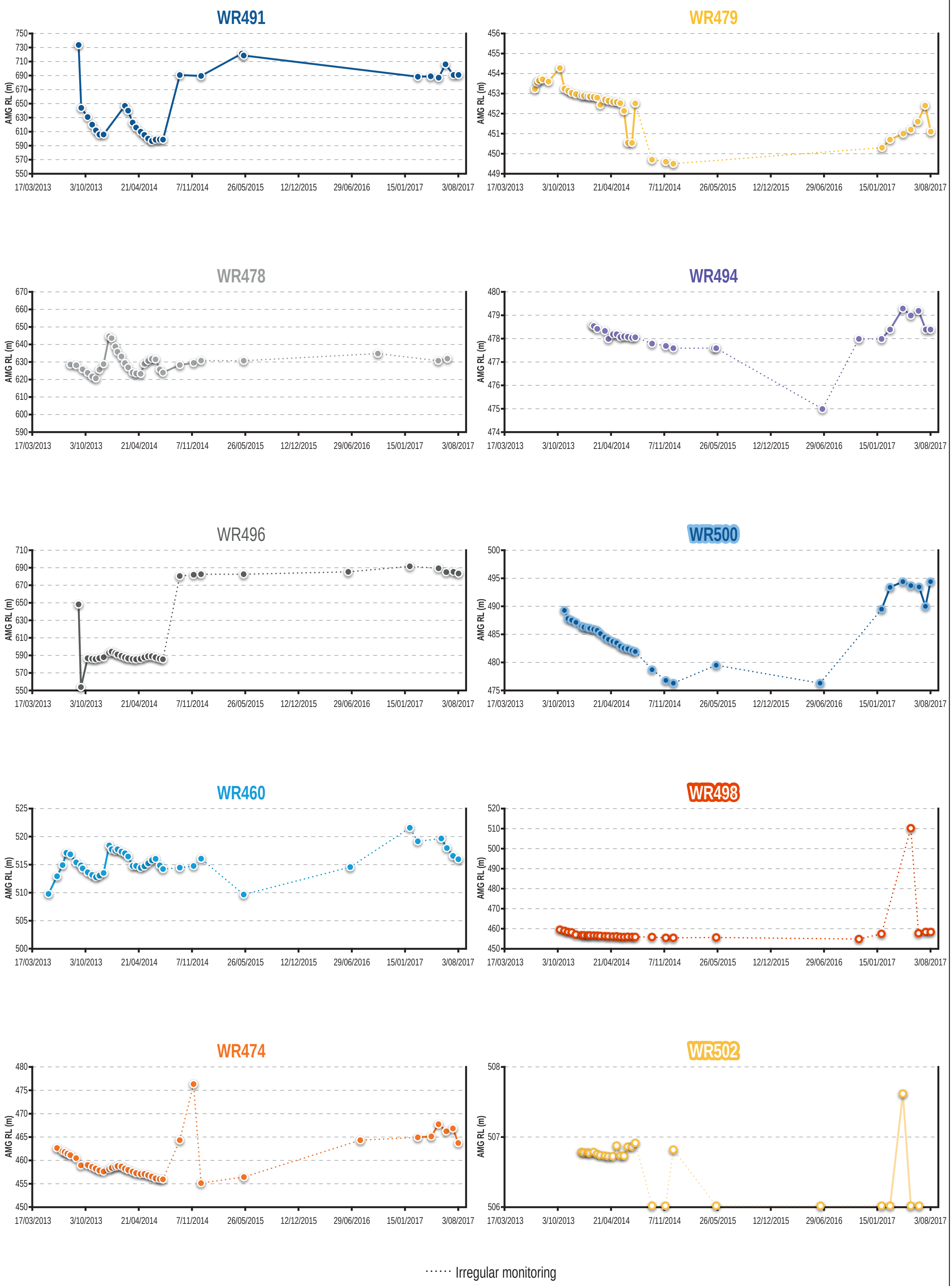
Date:
21.03.2018
Project:
754-ENAUABTF100520DD
File Name:
0520DD_10_F08.08_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Measured groundwater elevation and daily rainfall

Figure No:
8.8



Source:
WGJV 4.12.2017

coffey
A TETRA TECH COMPANY

Date: 21.03.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.09_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Temporal groundwater levels

Figure No: 8.9

8.3.4.4. Artesian Conditions

Artesian conditions have been identified in ten boreholes situated predominantly on the eastern slope of Mt Golpu in the deep bedrock strata. A comparison of collar elevations and maximum fault outcrop indicates that the main water-bearing faults are the Hekeng 2 Fault (intersected by all ten boreholes), the Overprint Fault (intersected by nine out of ten boreholes) and the Camp Fault (intersected by eight out of ten boreholes).

Artesian conditions have also been identified in two shallower boreholes WHDB014s (70mbgl) and WHDB013d (194mbgl) on the eastern slopes of Mt Golpu. These are also identified as encountering significant faulted zones thought to be associated with the Hekeng 2 Fault.

The flow from individual artesian boreholes is less than 0.5 litres per second (L/s) with pressure heads approximately 10m above ground level (SRK, 2011).

8.3.4.5. Springs

Five natural springs have been identified on the eastern slopes of Mt Golpu (Figure 8.10). There is limited information available about the spring hydrology, including discharge rates or seasonality in flows. The Yanta people identify several watercourses on this flank of the mountain as having high spiritual value (refer to Chapter 13, Cultural Heritage Characterisation).

Spring discharge has also been reported near the Wafi Exploration Camp, close to borehole WG428. There is some conjecture that this spring may be associated with the contact between the Owen Stanley Metamorphics and the Babuaf Conglomerate formations (SKM, 2011), however, the Owen Stanley Metamorphics is not mapped in this area. Data regarding the seasonality of the spring is limited.

8.3.4.6. Infrastructure Corridor Groundwater Levels

Groundwater levels were recorded in test pit excavations and sonic boreholes as part of the geotechnical investigations for the Infrastructure Corridor undertaken by Advisian (2017). The results show relatively shallow groundwater levels along the Infrastructure Corridor, with an average depth of 1.32m, a minimum of 0.1m and a maximum of 3m.

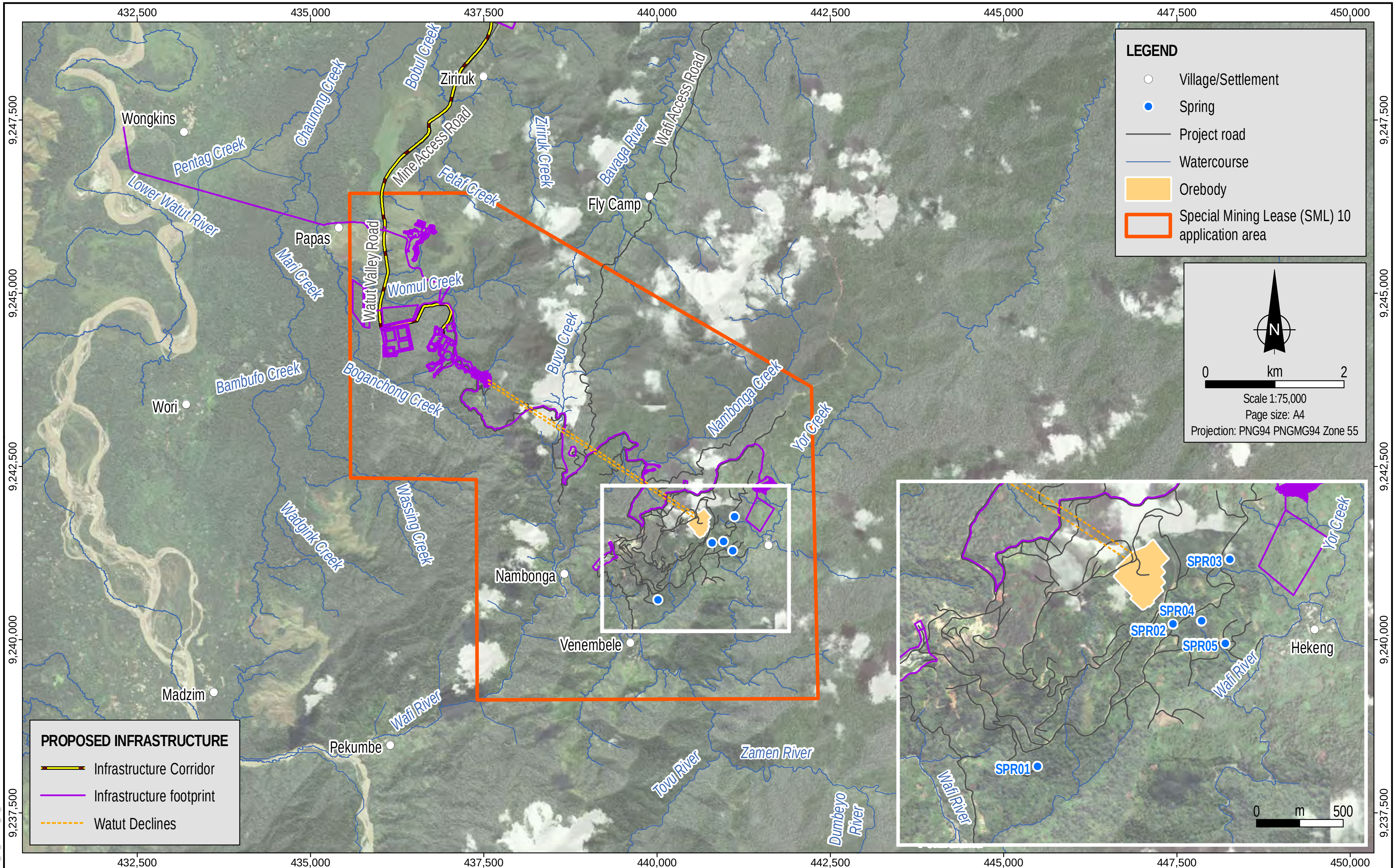
8.3.5. Groundwater Discharge and Use

Regional groundwater discharge within the Mine Area is expected to be to the Wafi River and Nambonga Creek, which drain the slopes of Mt Golpu.

Groundwater within the bedrock and weathered bedrock aquifers is expected to move along local flow paths controlled by the surface topography of the mountain towards the dense network of watercourses and local spring discharge points. Groundwater on the western slopes of the mountain is expected to migrate towards the Lower Watut River valley where it discharges via upward flow to the overlying alluvial aquifer.

Shallow groundwater in the alluvial aquifer of the Lower Watut River valley is expected to discharge via both direct evaporation from the watertable, as well as through transpiration by vegetation accessing shallow groundwater. Riparian vegetation is also likely to access shallow groundwater; however, given the abundance of surface water, ecosystem dependence on groundwater is thought to be limited mainly to extended dry periods.

The alluvial aquifer is considered to be a highly productive aquifer utilised by local communities. Further information on groundwater use by local villages is provided in Chapter 12, Socioeconomic Environment Characterisation.



MXD Reference: 0520DD_10_GIS078_v0_1

Source:
Watercourses from EnviroGulf and WGJV.
Springs from Piteau Associates.
SML and orebody from WGJV.
Villages, infrastructure and project roads from WGJV and Coffey.
Imagery from WGJV (capture date 2016).

coffey
A TETRA TECH COMPANY

Date: 05.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.10_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Springs on the eastern slopes of Mt Golpu

Figure No: 8.10

8.3.6. Groundwater – Surface Water Interaction

The Lower Watut River is a large meandering, braided river located west of the Mine Area. Monitoring at observation wells WTSF-BH28 and WTSF-BH28A, which are located closest to Lower Watut River, indicated that under normal conditions, the groundwater elevation and river levels are similar and relatively little flux is expected between groundwater and surface water. Following high rainfall events the river rises significantly and recharges the shallow alluvial aquifer. Conversely, during prolonged dry periods groundwater is expected to discharge to the river as baseflow in some areas.

The smaller tributary creeks crossing the Lower Watut River floodplain display a different relationship with groundwater, where the discharge of groundwater to the creeks is expected under normal and dry climate conditions (Advisian, 2016). Hydraulic gradients reverse following high rainfall events as water levels in the creeks rise resulting in localised recharge of the shallow groundwater system.

8.3.7. Groundwater Quality

Baseline groundwater quality data has been collected for key areas of the Project including the bedrock and shallow weathered bedrock aquifers in the vicinity of the proposed block cave and declines and the shallow alluvial aquifer in the vicinity of the Lower Watut River floodplain.

The available water quality results are considered to be representative of baseline groundwater conditions in the Mine Area.

8.3.7.1. Water Quality Objectives

Results from the baseline water quality assessment have been compared to relevant water quality objectives to assess the groundwater quality. Table 8.3 provides a summary of the relevant Environment (Water Quality Criteria) Regulation 2002 (PNG ER) criteria, the Environmental Code of Practice (2000): Environmental Code of Practice for the Mining Industry (ECoP) and the Public Health (Drinking Water) Regulation 1984 guideline values considered in the screening process.

Table 8.3: PNG Water quality objectives and guideline values

Parameter	Units	Water Quality Objectives and Guideline Values		
		PNG ER	PNG ECoP[1]	PNG Drinking Water Standards
Temperature	°C	No alteration >2°C	No alteration >2°C	-
Dissolved Oxygen (DO)	% saturation	-	>80-90% saturation	-
	mg/L	>6	> 6	-
Turbidity	NTU[2]	No alteration >25	<10% change from background seasonal mean	-
Electrical Conductivity (EC)	µs/cm	-	<1,500	-
pH	-	No alteration to natural pH	6.5 – 9.0	-
Total Suspended Solids (TSS)	mg/L	-	<10% change from background seasonal mean	-
Potassium (K)	mg/L	5	-	-
Sulphate (SO_4^{2-})	mg/L	400	-	400
Silver (Ag)	mg/L	0.05	0.0001	0.05
Arsenic (As)	mg/L	0.05	0.05	0.05

Parameter	Units	Water Quality Objectives and Guideline Values		
		PNG ER	PNG ECoP[1]	PNG Drinking Water Standards
Boron (B)	mg/L	1	0.5	-
Beryllium (Be)	mg/L	-	0.004	-
Cadmium (Cd)	mg/L	0.01	0.0007 *	0.01
Chromium (Cr)	mg/L	0.05	0.01	-
Cobalt (Co)	mg/L	Limit of detection	0.00024	-
Copper (Cu)	mg/L	1	0.007 *	-
Fluoride	mg/L	-	-	1.5 ***
Iron (Fe)	mg/L	1	1	-
Mercury (Hg)	mg/L	0.0002	0.0001	0.001
Manganese (Mn)	mg/L	0.5	-	0.5
Zinc (Zn)	mg/L	5	0.18 *	-
Selenium (Se)	mg/L	0.01	0.005	0.01
Lead (Pb)	mg/L	0.005	0.0013 *	0.1
Nickel (Ni)	mg/L	1	0.056 *	-
Aluminium (Al)	mg/L	-	0.1 (if pH >6.5) 0.005 (if pH <6.5)	-
Antimony (Sb)	mg/L	-	0.03	-
Tin (Sn)	mg/L	0.5	-	-
Ammonia**	mg/L	3.6	1.04	-
Nitrate	mg/L	40	-	50
Phenols (sum)	ug/L	2	-	-

Note: WQOs/guideline values for metals/metalloids are for dissolved metals/metalloids.
1 PNG ECoP values based on protection of aquatic life in freshwater.
2 Nephelometric turbidity units.
* WQOs/guideline values for Cd, Cu, Pb, Ni, Zn are based on a hardness of <50mg/L of $CaCO_3$ in PNG ECoP.
** Ammonia WQOs/guideline values are dependent on temperature and pH – WQO/guideline value listed is based on temperature of 25°C and pH of 7.
*** WHO Drinking water quality criteria.

8.3.7.2. Bedrock and Shallow Weathered Bedrock Aquifers

Groundwater samples were collected from five localities (WHDB010d, WHDB011d, WHDB012s, WHDB013d and WHDB014s) during pumping tests conducted in 2014. Samples were analysed for physical parameters, total and dissolved metals and major ions.

In May 2015, water samples were collected from 12 flowing (artesian) boreholes; ten located in the vicinity of the planned block cave (WHDB011d, WHDB013d, WHDB014s, WHMB001d, WR206, WR331, WR451, WR486 and WR489) and two located near the Watut Declines Portal (WR510 and WR516).

Table 8.4 presents a summary of the results from both the 2014 and 2015 sampling campaigns. The analytical results reported low total dissolved solids (TDS), typically less than 100 milligrams per litre (mg/L) and not exceeding 400mg/L. The very low TDS of these waters may indicate a short subsurface residence time. The groundwater is characterised by a sodium-calcium-sulphate-bicarbonate ionic composition and the overall low concentrations of major ions is consistent with low TDS.

