



Chapter 14

Physical and Biological Environment Impact Assessment

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

14. PHYSICAL AND BIOLOGICAL ENVIRONMENT IMPACT ASSESSMENT

This chapter presents the assessment and findings of potential impacts from Project activities on the physical and terrestrial biological environment described in Chapter 8, Physical and Biological Environment Characterisation, namely impacts on landform and soils (Section 14.2), groundwater (Section 14.3), terrestrial ecology (Section 14.4), air quality (Section 14.5) and noise and vibration (Section 14.7). A greenhouse gas assessment is also presented (Section 14.6). Surface water quality and freshwater ecology are discussed in Chapter 15, Freshwater Impact Assessment and marine water quality and ecology are discussed in Chapter 16, Nearshore Marine Environment Impact Assessment and Chapter 17, Offshore Marine Environment Impact Assessment.

14.1. Approach to Impact Assessment

As discussed in Chapter 4, Overview of Impact Assessment Methods, the environmental impact assessment approach generally adopts one of two methods to assess the level of residual environmental impacts of the Project on the identified values, with one exception: the greenhouse gas emissions assessment, as explained in Section 14.1.3. Unless otherwise stated, this impact assessment was conducted by Coffey Environments Australia Pty Ltd.

The significance assessment method has been adopted where a qualitative assessment is required. This method allows for the development of the most suitable and practical mitigation and proposed management measures, as it only considers credible impacts with a likelihood of occurring. Potential impacts to landform and soils (Section 14.2), groundwater (Section 14.3) and terrestrial ecology (Section 14.4) values were assessed using the significance assessment method.

The compliance standard assessment method has been adopted where a quantitative assessment is required. The method relies on international, national or best practice limits or guidelines to assess an impact. The compliance standard method was used for assessing potential impacts on air quality (Section 14.5) and noise and vibration (Section 14.7).

An understanding of the existing physical and terrestrial biological environment, as described in Chapter 8, Physical and Biological Environment Characterisation, is a key precursor to each impact assessment.

A summary of assessment inputs, e.g., values, definitions, modelling parameters, assessment criteria and/or key considerations is discussed along with potential impacts. Direct and indirect impacts resulting from Project activities are considered for all Project phases, i.e., construction, operations and closure, as described in Chapter 6, Project Description. An overview of proposed management measures to address these potential impacts is presented and the subsequent assessment of residual impacts assumes the successful implementation of these measures. The assessment of residual impacts also includes consideration of the additional management measures proposed within the Wafi-Golpu Project (the Project) Environmental Management Plan (EMP) provided in Attachment 3.

Socioeconomic impacts with the potential to manifest as a result of the environmental impacts described in this chapter are addressed in Chapter 18, Socioeconomic Impact Assessment.

The impact assessment section for each aspect described in this chapter concludes with a high-level discussion of environmental monitoring that is proposed to verify impact predictions. The Project EMP (Attachment 3) details the Project-wide monitoring requirements for assessing the Project's overall environmental performance.

14.1.1. Significance Assessment Method

The significance assessment method examines the degree to which the existing environment is expected to change as a result of Project-related activities. This assessment method is a function of the sensitivity of an environmental value and the magnitude of impact on that particular value which, together, determine the residual significance of the impact.

Sensitivity is defined as the susceptibility of an environmental value to change, including its capacity to adapt to, or accommodate, the kinds of changes that the Project may bring about. It also considers the intrinsic importance of that value to the environment.

For each of the potential impacts identified as resulting from Project activities in the construction, operations and closure phases, an assessment to understand the magnitude of impact was made. This assumed successful implementation of proposed management measures, and considers the:

- Severity of the residual impact: in terms of the proportion, degree and/or rate of change of disturbance experienced by the value.
- Spatial extent of the residual impact: the size of the area which may be directly or indirectly affected by Project-related activities.
- Temporal extent of the residual impact: whether the impact is likely to be immediate or delayed, occurs during the day or at night, is seasonal or, is short or long term.

For each assessment of landform and soils (Section 14.2), groundwater (Section 14.3) and terrestrial ecology (Section 14.4), the sensitivity of the values and the different levels of residual impact magnitude are uniquely defined in their respective sections of this chapter.

For the significance assessment of predicted residual impacts, the magnitude of the residual impact was determined and considered with respect to the sensitivity of the identified values impacted using the significance assessment matrix (Table 14.1).

Table 14.1: Matrix for assessing the level of significance of a residual impact

Magnitude of impact	Sensitivity of value				
	Very low	Low	Medium	High	Very high
Very high	Moderate	High	Major	Major	Major
High	Low	Moderate	High	Major	Major
Moderate	Low	Low	Moderate	High	High
Low	Low	Low	Low	Moderate	Moderate
Very low	Very low	Low	Low	Low	Moderate

14.1.2. Compliance Standard Assessment Method

The compliance standard assessment method was used to compare the results of modelling or other predictive techniques with statutory limits or guidelines. As described in Section 4.7, where PNG has no such published limits or thresholds then limits or thresholds from other jurisdictions or guidelines have been adopted. The adopted criteria are articulated in the respective sections for the air quality assessment (Section 14.5) and the noise and vibration assessment (Section 14.7).

14.1.3. Benchmarking

The assessment of greenhouse gas emissions generated by Project activities and associated facilities (Section 14.6) involved comparison of the emissions per unit of electrical energy generated by the Project and the efficiency of fossil fuels (i.e., diesel, fuel oil, brown and black coal and natural gas), in producing electrical energy. This method is referred to as 'benchmarking' which is standard practice for assessing the emissions intensity of project-related greenhouse gas emissions.

14.2. Landform and Soils

This section describes the potential and predicted residual impacts to landform and soils resulting from the Project, based on the Project activities described in Chapter 6, Project Description.

14.2.1. Assessment Method Inputs

Environmental values to be protected from a landform and soils perspective are:

- Stable landforms and soils.
- Soil capacity (quantity and quality).

The baseline environment characterisation (see Chapter 8, Physical and Biological Environment Characterisation) identified three 'terrain units' which form the basis of the assessment and the sensitivity of each value was assessed for each terrain unit.

Table 14.2 defines the sensitivity levels applied in the assessment and Table 14.3 presents the landform and soil characteristics of each terrain unit and their assessed sensitivity.

Table 14.2: Sensitivity of landform and soils environmental values definitions

Sensitivity	Definition
Very high	• Very poorly-developed soils with negligible organic matter and nutrients. • Highly erodible soils and/or contaminated soils from previous land use. • Highly unstable and erodible landforms in steep terrain. • Soil type and/or landform is poorly represented in Watut, Markham, Busu and Bumbu rivers catchments. • Soils are fragile and will not recover; landforms are fragile and will be difficult to stabilise, requiring extensive remedial work.
High	• Poorly-developed soils with low organic matter nutrients. • Erodible soils and/or potentially contaminated soils from previous land use. • Moderately unstable and erodible landforms in steep to undulating terrain. • Soil type and/or landform is represented in the Watut, Markham, Busu and Bumbu rivers catchments. • Soils are not very robust and recovery will be slow; landforms are not very robust and will recover over time with remedial work.
Medium	• Developed soils with some organic matter and nutrients. • Potentially unstable landform in undulating terrain. • Soil type and/or landform is limited in its distribution in the Watut, Markham, Bumbu and Busu rivers catchments. • Soils are moderately robust and will recover in time; landforms are moderately robust and will recover over time with some remedial work required.

Sensitivity	Definition
Low	• Moderately well-developed soils with moderate organic matter and nutrients. • Soil is not very erodible and is not contaminated by previous land use. • Moderately stable landform in gently undulating terrain. • Soil type and/or landform is less widely distributed and represented in the Watut, Markham, Bumbu and Busu rivers catchments. • Soils are relatively robust and will recover from disturbance; landforms are quite resilient and will stabilise with remedial work possibly required.
Not sensitive	• Well-developed soils fertile soils with high organic matter • Soils are not contaminated. • Highly stable landform in flat terrain that is not susceptible to erosion. • Soil type and/or landform is widely distributed and represented in the Watut, Markham, Bumbu and Busu rivers catchments. • Soils are robust and will quickly recover from disturbance; landforms are resilient and will quickly stabilise without remedial work.

Table 14.3: Sensitivity of landform and soils environmental values

Environmental Value	Terrain Unit	Associated Landform / Soil Characteristics	Sensitivity of the Environmental Value
Stable landforms and soils	Mountainous terrain with deeply incised valleys	Mountains and hills with weak or no structural control and overall slope gradients of 17 degrees (º) to 27º.	High
	Broad, alluvial valleys of mature rivers	Meander floodplains and back swamps with slopes of less than 2°.	Low
	Poorly drained areas	Recent alluvial fans with little dissection and slopes of less than 2°.	Low
Soil capacity (quantity and quality)	Mountainous terrain with deeply incised valleys	Non-dispersive, mostly shallow soils that show more variability than alluvial valley soils	Medium
	Broad, alluvial valleys of mature rivers	Mosaic of soil types with some well-drained and fertile and others weakly acidic.	Medium
	Poorly drained areas	Permanently saturated fine textured soils	Low

Table 14.4 defines the levels of the magnitude of potential impacts to the values, i.e., stable landform and soils, and the soil capacity.

Table 14.4: Definitions for the magnitude of impacts to landform and soils

Magnitude	Contributing Factor	Definition
Very high	Severity	Potential impacts will degrade soils and/or affect landform stability with little or no recovery. Changes irreversible.
	Spatial extent	Potential impacts extend from the disturbed area across both the Lower Watut and Lower Markham or lower Bumbu and Busu rivers catchments.
	Temporal extent	Potential impacts are long-term or permanent, extending beyond the life of the Project.
High	Severity	Potential impacts will degrade soils and/or affect landform stability with some recovery expected.

Magnitude	Contributing Factor	Definition
	Spatial extent	Potential impacts extend from the disturbed area across one of the following: the Lower Watut River catchment, the Lower Markham River catchment, the lower Bumbu River catchment or the lower Busu River catchment.
	Temporal extent	Potential impacts are medium to long-term extending up to 10 years.
Moderate	Severity	Potential impacts likely to degrade soils and/or affect landform stability with recovery towards pre-impact conditions expected.
	Spatial extent	Potential impacts confined to tributary catchments draining one of the following: the Lower Watut River, Lower Markham River, the lower Bumbu or the lower Busu rivers
	Temporal extent	Potential impacts are medium term extending up to five years.
Low	Severity	Potential impacts likely to have some effect on soils and/or landform stability with recovery expected.
	Spatial extent	Potential impacts confined to upper reaches of Lower Watut River or Lower Markham River tributary catchments or lower reaches of lower Bumbu River or lower Busu River tributary catchments draining the Project Area.
	Temporal extent	Potential impacts are short term extending up to one year.
Very low	Severity	Potential impacts unlikely to affect soils and/or landform stability with full recovery expected.
	Spatial extent	Localised potential impact restricted to the disturbed and abutting areas.
	Temporal extent	Once-off potential impact, less than one month.

14.2.2. Potential Impacts

This section presents the potential impacts that may affect the landform and soils values as a result of Project activities. They are discussed in relation to the terrain units.

Construction and operation of the Project will involve the excavation and movement of large volumes of material within the Project's disturbance footprint. Activities that will involve the excavation and movement of soils on site will include removal and storage of topsoil and waste rock (during decline development), quarrying, construction of roads, pipelines and Project infrastructure including the Watut Process Plant, power generation facilities, laydown areas and accommodation camps.

There are no credible impacts to geology as a result of the Project (other than the removal of the resource, which is the intention of the mine) and as such geology is not discussed further in this section.

Project-related activities that may result in impacts to the landforms and soils values are:

- Physical disturbance of landforms and soils including vegetation clearance and major earthworks.
- Chemical alterations to soils from accidental spills and leaks, seepage of acid and metalliferous drainage (AMD) or exposure of acid sulphate soils (ASS) and/or potential acid sulphate soils (PASS).

Physical disturbance exposes soils and, if unmanaged, this may lead to erosion and/or compaction of soils causing reduced or lost capacity to support vegetation, gardens or crops. Physical disturbance may also destabilise landforms causing or increasing the potential for landslips and erosion. Soil contamination may reduce the capacity of soils to support vegetation, gardens or crops.

Physical disturbance will be greatest during construction and closure, due to the concentration of ground-disturbing works. The potential impacts resulting from chemical alterations to soils will be greatest during operations, and may extend into closure. These impacts are discussed below.

14.2.2.1. Destabilisation of Landforms

14.2.2.1.1. Mountainous Terrain with Deeply Incised Valleys

The Project is located within a seismically active area and geological faults are present in the Mine Area. The areas of mountainous terrain with deeply incised valleys are prone to natural landslides and are common in areas of moderate to steep slopes. This has the potential to be exacerbated by Project-related physical disturbance, for example, vegetation removal, changes to surface water drainage pathways and excavation of slopes such as for new road developments.

The steepness of the terrain and the scale of the Project facilities will necessitate localised excavation, filling or cut-and-fill of the ground surface during construction. The most noticeable changes will be the development of the Watut Process Plant and portal terraces, development of the ventilation shaft and the Watut and Miapilli waste rock dumps, expansion and establishment of gravel extraction and borrow pits, and the formation of the subsidence zone on Mt Golpu. These ground-disturbing activities may affect the stability of slopes, particularly in steep terrain, if not properly designed and managed.

14.2.2.1.2. Broad, Alluvial Valleys of Mature Rivers and Poorly Drained Areas

Construction of the Infrastructure Corridor within the broad, alluvial valleys of the Lower Watut and Lower Markham rivers and poorly drained areas will require vegetation clearing and earthworks, construction of access tracks, watercourse crossings and other localised re-profiling of the existing terrain. Similarly, such construction activities are required at the Outfall Area, located within a poorly drained area on the floodplain of the Busu River. The slope of the Infrastructure Corridor and landform of the Outfall Area is generally shallow (less than 2°) and land instability is not expected.

14.2.2.2. Exposure and Loss of Soils

The Project is located in a high rainfall environment with mine infrastructure positioned in areas of moderate to steep slopes. Soils of the mountainous terrain with deeply incised valleys are naturally shallow, exposed to weathering and eroding processes (wind and rain). These natural characteristics and ground-disturbing work will lead to the exposure and potential loss of soils through erosion.

With the exception of poorly drained areas, all of the terrain units in the Project Area are susceptible to erosion, particularly those with soils situated on unstable landforms (i.e., colluvium, residual and slopewash soils) and those left exposed.

The key Project activities with the potential to increase erosion and sedimentation are clearing vegetation and bulk earthworks.

Erosion and landslides may contribute to the degradation of soil structure through the burial of fertile topsoil and plant propagules, breaking up soil aggregates, and exposing more dispersive subsoils. Other potential impacts include a reduction in the quantity of available topsoil, thereby hindering rehabilitation efforts, and increased sediment loads in runoff from work sites which may enter gullies, streams and creeks flanking the slopes of Mt Golpu and discharge to the Lower Watut River. The potential impacts of erosion and sedimentation to the downstream receiving environment are discussed in Chapter 15, Freshwater Environment Impact Assessment and have not been considered further here.

14.2.2.3. Degradation of Soil Capacity

The construction phase of the Project will require excavation, transport and stockpiling of soils. Poor soil stripping practices (e.g., not recovering all available topsoil or mixing the soil horizons) or poor management of soil (e.g., mixing stockpiled soils) may reduce the amount of suitable topsoil available for rehabilitation.

Construction activities along the Infrastructure Corridor and at the Outfall Area may result in exposure of ASS or PASS material.

During the operations and closure phases, the Project has the potential to result in soil contamination from seepage of AMD and/or accidental spills and leaks and changes to water quality from increased sediment loads. Contamination of soils may degrade soil capacity and hinder rehabilitation activities.

14.2.2.3.1. Accidental Spills and Leaks

Changes to soil chemistry may arise from spills or leaks of diesel, lubricating oils, hydraulic fluids, process solutions or reagents.

A potential impact resulting from changes to the chemical properties of soil during Project activities is a decrease in structure, nutrients and fertility affecting plant health.

14.2.2.3.2. Acid and Metalliferous Drainage

Based on geochemical analysis, it is expected that much of the waste rock excavated from the declines and ventilation shaft will be potentially acid forming (PAF) and could result in acidification of surface water and groundwater, potentially leading to leaching and mobilisation of heavy metals into the surrounding environment.

Contaminated soils have the potential to affect water quality, aquatic ecology and people and the impacts associated with this are addressed in:

- Chapter 15, Freshwater Environment Impact Assessment
- Chapter 18, Socioeconomic Impact Assessment

14.2.2.3.3. Exposure of Acid Sulphate Soils

The elevation, mapped geological units and inferred soil types at the Outfall Area and along the Infrastructure Corridor indicate there is potential that ASS/PASS soil types are likely to be encountered during construction.

If ASS or PASS material is exposed during construction, it could cause:

- Reduced soil fertility
- Reduced surface water quality
- Reduced groundwater quality
- Corrosion of buried and surface structures made from concrete and steel
- Loss of vegetation

These impacts have the potential to affect aquatic ecology and people and are addressed in:

- Section 14.3, Groundwater
- Chapter 15, Freshwater Environment Impact Assessment
- Chapter 18, Socioeconomic Impact Assessment
- Chapter 19, Health Risk Assessment

14.2.3. Proposed Management Measures

This section presents an overview of the proposed management measures to reduce the impacts on landforms, soils and soil capacity. The full suite of proposed measures is detailed in the Project EMP provided in Attachment 3.

To minimise physical disturbance and hence manage destabilisation of landforms and erosion and loss of soils (where practicable), measures proposed include:

- Plan the area to be cleared to be the minimum required to undertake works safely.
- Minimise vegetation clearing by using previously disturbed or degraded areas (e.g., existing access tracks or disturbed kunai grasslands, co-location of linear infrastructure such as the concentrate pipeline, power lines and access roads) as a first preference.
- Manage vegetation clearing in accordance with WGJV procedure, Permit for Land Disturbance.
- Stabilise large landslips, slumping, washouts, undercuts and other instability.
- Stabilise exposed areas susceptible to erosion using appropriate methods. For example, covering with vegetation debris, jute netting, geogrid matting, mulching or similar.
- Install erosion and sediment control structures to reduce fugitive sediment reporting to watercourses and surface water features.
- Install and maintain sediment control measures where required such as drainage diversion into surrounding vegetation, rip-rap aprons, sediment control ponds and sediment fences.
- Minimise the length of time that disturbed areas are exposed through planning progressive clearing and progressive rehabilitation of disturbed areas, unless areas are planned for additional disturbance at a later date.
- Limit the amount of sediment entering watercourses at crossings (e.g., bridges, roads and pipelines) by installing and maintaining sediment control measures such as drainage diversion into surrounding vegetation, rip-rap aprons, sediment control ponds and sediment fences.

To minimise chemical alterations to soils and hence manage degradation of soil capacity, proposed measures include:

- Undertake pre-construction sampling and mapping of ASS/PASS in high risk areas (e.g., oxbow lakes, mangroves) and map extent of confirmed ASS/PASS.
- Handle, store, treat, manage and dispose of ASS in accordance with the Queensland Acid Sulphate Soil Technical Manual: Soil Management Guidelines (2014) (in the absence of a comparable State of PNG guidelines).
- Treat and dispose or manage contaminated soils based on the type and scale of contamination.

- Store and handle hazardous materials including fuels, oils and chemicals in accordance with AS1940-2017: The storage and handling of flammable and combustible liquids.
- Salvage topsoil, seed bank and seedlings and use in rehabilitation of temporary work sites as soon as practicable to enhance potential for natural regeneration.
- Strip and stockpile topsoil and spoil separately in approved locations.
- Clearly sign stockpiles to ensure that topsoil must remain separated from subsoils.
- Avoid compaction of topsoil stockpiles by restricting vehicle, plant and equipment movement over topsoil stockpiles.

14.2.4. Residual Impact Assessment

The residual impact assessment presents the predicted significance of Project impacts on the landform and soils values assuming successful implementation of the proposed management measures outlined in Section 14.2.3.

14.2.4.1. Stable Landforms and Soils

Several soil types have been identified as present within the Project Area. Table 14.5 lists the disturbance to soil types as a result of the Project.

Table 14.5: Disturbance to soil types

Soil Type	Area to be Disturbed (ha)
Eutropepts	253
Fluvaquents	35
Hapludolls	113
Haplustolls	304
Hydraquents	240
Tropofluvents	43
Troporthents	261
Ustorthents	162
Total	**1,411**

The successful rehabilitation of disturbed areas will be reliant on the viability of the reinstated soils at the completion of mining. While Project activities may compact soil and/or invert its profile during reinstatement, management measures are proposed to minimise this occurrence. Impacts associated with this will be localised and of low severity; the re-handling of soil can occur prior to machinery being moved off-site at the completion of mining.

14.2.4.1.1. Mountainous Terrain with Deeply Incised Valleys

Due to the seismicity of the Mine Area, the very high rainfall and moderate to steep slopes, landforms within the mountainous terrain unit are prone to instability. Erosion of the shallow soils could reduce soil capacity or result in complete loss of soil capacity to support productive vegetation. Overall, the sensitivity of the mountainous terrain unit is assessed as **high**.

Unlike traditional open cut mining methods predominantly used in PNG, the proposed underground block cave mining method reduces the Project disturbance footprint and the volume of waste rock generated. Furthermore, the associated waste rock dumps will be encapsulated and decommissioned relatively quickly, as they are not required following the five-year construction period associated with the decline development. The most conspicuous and substantial change to landform in the Mine Area will result from the formation of the surface expression of the subsidence zone that results from block cave mining (see Chapter 6, Project Description). As indicated in Figure 6.10, the depth of the surface expression of the subsidence zone after 28 years of mining is expected to be approximately 400 metres below ground level (mbgl) while the diameter of the surface expression of the subsidence zone at its widest extent is expected to be approximately 975m. The subsidence zone is expected to cover an area of approximately 55ha. This unavoidable consequence will be a permanent change to the pre-mining landform. Considering the **high** sensitivity of the mountainous terrain unit and the **very high** magnitude of the impact owing to the long-term extent of the impact, the residual impact significance is **major**.

The unmitigated potential impacts of major cut-and-fill construction activities in the Mine Area are **high**. The proposed management measures developed to address this issue include avoidance and engineering design to reduce the potential for unstable landforms to be created. The implementation of measures to minimise physical disturbance and control erosion and sedimentation (detailed in Attachment 3, the Project EMP) will result in **low** magnitude of residual impacts.