The majority of analytical results are below the relevant WQOs and guideline values set out in Table 8.3. Values are regularly exceeded for aluminium, cobalt, iron and mercury. Lead, cadmium, copper and pH (more acidic) exceed the guideline values at some locations. Single exceedances of arsenic, manganese and nickel were also reported. The concentrations of these parameters is considered to be representative of the baseline conditions associated with mineralisation in the Mine Area.

8.3.7.3. Alluvial Aquifer

Groundwater samples were collected from 13 monitoring wells covering the alluvial aquifer from the western slopes of the Mine Area to the eastern bank of the Lower Watut River.

Groundwater in the shallow alluvial aquifer was reported to be fresh with TDS concentrations ranging from 259 to 411mg/L, and displaying relatively neutral pH ranging from 7.10 to 7.88 (field measured) (Advisian, 2016). There were no regional trends in TDS concentrations noted for the shallow alluvial aquifer, however, concentrations reported in the deep alluvial aquifer were consistently in the order of 10% lower than those in the shallow alluvial aquifer (Advisian, 2016).

The ionic composition of alluvial aquifers was calcium carbonate dominant and comparable to that of the bedrock and weathered bedrock aquifers as well as the Lower Watut River. Groundwater analytical results for the alluvial aquifers, presented in Advisian (2016), found no exceedances of the objectives presented in Table 8.3, and indicate:

- Hardness that exceeds the WHO aesthetic drinking water value, consistent with the calcium carbonate ionic composition.
- Detectable concentrations of organic compounds were reported in the sample collected from WTSF-BH08A including petroleum hydrocarbons (C6-C9), toluene, phenol and 2-Methylphenol. WTSF-BH08A will be resampled to confirm the presence and likely source of petroleum hydrocarbons.

A selection of these results are described in Table 8.5.

Table 8.4 Selected groundwater quality values from 2014/2015 sampling campaigns

Analyte*	Sampling site (captured in 2014)								Sampling site (captured in 2015)							
	WHDB010d	WHDB011d	WHDB012s	WHDB013d	WHDB014s	WHDB011d	WHDB013d	WHDB014s	WHMB001d	WR206	WR331	WR451	WR486	WR489	WR510	WR516
pH (field tested)	7.82	5.71	7.47	6.47	7.12	NR	NR	NR	NR	NR	NR	NR	NR	NR	0	0
Total Dissolved Solids	391	37	182	0	62	54	88	109	94	65	95	20	214	200	228	0
Aluminium (Al)	<0.01	0.06	0.01	<0.01	<0.01	<0.01	0.01	0.01	0.02	0.95	<0.01	0.01	0.11	<0.01	<0.01	0.01
Arsenic (As)	0.002	0.004	0.012	0.001	0.002	<0.001	0.004	0.008	0.017	0.002	0.055	0.003	0.002	0.006	<0.001	0.003
Cadmium (Cd)	<0.0001	<0.0001	0.0035	0.0008	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt (Co)	0.011	0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper (Cu)	0.006	0.005	0.015	0.001	0.008	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron (Fe)	2.98	2.17	0.61	0.21	<0.05	3.69	<0.05	0.58	1.17	2.57	12.2	<0.05	<0.05	<0.05	1.01	<0.05
Lead (Pb)	0.025	<0.001	0.006	0.001	<0.001	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	<0.001
Manganese (Mn)	0.67	0.051	0.003	0.158	0.157	0.118	0.154	0.072	0.043	0.009	0.324	0.063	0.002	0.125	0.183	0.004
Mercury (Hg)	<0.0001	0.0003	0.007	0.002	<0.0001	0.0052	0.0068	0.0083	0.0096	0.007	0.0047	0.0055	0.0043	0.0058	0.0047	0.0032
Nickel (Ni)	0.275	0.005	0.017	0.002	<0.001	0.001	<0.001	0.002	0.008	0.005	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium (Se)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc (Zn)	0.085	0.051	0.042	0.007	0.007	0.009	0.017	0.015	0.016	0.069	0.032	0.017	0.013	0.015	0.014	0.01

* All units in mg/l except pH (which is pH units).
NR denotes analyte not recorded.
Grey shading denotes exceedance of objectives or guidelines presented in Table 8.3.

Table 8.5 Selected groundwater quality values in alluvial and bedrock aquifers

Analyte	Units	Range of values for aquifer formation	
		Alluvium	Bedrock
pH (lab tested)	-	7.79 - 8.19	7.76
Electrical Conductivity (lab tested)	µS/cm	399 - 622	629 - 632
Total Dissolved Solids	mg/L	259 - 404	409 - 411
Iron (Fe)	mg/L	0.06 - 0.77	<0.05
Manganese (Mn)	mg/L	0.13 - 0.483	0.432
Aluminium (Al)	mg/L	<0.01	<0.01
Arsenic (As)	mg/L	<0.001 - 0.009	<0.001
Beryllium (Be)	mg/L	<0.001	<0.001
Boron (B)	mg/L	<0.05 - 0.07	<0.05
Cadmium (Cd)	mg/L	<0.0001	<0.0001
Chromium (Cr) (as Cr(III))	mg/L	<0.001	<0.001
Cobalt (Co)	µg/L	<0.001	<0.001
Copper (Cu)	mg/L	<0.001	<0.001
Lead (Pb)	mg/L	<0.001	<0.001
Mercury (Hg)	mg/L	<0.0001	<0.0001
Nickel (Ni)	mg/L	<0.001 - 0.002	<0.001
Selenium (Se)	mg/L	<0.01	<0.01
Zinc (Zn)	mg/L	<0.005	<0.005

Note: concentrations are of dissolved metals.

8.3.8. Conceptual Hydrogeological Model

A conceptual hydrogeological model of the Mine Area has been developed based on the results of geotechnical and hydrogeological investigations that have focussed primarily on the mineral resource zone of the Mine Area.

The conceptual hydrogeological model is presented in Figure 8.11. Groundwater systems in the Mine Area are summarised as follows:

- Groundwater systems are associated with alluvium in the Lower Watut River valley, as well as weathered, partially weathered and metasediment bedrock.
- Shallow depth to groundwater in the floodplains and variable depth to groundwater in the mountains and hills.
- Fault-controlled groundwater flow in the bedrock, with faults acting as both conduits for, and barriers to, groundwater flow.
- Regional groundwater flow direction in the bedrock aquifer (including weathered and partially weathered) controlled by local topography, generally flowing towards local surface drainage features.
- Artesian conditions observed in several deep boreholes on the slope of the Mt Golpu, suggesting thrust faults below Mt Golpu are pressurised.
- The underlying fractured bedrock has very low hydraulic conductivity with very little storage.
- Groundwater within the bedrock and weathered bedrock aquifer would typically be expected to flow along local flow paths controlled by surface topography towards local spring and creek discharge points.

- Groundwater on the western slopes of the mountains and hills is likely to migrate towards the Lower Watut River valley, where it would discharge via upward flow to the overlying alluvial aquifer.
- Groundwater flow direction in the alluvial aquifer towards the north, with the bulk of groundwater migrating through higher hydraulic conductivity gravel and sand horizons, which can be confined by very low conductivity clay.
- Discharge of groundwater from the alluvial aquifer via direct evaporation from the watertable and transpiration.
- Groundwater use from the shallow alluvial aquifer by local communities.
- Recharge occurs via direct rainfall infiltration, as well as leakage from rivers and creeks, and vertical migration from overlying and underlying aquifers.

8.4. Terrestrial Ecology

This section describes the terrestrial ecology in the Project Area, including vegetation, flora and fauna.

The terrestrial ecology characterisation is based on information in the following technical studies:

- Terrestrial Ecology Characterisation - Mine Area to Markham River, BAAM (Appendix C). This report characterises the Mine Area ecology, including the Infrastructure Corridor to Markham River (Figure 8.12). This study summarises data collected during previous ecology studies completed for the Project.
- Terrestrial Ecology Characterisation - Markham River to Wagang, Coffey (Appendix D). This report characterises the Infrastructure Corridor, from the Markham River crossing in the west to the Coastal Area (Figure 8.12).

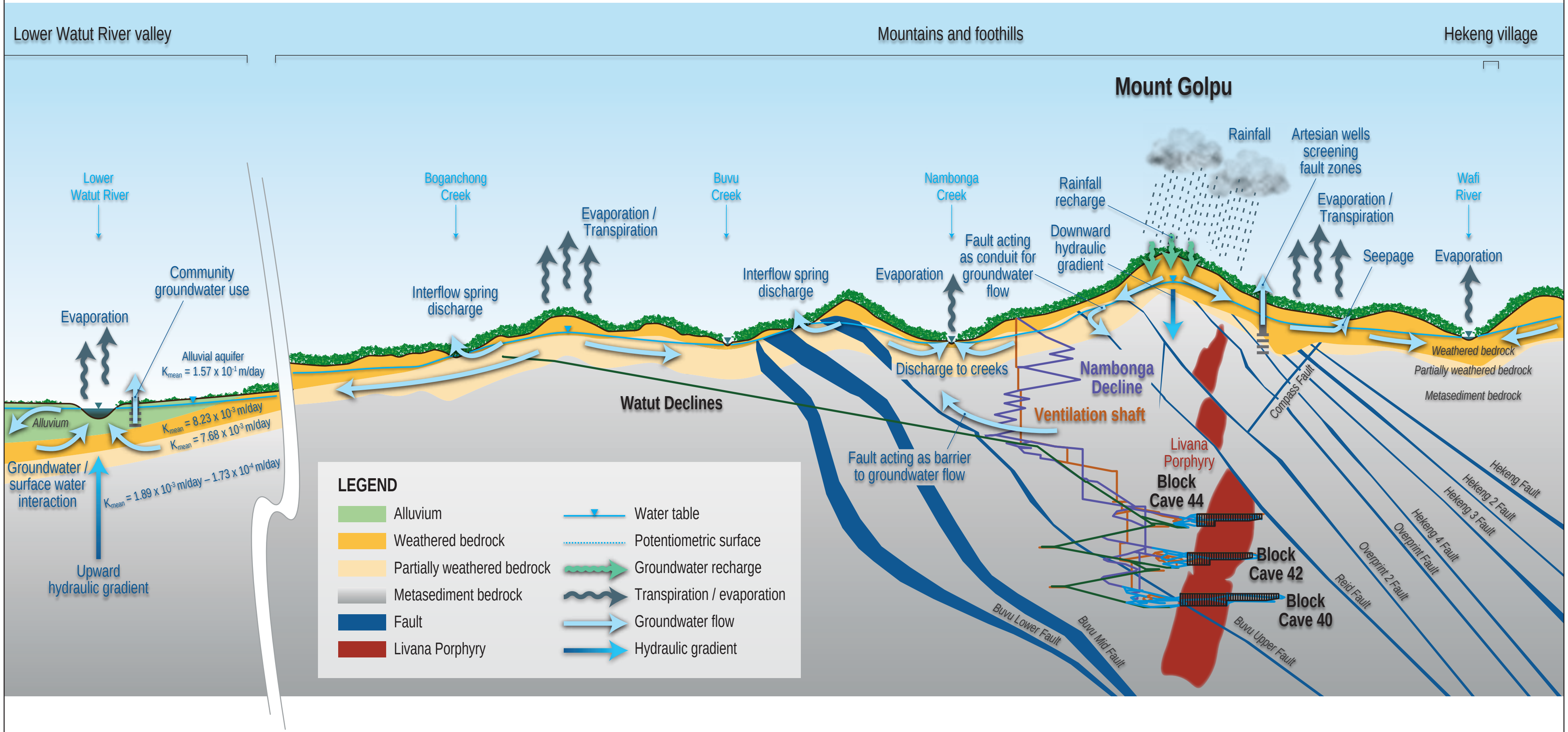
Baseline surveys were designed to sample representative terrestrial ecological values across the Project Area.

8.4.1. Terrestrial Ecology Study Area

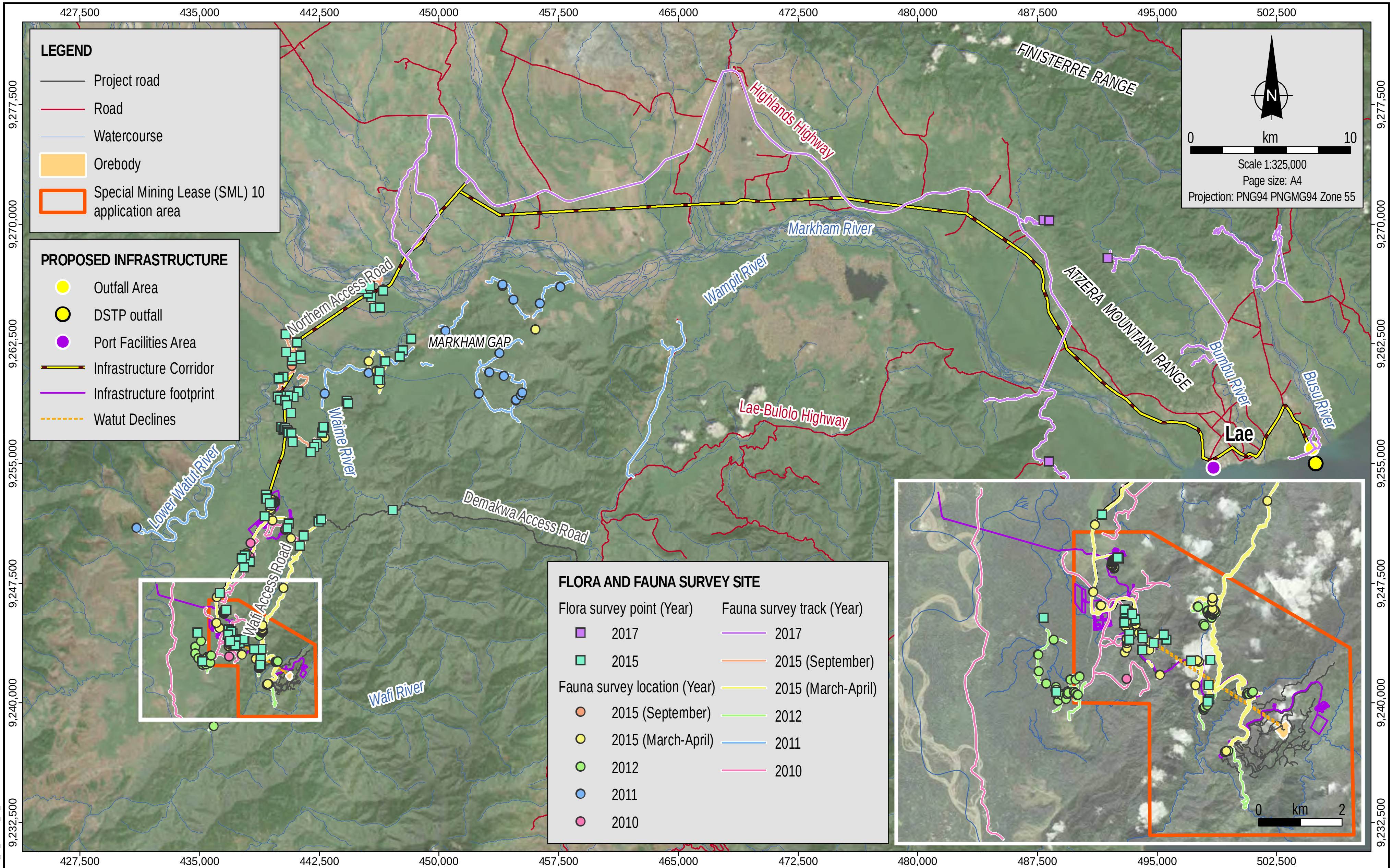
The terrestrial ecology study area covers approximately 900 square kilometres (km^2) (Figure 8.12), and includes the areas and associated environmental values that could be directly or indirectly impacted as a result of construction, operation and decommissioning of the Project.

The terrestrial ecology study area is located north of the main dividing range of PNG, in the Watut River Basin and the Lower Markham River Basin. The terrestrial ecology study area is defined by the topographic features in which the Project infrastructure (for example, roads and pipelines) will be located. The terrestrial ecology study area encompasses a broad area surrounding the Mine Area, the Infrastructure Corridor and the Coastal Area. It encompasses the Wafi River catchment, Nambonga Creek catchment, Buvu Creek catchment, Waime River catchment, lower Wampit River, Lower Watut River and associated floodplain, Markham Gap, Lower Markham River and associated floodplain, Atzera Mountain Range, lower Bumbu and Busu rivers and coast between the Markham River and Busu River.

Field surveys have been carried out across the Mine Area with targeted surveys conducted along the Infrastructure Corridor. Figure 8.12 shows the features in the terrestrial ecology study area. PNG's Forest Inventory Mapping System data was used to identify the spatial extent of vegetation types in the terrestrial ecology study area to provide context.



coffey A TETRA TECH COMPANY	Date: 05.06.2018 Project: 754-ENAUABTF100520DD File Name: 0520DD_10_F08.11_GRA	WAFI-GOLPU JOINT VENTURE Wafi-Golpu Project	Conceptual hydrogeological model	Figure No: 8.11



MXD Reference: 0520DD_10_GIS012_v0_7

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

coffey A TETRA TECH COMPANY

Date: 13.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.12_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Terrestrial ecology study area

Figure No: 8.12

8.4.2. Methods

The terrestrial ecology investigations informing this study comprised field surveys and desktop review of terrestrial biodiversity of the region.