Considering the **high** sensitivity of the mountainous terrain unit and the **low** magnitude of residual impacts on stable landforms and soils, the residual impact significance is **moderate**, except for the subsidence zone which is **major**.

14.2.4.1.2. Broad, Alluvial Valleys of Mature Rivers and Poorly Drained Areas

The meander floodplains and recent alluvial fans of the Infrastructure Corridor and Outfall Area are relatively stable, with slopes of less than 2º and a very low likelihood of slope failure. Soils in these areas have moderate recovery potential as the floodplain is a dynamic environment with flood events periodically depositing sediment across the landform, partially or completely infilling back swamps over time. Most soils are well-developed and fertile. Some low-lying areas are permanently saturated due to the high water table. Overall, the sensitivity of the broad alluvial valleys and floodplains of the Lower Watut River, Lower Markham River, and lower Bumbu and Busu rivers (and associated poorly drained areas) is assessed as **low**.

Potential impacts on the stability of landforms and soils in these areas are expected to be minor, as disturbance will largely be limited to trenching and road construction on flat to gently undulating terrain. The construction of the three proposed watercourse crossings may affect surface water flows and sediment transport. This is considered further in Chapter 15, Freshwater Environment Impact Assessment. The implementation of proposed management measures to minimise physical disturbance and control erosion and sedimentation (detailed in Attachment 3, the Project EMP) will result in **low** magnitude of residual impacts.

Considering the **low** sensitivity of the terrain units associated with the Lower Watut, Lower Markham, lower Bumbu and lower Busu rivers valleys and the **low** magnitude of residual impacts, the residual impact significance is **low**.

14.2.4.2. Soil Capacity (Quantity and Quality)

Soils in the mountainous terrain unit are shallow and are typical of those elsewhere in the Lower Watut River catchment. Overall, the sensitivity of soil capacity in these areas is **medium**.

A mosaic of soil types exists in the alluvial valleys, with some soils well-drained and fertile and other soils weakly acidic. These soils are common in major river floodplains. They have good recovery potential, as they are the product of the dynamic environment that results in channel avulsion and deposition of sediment. Overall, the sensitivity of the soil capacity is assessed as **medium**.

Soils in the poorly drained areas of the alluvial floodplains are permanently saturated and are a common feature of those landforms. Overall, the sensitivity of soil capacity in this terrain unit is assessed as **low**.

Implementation of proposed management measures based on appropriate management of wastes, contaminated soils and stockpiles, and topsoil management for rehabilitation, will minimise chemical alterations to soil and degradation of soil capacity and greatly reduce the severity and duration of the impact.

The shallow, variable soils of the Mine Area are more exposed to degradation and/or loss than the well-developed soils of the alluvial floodplains due to the combination of moderate to steep slopes and high rainfall environment. Significant loss of shallow soils will reduce recovery potential and potentially result in irreversible change.

Acid sulphate soils or PASS are not likely to be encountered in the Mine Area. Construction activities associated with the Infrastructure Corridor and Outfall Area may encounter ASS or PASS. Acid sulphate soils exposed at these locations will need to be managed to avoid acid formation.

On review of the proposed management measures and the Project activities proposed in each terrain unit, the magnitude of the residual impacts associated with each was assessed to be **low**.

Considering the **medium** sensitivity of the mountainous terrain with deeply incised valleys and broad, alluvial valleys of mature rivers, the **low** sensitivity of the poorly drained areas and the **low** magnitude of residual impacts, the residual impact significance is **low**.

Table 14.6: Summary of landform and soils residual impact assessment

Soil and Landform Environmental Value	Potential Impact	Impact Type	Intent of Management Measures Proposed to Protect Value	Residual Impact Assessment			
				Sensitivity	Magnitude	Residual Impact Significance	
Mountainous terrain with deeply incised valleys							
Stable landforms and soils	Unstable landforms / landslips Reduced soil capacity	Direct Indirect	• Minimise vegetation clearing and ground disturbance • Design and construct mine features in accordance with good engineering design standards • Reduce erosion impacts in specific areas and capture mobilised sediments where practicable	High	C / O – Low O / Cl – Very high	Moderate	Major
Soil capacity (quantity and quality)	Reduced soil capacity	Direct Indirect	• Minimise vegetation clearing and ground disturbance • Reduce erosion impacts in specific areas and capture mobilised sediments where practicable • Manage contaminated soils, ASS, fuels, chemicals and hazardous materials in accordance with appropriate standards and guidelines	Medium	C / O / Cl - Low	Low	
Broad, alluvial valleys of mature rivers							
Stable landforms and soils	Unstable landforms / landslips Reduced soil capacity	Direct Indirect	• Minimise vegetation clearing and ground disturbance • Design and construct mine features in accordance with good engineering design standards • Reduce erosion impacts in specific areas and capture mobilised sediments where practicable	Low	C / O - Low	Low	
Soil capacity (quantity and quality)	Reduced soil capacity	Direct Indirect	• Minimise vegetation clearing and ground disturbance • Reduce erosion impacts in specific areas and capture mobilised sediments where practicable • Manage contaminated soils, ASS, fuels, chemicals and hazardous materials in accordance with appropriate standards and guidelines	Medium	C / O / Cl - Low	Low	
Poorly drained areas							
Stable landforms and soils	Unstable landforms / landslips Reduced soil capacity	Direct Indirect	• Minimise vegetation clearing and ground disturbance • Design and construct mine features in accordance with good engineering design standards • Reduce erosion impacts in specific areas and capture mobilised sediments where practicable	Low	C / O - Low	Low	

Soil and Landform Environmental Value	Potential Impact	Impact Type	Intent of Management Measures Proposed to Protect Value	Residual Impact Assessment		
				Sensitivity	Magnitude	Residual Impact Significance
Soil capacity (quantity and quality)	Reduced soil capacity	Direct Indirect	• Minimise vegetation clearing and ground disturbance • Reduce erosion impacts in specific areas and capture mobilised sediments where practicable • Manage contaminated soils, ASS, fuels, chemicals and hazardous materials in accordance with appropriate standards and guidelines	Low	C / O / Cl - Low	Low

Note 'C' denotes construction phase, 'O' denotes operations phase and 'Cl' denotes closure phase.

14.2.5. Monitoring

Monitoring of impacts on landforms and soils includes inspection to ensure measures employed to create and maintain stable landforms and to protect and remediate contaminated soils are being effectively implemented. These include:

- Supervision of vegetation clearing activities to ensure unauthorised clearing does not occur.
- Regular inspection of erosion and sediment control structures including sediment fences, drains, sediment basins and retention ponds.
- Regular inspection of batters and embankments for signs of instability including erosion.
- Regular inspection of work sites for spills and leaks, and soil contamination.
- Regular inspection of hazardous materials storage facilities for spills and leaks and gross pollutant trap function.

14.3. Groundwater

This section describes the potential and predicted residual impacts to groundwater values based on the numerical groundwater modelling and the closure modelling conducted by Piteau Associates South Africa Pty Ltd (Piteau) and presented in appendices F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine, and X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone, respectively.

The operations phase for the Project, including commissioning, ramp-up and production, will continue for some 28 years as described in Chapter 6, Project Description. For consistency with the technical reports (which were based on an earlier Project description) that informed the impact assessment in this section however, the duration of the operations phase is referred to as 27 years. This discrepancy is immaterial to the assessments and conclusions presented in this section.

14.3.1. Assessment Method Inputs

Technical specialists defined groundwater values based on their experience, accepted practice and input from key stakeholders. The groundwater values to be protected are:

- Groundwater quantity
- Groundwater quality

The importance of groundwater and groundwater dependent surface water features (e.g., springs and watercourses) for local communities is summarised in Chapter 12, Socioeconomic Environment Characterisation and Chapter 13, Cultural Heritage Characterisation and for aquatic ecology is summarised in Chapter 15, Freshwater Environment Impact Assessment.

Sensitivity is defined as the susceptibility of groundwater systems to changes in quantity or quality, including the capacity of groundwater systems to adapt to, or accommodate, the kinds of changes that the Project may bring about. It also considers the intrinsic importance of the resource to groundwater users and the environment.

The groundwater-specific definitions for the varying levels of sensitivity relating to groundwater values that were adopted in this assessment are provided in Table 14.7.

Table 14.7: Definitions for sensitivity of groundwater values

Sensitivity Criteria	Very High Sensitivity	High Sensitivity	Moderate Sensitivity	Low Sensitivity	Very Low Sensitivity
Beneficial uses of groundwater Potential uses of groundwater related to the suitability of the water to support ecosystems, and consumptive and productive uses.	Attributes of the groundwater system are of high ecological importance and/or cultural or spiritual significance. Intrinsic attributes support the use of the groundwater for potable supply, agricultural use, and food production.	Attributes of the groundwater system are of high ecological importance. Intrinsic attributes support the use of the groundwater for secondary domestic supply and some agricultural uses.	Attributes of the groundwater system are of low to moderate ecological importance, and are characterised as slightly to moderately disturbed. Intrinsic attributes support the use of the groundwater for construction and irrigation purposes.	The groundwater system supports ecosystems of low ecological importance, and/or groundwater dependent surface water features which are characterised as highly altered from their natural state.	Attributes of the groundwater system (quality, occurrence, volume, extraction potential) are not suitable for beneficial uses.
Rarity of occurrence, abundance or distribution of groundwater system or aquifer type and availability of equivalent or representative alternatives	Attributes of the groundwater system are unique. There are no known available alternatives.	Attributes of the groundwater system are locally unique, and with few regionally available alternatives.	Attributes of the groundwater system are locally unique, but have regionally available alternatives.	Attributes of the groundwater system are common on a regional and national basis, and therefore, have regionally available alternatives.	Attributes of the groundwater system are common on a local and regional scale, and therefore have both local and regionally available alternatives.
Resilience to change, i.e., groundwater properties such as water level or pressure changes, porosity reduction	Intrinsic properties of the groundwater system are very susceptible to change. The overall function of the groundwater system would be permanently altered.	Intrinsic properties of the groundwater system are susceptible to change. The overall function of the groundwater system would be temporarily altered.	Intrinsic properties of the groundwater system are moderately susceptible to change. The overall function of the groundwater system could be moderately altered.	Intrinsic properties of the groundwater system are slightly resistant to change. However, the overall function of the groundwater system remains relatively unchanged.	Intrinsic properties of the groundwater system are resilient to change.
Dynamics of existing environment, i.e., hydrogeologic processes	Groundwater systems with very low recharge rates and very slow recovery periods.	Groundwater systems with low recharge rates and slow recovery periods.	Groundwater systems with moderate recharge rates and medium-term recovery periods.	Groundwater systems with high recharge rates and short recovery periods.	Groundwater systems with very high recharge rates and very short recovery periods.
Recovery potential	Extremely limited recovery potential if impact on the value cannot be avoided. Permanent quality or quantity changes may result.	Recovery potential is limited or only successful in the minority of cases. Impact may require decades to centuries to resolve.	Recovery is likely to be slow or only partially successful.	Recovery will be successfully achieved in the majority of cases.	Recovery will be successfully achieved in all cases.

The sensitivity of groundwater quantity and groundwater quality is informed by the definitions in Table 14.7. Groundwater value sensitivity is presented in Table 14.8.

Table 14.8: Groundwater value sensitivity

Groundwater Value	Sensitivity	Justification
Groundwater quantity	Very high	Groundwater-fed springs are the primary drinking water source for communities within the Mine Area. Communities have constructed piped water delivery systems around some springs. Groundwater fed springs hold important cultural and spiritual values to the local communities. Spring flow and the associated ecological and spiritual values are highly sensitive to groundwater level reduction and could be permanently altered. Other groundwater discharge features, such as nearby creeks and rivers, rely on baseflow contribution from groundwater. Reduced baseflow may affect flows, particularly during dry periods. Very long recovery periods are predicted for deep regional scale changes to groundwater quantity affecting the deep aquifer.
Groundwater quality	Very high	Groundwater in the Mine Area supports human consumptive beneficial uses, including potable water supply (sourced from springs) and food supply (fishing). These groundwater discharge features are highly sensitive to changes in water quality. Groundwater dependent ecosystems are sensitive to quality changes, including potential of hydrogen (pH) and dissolved metal concentrations which can be toxic. Reduced groundwater quality would have potential to impact fish numbers in nearby rivers and streams which are an important food source for local and downstream communities. Increased concentrations of dissolved metals in drinking water and food sources could also have human health impacts. Changes to groundwater quality would likely persist over a period of several decades to centuries due to the long residence time of groundwater, particularly in deeper aquifers. Similar systems are expected to occur on local and regional scale.

Table 14.9 defines the levels of the magnitude of potential and residual impacts to the groundwater values.

Table 14.9: Definitions for the magnitude of impacts to groundwater

Magnitude Category	Severity	Geographic Extent	Temporal Extent
Very low	Some isolated occurrences of very minor impacts, but generally changes to groundwater quantity and/or quality are likely to be below detectable levels.	Impact is restricted to perched aquifer or groundwater discharge feature.	No short-term or long-term project impacts likely to environmental values.
Low	Some minor impacts to groundwater values are likely.	Impact is restricted to a local aquifer and other aquifers or groundwater discharge features are not affected.	Impacts likely for short duration only (less than 5 years), with rapid recovery following the end of impacting activity.
Moderate	Some moderate project impacts likely to occur to groundwater. Effects to quantity and/or quality will result in a reduced capacity to provide water supply and/or suitable water quality to people or the environment, but effects will not be severe.	Impact may occur across aquifers and groundwater discharge features may be affected.	Impacts likely short duration only, with rapid recovery following end of impacting activity.

Magnitude Category	Severity	Geographic Extent	Temporal Extent
High	Some moderate to major impacts to groundwater quantity or quality.	One or more aquifers impacted; groundwater discharge features are also likely to be affected.	Moderate impacts likely to persist over long term, or major impacts likely to persist for a short duration.
Very high	Major impacts to groundwater quality or quantity.	Multiple aquifers and groundwater discharge features affected.	Moderate or major impacts likely to persist long term or permanently.

14.3.2. Potential Impacts

The Project activities and related processes that may cause impacts on groundwater quantity during construction, operation and closure are detailed below.

Groundwater drawdown and flow reduction caused by:

- Partial dewatering of the hydrogeological units above and in the vicinity of the declines and block caves.
- Interception of groundwater flow which would have, under natural conditions, discharged to the surface drainages, provided baseflow to the rivers, or contributed to deeper regional groundwater flow.
- Permanent changes to the natural surface topography and local groundwater system during mine development and following mine closure.

Solute migration caused by:

- Seepage of potentially contaminated groundwater into surrounding rock formations, migrating towards springs and other groundwater discharge features.

Subsidence zone lake discharge causing:

- Potential infiltration of water from the subsidence zone lake into the groundwater system, migrating towards springs and other groundwater discharge features following mine closure.

Waste rock dump and landfill seepage causing:

- Leaching from waste rock dumps, landfills, contaminated water ponds and ASS treatment pads to underlying groundwater systems.

Contamination of groundwater and/or discharge of contaminated water caused by:

- Accidental spills and leaks of hazardous materials directly or indirectly (infiltration) to the shallow groundwater systems.

As a result of the above, potential impacts on groundwater quantity are:

- Permanent or temporary impairment of aquifer or groundwater system.
- Permanent or temporary loss or reduction of baseflow contributions to surface water features including springs and groundwater-dependent ecosystems.

As a result of the above, potential impacts on groundwater quality are:

- Poor groundwater quality.

14.3.3. Proposed Management Measures

This section presents an overview of the proposed management measures to reduce the predicted impacts on groundwater values. The full suite of management measures are detailed in the Project EMP provided in Attachment 3.

To limit predicted impacts relating to groundwater quality and quantity, WGJV proposes to:

- Implement a risk-based emergency and spill prevention and response plan.
- Use a low permeability liner such as clay or NAF rock for waste rock dump basal layer.
- Actively manage PAF materials and control runoff and potential leachate from areas containing PAF material such as:
    - In situ treatment or reprocessing stockpiled material through the Watut Process Plant.
    - Diversion of clean surface water where required.
    - Interception of potential leachate from the site and applying appropriate treatment methods if required prior to discharge.
- Capture and treat mine wastewater where necessary prior to discharge to meet environment permit conditions.
- Apply appropriate containment for hazardous materials when servicing mobile equipment away from designated workshop areas.
- Capture and treat if required runoff from fuel and hazardous materials storage areas before discharge to the receiving environment.
- Regularly monitor for changes in surface water or groundwater quality at defined locations in accordance with environment permits and apply remedial actions where required if impacts are detected.
-

14.3.4. Residual Impact Assessment – Groundwater Quantity

The predicted residual impacts on groundwater quantity associated with groundwater drawdown and flow reduction during the construction, operation, and closure of the Mine Area are discussed in the following sections.

The predicted residual impacts are discussed in the context of the proposed engineering design management measures.

14.3.4.1. Groundwater Drawdown and Flow Reduction

Predicted changes in the local water table have been simulated using a numerical groundwater model developed by Piteau (Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine). The model was used to predict the potential effects of the Project development within the 153 square kilometres (km^2) model domain which is centred on the Mine Area (Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine).

The model was calibrated to represent the current hydrogeological conditions, i.e., pre-mining conditions. Dewatering and associated drawdown impacts to groundwater have been modelled and reported at time periods that align with the major construction phases and mining schedule.

The groundwater model developed by Piteau was based on a 36 year mine plan (six years of construction followed by 30 years of operation). The mine plan has since changed to reflect a higher 16.84Mtpa production rate over a 28 year operations period.

The predicted drawdown and flow reduction impacts discussed in detail in the following sections are based on a superseded 36 year mine plan. However, as the model outputs presented by Piteau are aligned with major construction and operational milestones (i.e., construction of the Nambonga and Watut declines, commencement of mining BC42 and BC40, and end of mining), the predicted impacts to groundwater are considered to be transferable to the current mine plan.

14.3.4.1.1. Construction

Groundwater modelling was conducted to predict groundwater drawdown that is expected following excavation and dewatering of the Watut and Nambonga declines as well as partial construction of Block Cave (BC) 44.

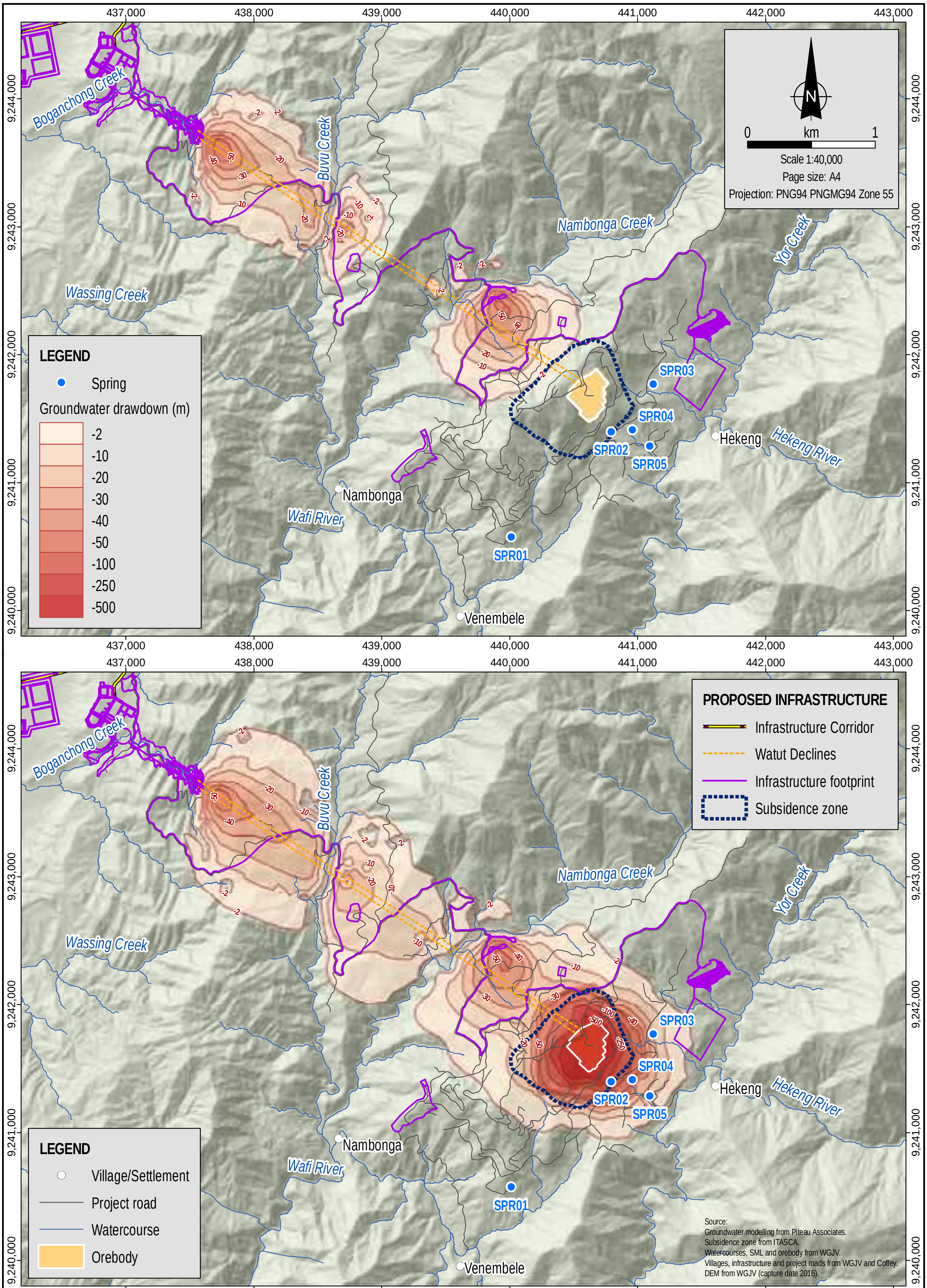
The first 200 metres (m) to 500m of the Watut Declines will be driven through the weathered zone. It is likely that the groundwater system in this area is well connected, and may provide a significant amount of water inflow to the tunnels. The predicted long term, steady-state rates of unimpeded groundwater inflow to the Nambonga and Watut declines are in the order 10 litres per second (L/s) and 40L/s, respectively (Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine). As the declines advance, rock encountered is expected to become increasingly competent with depth.

The predicted changes in the local water table following completion of the Nambonga and Watut declines are shown in the top panel of Figure 14.1. Changes are presented as drawdown from pre-mining conditions with a cut-off value of 2m. Drawdown of less than 2m is considered to fall within the natural range of groundwater fluctuations and unlikely to have a measurable long-term impact on the groundwater system.