Wafi-Golpu Joint Venture has considered the IFC Performance Standard (PS) 6 Biodiversity Conservation and Sustainable Natural Resource Management (IFC PS 6) (IFC, 2012) in the identification, avoidance, mitigation and management of impacts to terrestrial ecology values.

8.4.2.1. Desktop review

Data sources used to characterise the terrestrial ecology within the terrestrial ecology study area include:

- Previous floristic and fauna assessments undertaken for the Project including Booyong Forest Science (2011a, 2011b and 2013), Woxvold (2010, 2011 and 2012) and Woxvold and Aplin (2013) and a PNG Forestry Research Institute assessment (PNGFRI, 2011) undertaken in the Project Area.
- Databases including the Papua New Guinea (PNG) Plants Database (Conn et al., 2006), spatially referenced records of PNG plant records held by the Queensland Herbarium (Queensland Herbarium, 2015), PNG National Herbarium and the Bishop Museum (2015).
- Descriptive texts by Paijmans (1975 and 1976), Whitmore (1984), Conn (1995) and Womersly (1978).
- Vegetation type, land classification and land use mapping, including the Papua New Guinea Resources Information System (PNGRIS, 3rd Edition) (Shearman and Bryan, 2008) and PNG's Forest Inventory Mapping System (FIMS[4]) (Hammermaster and Saunders, 1995).
- The International Union for Conservation of Nature (IUCN) Red List of Threatened Species.
- Published scientific literature, such as peer-reviewed journals, books and private sector, government and non-government organisation reports.

8.4.2.2. Field surveys

Field surveys were undertaken to provide baseline data on the composition, condition and conservation significance of terrestrial species, communities and habitats present within the terrestrial ecology study area. The combined survey effort of these surveys totalled 67 days across 7 survey campaigns between 2010 and 2017. These surveys covered a range of seasons, locations and habitat types within and adjoining the Project Area. Figure 8.12 shows the location of the targeted floristic and fauna survey sites and tracks for each of the field campaigns.

[4] Vegetation is described with reference to national scale FIMS vegetation mapping produced at 1:250,000 scale as reported in McAlpine and Quigley (1998). The FIMS has a coarser spatial resolution than ground-truthed mapping and represents the extent of vegetation communities in 1996. Rules adopted to address differences in resolution and change over time are described in Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River.

The methods used for surveying different habitats and species are described in detail in Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River, and Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang, and are summarised below:

- **Vegetation.** Major vegetation types across the terrestrial ecology study area were characterised initially using the FIMS dataset. Vegetation mapping units at selected sites were then verified through ground-truthing and aerial surveys to characterise both structural and floristic composition.
- **Flora.** Vascular plants (i.e., ferns, gymnosperms, angiosperms) were recorded either by sight (for more common and easily recognised species) or by collecting plant specimens (i.e., flowers or fruiting parts) and comparing to specimens held by the PNG National Herbarium in Lae and the Queensland Herbarium in Brisbane, Australia.
- **Birds.** Diurnal surveys for birds using visual and aural methods, were completed along forest tracks primarily within the first four hours of sunrise in a range of habitats. Other methods included night-time spotlighting, digital camera-trapping, recordings of bird calls, call playbacks and using mist nets.
- **Herpetofauna.** Diurnal searches for reptiles during the warmer parts of the day when reptile activity is greatest, and opportunistically whenever reptile movement was detected while undertaking other surveys. Nocturnal searches for frogs and identification of their calls while working along walking trails.
- **Non-flying (non-volant) mammals.** Small and medium-sized mammals (i.e., rodents and marsupials) were recorded during nocturnal searches using spotlights, trapping and digital camera traps.
- **Bats.** Ultrasonic echolocation calls of echo-locating bats were recorded using ultrasound recording unit and subsequently analysed to determine the species present. Mist-netting was undertaken for flying foxes.

A summary of ecological surveys completed in the terrestrial ecology study area is described in Table 8.6 and shown in Figure 8.12. Detailed descriptions of the methods used and results of these surveys are provided in Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River, and Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang.

Table 8.6: Summary of terrestrial ecology surveys in the terrestrial ecology study area

Survey team and period of survey	Survey method	Survey area(s)
Flora and vegetation field surveys		
Coffey (February and June 2017) (Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang)	Opportunistically recorded flora assemblages within key habitats characterised in the terrestrial ecology study area.	Markham River valley, Atzera Mountain Range, headwaters of Bumbu River and the mouth of the Busu River.
BAAM (March, April, July and September 2015) (Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River)	**Secondary site surveys**. A comprehensive collection and identification of all canopy species recorded in a plot-less sweep of area. **Quaternary site surveys**. A recording of forest structure supplemented with a search for IUCN-listed flora species and any plants with fertile material for collection.	Lower Watut River, Lower Watut River valley and the Markham River valley.
Booyong Forest Science (June 2012)	Unbounded plots (400 to 500m^2) used to record the plant species for the main plant life forms (e.g., trees, shrubs,	Watut River Basin.
Booyong Forest Science (December 2011)		Lower Watut River valley, the Markham River valley and Markham Gap.

Survey team and period of survey	Survey method	Survey area(s)
Booyong Forest Science (November and December 2010)	palms, pandans, ferns, herbs, grasses and sedge). At each change in vegetation type, searches for legislatively protected species.	Watut River Basin and Lower Watut River valley.
Fauna field surveys		
Coffey (February and June 2017) (Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang)	Opportunistically recorded fauna assemblages within key habitats characterised in the terrestrial ecology study area.	Markham River valley, Atzera Mountain Range, headwaters of Bumbu River and the mouth of the Busu River.
BAAM (March, April and September 2015) (Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River)	Observational ground surveys accessed by road and helicopter, general fauna trapping surveys and mist-netting.	Lower Watut River, Lower Watut River valley, Markham River valley and the Markham Gap.
Woxvold and Aplin (May 2012)	Aerial reconnaissance, active searching, mist netting and trapping.	Lower Watut River and the Lower Watut River valley.
Woxvold (November 2011)	Aerial reconnaissance and active searching.	Lower Watut River, Lower Watut River valley and the Markham Gap.
Woxvold (November and December 2010)	Aerial reconnaissance, active searching, mist netting and trapping.	Lower Watut River and the Lower Watut River valley.

8.4.2.3. Conventions

Conventions used for classifying flora and fauna are provided in Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River.

A focus of the terrestrial ecological studies for the Project has been to identify species that are of conservation significance. These are defined as:

- Species of international conservation significance, listed as threatened (Critically Endangered, Endangered or Vulnerable) or Near Threatened in the IUCN Red List of Threatened Species. Other IUCN categories (i.e., least concern, not evaluated and Data Deficient) were not defined as being of conservation significance.
- Species of international conservation significance, listed under Appendix I of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as species threatened with extinction which are, or may be, affected by trade.
- Species of national conservation significance, listed under the *PNG Fauna (Protection and Control) Act 1966* (Fauna Act) as Protected or Restricted.
- New or undescribed species.

The State of PNG does not have a formal vegetation classification system nor a system for classifying threatened vegetation communities.

BAAM used for reference *Guidelines for Nominating and Assessing the Eligibility for Listing of Ecological Communities as Threatened according to the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and the EPBC Regulations 2000 (EPBC Regulations)* (TSSC, 2013), to assess the risk of extinction of vegetation (i.e., Critically Endangered, Endangered and Vulnerable). See Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River, for the detailed description of the criterion.

8.4.3. Bioregional Context

The island of New Guinea is among the most biologically diverse and endemically rich regions on earth. It contains the third largest block of unbroken tropical forest (behind the Amazon and the Congo) and the largest tract of primary forest remaining in the Asia-Pacific region (Shearman and Bryan, 2011). New Guinea's forests support more than 5% of the world's plant and animal species on less than 1% of the earth's land surface (Faith et al., 2001). Approximately two thirds of New Guinea's flora and fauna is endemic, i.e., restricted to New Guinea. The high degree of biodiversity is thought to have resulted from a complex interaction of dynamic geological and climatic processes.

The long-isolated island of New Guinea includes elements of Gondwana and Southeast Asian flora (Paijmans, 1976), but lacks seed dispersing primates and large ground-dwelling herbivores.

Morobe Province contains a variety of habitats and flora and fauna communities. The Huon Peninsula, forming most of the province, has moderate to high species richness with a variety of threatened mammal fauna (Flannery, 1995). Of the approximately 3.3 million hectares, approximately two thirds is forest, although the areas of lowland forest have been heavily deforested or degraded (Shearman and Bryan, 2011).

8.4.4. Protected and Special Purpose Areas

Papua New Guinea currently has three areas formally protected as national parks, namely Lake Kutubu, Varirata National Park and McAdam National Park. Only the McAdam National Park is located in Morobe Province, and it is over 40km from the terrestrial ecology study area, in the upper reaches of the Watut River catchment.

One conservation area is located in Morobe Province, the Yus Conservation Area, which is situated on the Huon Peninsula over 60km north of the Project Area. While the 760km^2 area remains under local customary ownership, 35 villages have formally committed to prohibit all hunting, logging and mining within the area (Conservation International, 2017).

The only wildlife management area in Morobe Province is the Kamiali Wildlife Management Area located in the Salamaua District, about 80km south along the coast from Lae.

Papua New Guinea has two wetlands listed under the Ramsar Convention, Lake Kutubu in the Southern Highlands and Tonda Wildlife Management Area in the Western Province.

These protected and conservation areas are beyond the potential influence of the Project and are not considered further.

8.4.5. Vegetation and Flora

Vegetation, or the community of plants considered collectively in a particular area or habitat, is described in this section using the community classification system (Paijmans, 1976), grouped into respective FIMS forest types. The associated FIMS descriptions are referred to as the various vegetation communities within the terrestrial ecology study area (Table 8.7). Field surveys used a combination of surveys (local) and FIMS mapping (regional) to categorise vegetation communities.

8.4.5.1. Vegetation communities

The Project is located on the northern slopes of the main dividing range of PNG between the Lower Watut and Wampit rivers. The region includes two distinctive landforms, which in turn influence vegetation types. These are the:

- Northern hills of the main dividing range of PNG, characterised by steep terrain intersected with steep valleys and waterways.
- Alluvial plains and foothill terraces of the Lower Watut River valley, and further downstream, the Lower Markham River valley to the Huon Gulf.

The major landforms of the terrestrial ecology study area can be broadly grouped into:

- Foothills and mountains below 1,000mASL
- Lowland alluvial plains and fans
- Lowland freshwater swamps
- Saline and brackish swamps
- Beach ridges and flats

These landforms form the basis for classification of forest types in FIMS and the terrestrial ecology study area. Forest types in FIMS are subdivided into 16 distinctive and consistently recognised vegetation communities. These vegetation communities along with their corresponding FIMS classifications are described in Table 8.7 and shown in Figure 8.13.

Vegetation occurring on upland areas (i.e., mountains or foothills) comprises Medium Crowned Forest/Small Crowned Forest (FIMS Hm/Hs). Vegetation occurring on the Lower Watut River floodplain comprises Large to Medium Crowned Forest (FIMS Pl). Vegetation occurring in the adjacent back plains (i.e., low-lying, permanently swampy areas) adjacent to the major watercourses consists of Mixed Swamp Forest (FIMS Fsw/FswC) and Swamp Woodland (FIMS Wsw). Grasslands (FIMS G) were also present in the foothills south of the Lower Watut River floodplain and in the Markham River valley to the north.

The majority of the broad alluvial floodplain of the Lower Watut River is vegetated with large tracts of intact and relatively unmodified primary lowland forest. In contrast, the vegetation along the Infrastructure Corridor between the Markham River crossing and the Coastal Area, is mostly cleared and anthropogenically modified falling under the ‘Other non-vegetation and areas dominated by land use’ FIMS category.

Table 8.7: Vegetation communities within the terrestrial ecology study area

Vegetation Community Description[1]	FIMS Classification[2]	FIMS Description
Natural Vegetation Communities/Naturally Bare Areas		
Mixed alluvium forest	Low altitude forest on plains and fans below 1000m	Pl: Large to Medium Crowned Forest
Mixed alluvium forest (heavily disturbed)		
Mixed hill forest	Low altitude forest on uplands below 1000m	Hm/Hs: Medium Crowned Forest/ Small Crowned Forest
Mixed hill forest (heavily disturbed)		
Mixed hill forest	Low altitude forest on uplands below 1000m	Hm/Hl: Medium to Large Crowned Forest
Beach ridges and flats	Littoral forest	B: Littoral (Beach) Communities
Saccharum/*Imperata* grassland (foothills)	Grassland and herbland	G: Grassland
Saccharum/*Imperata* grassland (alluvial plains)		
Woodland (with *Nauclea orientalis*, *Melaleuca leucadendra*)	Woodland	W: Woodland
Mixed swamp forest	Swamp forest	Fsw/FswC: Mixed Swamp Forest
Mixed swamp forest	Swamp forest	
Saccharum/Phragmites grass swampland/Pandan swamp woodland mosaic	Grassland and herbland	Gsw: Swamp Grassland
Mixed swamp forest	Swamp forest	Hsw: Herbaceous swamp
Sago swamp woodland	Swamp Woodland	Wsw: Swamp Woodland
Saline and brackish swamps	Estuarine communities	M: Mangrove
Seral forest (pioneer vegetation communities) with *Planchonea papuana* and *N. orientalis*	Secondary floodplain successions	Fri: Riverine Mixed Successions

Vegetation Community Description[1]	FIMS Classification[2]	FIMS Description
Scrub (with dominant *Mallotu* ssp.)	Scrub	Sc: Scrub
Watercourse	Non-vegetation and areas dominated by land use	E: Lakes and Larger Rivers
River alluvium/gravel bar	Grassland and herbland	Gri: Riverine Successions Dominated by Grass
Modified Vegetation Communities/Areas Devoid of Vegetation		
Secondary forest (regrowth from mixed alluvium forest)	Non-vegetation and areas dominated by land use	O: Other Non-Forest Areas Dominated by Land-use
Secondary forest (regrowth from mixed hill forest)		
Mixed native / exotic grasslands and shrublands of uncertain origin		
Mixed native / exotic grasslands and shrublands degraded through cattle grazing, typically with emergent *Samanea saman* (Raintree)		
Mixed regrowth/exotic regrowth		
Mixed regrowth/exotic regrowth		
Older cultivated areas		
Other disturbed areas		
Plantation		

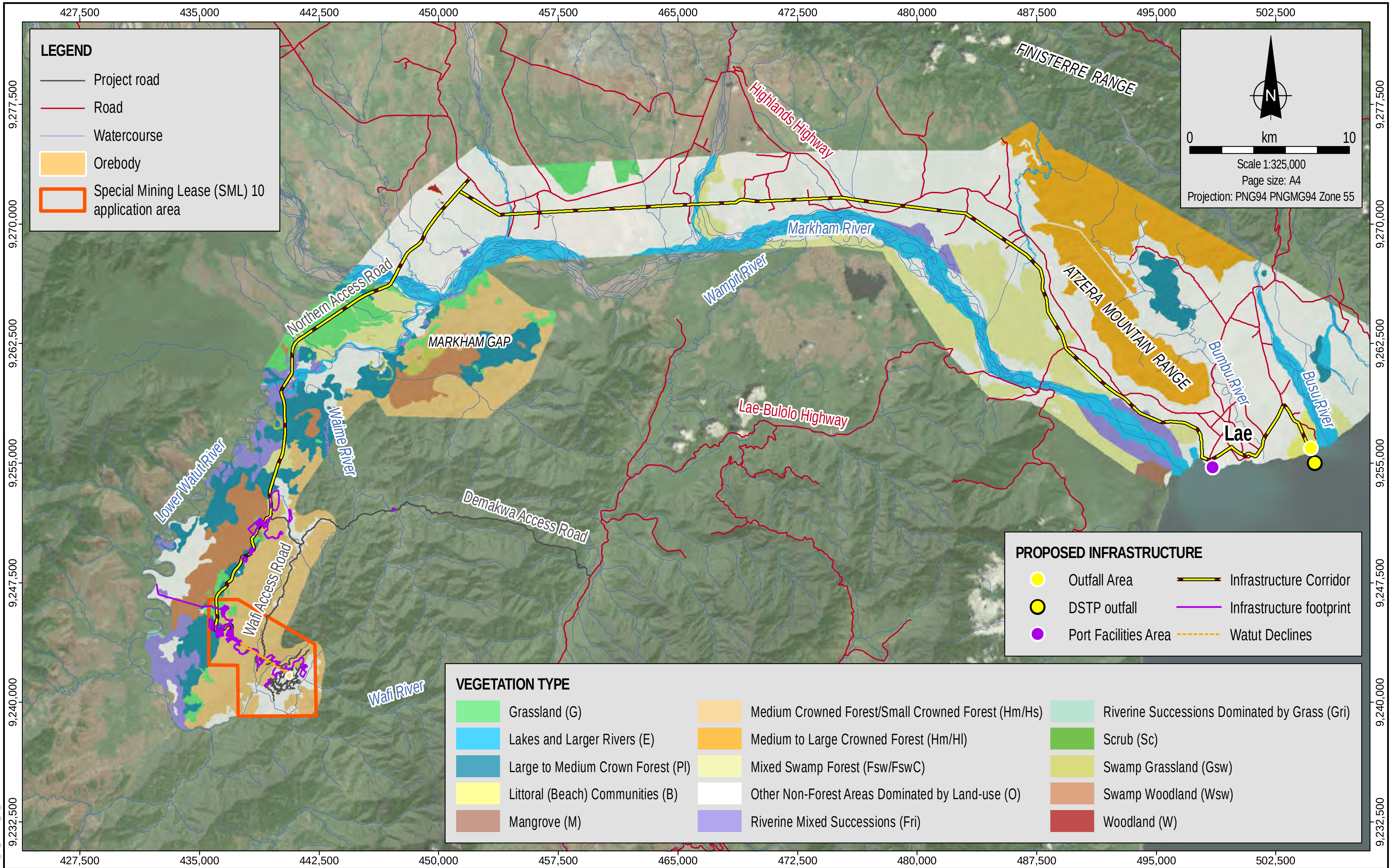
[1] Description derived from Paijmans (1976), applied to natural vegetation communities only.
[2] Classification derived from Hammermaster and Saunders (1995).