At Year 4 groundwater drawdown is predicted to be centred around the two portal areas of the Watut Declines and Nambonga Decline. Maximum drawdown of up to 50m is predicted around the Watut and Nambonga portals with two radial drawdown cones extending approximately 500m and 700m, respectively.

Nambonga Creek, Buvu Creek and the upper reaches of Boganchong Creek limit the advance of the zone of groundwater drawdown suggesting that where drawdown extends beneath watercourses, surface water will recharge groundwater and locally offset groundwater drawdown. This represents a reversal of the natural groundwater-surface water interaction where, under pre-mining conditions, groundwater is expected to discharge to surface water contributing baseflow to the total stream flow. Reversal of hydraulic gradients along reaches of rivers and creeks where they cross the zone of drawdown will result in a reduction in baseflow rates.

The numerical groundwater model was used to predict the residual impact of dewatering on baseflow contributions to four catchments that are likely to be affected by groundwater drawdown: Buvu Creek; Nambonga Creek; Hekeng River, and; Wafi River. For the purpose of the impact assessment, the Hekeng River catchment (a subcatchment of the Wafi River catchment) and Wafi River catchment are considered together.



MXD Reference: 0520DD_10_GIS044_v0_3

coffey A TETRA TECH COMPANY	Date: 24.04.2018 Project: 754-ENAUABTF100520DD File Name: 0520DD_10_F14.01_GIS	WAFI-GOLPU JOINT VENTURE Wafi-Golpu Project	Simulated groundwater drawdown during construction and Year 6	Figure No: 14.1

Following construction of the Nambonga and Watut declines the Nambonga and Buvu creek catchments are predicted to experience reduced surface water flow due to the loss of baseflow in areas where groundwater is drawn down below the stream base. Nambonga Creek is projected to be the first watercourse that will experience flow reduction corresponding with the construction and dewatering of the Nambonga Decline. Changes to flow rates in Buvu Creek are unlikely to be noticeable at this time. Other catchments are not predicted to be impacted during the construction period.

The impact of groundwater drawdown on Boganchong Creek has not been modelled; however, it is likely to be negligible considering the planned construction of the portal terrace and raw water dam further downstream of the Watut and Nambonga declines. Flow reduction to Boganchong Creek has not been considered further.

All mapped springs (see springs identified as SPR01 to SPR05 on Figure 14.1) on the eastern side of Mt Golpu are outside of the predicted 2m drawdown cone and are unlikely to be substantially impacted at this time.

14.3.4.1.2. Operations - Year 6

At Year 6, mining of BC 44 will have been ongoing for a period of five to six years and the subsidence zone is expected to have propagated to the ground surface. Mining of the lower BC 42 level will commence at this time.

Groundwater modelling predicts drawdown around the Watut and Nambonga declines by up to 50m. The simulated drawdown zone, with a cut-off value of 2m of drawdown, extends along the full alignment of the Watut Declines to a maximum horizontal distance of approximately 500m north and south of the decline alignment. Recharge of the weathered bedrock by Nambonga and Buvu creeks continues to limit the propagation of the drawdown cone as recharge rates are predicted to be greater than the rate of dewatering.

With the propagation of the block cave to the ground surface, groundwater drawdown of up to 500m is expected on the eastern side of Mt Golpu. A modelled drawdown contour extends approximately 700m to 800m from the centre of the subsidence zone to the 2m drawdown cut-off value and combines with the drawdown zone that had developed around Nambonga Decline. Hekeng River and Wafi River, together, form the eastern boundary of the 2m drawdown contour and, like Nambonga and Buvu creeks, surface water is expected to be recharging groundwater where it crosses the drawdown zone (see the bottom panel of Figure 14.1).

The reduced baseflow contribution to Buvu Creek will likely be approaching maximum impact by Year 6, with an estimated 25% reduction in baseflow across the affected reaches. Reduced flow rates could add stress to the aquatic ecosystem and groundwater dependent vegetation associated with Buvu Creek, particularly during dry periods when baseflow accounts for most of the total stream flow.

The size and geometry of Nambonga Creek is expected to result in a reduced impact to baseflow at Year 6 when compared to the Buvu Creek catchment. Approximately 15% reduction in base flow is anticipated by Year 6.

At this time, the 10m drawdown contour is predicted to extend to approximately 600m from the subsidence zone. With the exception of spring SPR01, groundwater beneath the mapped springs is expected to be drawn down by more than 10m and the springs will likely experience partial or complete loss of flow by Year 6. Drawdown of less than 2m is predicted beneath Spring SPR01 which is unlikely to be impacted at this point.

14.3.4.1.3. Operations - Year 12 to End of Mining, Year 27

Mining at BC 40 (the deepest extraction point) commences at Year 12 and continues to the end of mining.

Groundwater drawdown along the alignment of the Watut Declines is projected to increase marginally by Year 12 with the lateral expansion of the drawdown cone approximately 150m north and south (see top panel of Figure 14.2). Drawdown at the portal reaches a maximum of 30m.

At Year 12, the groundwater cone of depression centred around the block caves is predicted to have expanded, with the 2m drawdown contour extending 1.3 to 1.4km from the block caves. At this time, the 10m drawdown contour is predicted to extend approximately 1km from the block caves (see top panel of Figure 14.2).

By Year 12, flow rates are likely to be impacted at all springs and groundwater beneath spring SPR01 is predicted to have been drawn down by between 2m and 10m (see top panel of Figure 14.2).

At the end of mining (Year 27), groundwater is predicted to reach maximum drawdown; however, this is not predicted to represent a significant change from Year 12 (see bottom panel of Figure 14.2). The total area where groundwater is predicted to be drawn down by more than 10m covers an area of approximately 9.4km^2. Residual impacts on spring-based ecosystems and vegetation that access shallow groundwater are discussed in Chapter 15, Freshwater Environment Impact Assessment and their beneficial uses in Chapter 18, Socioeconomic Impact Assessment.

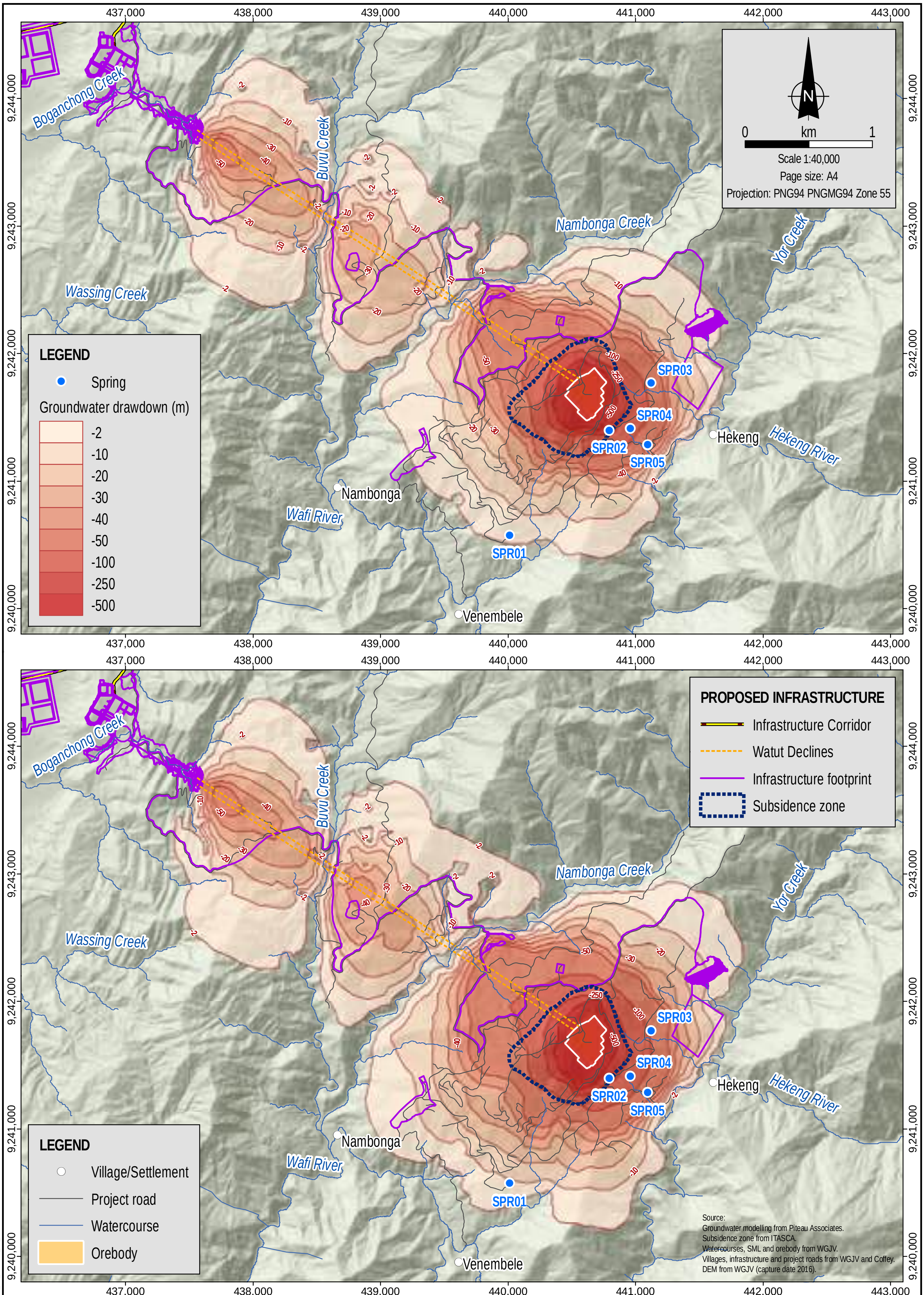
The watertable around the Watut Declines portal is predicted to reach a maximum drawdown of 40m below the pre-mining groundwater level with a lateral expansion of the 2m drawdown contour by approximately 160m (see bottom panel of Figure 14.2).

Groundwater drawdown centred on the block caves also is predicted to expand marginally between Year 12 and Year 27. The 2m drawdown contour around the mine subsidence zone is projected to spread laterally by a further 300m to the northeast and southwest (see bottom panel of Figure 14.2).

Groundwater conditions at the end of mining represent the maximum potential zone of impact to surface water features. Table 14.10 provides the approximate length of each watercourse crossing the zone of groundwater drawdown where a reversal of hydraulic gradients and a loss of baseflow is expected to occur. The total percent loss of baseflow from the affected reaches is also provided for the end of mining.

Table 14.10: Estimated stream length impacted by groundwater drawdown at end of mining

Watercourse Name	Estimated Length of Watercourse within 2m Drawdown Zone	Predicted Reduction in Baseflow (%)
Wafi River catchment (incl. Hekeng River)	4.1km	9
Nambonga Creek	2.5km	26
Buvu Creek	2.2km	34
Boganchong Creek	500m	Negligible (see Section 14.3.4.1.1)



MXD Reference: 0520DD_10_GIS045_v0_4

coffey
A TETRA TECH COMPANY

Date: 24.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.02_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Simulated groundwater drawdown at Year 12 and Year 27

Figure No: 14.2

After 27 years of operation, it is predicted that baseflow in Buvu and Nambonga catchments will reduce by 34% and 26%, respectively. These effects may be less noticeable during wet periods where surface runoff accounts for a high proportion of stream flow. However, during dry periods the inverse is true, with baseflow accounting for most of the total stream flow. Therefore, the potential exists for aquatic ecosystems of Nambonga and Buvu creeks to be impacted by reduced flow rates particularly during dry periods (see Chapter 15, Freshwater Environment Impact Assessment for the assessment of this impact on aquatic ecosystems).

The combined Hekeng River and Wafi River catchments are substantially larger and are predicted to have a much smaller reduction in baseflow (9%) across the catchment (Table 14.10). The magnitude of the impact to stream flow in these catchments as a result of reduced groundwater quantity is likely to be less significant.

Reduced groundwater quantity resulting from dewatering the declines and block caves is predicted to result in reduced stream flow rates in the surrounding catchments and reduction or loss of spring flow in the vicinity of the block caves, portal terrace and declines. The impact of these changes to the pre-mining groundwater system may include loss of aquatic and groundwater dependant terrestrial ecosystems, loss of potable water supply, economic impacts associated with the loss of fishing resources, and the loss the cultural and spiritual values of springs. The impacts that could manifest from the reduced groundwater quantity are assessed in:

- Chapter 15, Freshwater Environment Impact Assessment
- Chapter 18, Socioeconomic Impact Assessment
- Chapter 19, Health Risk Assessment
- Chapter 20, Cultural Heritage Impact Assessment

14.3.4.1.4. Post-Closure

Dewatering of the mine void is required throughout the period of active mining. Inundation of the mine void will commence immediately following the termination of dewatering, as groundwater discharges to the declines and block caves. The inundation of the mine void and rate of groundwater level recovery will be driven by local recharge vertically through the subsidence zone and laterally through regional groundwater flow towards the block cave and Watut Declines. Simulations of the post-closure recovery period have been modelled and include both vertical (downward) infiltration of rainfall recharge through the subsidence zone, as well as lateral groundwater migration towards the block caves and declines (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone).

Rising water levels post-closure will also lead to the inundation of the Nambonga and Watut declines. Without intervention, recovering groundwater levels could result in the perpetual decant of groundwater at the Watut Declines portal (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). To avert this, the present closure concept involves the installation of hydraulic plugs at the portal elevation and at points below ground within the declines. Three post-closure groundwater recovery scenarios have been modelled (see Chapter 6, Project Description).

The preferred scenario assumes accelerated flooding of the cave zone through pumping of water from a fluvial source at a nominal rate of 500L/s until such time as groundwater levels reach the base of the surface expression of the subsidence zone (250mASL), with the inclusion of lime dosing. Under this scenario recovery of groundwater levels will be achieved within 4 years followed by subsequent natural (i.e., groundwater inflow and rainfall infiltration) filling of the surface expression of the subsidence zone within 35 years.

Groundwater levels around the subsidence zone lake were originally modelled based on a 200m deep subsidence zone and a lake spill point of 450mASL (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). The estimated subsidence zone is now predicted to have a slightly smaller footprint, 975m long by 750m wide, and is deeper (approximately 400m deep) than the subsidence zone originally adopted for the post-closure groundwater modelling. The final subsidence zone lake water level (controlled by an engineered spill point or pit rim elevation) is unlikely to change substantially from the 450mASL level previously assumed (see Figure 6.10).

These changes are likely to have the following effects on groundwater level recovery and subsidence zone lake filling that have not been accounted for in the present closure modelling:

1. Marginal reduction of the rainfall recharge contributing to the block cave and subsidence zone lake filling.
2. Increased subsidence zone lake depth will result in an increase period of time to fill the lake based on the new stage-volume curve.
3. Overall changes to groundwater inflow and outflow are not expected to be significant, and are probably within the current error margin for the existing model.

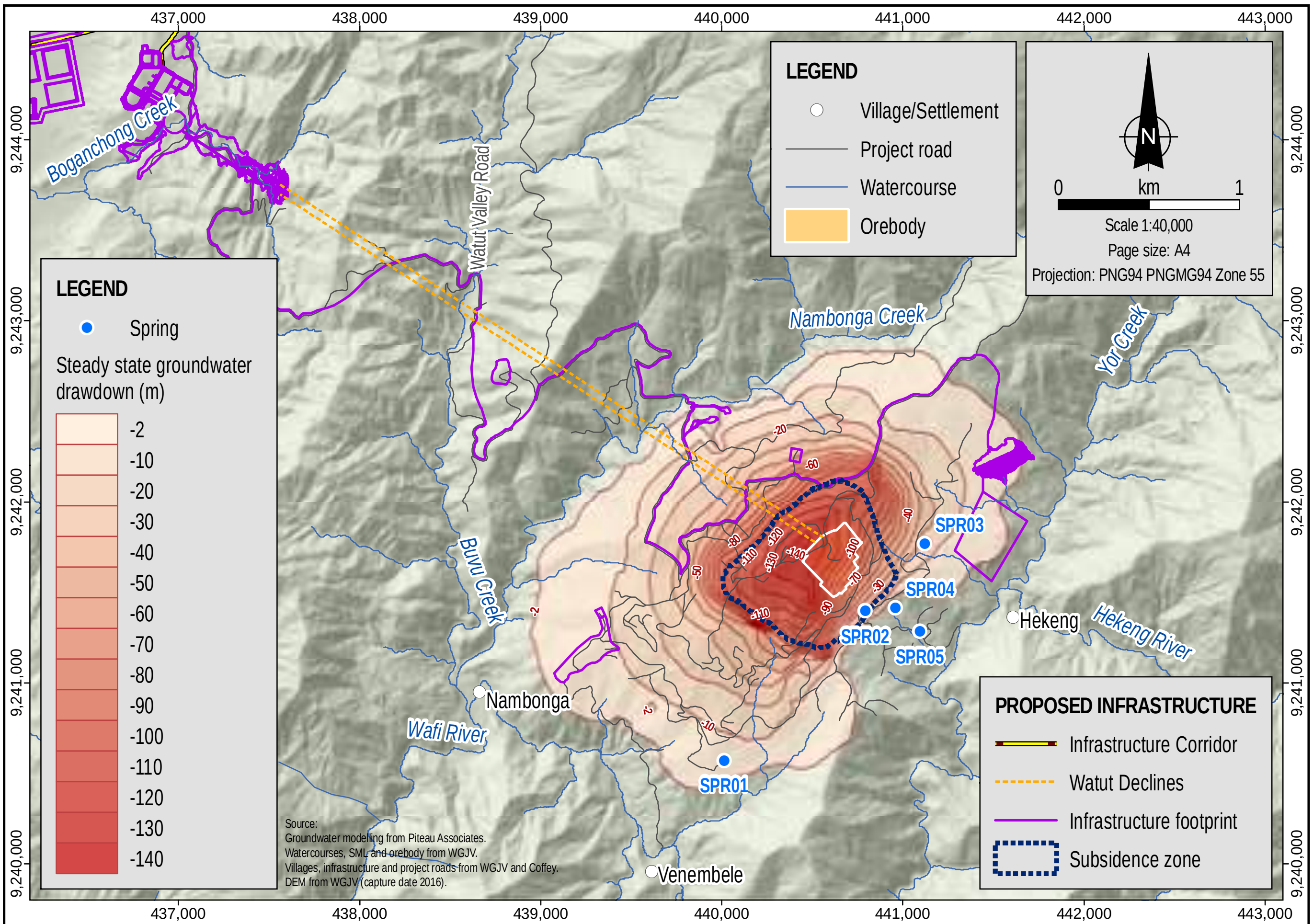
The final subsidence zone lake water level is the primary factor controlling the long-term regional groundwater level recovery. As this remains unchanged, the conclusions of the original closure modelling (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone) are considered a reasonable approximation of the long-term changes to groundwater levels.

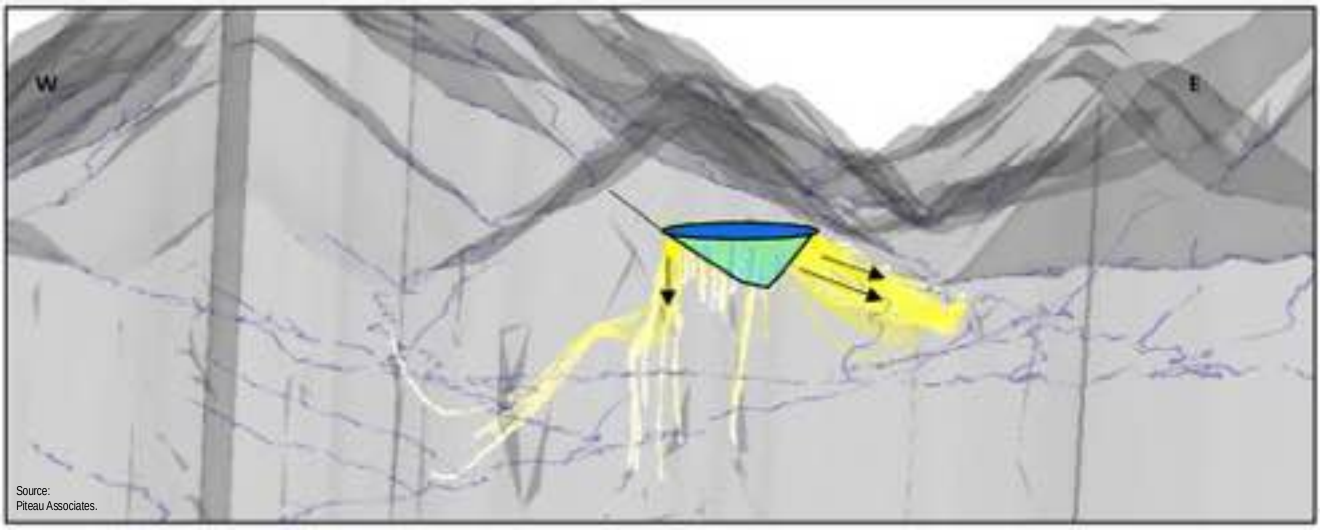
Groundwater levels around the subsidence zone lake are predicted to reach a new equilibrium with groundwater flow away from the subsidence zone lake to the east. This new steady state condition will represent a permanent reduction in groundwater levels around the subsidence zone by a maximum of 140m compared to pre-mining levels (top panel of Figure 14.3).

The zone of permanently lowered groundwater level (post recovery) is predicted to have a maximum 1.3km radius from the subsidence zone lake to the 2m drawdown cutoff level, bound by the Wafi River to the east and south, and Nambonga Creek to the west (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone).

Post-closure modelling of baseflow reductions indicates that all modelled catchments (Buvu Creek, Nambonga Creek, and the Hekeng River/Wafi River catchment) recover to between 98% and 99% of the pre-mining conditions 100 years after closure.

Numerical model simulations suggest that the re-activation of springs will occur at around 38 years post-closure (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). Certainty around the potential long-term impacts of mining on the mapped springs on the eastern side of Mt Golpu is difficult. While the modelling results predict that springs will be reactivated, significant changes will have occurred to geological structures. These changes could have a range of potential effects on the springs including an increase or decrease in flow rates, or the development of new springs.





MXD Reference: 0520DD_10_GIS046_v0_5

coffey
A TETRA TECH COMPANY

Date: 04.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.03_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Simulated post closure steady state groundwater drawdown (a) and lake particle tracking (b)

Figure No: 14.3

14.3.4.2. Residual Impacts

An assessment of predicted residual impacts on groundwater quantity has been made following application of the proposed management measures outlined in Section 14.3.3. Only impacts with a residual significance of Moderate, High and Major are discussed below and are summarised in Table 14.15.