8.4.5.1.1. Large to Medium Crowned Forest (Pl)

Extensive tracts of Large to Medium Crowned Forest occur on the broad alluvial plain of the Lower Watut River, dispersed within complexes of swamp forest and grassland (refer to Figure 8.14 and Figure 8.15). Most canopy trees are strongly buttressed with typical canopy heights ranging from 35 to 55m in undisturbed habitats. Erima (*Octomeles sumatrana*) is typically the tallest tree, dominating in some areas, while other prominent canopy species include New Guinea walnut (*Dracontomelum dao*), taun (*Pometia pinnata*), *Pterocymbium beccarii*, *Celtis latifolia*, *Aglaia cucullata*, *Terminalia complanata*, garamut (*Vitex cofassus*), milky pine (*Alstonia scholaris*), *Flacourtia zippelii*, *Polyalthia oblongifolia*, *Ficus* spp., *Tristiropsis acutangula*, *Wrightia laevis*, *Antiaris toxicaria*, New Guinea rosewood (*Pterocarpus indicus*) and occasional kwila (*Intsia bijuga*). Kwila generally occurs at the interface between alluvial and foothill forests and is not common through the general forest mosaic.

In the broad alluvial plain of the Lower Watut River, the forest canopy is largely undisturbed over extensive areas, with only scattered canopy gaps caused by tree-fall and establishment of small garden areas in some localities. Close to road edges, portable sawmilling operations have selectively logged some canopy trees, focusing on valuable timber species including kwila (*I. bijuga*), New Guinea walnut and taun. While having some impact on forest structural integrity, these selective logging practices favour retention of the original canopy structure over a predominant proportion of the forest.

Additionally, small patches of Large to Medium Crowned Forest occur north of Lae, on relatively well drained alluvial plains and fans and is considered to represent the original forests of the now deforested areas between the Bumbu and Busu rivers (i.e., the proposed Outfall Area) (Figure 8.16).



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

coffey A TETRA TECH COMPANY

Date: 13.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.13_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Vegetation communities

Figure No: 8.13

MXD Reference: 0520DD_10_GIS026_v0_7

Photo credit: WGJV

Figure 8.14
Typical structure of Large to Medium Crowned Forest on plains

Photo credit: WGJV

Figure 8.15
Typical structure of Large to Medium Crowned Forest on the banks of the Waime River

Photo credit: Coffey

Figure 8.16
Typical Large to Medium Crowned Forest along the Busu River near Bomsi village

8.4.5.1.2. Medium Crowned Forest and Small Crowned Forest (Hm/Hs)

Small Crowned Forest typically occupies ridgelines and drier habitats with the tall trees *Hopea iriana* and anisoptera (*Anisoptera thurifera*) dominating the canopy (Figure 8.17). This is a structurally simple forest with a limited number of canopy species with un-buttressed boles ranging in height from 30 to 45m. Associated canopy species include kwila (*I. bijuga*), white beech (*Gmelina moluccana*), *Ficus nodosa*, *Syzygium* sp. and *Anthocephalus chinensis* in some localities.

In moister locations, along lower footslopes and gully lines, the dipterocarps (tropical lowland forest trees) become less prominent and the forest transitions into Medium Crowned Forest in which vines are prominent (dominantly mesophyll, i.e., leafy). These locations also have a more diverse mix of canopy species dominated by, among others, taun (*P. pinnata*), kwila, New Guinea rosewood (*P. indicus*), *Homalium foetidum*, *Maniltoa psylogyne*, *Syzygium buettnerianum*, *C. latifolia*, *Polyalthia longifolia* and *T. acutangula*.

This vegetation community exists as a mosaic of these two forest types, Medium Crowned Forest and Small Crowned Forest. This vegetation community is present (and is the most extensive habitat) in the broad alluvial plain of the Lower Watut River to the Markham River, occupying all locations from footslopes fringing the eastern margins of the Lower Watut River floodplain, and extending eastwards through the mountains surrounding Wafi Exploration Camp.

8.4.5.1.3. Medium to Large Crowned Forest (Hm/Hl)

Medium to Large Crowned Forest was observed on the northern side of the Infrastructure Corridor, near the Waime River and on the Atzera Mountain Range. It occurs across a wide range of elevations up to 1,000mASL (Figure 8.18). Within this broadly characterised forest are patches of Large Crowned Forest, which are not distinct enough to be recognised separately. This forest type has been selectively logged. Canopy height ranges from 25 to 35m, with the tallest specimens reaching up to 40m. The forest type is richer in species compared to other forest types, and is the transitional zone for species inhabiting the upper elevations of foothill forests and the lower elevations of montane forests.

The forests on slopes and ridges were mostly dominated by *I. bijuga* and *P. pinnata*, but previously *A. thurifera* was the most dominant species in this forest type (see Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang). Other common canopy trees include *Celtis*, *Dysoxyllum*, *Hopea*, *Pouteria*, *H. foetidum*, *Cryptocarya*, *Elaeocarpus*, *Terminalia*, *Endospermum*, *V. cofassus*, *D. dao* and *A. scholaris*.

8.4.5.1.4. Littoral (Beach) Communities (B)

Strand Littoral (Beach) Communities were observed between Wagang village and the mouth of the Busu River. The beach is littered with driftwood, likely deposited there by regular flooding in the Busu, Bumbu and Markham rivers. The strand vegetation is heavily impacted by human activities, with most of the larger trees removed and exotic tree species introduced. This forest type was dominated mainly by *Pandanus tectorius* and a few small trees of usual strand species.

Figure 8.17
Small Crowned Forest on ridgelines

Figure 8.18
Typical structure of Medium Crowned Forest on foothills

Figure 8.19
Grassland areas in the Markham River valley

The strand vegetation ranges from pioneer herbaceous communities on sandy beaches to shrubberies, and to tall littoral forest further away from the high tide mark. Above the high tide mark, herbaceous communities are present comprising mainly of creeping plants such as *Ipomoea pescaprae* and *Canavalia maritima*, as well as the parasitic *Cassytha filiformis* scrambling over the beach shrubs. Grasses and sedges, e.g., *Ischaemum muticum*, *Fimbristylis*, *Remirea*, *Cyperus* spp., often occur among the herbs and low shrubs. The inner sand dunes are dominated by *P. tectorius* with a few small tree species such as *Calophyllum inophyllum*, *Milletia pinnata* and *Hibiscus tiliaceus*. Further inshore, bordering with mixed swamp forests, taller trees of *P. indicus*, *I. bijuga*, *Celtis*, *Sterculia* and coconut palms (*Cocos nucifera*) occur.

8.4.5.1.5. Grassland (G)

Extensive native grassland habitats occur on the footslopes of the Lower Watut River valley and on its floodplain. They occur in the Markham River valley, north and south of the Markham River (Figure 8.19). These grasslands, referred to throughout PNG as kunai grassland due to the general dominance of kunai (*Imperata cylindrica*), are anthropogenic, having developed as a consequence of a long history of human use of fire for clearing and hunting. Paijmans (1976) recognises native grasslands as either representing communities changed by human-induced fire regimes or, in the case of kunai grassland, indicating historical clearing for cultivation.

In upland areas, a shorter type of grassland occurs, usually dominated by *Themeda australis*, *I. cylindrica*, *Ischaemum barbatum*, and other common grasses. Trees are sometimes scattered among the grasses, such as *N. oreantalis*, *Timonius timon*, *Pittosporum* spp., *Antidesma* spp. and *Albizia* spp.

8.4.5.1.6. Woodland (W)

A few small areas of natural Woodland are mapped in the terrestrial ecology study area, occurring only near the intersection of the Northern Access Road and the Highlands Highway. While surveyed from helicopter only, it was apparent the habitat is dominated by *N. orientalis* and *M. leucadendra* over a ground cover of native grass species, predominantly kunai (*I. cylindrica*). These woodland habitats form scattered patches amongst the broader expanse of grassland degraded through cattle grazing.

8.4.5.1.7. Mixed Swamp Forest (Fsw)

Mixed Swamp Forest covers extensive areas of the Lower Watut River and Markham River floodplains (Figure 8.20), as well as near the mouth of the Busu River, often forming a transitional community between the well-developed Large Crowned Forest and the permanently wet Swamp Woodlands dominated by sago palm (*Metroxylon sagu*). This vegetation type also includes areas dominated by *Campnosperma* spp. (FIMS FswC) along the eastern banks of the Erap River.

Photo credit: WGJV

Figure 8.20
Mixed Swamp Forest

Photo credit: WGJV

Figure 8.21
Swamp Grassland with dominant *Phragmites vallatorius* fringing an oxbow lake

Photo credit: WGJV

Figure 8.22
Swamp Woodland emergent trees above sub-canopy of sago palm

The characteristic feature of Mixed Swamp Forest is the semi-permanent wet nature of the forest floor, which results in the reduction of floristic complexity of the shrub and ground cover layers, while retaining the tall forest stature of well-developed forest. The swampy nature of the habitat affords some buffer from fire, meaning the boundaries are considerably more stable than Large Crowned Forest that is prone to boundary retreat when subjected to regular burning of adjoining grassland. Typical canopy heights in most localities range from 30 to 45m, with dominant canopy trees comprising *Terminalia impediens*, *Neonauclea* sp., *Eleaocarpus* sp., *Ficus* sp., kwila (*I. bijuga*) in better drained localities, milky pine (*A. scholaris*), *A. chinensis*, *Inocarpus fagifer*, New Guinea walnut (*D. dao*) and New Guinea rosewood (*P. indicus*). Strong buttressing is apparent in many canopy trees, but is not as well developed as in Large to Medium Crowned Forest.

In the areas surrounding Lae, this vegetation type has been heavily impacted by small-scale logging using mobile mills. Likewise, encroachment by settlers is quickly changing and reducing this vegetation type.

8.4.5.1.8. Swamp Grassland (Gsw)

This vegetation type is present across the floodplain of the Lower Watut River, where numerous oxbow lakes and wetlands have been formed and are isolated due to the ongoing migration of the river's broad meanders. These swamplands form a mosaic of open wetlands, swamp grasslands and *Pandanus* spp. forests. With increasing saturation, woodland and forest habitats are replaced by shrubs, and ground cover is dominated by forbs (herbaceous, not woody, flowering plants other than grasses) and swamp tolerant grasses including *Phragmites vallatorius*, *Leersia hexandra* and the sprawling fern *Stenochlaena palustris* (Figure 8.21). Emergent trees and shrubs may occur, typified by *T. timon* and *N. orientalis,* and parts of the mosaic may be dominated by *Pandanus* spp. forest fringed by areas of sago palm.

8.4.5.1.9. Herbaceous Swamp (Hsw)

Small complexes of freshwater swamps were observed along the coast between Wagang village and the mouth of the Busu River, i.e., within the Littoral (Beach) Communities. These stagnant, permanent and deep pools of water occur between the sand dunes and the swamp forests, and are inhabited by herbs, sedges, ferns and floating weeds (*Azolla imbricata*, *Pistia stratiotes* and *Eichhornea crassipess*). The most common sedge observed in these freshwater swamps was *Schoenoplectus mucronatus*.

8.4.5.1.10. Swamp Woodland (Wsw)

Permanently saturated areas on the Lower Watut River floodplain are generally occupied by extensive woodlands and forests dominated by sago palm (Figure 8.22 and Figure 8.23). Typical structural characteristics are a dense monotypic sub-canopy of sago palm with heights ranging from 11 to 17m, and a mid-dense canopy occupied by *T. impediens*, milky pine (*A. scholaris*), *N. orientalis*, *Bischofia javanica*, *Garamut* spp., *Horsefieldia* spp., *Cananga odorata*, *Pimeleodendron amboinicum*, *Hydriastele costata* and *Campnosperma brevipetiolatum*. In some locations, the upper canopy is dominated by *T. timon* reaching heights of 25m.

Photo credit: WGJV

Figure 8.23
Swamp Woodland visible as grey wash of emergent tree crowns above sub-canopy of sago palm

Photo credit: Coffey

Figure 8.24
Lower Watut River showing continuum of several stages from point bars to developing grassland and shrubland on meandering river channel

Photo credit: Coffey

Figure 8.25
Markham River braids partially stabilised by *Saccharum robustum* below the Watut confluence

Patches of this forest type were also recorded amongst Mixed Swamp Forest near the mouth of the Markham River (shown as a discrete patch of FIMS Fsw/FswC on Figure 8.13). Permanently inundated woodland swamp communities occur through most of the area between the Markham River and Lae. These vegetation communities are heavily impacted by human activities, and dominated by sago palms (*M. sagu*) with thick ground cover of reeds (*P. vallatorius*). Trees are scattered throughout the area, thought to be due to selective cutting by settlers around Lae.

8.4.5.1.11. Mangrove (M)

Small mangrove communities occur sporadically along the coastline between the mouths of the Markham and Busu rivers and a well-developed mangrove community occurs around the Labu Lakes, just south of the mouth of the Markham River. This well-developed mangrove community was not surveyed for the Project, however Coffey described this community from past observations (see Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang).

The mangrove community around the Labu Lakes is a tall and luxuriant forest, comprising mainly of *Rhizophora* (mainly *R. apicualta*), *Bruguiera*, *Lumnitzera*, *Xylocarpus*, *Sonneratia* and *Heritiera*. The taller stands further away from the coast are almost pure stands of *Rhizophora*, *Ceriops tagal* or *Bruguiera gymnorrhiza*. Nypa palms (*Nypa fruticans*) occur along the inlets, often intermixing with sago palm (*M. sagu*).

8.4.5.1.12. Riverine mixed successions (Fri)

Broad areas of this young forest type occur on the western margins of the Lower Watut River, with a low dense canopy ranging in height from 15 to 25m dominated by *N. orientalis* and *P. papuana*. Gaps in this forest are typically occupied by thickets of the invasive weeds, bamboo piper (*Piper aduncum*) and leucaena (*Leucaena leucocephala*), that may be extensive in former garden areas. This habitat is floristically and structurally simple, representing an intermediate stage in the development of more complex Large Crowned Forest.

This forest type was also recorded along the banks of the Markham River, with the most developed community near the mouth of the Markham River. These communities were found to be a heterogeneous forest with small to medium crown trees and with an irregularly open canopy. They were dominated by pioneer tree species such as *Macaranga*, *Mallotus*, *Trichospermum pleiostigma*, *Commersonia bartramia*, *Neolarmarckia cadamba*, *O. sumatrana*, *Ficus*, *Kleinhovia hospita*, *T. timon* and *Pipterus argenteus*. The ground cover is mostly dominated by grasses, sedges and tree seedlings and along the river banks, tall grasses such as *Saccharum robustum*, S. *spontaneum* and *P. vallatorius* occur.

8.4.5.1.13. Scrub (Sc)

This forest type represents transitional vegetation, forming a fringe between regularly burned kunai grassland and forest, and is floristically and structurally very simple. This forest type is present in small patches within the Lower Watut River valley, immediately south of its confluence with the Markham River, in association with a hill ridgeline of kunai grassland. The low canopy is uneven, ranges in height from 3 to 7m and is dominated by *Mallotus* sp. with *Morinda citrifolia*, *Macaranga involucrata* and *Ficus* sp. sub-dominant.

8.4.5.1.14. Lakes and Larger Rivers and Riverine Successions Dominated by Grass (E, Gri)

Review of satellite imagery at various dates of capture reveals the dynamic nature of the Watut and Markham rivers, with regular meander shifts as the rivers migrate across the floodplain (Figure 8.24). The rapidly evolving channel planform creates a continuum of fluvial features in seral stages ranging from bare river braids to point bars occupied by grasslands and developing shrublands. Dense swards of *S. robustum* typify many of these features, interspersed with areas of *P. vallatorius*, *S. palustris* and developing shrublands and low forests of *Artocarpus altilis*, *C. bartramia*, *Voacanga grandifolia*, *A. chinensis* and *Mallotus* sp. With regular flooding and continuous migration of river channels, these seral communities are regularly reclaimed in the natural process of riverine erosion and deposition, with few examples holding sufficient long-term stability to develop more complex floristic and structural features. Examples of braids showing partial stabilisation by *S. robustum* were recorded along the Markham River (Figure 8.25).

8.4.5.1.15. Secondary Habitats, Villages and Cultivated Areas (O)

Regrowth forests are most abundant near villages and other settled areas and represent regrowth from total clearing or untended gardens. Secondary or regrowth vegetation refers to the various stages of vegetation succession, from bare ground after disturbance to almost mature forest. Areas derived from regrowth of primary forest typically comprise a limited number of colonising species with even canopy heights. Next to access roads, and in other disturbed locations, secondary forests are comprised primarily of *A. chinensis* with sprawling mats of the smothering vine *Merremia peltata*. Other secondary tree species may include *Protium macgregorii*, *Ficus* spp., *C. bartramia*, *Macaranga* sp., *Homolanthus* sp. and *Alphitonia oblata*. In the more advanced regrowth observed (particularly surrounding Lae), common trees include *Neolamarckia cadamba*, *Endospermum*, *O. sumatrana*, *Trichospermum*, *Macaranga*, *C. bartramia*, *A. altilis*, *K. hospita*, *Cananaga odorata*, *T. timon*, *Euodia*, *Ficus* and other species.

Overgrown garden areas support a complex mix of native and introduced food resource plants that are grown in a sustainable and self-sufficient system. On the northern side of the Markham River crossing within the Infrastructure Corridor, alluvial areas comprise grassland with dense pockets of forest dominated by the exotic and invasive raintree (*S. saman*).

8.4.5.2. Vegetation Condition

Vegetation condition was assessed based on the structural integrity of the vegetation communities, with vegetation categorised as intact, moderately disturbed, degraded or highly modified (Table 8.8). Intact and moderately disturbed vegetation is considered to be natural habitat, and degraded and highly modified vegetation is considered to be modified habitat as defined by the IFC (Section 8.4.2). The condition classification specifically aims to identify those habitats subject to minimal human intervention, thus demonstrating a high degree of 'intactness'.

Table 8.8: Vegetation condition

Condition Category	Description
Intact	The vegetation community exists in unmodified condition. No structural disturbance of canopy, sub-canopy or ground cover layers is evident. Some selective harvesting of poles or timber species may have occurred, although this is minor in nature and has not compromised structural integrity of the vegetation community.
Moderately disturbed	The vegetation community has been subject to structural modification, resulting in a general reduction in forest stature and complexity. A sub-set of the original floristic diversity is retained within the habitat and small vestiges of unmodified habitat may remain. Habitats within this condition category are generally derived from severe thinning and harvesting of forest products.

Condition Category	Description
Degraded	Secondary forest composed of native pioneer species in which the structure and floristic assemblage of the original forest has been destroyed through prior complete clearing or long term continuous disturbances. This category also includes modified habitats composed of native species that have had long term stability through regular human intervention, e.g., kunai grassland that represents rainforest transformed to grassland through a long history of regular burning.
Highly modified	Modified habitats generally comprising a mix of native and exotic food plants, garden plants and also weeds. Includes maintained and abandoned garden areas with large areas of the latter occupied by the invasive pest plants such as bamboo piper (*P. aduncum*).

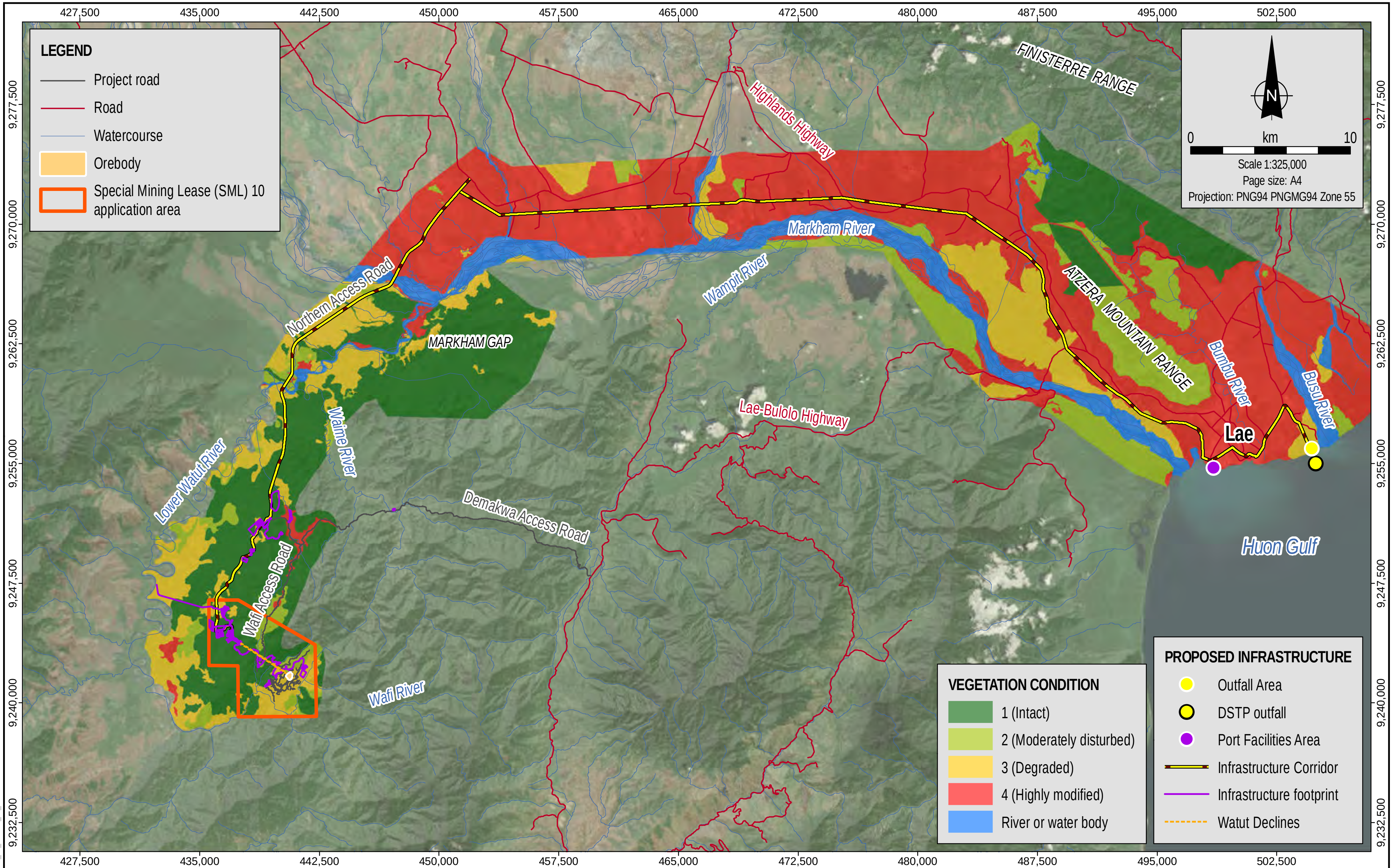
Figure 8.26 shows the condition of the mapped forest types across the terrestrial ecology study area. Major factors influencing vegetation condition are distance from human occupation (Lae and villages) and access (proximity to and condition of roads). The Mine Area was assessed as supporting largely intact vegetation, a likely reflection of its relative remoteness, and steep, mountainous terrain. Areas along the Infrastructure Corridor east of the Markham River crossing and the Coastal Area, which are proximate to the Highlands Highway, numerous villages and the city of Lae, the second largest city in PNG, are highly modified.

Extensive tracts of intact vegetation, consisting of relatively undisturbed Medium Crowned Forest and Small Crowned Forest occur in footslope locations extending across areas of the Lower Watut River alluvial plain within a well-preserved mosaic of Large Crowned Forest, Mixed Swamp Forest and Swamp Woodland. Preservation of these habitats is largely the result of historically poor access, coupled with an abundance of arable land close to established village areas.

Areas of highly modified and degraded vegetation within the Lower Watut River alluvial plain occur in the vicinity of villages and garden areas, such as Wori village to the west of the Mine Area, and from Ziriruk village north along the Infrastructure Corridor to Bavaga village where large areas of highly modified vegetation are mapped. These cultivated areas surrounding villages invariably have the lowest condition value (highly modified) due to the lack of any resemblance to natural habitats. Other small pockets of highly modified vegetation occur adjacent to the Wafi Access Road from Bavaga village to Wafi Exploration Camp.

In addition to village areas, extensive areas of the Lower Watut River alluvial plain have been classified as degraded vegetation, where a regenerating mix of secondary shrubs and trees, mixed with native grasses (typically *S. robustum*) and both woody and herbaceous weeds were mapped.

A number of large islands of anthropogenic kunai grassland occur on the eastern flanks of the Lower Watut River valley. Kunai grassland is an anthropogenic habitat resulting from the total or near-total removal of forest cover and is maintained and extended by regular burning. It supports an impoverished native faunal community and is classified as degraded vegetation (Woxvold and Aplin, 2012). Kunai grassland is well represented locally throughout the Lower Watut River and Lower Markham River valleys.



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

coffey
A TETRA TECH COMPANY

Date: 13.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.26_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Vegetation condition

Figure No: 8.26

MXD Reference: 0520DD_10_GIS029_v0_6

From the Markham River crossing within the Infrastructure Corridor, most of the forests traversed during surveys were found to have been dramatically altered from their original state to a highly fragmented landscape, especially the areas surrounding the city of Lae and to the north along the Atzera Mountain Range (see Figure 8.26). Human activities, mainly small-scale logging and subsistence gardening, have impacted significantly the natural vegetation and landscape of the area, especially along the Atzera Mountain Range, the foothills of the Finisterre Range behind Igam Barracks and along the Bumbu and Busu rivers.

A number of highly invasive species were observed encroaching into the native forest, especially the long-established bamboo piper (*P. aduncum*), African tulip (*Spathodea campanulata*) and siam weed (*Chromolaena odorata*).

Early introduction of farming and livestock grazing around Lae is believed to have contributed to the introduction of many of the weedy plants seen around Lae and in the Markham River valley (Appendix D Terrestrial Ecology Characterisation - Markham River to Wagang).

8.4.5.3. Threatened Vegetation Communities

Projected forest clearing rates reported in Shearman et al. (2008, 2009) and Bryan et al. (2015) were used as a basis to assess the conservation status (at national level) of the principal forest types present in the terrestrial ecology study area. To allow comparisons with this published work to areas within the terrestrial ecology study area, the following three ecological subdivisions were made:

- Floodplain Forest, which includes the FIMS units of Large to Medium Crowned Forest (Pl), Open Crowned Forest (Po) and Small Crowned Forest (Ps). BAAM grouped these FIMS types because the physiognomic (general appearance) distinction between units is arbitrary, and not consistently mappable.
- Mixed Hill Forest, which includes Medium Crowned Forest (Hm) and Small Crowned Forest (Hs) on foothills.
- Swamp Forest, which includes Mixed Swamp Forest (Fsw) and Swamp Woodland (Wsw).

The Floodplain Forest vegetation community was assessed as Vulnerable by BAAM, since its extent has reduced by more than 30% over the past 50 years (Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River). This has been attributed to the recent and ongoing commercial logging across PNG (Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River). Approximately 1,909,000 hectares (ha) of Floodplain Forest is estimated to remain in PNG in 2017.

The reduction in extent of Mixed Hill Forest was estimated to be less than 30% over the past 50 years, and was therefore not considered to be threatened (Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River). Furthermore, this vegetation type has an estimated area of occurrence of approximately 13.3 million hectares across PNG.

Swamp Forest was not assessed to be threatened due to the difficulty of safely accessing these forest types, and because PNG has not yet experienced broad-scale draining and clearing of swamps for agriculture.

8.4.5.4. Flora

New Guinea is well recognised as one of the world's centres of plant diversity (Barthlott et al., 2005; Mutke and Barthlott, 2005; Kier et al., 2005; Gideon, 2015). Almost half of the botanical collections in PNG come from the Mamose region (which consists of the East

Sepik, Madang, Morobe and Sanduan provinces), especially Morobe Province, which accounts for 28% of all the collections. This is due mainly to the fact that the PNG National Herbarium (PNG Forest Research Institute) is located in Lae, which has been the centre for botanical research in PNG since its establishment in 1946. The flora of the areas surrounding Lae are therefore fairly well known and well represented in herbarium collections both in PNG and overseas.

Combined survey results, incorporating the findings of previous surveys and botanical collections contained in herbarium records (Queensland Herbarium, 2015), identified 885 flora species within the broad alluvial plain of the Lower Watut River, including 63 fern species, eight species of conifer and allies, two species of dipterocarp and 812 species of flowering plant (described in Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River). The recorded plant species list includes a considerable number of species that have not been verified through herbarium submission.

Additionally, the surveys conducted by Coffey recorded a total of 103 flora species within the eastern portion of the terrestrial ecology study area, from the Markham River crossing to the Coastal Area, comprising 3 fern species, 1 species of conifer and allies, and 99 species of flowering plant.

Due to the nature of botanical investigation in PNG, where there is historically limited information at the national and provincial scale, coupled with the survey effort required to achieve a full inventory of flora, the species recorded are likely to represent a subset of the species present within the terrestrial ecology study area.

A full survey species list, including information from all sources that were accessed, is provided in Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River and Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang.

8.4.5.4.1. Threatened Flora

Seventeen flora species of conservation significance were recorded. Thirteen were present in Medium Crowned Forest and Small Crowned Forest, two were present in Medium to Large Crowned Forest, and one in each of Grassland, and a mosaic of Medium Crowned Forest, Large Crowned Forest and Mixed Swamp Forest (Table 8.9).

Two species are classified as Critically Endangered; however BAAM report that based on recent records, *Disopyros lolinopsisis* is unlikely to meet the Critically Endangered criteria and speculate that it should be revised to Vulnerable (see Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River). Three species are classified as Endangered, four as Vulnerable and the remaining nine as Near Threatened.

A further 32 IUCN-listed species were assessed as either likely to occur (four) or to possibly occur (28) based on their respective habitat requirements and geographic distribution, but were not found during surveys for the Project. These include one listed as Critically Endangered, one listed as Endangered, 17 listed as Vulnerable and the remaining 13 either Near Threatened (nine), Data Deficient (two) or Least Concern (two).

Table 8.9 describes the 17 species of conservation significance which were confirmed as occurring within the terrestrial ecology study area.

Table 8.9: Conservation significant flora species from IUCN Red List

Species	IUCN status†	Description and ecology	Record of occurrence in the terrestrial ecology study area
Diospyros lolinopsis (Figure 8.27)	CE	Species recorded at altitudes ranging from 50 to 650m in the Madang and Milne Bay provinces. While currently listed as Critically Endangered, from Eddowes (1998a) which reported only a single occurrence of this tree, recent information provided by the PNG National Herbarium described eight additional specimens recorded from five locations. These additional records significantly increase the species' area of occurrence, and in the opinion of BAAM a reassessment under IUCN guidelines would change the status to Vulnerable.	A common species in the sub-canopy, and occasionally canopy, in Medium Crowned Forest, particularly from the location of the Northern Access Road borrow pit to just north of Chiatz village. A single specimen was also recorded in the Buvu Creek valley. The species was verified with voucher specimens lodged to the Queensland Herbarium. The species was also recorded in the Bavaga area during timber assessments undertaken by PNGFRI (2011) and was reported to be common on hillslopes (Booyong, 2013).
Halfordia papuana	CE	Species is scattered in submontane and montane rainforest between 1,200 and 2,700mASL with some collections as low as 250mASL. Mostly confined to the Bulolo/Wau region in Morobe Province, although several specimens recorded in the East Sepik Province (Conn et al., 2006) and there are PNG National Herbarium collections for the West Sepik, Chimbu, Central Highlands, Eastern Highlands, Enga and Southern Highlands provinces (Booyong, 2011b).	The species was identified in Swamp Forest in the Markham Gap Basin area. Although the majority of the terrestrial ecology study area provides sub-optimal habitat and the species is unlikely to be present in significant populations.
Diospyros insularis	EN	Species of primary lowland forest, found in only a few localities in the Solomon Islands and New Ireland of the Bismarck Archipelago (Eddowes, 1998f). PNG National Herbarium holds specimens for the island provinces of Milne Bay, West New Britain and East New Britain and the species has not been previously recorded from the mainland provinces (Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River).	Species was common on ridges and occasional on plains. BAAM treated its identified presence in the terrestrial ecology study area with caution given its lack of record on mainland PNG (see Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River).
Flindersia pimenteliana	EN	Species found mainly in lower montane rainforest or in foothill rainforest. In PNG it is widespread but uncommon and sporadic. Fifty collections throughout the Central, Morobe, Milne Bay Provinces and Papua (Indonesia), as well as collections in the Lae district (Eddowes, 1998g).	Species was recorded along the Watut Valley Road.
Aglaia brownii	VU	Species occurs in PNG, Indonesia and Australia. Previously recorded in the Atzera Mountain Range above Bubia. This tree species is endemic to New Guinea, known from only a few collections and threatened from logging.	Recorded during field surveys in the Atzera Mountain Range.
I. bijuga (kwila)	VU	A pan-tropical species of lowland rainforest distributed throughout south-east Asia and Melanesia, which produces one of the most valuable timbers of South East Asia (World Conservation Monitoring Centre, 1998).	Recorded during surveys in Medium Crowned Forest and Small Crowned Forest on hillslopes. The species is extremely common forming dense stands in some forested areas. Scattered specimens also located in Large Crowned Forest on the Lower Watut River alluvial plain.
Myristica buchneriana (Figure 8.28)	VU	Tree of primary rainforest frequently found on ridge tops between 300 and 1,300mASL (Eddowes, 1998d).	The species was collected during field surveys in Medium Crowned Forest near the Finchif area. Scattered herbarium records throughout lowland and sub-montane forest, mostly in northern PNG. Identity confirmed through submission of fertile voucher specimen to the PNG National Herbarium.