14.3.4.2.1. Permanent or Temporary Impairment of Aquifer or Groundwater System.

Groundwater drawdown will peak at the end of mining (Year 36). The water table around the Watut Declines Portal Terrace will reach a maximum drawdown of 40m while groundwater around the block caves will reach a maximum drawdown of 500m.

The total area where groundwater has been drawn down by more than 10m from pre-mining levels is predicted to extend across a 9.4km^2 area.

The consequential residual impacts of this unavoidable impact are permanent or temporary loss or reduction of baseflow contributions to surface water features including springs and groundwater-dependent ecosystems, which are discussed below.

14.3.4.2.2. Permanent or Temporary Loss or Reduction of Baseflow Contributions to Surface Water Features

14.3.4.2.2.1. Surface Water Baseflow Reduction

Numerical modelling indicates that groundwater drawdown is likely to result in reduced baseflow contributions to Buvu Creek, Nambonga Creek, Hekeng River and Wafi River to varying degrees. The smaller catchments (Nambonga catchment and Buvu catchment) will be most significantly affected during construction and operations with baseflow reductions ranging from 26 to 34%, respectively (Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine). This could translate to a similar reduction to the total stream flow rate during dry periods where baseflow accounts for most stream flow.

A smaller baseflow reduction of 5% across the Hekeng River catchment reflects a greater portion of the catchment falling outside of the zone of groundwater drawdown.

A 4% reduction of baseflow is expected for Wafi River at Nambonga after passing the mine area between Hekeng and Nambonga. This is unlikely to have a measurable effect on the net flow rate of Wafi River further downstream at Pekumbe owing to the contribution of baseflow along the 4.5km reach that falls outside of the zone of groundwater drawdown.

The magnitude of impact resulting from baseflow reduction varies between catchments and is summarised in Table 14.11. The sensitivity of the groundwater quantity has been assessed as **very high** and the magnitude of the residual impact to baseflow is assessed as **moderate** (Wafi River and Hekeng River) and **major** (Nambonga Creek and Buvu Creek) assuming implementation of the proposed management measures outlined in Section 14.3.3. Impacts to the consumptive uses of the rivers and creeks by local communities are discussed in Chapter 18, Socioeconomic Environment Impact Assessment.

Table 14.11: Predicted baseflow reduction residual impact assessment

Catchment	Peak Baseflow Reduction (%) [(a)]	Recovery period (years)	Permanent Baseflow Reduction (%) [(a)]	Period of Impact	Magnitude	Significance
Buvu Creek	34	20	1	Temporary	High	Major
Nambonga Creek	26	80	2	Temporary	High	Major
Hekeng River	5	80	1	Temporary	Medium	High
Wafi River (at Nambonga)	4	80	1	Temporary	Medium	High

(a) Estimates of peak baseflow reduction provided in Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine

14.3.4.2.3. Groundwater Dependent Ecosystems

The spring survey conducted by Piteau during March 2017 identified a number of smaller springs and permanent surface water pools throughout the study area that were considered to be groundwater fed.

Road access across the wider Mine Area is limited and unmapped springs and groundwater dependent ecosystems are likely to occur within the 9.4km^2 area where the water table is predicted to be lowered by 10m or more at the end of mining.

The proposed management measures listed in Section 14.3.3 would likely reduce the potential for contamination of these surface water features and the groundwater dependent ecosystems which were assessed as **very high** sensitivity. Due to the distribution of, and potential for, groundwater dependent ecosystems, the residual impact magnitude is assessed as **low**, resulting in a **moderate** impact significance.

14.3.4.2.3.1. Groundwater Springs

Dewatering of the block caves will lead to the loss of flow from these springs during mining and for a period of 38 years post-mining (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). Spring SPR02 is likely to be within the predicted subsidence zone and may potentially be submerged by the subsidence zone lake. If these springs are reactivated following closure, it is likely that the flow rates could vary from pre-mining conditions. The ecological significance of groundwater springs and seeps is discussed in Chapter 15, Freshwater Environment Impact Assessment and the cultural significance of impacts to these springs is considered in Chapter 20, Cultural Heritage Impact Assessment.

Groundwater-fed springs were assessed as having **very high** sensitivity to impacts from reduced flow. The proposed management measures listed in Section 14.3.3 mitigate potential contamination but do not protect flows. The impact magnitude remains **very high** resulting in a **major** impact significance.

14.3.5. Residual Impact Assessment – Groundwater Quality

The predicted residual impacts on groundwater quality associated with the construction, operation, and closure of the Mine Area are discussed below for the following causes of impacts:

- Extracted groundwater
- Waste rock dump seepage
- Landfill seepage

- Contamination of groundwater and/or discharge of produced water
- Solute migration
- Subsidence zone lake discharge

The residual impacts are discussed in the context of the proposed engineering design measures.

14.3.5.1. Wastewater Management

This section discusses the various wastewater streams that contribute to the net generation of wastewater from the Mine Area. Comment is provided on the residual impacts to groundwater quality associated with each waste source.

14.3.5.1.1. Extracted Groundwater

Based on the geochemical characteristics of the rock extracted from, and remaining in the walls of the declines and block caves, it is predicted that groundwater extracted from the underground mine and potentially, seepage and runoff from the extracted waste rock, will be acidic, with elevated dissolved metals and sulphate.

To estimate the quality of water seeping into the block caves and declines, and ultimately requiring extraction and management at surface, the PHREEQC geochemical modelling software package was used to model the interactions of groundwater and rock in the declines, block caves and subsidence zone during construction and operations. Table 14.12 details predicted block cave and subsidence zone water quality based on column leach tests on representative rock samples.

In general, the quality of contact water during the early stages of development is predicted to be better than water quality anticipated later in the mine life, indicative of the transition from non-acid forming (NAF) to PAF material as the declines are developed.

Where practicable, water will be intercepted (by dewatering) before it can enter the block cave zone or prevented from entry into the decline by shotcreting or grouting. Produced groundwater will be reused or treated, if required, using a water treatment plant before discharge to the environment. During construction, between 10% to 50% is likely to be reused for construction activities. Surplus wastewater will be discharged via a pipeline to the Lower Watut River with the outlet located adjacent to Wongkins.

The groundwater-surface water interaction along the Lower Watut River floodplain is considered to be in a state of dynamic equilibrium and any impact to the water quality of the Lower Watut River could affect groundwater within the shallow alluvial aquifer.

The mine is expected to run at a net water deficit throughout operations with few exceptions where a water surplus will exist. Encountered groundwater will be used to fulfil the process water demand requirements during operations.

Table 14.12: Indicative block cave and subsidence zone water quality

Parameter	Unit	Block Cave Groundwater Ingress Chemistry
pH	pH	3.82
SO_4^{2-}	mg/L	2,263
TDS	mg/L	2,880
Acidity	mg/L	371
Al	mg/L	12.4
As	mg/L	<0.002

Parameter	Unit	Block Cave Groundwater Ingress Chemistry
Ca	mg/L	596
Cl	mg/L	187
Cr	mg/L	<0.002
Cu	mg/L	46.1
Fe	mg/L	0.61
Hg	mg/L	0.00073
K	mg/L	49.7
Mg	mg/L	114
Na	mg/L	115
Co	mg/L	0.32
Mn	mg/L	34.1
Zn	mg/L	88.3

14.3.5.1.2. Waste Rock Dump and Ore Stockpile Seepage

A total of approximately 2.66 million tonnes (Mt) of waste rock is expected to be excavated from the declines and the ventilation shaft. This material will be stored in two engineered waste rock dumps: Miapilli Waste Rock Dump and Watut Waste Rock Dump.

Based on geochemical analysis, it is expected that approximately 2.14Mt of waste rock will be classified as PAF and approximately 0.52Mt classified as NAF. Potential exists for poor quality water (low pH, high soluble metals) to accumulate in the PAF cells of the waste rock dump, and infiltrate to groundwater. Encapsulation of the PAF waste rock will be employed to reduce this potential.

Extracted ore will be managed at the surface in two ore stockpiles; a temporary ore stockpile and a coarse ore stockpile. Although the temporary ore stockpile will be infiltrated by rainfall, which will interact with the ore before seeping from the base or toe of the stockpile, all runoff will be captured and treated as required. The low-permeability base will limit seepage to the groundwater. Negligible impacts to groundwater are anticipated because of these design features.

14.3.5.1.3. Landfill Seepage

A dedicated waste management facility for the Mine Area, including a landfill, will be located near the Watut Process Plant. The area will be compacted and runoff collected for treatment.

Impact to groundwater due to the potential for landfill leachate to infiltrate to groundwater is assessed as **low** owing to the appropriate design, construction and operation of the landfill reducing the potential for leachate infiltration to groundwater. Implementation of the proposed management measures listed in Section 14.3.3 will confine the areal extent of seepage to that of the interception and capture systems employed.

14.3.5.2. Solute Migration from the Block Cave

Infiltration of water from the subsidence zone to the underlying material, which hosts epithermal mineralisation with high acid-forming potential, is likely to result in poor water quality (low pH and elevated metals concentrations) within the block cave voids.

In addition to infiltration from the overlying subsidence zone, a component of groundwater flow through the surrounding host-rock will contribute to filling of the block caves and recovery of groundwater levels. This flow of water through the host rock will progressively flush sulphide oxidation products into groundwater.

Generation of poor quality groundwater within the block caves represents a potential source of long-term impact to groundwater discharge features, particularly the mapped springs, Nambonga Creek and Wafi River.

Numerical modelling was undertaken by Piteau to predict changing water quality within the block caves, and to map the likely discharge points for this impacted groundwater (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). The modelling approach included numerical groundwater flow modelling (using FEFLOW) in parallel with GoldSim to simulate the subsidence zone lake water balance, coupled with PHREEQC to predict water quality.

The preferred closure scenario includes the potential addition of hydrated lime ($Ca(OH)_2$) to the artificial recharge pumped from a fluvial source. The rationale for this is to neutralise the acidity produced during active flooding. This may offer a sustained benefit following inundation due to the limited potential for acid production. Modelled groundwater quality estimates are provided for year five (following complete inundation of the mine void) and at time steps 50 and 100 years following mine closure (Table 14.13). Results suggest that liming of the recharge stream could lead to improved water quality with increased pH resulting in reduced concentrations of dissolved metals.

Table 14.13: Predicted groundwater quality within the block caves at closure

Year (post closure)	Net-inflow	pH	SO4	Fe	Mn	Cu	Al
Units	L/s	N/A	mg/L	mg/L	mg/L	mg/L	mg/L
5	550	6.9	1,740	71	44	0.6	1.1
50	0	6.2	1,330	61	29	0.9	2.2
100	0	5.6	1,220	54	21	0.8	2.1

It is expected that AMD generation will cease from inundated PAF material as the block cave and subsidence zone saturates, approximately 4 years post closure (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). After this time, surface recharge to the subsidence zone will gradually dilute the AMD and is predicted to reduce the concentration of solute released to the surrounding bedrock. The theoretical time predicted for vertical rainfall infiltration and regional groundwater flow to result in the complete replacement of a 'void volume' of water in the cave zone is predicted to be of the order of 495 years (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). The implication of this long residence time is that improvement of water quality in the cave zone following flooding will occur extremely slowly.