Species	IUCN status[†]	Description and ecology	Record of occurrence in the terrestrial ecology study area
P. indicus (New Guinea rosewood) (Figure 8.29)	VU	A widespread tree found in lowland primary and some secondary forest, mainly along tidal creeks and rocky shores (Eddowes, 1998b).	Scattered trees found within Medium Crowned Forest on footslopes, Large Crowned Forest on the Lower Watut River alluvial plain and also Mixed Swamp Forest.
Aglaia euranthera	NT	A small tree found in many forest habitats up to 2,100mASL (Pannel, 1998b). Six collections throughout PNG (Conn et al., 2006).	Species was recorded along the Watut Valley Road.
Aglaia sexipetala	NT	Small sub-canopy tree occurring in lowland forest. Cosmopolitan species known from Indonesia, Irian Jaya, Malaysia and PNG.	Recorded in disturbed Large Crowned Forest on the margins of the Waime River, with the identity confirmed through submission of a fertile specimen to PNG National Herbarium.
Aglaia silvestris	NT	A widespread, variable species of various habitat types, occurring up to 2,100mASL. This species has a scattered distribution throughout PNG (Pannel, 1998a).	Recorded commonly on ridges and occasionally on alluvial plains, and also recorded along the Watut Valley Road.
*Cycas apoa**	NT	A forest cycad growing to heights of 4 to 7m (RBGSYD, 2012a). Known from northern coastal New Guinea, from the Huon Peninsula west to at least the Mamberamo River in Indonesian New Guinea. This species is scattered in closed mesophyll forest in wet lowland areas, most typically on low ridges (Hill, 2010b).	Recorded in Medium Crowned Forest on hillslopes in a large number of localities in the Lower Watut River valley.
*Cycas campestris**	NT	All collections from the Central Province, mostly in the vicinity of Port Moresby (Hill, 2010a).	Species recorded occasionally on ridges in hill forest and rarely on alluvial plains.
*Cycas scratchleyana**	NT	Species is found within the Western, Gulf, Central, and Milne Bay provinces plus Irian Jaya in coastal rainforest to hills (Hill, 2010d). The plant is considered to be widespread within its known range, occurring from near-coastal sites to foothills (5 to 900mASL).	Species recorded commonly in hill forest on ridges and occasionally on flats.
*Cycas schumanniana**	NT	A grassland species of cycad growing to 2m (RBGSYD, 2012b). It is endemic to PNG occurring on the northern side of the island along the foothills of the Bismarck Range, predominantly in the valleys of the Markham and Ramu rivers, and extending south from Lae along the Bulolo River as far as Wau and Madang. Recorded from low to high elevations, up to 1,600mASL (Hill, 2010c).	The species was recorded on a low ridgeline adjacent to the Markham River on the Northern Access Road. Scattered small individual plants were associated with frequently burnt kunai grassland on the ridgeline but the species was more abundant on the transition line from the kunai grassland to the adjoining scrub that afforded the species some protection from the frequent burning.
Flindersia amboinensis	NT	A large tree with widespread but sporadic occurrence within lowland and sub-montane rainforest throughout PNG (Eddowes, 1998c).	A scattered tree on footslopes located in Medium Crowned Forest in the Buvu Creek valley as well as several specimens located in the vicinity of the proposed Northern Access Road borrow pit.
Myristica globosa	NT	Occurs in rainforest up to 1,200mASL (Eddowes, 1998e).	The species was collected during field surveys in Medium Crowned Forest in the vicinity of the Northern Access Road borrow pit.

* The Cycas spp. are listed under CITES.
[†] Conservation status under the IUCN Red List (IUCN): CE = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened.

Photo credit: BAAM, 2017

Figure 8.27
Fruit and leaves of *Diospyros lolinopsis*
(IUCN: Critically Endangered)

Photo credit: BAAM, 2017

Figure 8.28
Fruiting specimen of *Myristica buchneriana*
(IUCN: Vulnerable)

Photo credit: BAAM, 2017

Figure 8.29
Winged seed of New Guinea rosewood
(*Pterocarpus indicus*) (IUCN: Vulnerable)

Two species have the potential to occur in the terrestrial ecology study area based on their distribution and habitat requirements. These are *Calophyllum morobense* (listed as Endangered) and *Helicia subcordata* (listed as Critically Endangered).

Seventeen plant species listed as Vulnerable by the IUCN have the potential to occur in the terrestrial ecology study area based on their distribution and habitat requirements. These are: *Aglaia flavescens, Aglaia lepiorrhachis, Polyscias prolifera, Calophyllum robustum, Gluta papuana, Aglaia brassii, Aglaia cremea, Cupaniopsis bullata, Guioa unguiculata, Horsfieldia clavata, Mammea papyracea, Mangifera altissima, Myristica pygmaea, Myristica schlechteri, Myristica sinclairii, Chisocheton stellatus* and *Pleuranthodium papilionaceum*.

Twelve species listed as Near Threatened by the IUCN have the potential to occur in the terrestrial ecology study area based on their distribution and habitat requirements. These are: *Cycas apoa, Cycas rumphii, Myristica globosa, Aglaia silvestris, Aglaia euranthera, Adinandra forbesii, Aglaia flavida, Aglaia lepidopetala, Aglaia rimosa, Aglaia subcuprea, Eucalyptopsis papuana* and *Podocarpus rumphii*.

8.4.5.4.2. Exotic Flora

Invasive exotic (i.e., introduced either deliberately or accidentally) species pose a serious threat to biodiversity especially in lowland rainforest areas where canopy disturbance provides ideal growth conditions for tropical weeds.

A total of 87 introduced plant species were recorded in the terrestrial ecology study area, 23 of which are considered to pose a specific risk to biodiversity values as invasive weed species, particularly in areas of disturbance, and are described in either Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River, or Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang. Twelve of these are listed on the Global Invasive Species Database (2015), with five identified as being among the 'world's 100 worst invasive alien species'. Additionally, 19 of the 87 species were assessed as high risk in the Pacific Island Ecosystems at Risk Database (PIER, 2013).

Introduced species are a common part of the landscape and are associated with an ongoing disturbance regime for gardening. The majority of these weeds are widespread herbaceous species and, although capable of rapid invasion to disturbed areas, are not considered highly invasive or a threat to native vegetation.

The area around Lae has experienced a relatively long history of contact with Europeans, going back almost 200 years, but especially in the last 100 years. Gold was discovered in the Wau and Bulolo valleys in the 1920s and at the height of the gold rush in 1938 there were about 700 Europeans in the area. During that period there was massive movement of cargo and personnel by planes between the coast and the two valleys. All of these early contacts may have intentionally or accidently introduced foreign flora to the area. Agricultural intensification around Lae and the Markham River valley after World War II is probably responsible for introducing most of the serious weeds and invasive species into the area through the movement of personal, cargo, equipment and livestock.

In the broad alluvial plain of the Lower Watut River, highly invasive weeds such as bamboo piper (*P. aduncum*) (Hartemink, 2010) and siam weed (*C. odorata*) are prevalent along disturbed roadsides, in garden areas and at other sites of disturbance. Bamboo piper (*P. aduncum*) dominates large areas of hillslope where garden areas have been abandoned. Highly invasive weeds are more prevalent in foothill and lowland habitats with infestations of siam weed, giant sensitive weed (*Mimosa diplotricha*), *Leucaena* and tropical kudzu (*Pueraria phaseoloides*) commonly observed, particularly along access roads and tracks.

In the eastern part of the terrestrial ecology study area, from the Markham River crossing to the Coastal Area, weeds known to pose serious threats to local ecosystems include bamboo piper (*P. aduncum*), *Lantana camara*, *S. campanulata* and *C. odorata*. In aquatic and wetland areas, water hyacinth (*Eichhornia crassipes*), salvinia (*Salvinia molesta*) and water lettuce (*Pistia stratioites*) can pose serious threats. All these and others continue to negatively impact the natural ecosystems in this part of the terrestrial ecology study area.

8.4.6. Fauna

The rich diversity of fauna, including several threatened (i.e., Critically Endangered, Endangered and Vulnerable), Near Threatened or otherwise rare, forest-dependent species typically found only in relatively large, undisturbed tracts of primary forest, indicates that forested habitats across the broad alluvial plain of the Lower Watut River are in good condition.

A total of 262 terrestrial vertebrate fauna species were recorded within the broad alluvial plain of the Lower Watut River during the five surveys conducted over the period 2010 to 2015. The records comprise 44 mammal species, 170 bird species, 33 reptile species and 15 amphibian (frog) species. The 44 mammal species includes 18 species of non-volant (non-flying) mammals and 26 species of flying mammals (bats). A full species list, including all sources, is provided in Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River.

Additionally, the surveys conducted by Coffey recorded a total of 155 terrestrial vertebrate fauna species within the eastern part of the terrestrial ecology study area, from the Markham River crossing to the Coastal Area, comprising six mammal species, 140 bird species, seven reptile species and two amphibian species. The six mammal species included four species of non-volant mammals and two species of flying mammals. A complete list of species recorded during the surveys is provided in Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang.

This section describes the fauna species, and where relevant, their conservation significance, in relation to the habitat types they were recorded in.

8.4.6.1. Habitats

Five main terrestrial fauna habitat types were characterised within the terrestrial ecology study area, these being alluvial forest, hill forest, grassland, watercourses and wetlands, and highly disturbed anthropogenic habitats.

8.4.6.1.1. Alluvial Forest

Alluvial forest dominates the broad Lower Watut River alluvial plain as a complex mosaic of Large to Medium Crowned Forest, Mixed Swamp Forest and Swamp Woodland. These floodplain forests are also present within the eastern part of the terrestrial ecology study area, from the foothills around the Atzera Mountain Range, and include forests along the road edges near the Busu and Bumbu rivers, the Marambi River and areas towards the mouth of the Markham River. Vegetation in these areas include grasslands, swamp forests, lowland medium to large crowned forests and anthropogenic vegetation.

The height, floristic and structural complexity of both alluvial and hill forest provides for a wide variety of ecological niches for fauna. As such, both lowland forest types support an equally rich diversity of terrestrial fauna species across the terrestrial ecology study area. The rich diversity of birds, including several threatened (i.e., Critically Endangered, Endangered and Vulnerable), Near Threatened or otherwise rare, forest-dependent species typically found only in relatively large, undisturbed tracts of primary forest, indicates that forested habitats across the broad alluvial plain of the Lower Watut River are in good condition for supporting bird diversity typical of intact, primary forest.

Alluvial forest provides habitat for a variety of species more associated with wet forests, including birds such as red-necked crake (*Rallina tricolor*), azure kingfisher (*Ceyx azureus*), little kingfisher (*Ceyx pusillus*), and the rare blue-black kingfisher. Other bird species recorded only in alluvial forest included ochre-collared monarch (*Arses insularis*), large-billed gerygone (*Gerygone magnirostris*) and black-headed whistler (*Pachycephala monacha*). The abundance of frogs in alluvial forest swamps supports a number of frog-eating snakes, including many-scaled keelback (*Tropidonophis multiscutellatus*) and New Guinea ground boa (*Candoia aspera*).

8.4.6.1.2. Hill Forest

Hill forest occupies the gentle to steeply sloping terrain of the foothills throughout the eastern parts of the broad alluvial plain of the Lower Watut River, and incorporates the Medium Crowned Forest and Small Crowned Forest on foothill vegetation communities. The eastern part of the terrestrial ecology study area, from the Markham River crossing to the Coastal Area, is dominated by hill and foothill forests characterised by steep hills and river valleys including some flatter and gentle areas located at the base of the foothills. Hill forests in this area can be found along the upper ridges and slopes of the Atzera Mountain Range starting from Yalu village and extending eastwards towards the hills around Bomsi, Gwabedik, West Taraka and Buimo Prison. The foothill forests within this area are predominantly found along the roads leading to the upper reaches of the Bumbu and Busu rivers.

Most species found in alluvial forest also occur in hill forest, however species recorded predominantly, or only, in hill forest, included the dwarf cassowary (*Casuarius bennetti*), variable goshawk (*Accipiter hiogaster*), papuan hawk owl (*Uroglaux dimorpha*), white-eared catbird (*Ailuroedus buccoides*), scrub honeyeater (*Meliphaga albonotata*), Meyer's friarbird (*Philemon meyeri*), Papuan black myzomela (*Myzomela nigrita*), tawny straightbill (*Timeliopsis griseigula*), pygmy longbill (*Oedistoma pygmaeum*), pale-billed scrubwren (*Sericornis spilodera*), great woodswallow (*Artamus maximus*) and black-fronted white-eye (*Zosterops minor*).

8.4.6.1.3. Grassland

Large patches of native grassland occur on the footslopes of the Lower Watut River valley, extending onto the alluvial plain in some localities, particularly to the west of the Lower Watut River. Within the eastern part of the terrestrial ecology study area, from the Markham River crossing to the Coastal Area, grassland areas extend along the Markham River. Smaller grassland areas also exist along the Busu and Bumbu rivers.

By comparison with the surrounding forests and wetland habitats, grassland habitats support a relatively species poor but distinct fauna. Mammals associated with this habitat include grassland melomys (*Melomys lutillus*) and polynesian rat (*Rattus exulans*), which is an introduced species (Woxvold and Aplin, 2013). The bird community is a little more diverse, including species such as eastern grass owl (*Tyto longimembris*), pheasant coucal (*Centropus phasianinus*), black-billed coucal (*C. bernsteini*), pied bush chat (*Saxicola caprata*), white-shouldered fairywren (*Malurus alboscapulatus*), Horsfield's bushlark (*Mirafra javanica*) and golden-headed cisticola (*Cisticola exilis*).

8.4.6.1.4. Watercourses and Wetlands

A variety of watercourses flow through the terrestrial ecology study area, from large and generally turbid alluvial plain rivers to small, fast-flowing mountain streams with clear water, and low-gradient, slow-flowing floodplain tributary streams.

The fringes of rivers, oxbow lakes and swamp grassland provide foraging habitat for waterbirds such as egrets and cormorants that occur in small numbers in the terrestrial ecology study area. Oxbow lakes are particularly rich in wetland fauna, supporting waterfowl such as ducks, grebes, cormorants, dusky moorhen (*Gallinula tenebrosa*), white-browed crake (*Porzana cinerea*) and comb-crested jacana (*Irediparra gallinacea*). White-bellied sea-eagle (*Haliaeetus leucogaster*) and eastern osprey (*Pandion cristatus*) are occasional visitors foraging for fish in larger areas of open water.

The clear, fast-flowing waters of mountain creeks provide breeding habitat for a variety of frogs, including species such as *Nyctimystes* cf *cheesmanae* and *Litoria eucnemis* (Woxvold and Aplin, 2013).

8.4.6.1.5. Highly Disturbed Anthropogenic Habitats

Highly disturbed habitats largely cleared of forest are most abundant close to villages and other settled areas, most notably Lae and its surrounds.

Species recorded only or more commonly in these highly disturbed habitats included singing starling (*Aplonis cantoroides*), metallic starling (*A. metallica*), peaceful dove (*Geopelia striata*), chestnut-breasted mannikin (*Lonchura castaneothorax*) and streak-headed mannikin (*Lonchura tristissima*).

8.4.6.2. Fauna Species of Conservation Significance

Seven species of conservation significance were recorded. A further three species of conservation significance, not recorded during surveys, have been reported to occur in the terrestrial ecology study area.

Of the species confirmed within the terrestrial ecology study area, one was found in Swamp Woodland, two within Mixed Swamp Forest, two within Medium Crowned Forest and Small Crowned Forest and two in villages. One species was classified as Critically Endangered, three species as Vulnerable, one as Near Threatened and the remaining two as Data Deficient.

The seven conservation significant species listed on the IUCN Red List and confirmed to occur within the terrestrial ecology study area are listed in Table 8.10.

Table 8.10: Conservation significant fauna species from IUCN Red List

Species	IUCN status	PNG Fauna Act	Description and ecology	Record of occurrence within the terrestrial ecology study area
Goodfellow's tree kangaroo (*Dendrolagus goodfellow*)	CE	-	Goodfellow's tree kangaroo is endemic to the island of PNG, occurring in the mid-montane areas of the Central Cordillera (south of the Mine Area), historically ranging in elevation from sea level up to 2,860mASL (Leary et al., 2016a). This species is now restricted to montane tropical forest (Leary et al., 2016a).	This species was recorded as a pet at Madzim village, and reported to have been captured as a juvenile in montane forest in the Upper Watut valley.
New Guinea pademelon (*Thylogale browni*) (Figure 8.30)	VU	-	New Guinea pademelon is widely distributed throughout northern and northeastern PNG, ranging in elevation from sea level up to around 3,200mASL (Leary et al., 2016b). The New Guinea pademelon occurs in primary and secondary tropical moist forest, but seems to prefer disturbed areas, including forest edges and is found in alpine grassland areas (Leary et al., 2016b).	This species was recorded as a captive individual observed in Pekumbe village.

Species	IUCN status	PNG Fauna Act	Description and ecology	Record of occurrence within the terrestrial ecology study area
Papuan eagle (*Harpyopsis novaeguineae*) (Figure 8.31)	VU	P	Papuan eagle is widely distributed across New Guinea, inhabiting forested landscapes and is most common in undisturbed forest at elevations from sea level to 3,700mASL (BirdLife International, 2016a). In suitable habitat of extensive, old-growth forest, pairs occupy large home ranges that average 13km^2 (Watson and Aysoma, 2001). The papuan eagle feeds mainly on mammals, particularly marsupials and rats, but also pigs and dogs, and sometimes other birds, lizards and snakes (BirdLife International, 2016a).	The Project occurs within the home range of at least one resident breeding pair inhabiting primary forest in the terrestrial ecology study area.
Pesquet's parrot (*Psittrichas fulgidus*)	VU	P	Pesquet's parrot is patchily distributed across New Guinea, and has historically and recently been extirpated from large areas, especially in PNG. It is generally rare and seen in small numbers (birds are wide-ranging). Pesquet's parrot is restricted to hill and lower montane forest and at lower altitudes appears to occur only in hills and at the base of mountains (Birdlife International, 2017).	This species was recorded in the terrestrial ecology study area, near Yalu, Bomsi and Labu villages, with each of the records being made within hill forest vegetation.
Gurney's eagle (*Aquila gurneyi*)	NT	-	Gurney's eagle is widely distributed in Indonesia and New Guinea, inhabiting a variety of forested habitats up to 1,000mASL, while seeming to prefer primary, relatively undisturbed forest (BirdLife International, 2016b).	At least one breeding pair appears to be resident in primary rainforest in the terrestrial ecology study area.
Blue-black kingfisher (*Todiramphus nigrocyaneus*)	DD	-	The species occupies a wide distribution in lowland habitats across New Guinea, but appears to be inexplicably rare throughout its range, being known from few scattered records from streams, swamps and ponds in forest to 600mASL (BirdLife International, 2015a). The species' population is suspected to be in decline owing to ongoing habitat destruction, particularly through logging of lowland swamp forests (BirdLife International, 2015a), although swamp forests may be relatively inaccessible to logging.	This species is resident within alluvial forest close to Mixed Swamp Forest with sago palm, including in the Markham Gap Basin.
Papuan hawk-owl (*Uroglaux dimorpha*) (Figure 8.32)	DD	-	Papuan hawk-owl is sparsely distributed across a wide range in New Guinea in lowland rainforest and gallery forest in savannah, occasionally up to 1,500mASL (BirdLife International, 2015b). The papuan hawk-owl appears to be very scarce or rare, however its population is suspected to be stable in the absence of evidence for any declines or substantial threats (BirdLife International, 2015b).	This species is resident in hill forest in the terrestrial ecology study area and possibly also alluvial forest.

Note conservation status under the IUCN Red List (IUCN) and Fauna Act (PNG): CE = Critically Endangered; VU = Vulnerable; NT = Near Threatened; DD = Data Deficient; P = Protected.

Two other Near Threatened species, Doria's goshawk (*Megatriorchis doriae*) and forest bittern (*Zonerodius heliosylus*), were identified as being likely (Doria's goshawk), or having potential to occur (forest bittern) in the terrestrial ecology study area. These species were not recorded during surveys for the Project.

Photo credit: BAAM, 2017

Figure 8.30
New Guinea pademelon (*Thylogale browni*)
(IUCN: Vulnerable)

Photo credit: BAAM, 2017

Figure 8.31
Papuan eagle (*Harpyopsis novaeguineae*)
(IUCN: Vulnerable)

Photo credit:Woxvold and Aplin, 2013

Figure 8.32
Papuan hawk owl (*Uroglaux dimorpha*)
(IUCN: Data Deficient)

Three species were assessed to be unlikely to occur in the Project Area, but have the potential to occur at higher elevations in proximity to possible resettlement sites (up to approximately 1,000mASL). The eastern long-beaked echidna (*Zaglossus bartoni*), listed as Critically Endangered, may historically have occurred within the Project Area, as it is within its known range. The species has been recorded in the upper Watut River valley at approximately 2,300mASL (Gressitt and Nadkarni 1978) and local residents interviewed during the 2010 and 2011 surveys recognised this species and indicated that it occurs only in higher elevation forests (Woxvold and Aplin, 2012). Similarly, the Near Threatened New Guinea quoll (*Dasyurus albopunctatus*) and small dorcopsis (*Dorcopsulus vanheurni*) also have the potential to occur in the Project Area, but based on their distribution and habitat preferences are more likely to occur at higher elevations outside the Project Area. The black-spotted cuscus (*Spilocuscus rufoniger;* Critically Endangered) may historically have occurred within the terrestrial ecology study area, as it is within its known range. However in Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River, BAAM consider this unlikely, as the species has been completely removed from parts of its range through overhunting and its intolerance of human disturbance, and is known only from areas north of Lae (Leary et al., 2016c).

A total of 11 species declared Protected (Table 8.11) and a further 19 species declared Restricted under the Fauna Act were recorded within the terrestrial ecology study area. These are primarily conspicuous species including birds-of-paradise, raptors, and waterbirds that are protected for their cultural value and not necessarily their conservation value. The exceptions are species listed under the IUCN Red List. The recorded species occupy wide ranges across PNG and none is of particular conservation concern except for the Papuan eagle.

Table 8.11: Conservation significant fauna species listed in Fauna Act

Common Name	Scientific Name	Status*	
		IUCN	PNG
Birds			
Pesquet's parrot	*Psittrichas fulgidus*	VU	P
King Bird-of-paradise	*Cicinnurus regius*	-	P
Raggiana Bird-of-paradise	*Paradisaea raggiana*	-	P
Palm cockatoo	*Probosciger aterrimus*	-	P
Papuan eagle	*Harpyopsis novaeguineae*	VU	P
Great egret	*Ardea alba*	-	P
Intermediate egret	*Egretta intermedia*	-	P
Blyth's hornbill	*Aceros plicatus*	-	P
Crinkle-collared manucode	*Manucodia chalybata*	-	P
Glossy-mantled manucode	*Manucodia atra*	-	P
Eastern osprey	*Pandion cristatus*	-	P

*Conservation status under the IUCN Red List (IUCN) and Fauna Act (PNG): VU = Vulnerable; P = Protected.

A number of undescribed species were recorded within the terrestrial ecology study area including:

- Two bats – a tube-nosed bat of the genus *Nyctimene*, and a blossom bat of the genus *Macroglossus* – that have not formally been named.
- Microhylid frog *Mantophryne* sp. an undescribed species. Woxvold and Aplin (2012) reported that it is known to occur widely across the lowlands of northern PNG.

Woxvold and Aplin (2013) noted that on 23 May 2012 two scrubwrens (*Sericornis* sp.) of uncertain affinity were observed on sloping terrain in hill forest in the Buvu Creek headwaters. BAAM subsequently completed a targeted survey and concluded the aforementioned species are most likely the Least Concern pale-billed scrubwren (*S. spilodera*).

8.4.6.3. Exotic Fauna

At least six different exotic (i.e., introduced) fauna species were recorded within the terrestrial ecology study area, including:

- Four mammals – Water buffalo (*Bubalus bubalis*), feral pig (*Sus scrofa*), feral cat (*Felis catus*) and polynesian rat (*R. exulans*).
- One reptile that is restricted to human settlements – Common house gecko (*Hemidactylus frenatus*).
- One amphibian that is widely distributed but more common in disturbed areas – Cane toad (*Bufo marinus*).

While feral pig has potential to damage forest habitats when it occurs in high density (Mitchell et al., 2008; Taylor et al., 2011), local population density is constrained by the heavy hunting pressure that targets this species.

8.5. Noise

Noise monitoring was undertaken in 2011 (Coffey, 2011a) for villages in proximity to the Mine Area (Figure 8.33). This data remains relevant due to the absence of development since that time. These villages were:

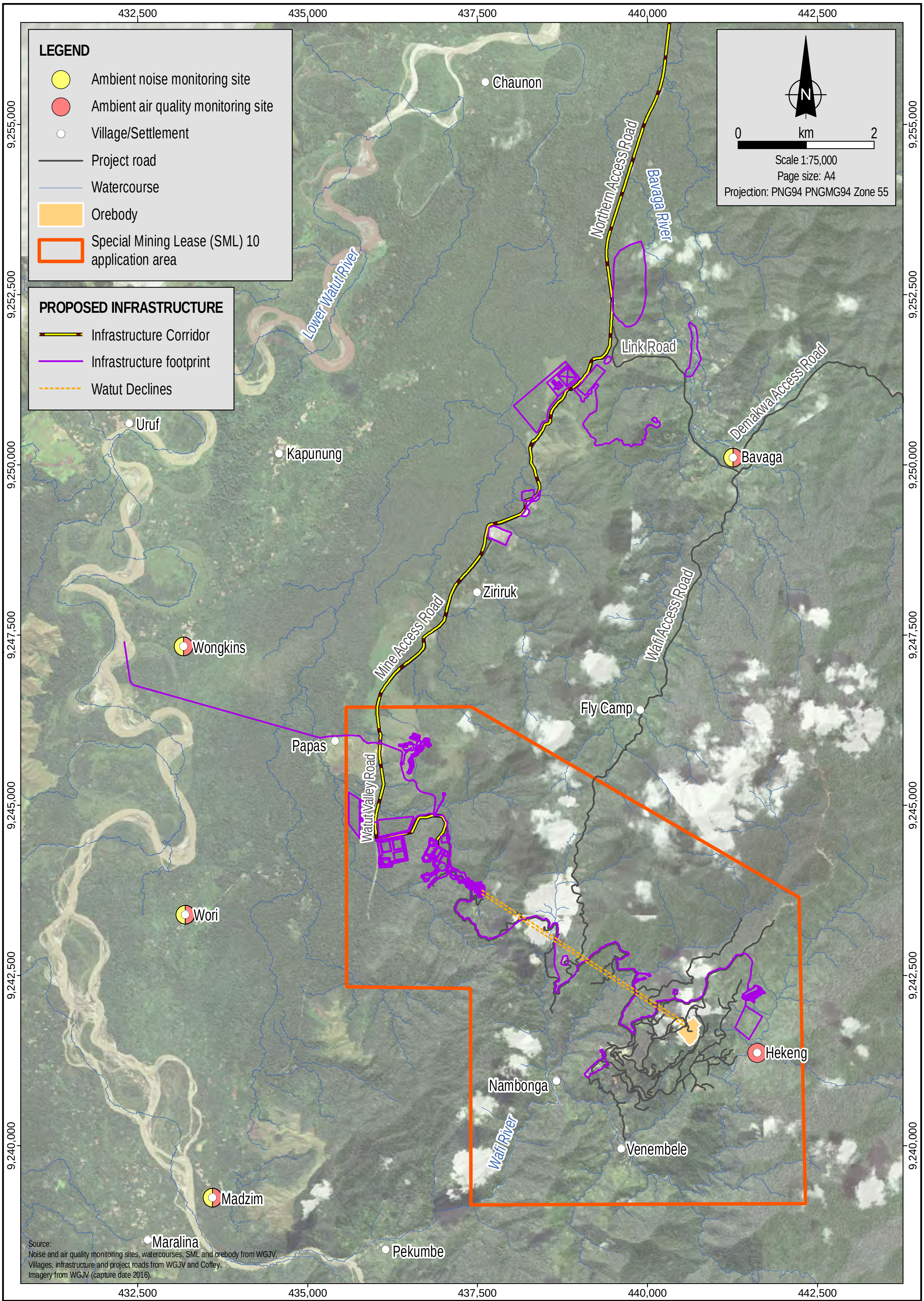
- Wongkins, located approximately 5.5km northwest of the Watut Declines Portal Terrace.
- Wori, located approximately 4km west of the Watut Declines Portal Terrace.
- Bavaga, located next to the junction of the existing Wafi Access Road and Link Road.
- Madzim, located approximately 6km southwest of the Watut Declines Portal Terrace.

These villages are geographically dispersed and the results are considered representative of conditions at other villages within the vicinity of the Mine Area. Monitoring was undertaken for approximately 24 hours at each of the four villages. Average noise levels are provided in Table 8.12, along with typical ranges from background noise monitoring conducted in similar environments within PNG (described in Appendix B, Noise and Vibration Impact Assessment).

Table 8.12: Noise monitoring results

Location	Date	Arithmetic Average of Measured 15 Minute Noise Level, L_{A90} (dBA)			Comments
		Day	Evening	Night	
Wongkins	15-16 July 2011	42	44	41	-
Wori	21-22 July 2011	44	47	43	Rain reported through the night period
Bavaga	14-15 July 2011	41	54	51	Consistently high levels from 7pm to 6am, suggesting insect noise
Madzim	24-25 July 2011	46	45	42	Afternoon storm
PNG (typical)		30 to 43	40 to 49	34 to 46	Based on SLR's work on multiple projects in PNG

Source: Appendix B, Noise and Vibration Impact Assessment.



MXD Reference: 0520DD_10_GIS004_v0_8

coffey
A TETRA TECH COMPANY

Date:	05.06.2018
Project:	754-ENAUABTF100520DD
File Name:	0520DD_10_F08.33_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Ambient noise and air quality monitoring sites

Figure No: **8.33**

These measurements show that background noise in the villages generally fall within the range typical of a rural setting within PNG. The exception was Bavaga village where high noise levels were measured during the evening and night periods, which is thought to be due to insects.

8.6. Air Quality

Due to the remote location of the Mine Area, high rainfall, low wind speeds and dense vegetation of the area, background concentrations of gaseous pollutants and particulate matter are negligible. Exceptions include areas affected by road dust, burning of the kunai grassland by landowners or regionally significant events such as a volcanic eruption.

A monitoring program to characterise existing air quality for the Mine Area was conducted between 11 May 2011 and 14 May 2011 (Coffey, 2011b). This data remains relevant due to the absence of development since that time. Four villages in proximity to the Mine Area were selected for the characterisation survey of dust deposition rates and PM_{10} concentrations. These villages were (see Figure 8.33):

- Wongkins, located approximately 5.5km northwest of the Watut Declines Portal Terrace.
- Wori, located approximately 4km west of the Watut Declines Portal Terrace.
- Bavaga, located next to the junction of the existing Wafi Access Road and Link Road.
- Madzim, located approximately 6km southwest of the Watut Declines Portal Terrace.

At each village, air quality monitoring equipment was placed in a central location, and villagers were asked to go about their normal daily activities, in an effort to collect data that is representative of normal village conditions and activities. In addition, a dust deposition monitoring program at the same locations has been ongoing since June 2011, as well as at Hekeng village since May 2015.

The results of the PM_{10} and dust deposition monitoring are summarised in Table 8.13.

Table 8.13: PM_{10} monitoring data

Location	24-Hour Average Concentration (µg/m^3)	Averaging Period
Wongkins	33	24 hour period ending 11:00am 12 May 2011
Wori	4	24 hour period ending 2:50pm 12 May 2011
Bavaga	26	24 hour period ending 12:00pm 14 May 2011
Madzim	5	24 hour period ending 4:00pm 14 May 2011

Source: Appendix A, Air Quality and Greenhouse Gas Impact Assessment.

The data shows that ambient PM_{10} concentrations are highest at Wongkins and Bavaga villages and very low at Wori and Madzim villages.

These concentrations will vary seasonally and will also be dependent on the activities occurring in and around the villages (e.g., construction of new dwellings, burning of vegetation, land clearance, etc.).

The results demonstrate compliance with the WHO 24-hour average guideline of 50µg/m^3 for PM_{10}, and while it is not possible to draw firm conclusions as to the typical concentrations in these locations, due to the limited temporal extent of the measurements, the findings are consistent with experience at similar locations elsewhere in PNG (described in Appendix A, Air Quality and Greenhouse Gas Impact Assessment).

Source:
WGJV: 532-1208-EN-REP-0009-1.8-XLS_DustDepositionData

coffey A TETRA TECH COMPANY

Date: 05.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F08.34_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Dust deposition monitoring data (2011 - 2017)

Figure No: 8.34

Dust deposition rates from ongoing monitoring at Wongkins, Bavaga and Hekeng villages are consistently low and below the maximum cumulative nuisance-based criterion of 4g/m^2/month[5] used in Australia (Figure 8.34). The New South Wales, Australia dust deposition guideline (NSW OEH, 2005) was adopted given the lack of such criteria in the WHO air quality guidelines. Elevated dust deposition rates measured on occasions at Wori village, and single occasions at Madzim and Bavaga villages, appear to be uncommon for the area. All five villages demonstrate average dust deposition rates below the criterion.

Air quality along the majority of the Infrastructure Corridor and at the Outfall Area is expected to be similar to that surrounding the Mine Area, and to that of the majority of rural PNG. However, at the Port Facilities Area, the existing air quality will be influenced by air emissions from the current port activities (e.g., shipping emissions), as well as other commercial, industrial and residential air emissions sources located within Lae, including vehicle emissions from local traffic. These activities have the potential to result in elevated concentrations of NO_2, SO_2 and particulates.

8.7. References

Advisian. 2016. Watut tailings storage facility hydrogeological report. Ref: 201310-13317-532-1068-FS-REP-0003. 16 September 2016.

Advisian, 2017. Deep Sea Tailings Placement Pipeline – Terrestrial Geotechnical Report. Ref: 532-4000-FS-REP-34004. 30 October 2017.

Barthlott, W., J. Mutke, M.D. Rafiqpoor, G. Kier & H. Kreft. 2005. *Global centres of vascular plant diversit*y. Nova Acta Leopoldina, 92 (342): 61—83.

BirdLife International. 2015a. Todiramphus nigrocyaneus. The IUCN Red List of Threatened Species, Version 3.1. <www.iucnredlist.org>.

BirdLife International. 2015b. Uroglaux dimorpha. The IUCN Red List of Threatened Species, Version 3.1. <www.iucnredlist.org>.

BirdLife International. 2016a. Harpyopsis novaeguineae. The IUCN Red List of Threatened Species, Version 3.1. <www.iucnredlist.org>.

BirdLife International. 2016b. Aquila gurneyi. The IUCN Red List of Threatened Species, Version 3.1. <www.iucnredlist.org>.

Birdlife International. 2017. *Psittrichas fulgidus*. The IUCN Red List of Threatened Species, Version 3.1. <www.iucnredlist.org>.

Bishop Museum. 2015. Online Natural Sciences Collections Database, Bernice Pauahi Bishop Museum, Honolulu, Hawaii. http://nsdb.bishopmuseum.org/.

Booyong Forest Science. 2011a. *Terrestrial Flora Survey for the MMJV Wafi-Golpu Project*. Unpublished report prepared for Coffey Environments.

Booyong Forest Science. 2011b. *Terrestrial Flora Survey for the Markham Gap Basin Tailings Storage Facility for the WGJV Wafi-Golpu Project*. Unpublished report prepared for Coffey Environments.

Booyong Forest Science. 2013. *Terrestrial Flora Survey for the Wafi Golpu Advanced Exploration Project*. Unpublished report prepared for Coffey Environments.

[5] The New South Wales, Australia dust deposition guideline for cumulative nuisance-based criteria states that deposition should not exceed 4g/m2/month, or no more than 2g/m2/month incremental change above background (NSW OEH, 2005).

Bryan, J.E., Shearman, P., Aoro, G., Wavine, F. and Zerry, J. 2015. The current state of PNG's forests and changes between 2002 and 2014. In: Shearman, P. and Bryan, J. E. (Eds) The State of the Forests of Papua New Guinea 2014: Measuring change over the period 2002-2014, pp. 7-42. University of Papua New Guinea Remote Sensing Centre.

Coffey. 2011a. *Noise Characterisation - Wafi-Golpu Project.* Prepared for Wafi-Golpu Joint Venture by Coffey Environments Australia Pty Ltd.

Coffey. 2011b. *Air Quality Characterisation - Wafi-Golpu Project.* Prepared for Wafi-Golpu Joint Venture by Coffey Environments Australia Pty Ltd.

Coffey. 2013. *Environmental Impact Statement: Wafi-Golpu Advanced Exploration Project: Biophysical Impacts Assessment* (unpublished draft). Prepare for Wafi-Golpu Joint Venture by Coffey Environments Australia Pty Ltd.

Conn, B.J. (Ed.). 1995. *Handbooks of the flora of Papua New Guinea - Volume 3*. Melbourne University Press.

Conn, B.J., Lee, L.L., and Kiapranis, R. 2006. *PNG plants database: Plant collections from Papua New Guinea*. Accessed from http://www.pngplants.org/PNGdatabase on 07 September 2011.

Conservation International. 2017. Papua New Guinea Declares First National Conservation Area. A WWW resource accessed from http://www.conservation.org/NewsRoom/pressreleases/Pages/Papua New Guinea Conservation Area Tree Kangaroo Local Villages.aspx.

Eddowes, P.J. 1998a. *Diospyros lolinopsis*. The IUCN Red List of Threatened Species. Version 2015.2. <www.iucnredlist.org>. Downloaded on 04 July 2015.

Eddowes, P.J. 1998b. Pterocarpus indicus. The IUCN Red List of Threatened Species. 1998: e.T33241A9770599. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Eddowes, P.J. 1998c. Flindersia amboinensis. The IUCN Red List of Threatened Species. 1998: e.T38146A10102509. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Eddowes, P.J. 1998d. Myristica buchneriana. The IUCN Red List of Threatened Species. 1998: e.T37857A10082239. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Eddowes, P.J. 1998e. Myristica globosa. The IUCN Red List of Threatened Species. 1998: e.T37876A10077890. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Eddowes, P.J. 1998f. Diospyros insularis. The IUCN Red List of Threatened Species. 1998: e.T38346A10113128. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Eddowes, P.J. 1998g. Flindersia pimenteliana. The IUCN Red List of Threatened Species. 1998: e.T38149A10102702. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Embassy of Papua New Guinea to the Americas. 2004. *Topographical and Geological Features*. Retrieved July 16, 2015, from Papua New Guinea: http://www.pngembassy.org/topographical.html.

Everingham, I. 1973. *A Submarine Slump and Tsunami in the Lae Area of Papua New Guinea*. Department of Minerals and Energy, Bureau of Minearl Resources, Geology and Geophysics, record 1973/20, 8 pp.

Faith, D. P., Margules, C. R., Walker, P. A., Stein, J., and Natera, G. 2001. Practical application of biodiversity surrogates and percentage targets for conservation in Papua New Guinea. Pacific Conservation Biology 6: 289-303.

Flannery, T. F. 1995. *The Mammals of New Guinea*. Chatswood, NSW: Reed Books.

Food and Agriculture Organisation of the UN. 2014. Global Water information system – Aquastat. Accessed from http://www.fao.org/nr/water/aquastat/data/wrs/readPdf.html?f=PNG-WRS_eng.pdf,.

Geoscience Australia. 2015. *Earthquakes at Geoscience Australia*. Retrieved June 2015, from: http://www.ga.gov.au/earthquakes/.

Gideon, O.G. 2015. The Flora of New Guinea: its origins, affinities, and patterns of diversity and endemism. In: Bryan JE & PL Shearman (Eds.); The State of the Forests of Papua New Guinea: measuring change over the period 2002 – 2014. University of Papua New Guinea, Port Moresby. Pp. 115 – 135.

Global Invasive Species Database. 2015. Available at: <www.issg.org>.Accessed on 26 May September 2015.

Gressitt, J. L. & Nadkarni, N. (1978) Guide to Mt. Kaindi. Background to New Guinea montane ecology. Wau Ecology Institute, Handbook No. 5.

Hammermaster, E. T., and Saunders, J. C. 1995. *Forest Resources and Vegetation Mapping of Papua New Guinea*. PINGRIS Publication 4. CSIRO and AIDAB, Canberra, Australia.

Hartemink, A. E. 2010. *The invasive shrub* Piper aduncum *in Papua New Guinea: a review*. Journal of Tropical Forest Science 22: 202-213.

Hill K. D. 2010a. Cycas campestris. The IUCN Red List of Threatened Species. 2010: e.T42072A10618293. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Hill K. D. 2010b. Cycas apoa. The IUCN Red List of Threatened Species. 2010: e.T42068A10642573. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Hill K. D. 2010c. Cycas schumanniana. The IUCN Red List of Threatened Species. 2010: e.T42082A10623647. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Hill K. D. 2010d. Cycas scratchleyana. The IUCN Red List of Threatened Species. 2010: e.T42083A10624172. <www.iucnredlist.org>. Downloaded on 31 May 2017.

IFC. 2012. *Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources*. International Finance Corporation.

INAP. 2018. *Elemental composition of mineralized rocks*. The International Network for Acid Prevention. Accessed on 30 January 2018 from: http://www.gardguide.com/index.php?title=Elemental_composition_of_mineralized_rocks.

KCB. 2013. *Wafi-Golpu Soils Assessment Surface Soils Assessment FINAL.* Report prepared by Klohn Crippen Berger for the Morobe Mining Joint Venture.

Kier, G., J. Mutke, E. Dinerstein, T.H. Ricketts, W. Küper, H. Kreft & W. Barthlott. 2005. Global patterns of plant diversity and floristic knowledge. J. Biogeogr.32:1107—1116.

Leary, T., Seri, L., Flannery, T., Wright, D., Hamilton, S., Helgen, K., Singadan, R., Menzies, J., Allison, A., and James, R. 2016. Thylogale browni. The IUCN Red List of Threatened Species. 2016: e.T21874A21958526. <www.iucnredlist.org>. Downloaded on 5 December 2017.

Leary, T., Seri, L., Wright, D., Hamilton, S., Helgen, K., Singadan, R., Menzies, J., Allison, A., James, R., Dickman, C., Aplin, K., Flannery, T., Martin, R., and Salas, L. 2016a. Dendrolagus goodfellowi. The IUCN Red List of Threatened Species. 2016. e.T6429A21957524. <www.iucnredlist.org>. Downloaded on 5 December 2017.

Leary, T., Singadan, R., Menzies, J., Helgen, K., Allison, A., James, R., Flannery, T., Aplin, K., Dickman, C., and Salas, L. 2016b. Spilocuscus rufoniger. The IUCN Red List of Threatened Species. 2016. e.T20639A21949788. <www.iucnredlist.org>. Downloaded on 5 December 2017.

McAlpine, J., and Quigley, J. 1998. Summary Statistics from the Forest Inventory Mapping (FIM) System. Coffey MPW.

Mitchell, J., Dorney, W., Mayer, R., and McIlroy, J. 2008. *Ecological impacts of Feral Pig diggings in north Queensland rainforests*. Wildlife Research 34(8): 603-608.

Mutke, J. & W. Barthlott. 2005. Patterns of vascular plant diversity at continental to global scales. Biol. Skrifter 55: 521—537.

NSW OEH. 2005. Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales. Prepared by the NSW EPA of NSW Office of Environment and Heritage (OEH). Retrieved from http://www.environment.nsw.gov.au/resources/air/ammodelling05361.pdf.

Paijmans, K. 1975. *Explanatory Notes to the Vegetation Map of Papua New Guinea*. Land Research Series No. 35. Commonwealth Scientific and Industrial Research Organisation, Canberra.

Paijmans, K. (Ed.). 1976. *New Guinea Vegetation*. CSIRO and Australian National University Press. Canberra, Australia.

Pannell, C.M. 1998a. Aglaia silvestris. The IUCN Red List of Threatened Species. Version 2015.2. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Pannell, C.M. 1998b. Aglaia euryanthera. The IUCN Red List of Threatened Species. Version 2015.2. <www.iucnredlist.org>. Downloaded on 31 May 2017.

PIER. 2013. Pacific Island Ecosystems at Risk. Online resource at http://www.hear.org/pier/.

PNGFRI. 2011. Forest Resources Inventory Along Access Road to Wafi-Golpu Mine Exploration Site, Lower Watut Area, Morobe Province, Papua New Guinea, Lae. Report prepared by Papua New Guinea Forestry Research Institute.

Queensland Herbarium. 2015. *Extract from the Queensland Herbarium Herbrecs Database*. Morobe Province. Queensland Government, Brisbane.

RBGSYD. 2012a. Cycas apoa. Royal Botanic Gardens Sydney. Accessed at http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/cycadpg?taxname=Cycas+apoa.

RBGSYD. 2012b. Cycas schumanniana. Royal Botanic Gardens Sydney. Accessed at http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/cycadpg?taxname=Cycas+schumanniana.

Shearman, P. L., and Bryan, J.E. 2011. A bioregional analysis of the distribution of rainforest cover, deforestation and degradation in Papua New Guinea. Austral Ecology 36(1): 9-24.

Shearman, P. L., Bryan, J.E., Ash, J., Hunnam, P., Mackey, B., and Lokes, B. 2008. *The state of the forests of Papua New Guinea: Mapping the extent and condition of forest cover and measuring the drivers of forest change in the period from 1972 to 2002*. University of Papua New Guinea.

Shearman, P. L., Ash, J., Mackey, B., Bryan, J. E., and Lokes, B. 2009. *Forest conversion and degradation in Papua New Guinea 1972–2002*. Biotropica 41(3): 379-390.

SKM. 2011. *Groundwater Supply Desk Study, Wafi Golpu Project - Pre-Feasibility Study.* 532-0034-PF-REP-E4-0001.

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

SRK. 2011. Morobe Mining Wafi Golpu JV. Hydrogeological Review: MRB0004. Report prepared by SRK Consulting (Australasia) Pty Ltd. Sydney, Australia.

Stanaway, R. 2008. *PNG on the move - GPS Monitoring of Plate Tectonics and Earthquakes*. Port Moresby.

Taylor, D. L., Leung, L. P., and Gordon, I. J. 2011. *The impact of feral pigs (*Sus scrofa*) on an Australian lowland tropical rainforest*. Wildlife Research 38(5): 437-445.

TSSC. 2013. *Guidelines for Nominating and Assessing the Eligibility for Listing of Ecological Communities as Threatened according to the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and the EPBC Regulations 2000 (EPBC Regulations)*. Prepared by Threatened Species Scientific Committee for Department of the Environment, Canberra.

University of PNG Remote Sensing Centre, 2008. *Papua New Guinea Resource Information System (PNGRIS),* Port Moresby.

Watson, M., and Asoyama, S. 2001. Dispersion, habitat use, hunting behavior, vocalizations, and conservation status of the New Guinea Harpy Eagle (Harpyopsis novaeguineae). Journal of Raptor Research 35: 235-239.

Whitmore, T.C. 1984. *Tropical rainforests of the Far East*. Oxford University Press, London.

Womersly J. S. 1978. *Handbooks for the flora of PNG – Volume 1.* Government of Papua New Guinea, Melbourne University Press.

World Conservation Monitoring Centre. 1998. Intsia bijuga. The IUCN Red List of Threatened Species. 1998: e.T32310A9694485. <www.iucnredlist.org>. Downloaded on 31 May 2017.

Woxvold, I. A. 2010. Terrestrial vertebrate fauna potentially occurring in the Wafi-Golpu Project area. Unpublished report prepared for Coffey Environments, November 2010.

Woxvold, I. A. 2011. Terrestrial Fauna of the Wafi-Golpu Project Area: Communities, Pre-feasibility Exploration Impacts and Recommendations. Unpublished report prepared for Coffey Environments, January 2011.

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. Unpublished report prepared for Coffey Environments, March 2012.

Woxvold, I. A., and Aplin, K. 2012. *Terrestrial Fauna Study of the northern Wafi Golpu Project Stage 2 Early Works Program: Faunal Communities and Conservation Values.* Unpublished draft report prepared for Coffey Environments, August 2012.

Woxvold, I. A., and Aplin, K. 2013. *Terrestrial fauna study and impact assessment of the Wafi-Golpu advanced exploration project*. Unpublished draft report prepared for Coffey Environments, 4 April 2013.

WSP. 2016. Golpu Stage 1: Evaluation of mine inflows – Modelling of inflows to Golpu underground using Seep/W. 28 November 2016. Ref: 56072TM07v0.