The ultimate fate of impacted groundwater within the block caves has not been fully defined. However, it is expected that the regional flow of deep groundwater will be predominantly towards the watercourses to the east (Wafi River), with minor flow to the west (Nambonga Creek) and south (Wafi River).

The likely timeframe for impacted groundwater reaching Wafi River and Nambonga Creek has not been estimated. Peak seepage concentrations could reasonably be expected within the first 50 years following inundation of the mine void.

14.3.5.3. Subsidence Zone Lake Discharge

The source, quality and fate of water within the subsidence zone lake (which only forms post mine closure) are distinctly different to groundwater within the block cave described in Section 14.3.5.2. Therefore, the potential impacts associated with the subsidence zone lake are considered separately within this section.

The initial water quality of the subsidence zone lake is expected to be a combination of the water quality in the block cave and subsidence zone and rainfall runoff water quality in the subsidence zone lake. Further model refinement is required to take into account the increased subsidence zone depth as this is anticipated to increase the likelihood of stratification of water quality to occur within the subsidence zone lake.

Subsidence zone lake water quality predictions with lime dosing of flooding water are presented in Table 14.14. This reflects the effect of interaction with lime amended water sourced from the underlying block cave zone. Over time, the significance of the contribution to the overall lake water balance declines resulting in a reduction of lake pH to 5.5 by the time discharge from the spill point occurs. Trends in pH and other subsidence zone lake water quality parameters are predicted to stabilise after approximately 20 years of filling. Exceptions are noted with the continued reduction in sulphate concentrations and increased aluminium concentrations in later years.

Table 14.14: Simulated subsidence zone lake water quality during post-closure filling

Year (post closure)	pH	SO_4	Fe	Mn	Cu	Al
Units	N/A	mg/L	mg/L	mg/L	mg/L	mg/L
Water quality objectives*	6.5-9.0	400	1	0.5	0.007	0.005
1	6.2	1120	21.5	19.3	0.4	0.8
10	5.7	960	3.5	12.7	0.2	1.1
50	5.5	240	2.9	3.2	0.2	1.6

* Derived from the PNG Environment (Water Quality Criteria) Regulation 2002 and the PNG Environmental Code of Practice (2000): Environmental Code of Practice for the Mining Industry.

Once the level of the subsidence zone lake spill point has been reached, any additional input to the lake water balance in excess of losses through seepage or evaporation will induce spillage to the natural surface drainage system at rates of between 10 and 25 L/sec (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). This overland flow will report to the Wafi River and, without intervention, represents a source of impact to the established aquatic ecosystem. The potential impacts associated with overland flow of subsidence zone lake discharge on surface water quality and freshwater ecology are discussed in Chapter 15, Freshwater Impact Assessment.

However, prediction of the water quality in the subsidence zone lake is very complex and modelling to date does not include some factors that may influence final water quality. For example, predicted lake chemistries assume a fully mixed water column, where in reality the lake water is likely to be stratified. Also not modelled to date is the potential for adsorption of dissolved metals into particulate matter. CSIRO tests on Lower Watut River water has shown significant metals attenuation is likely (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River). Modelling of final pit lake water quality and engineering solutions will be progressively improved as actual data is accumulated during operations.

Catchment water from the subsidence zone lake is expected to pass through the groundwater system predominantly on the eastern side of Mt Golpu (see the bottom panel of Figure 14.3), ultimately discharging in one or more springs or to the Wafi River in the east and south (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). Discharge from spring SPR02 is expected to drain towards the subsidence zone lake. Spring SPR03, a sacred spring (Gova) to the east of the subsidence zone (see Chapter 13, Cultural Heritage Characterisation), is located at an elevation higher in the catchment than that of the final lake elevation (450mASL) and, if it reactivates, its water quality is unlikely to be impacted. Spring SPR04 is expected to be located in proximity to the projected limit of the subsidence zone and has the potential to form a discharge point.

The predicted quality of water within the subsidence zone lake that may migrate via groundwater towards nearby springs and Wafi River is of a lower quality than the baseline groundwater quality reported for the mine area. However, it is recognised that groundwater of the shallow weathered bedrock and fresh bedrock aquifers contains naturally elevated concentrations of aluminium, cobalt, cadmium, copper, iron and mercury that regularly exceed the adopted criteria. Single exceedances of arsenic, manganese and nickel were also reported.

14.3.5.4. Residual Impacts

An assessment of predicted residual impacts on groundwater quality was made following application of the proposed management measures outlined in Section 14.3.3. Only impacts with a residual significance of Moderate, High and Major are discussed below and summarised in Table 14.15.

14.3.5.4.1. Solute Migration from the Block Caves

Generation of poor quality groundwater within the block caves following mine closure represents a potential source of long term impact to groundwater resources, and groundwater discharge features, particularly Nambonga Creek and Wafi River.

Some residual impacts are likely to be realised given the large volume of poor quality water in the block cave voids, and the practical difficulty of effectively retaining or treating this water over the long term.

A groundwater and surface water monitoring program will provide early warning of reducing groundwater quality. Contaminant fate and transport modelling will also be undertaken during the operations phase, as aquifer hydraulic properties are refined and the understanding of regional groundwater flow is improved.

Groundwater quality has been assessed as having a **very high** sensitivity.

The proposed management measures listed in Section 14.3.3 would manage contaminated discharge and groundwater expressions, thereby reducing impacts on beneficial uses and downstream users. Solute migration was assessed as having a **high** impact magnitude, resulting in a **major** impact significance on groundwater quality.

14.3.5.4.2. Subsidence Zone Lake Discharge

The subsidence zone lake will fill over a period of up to 35 years following complete inundation of the underlying block cave.

Predictions of lake water quality have been provided for periods 10 years and 50 years after the commencement of filling. Results indicate that lake water will be acidic (initially pH 5.7, decreasing to pH 5.5 50 years post-closure). Concentrations of dissolved metals including iron, manganese and copper will generally reduce over time. However, subsidence zone lake water is predicted to exceed the water quality objectives for several metals and pH and represents a risk to groundwater (see Table 14.14).

The predicted water quality at 50 years after the start of inundation is reflective of the water that may infiltrate to groundwater in the subsidence zone beneath the lake and ultimately discharge on the eastern side of Mt Golpu to springs or seeps.

Options for the management of the subsidence zone lake water and potential discharges to groundwater will be further investigated during mine operation as understanding of the geological, hydrogeological and geochemical conditions improves.

Groundwater quality has been assessed as having a **very high** sensitivity. The proposed management measures listed in Section 14.3.3 will manage contaminated discharge and groundwater expressions reducing impacts on beneficial uses and downstream users. Subsidence zone lake discharge was assessed as having a **moderate** impact magnitude, resulting in a **high** residual impact significance on groundwater quality.

14.3.5.4.3. Contamination of Groundwater and/or Discharge of Produced Water

Groundwater formations in the Lower Watut and Lower Markham river valleys are shallow and connected to the rivers. Water levels in the shallow aquifers mimic river levels with flow to the rivers in dry periods and recharge during wet periods. Construction of the Infrastructure Corridor may intercept the water table (0.28mbgl to 2.54mbgl) during excavation of pipeline trenches, bridge abutments and road formations.

Similar conditions are expected at the Port Facilities Area and Outfall System where the shallow aquifer (recharged by the coastal swamps, freshwater creeks and urban runoff and infiltration) may be encountered in excavating pipeline trenches and foundations.

Shallow aquifers inland of the coast and connected to the Bumbu and Busu rivers are unlikely to be intercepted except at the Bumbu River crossing, as inland of the coast, these rivers are incised with well-formed channels.

Trench and excavation dewatering may be required at some sites to facilitate pipe jointing, coating repairs and construction of foundations. Contamination of land and surface waters from dewatering potentially contaminated trench and excavation water (for example, by ASS/PASS) and contamination of the shallow aquifer by spilt or leaked hazardous materials is possible unless appropriately managed.

With application of the proposed management measures listed in Section 14.3.3, the residual impact magnitude of discharging contaminated groundwater or contaminating groundwater during trenching and excavation of foundations is assessed as **very low** for the **very high** sensitivity groundwater quality. This results in a **moderate** residual impact significance for construction, operation and decommissioning of infrastructure in the Infrastructure Corridor, Port Facilities Area and Outfall System assuming implementation of the proposed management measures.

Table 14.15: Summary of groundwater predicted residual impact assessment

Impact				Proposed Management Measures	Predicted Residual Impact Assessment		
Project Infrastructure or Activity	Potential Impact	Project Phase	Potentially Affected Groundwater Value		Magnitude of Impact	Sensitivity	Residual Impact Significance
Dewatering during construction and operation resulting in long term and permanent groundwater drawdown	Reduced baseflow contribution to Buvu Creek and Nambonga Creek	Construction, operations and closure	Groundwater quantity	• Monitoring to identify adverse changes and triggers for remedial action	High	Very high	Major
	Reduced baseflow contribution to Wafi River and Hekeng River	Operations and closure	Groundwater quantity	• Monitoring to identify adverse changes and triggers for remedial action	Moderate	Very high	High
	Restricted flow to springs, loss of associated aquatic ecosystems, cultural and spiritual values.	Operations and closure	Groundwater quantity	• Monitoring to identify adverse changes and triggers for remedial action	Very high	Very high	Major
	Loss of unmapped groundwater dependent ecosystems	Construction, operations and closure	Groundwater quantity	• Monitoring to identify adverse changes and triggers for remedial action	Low	Very high	Moderate
Inundation of the block cave voids generating poor quality groundwater	Poor quality groundwater migrating towards, and discharging to Nambonga Creek and Wafi River	Closure	Groundwater quality	• Ongoing level and quality monitoring for pre-emptive groundwater management • Post closure reactive management plan • Sealing declines and ventilation shafts	High	Very high	Major
Recovery of groundwater levels leading to development of a subsidence zone lake of poor quality	Poor quality lake water infiltrating to groundwater. Potential migration of impacted groundwater towards and discharge to springs and creeks.	Closure	Groundwater quality	• Management of diffuse seepage and breakouts • Level and quality monitoring of subsidence zone lake • Management options to be included in adaptive management plan • Discharging water will be treated until water quality requirements are met • Subsidence zone lake water will be treated if required	Moderate	Very high	High

14.3.6. Monitoring

Monitoring the impacts of the Project on the groundwater values and the performance of the proposed management measures will include the following:

- Monitoring water extracted from underground workings and other potentially contaminated sites to determine if it is of suitable quality for direct discharge to the downstream environment or whether pre-discharge water treatment is required to meet environment permit criteria.
- Continued use of gauging stations to monitor water level and flow.

14.4. Terrestrial Ecology

This section describes the potential and predicted residual impacts to terrestrial ecology resulting from the Project, based on the Project activities described in Chapter 6, Project Description.

14.4.1. Assessment Method Inputs

The impact assessment method presented herein is based on methods and procedures outlined in industry standard guidelines including:

- Ecological Impact Assessment guidelines for use in New Zealand: terrestrial and freshwater ecosystems (EIANZ, 2015).
- Guidelines for Ecological Impact Assessment in the UK and Ireland: Terrestrial, Freshwater and Coastal (CIEEM, 2016).
- Good Practices for Biodiversity Inclusive Impact Assessment and Management Planning (Hardner et al., 2015).
- Environmental Assessment Handbook: Ecological Impact Assessment (SNH, 2002).
- Guidelines for ecological evaluation and impact assessment (Regini, 2000).

Ecological values are defined in this assessment as:

- A feature (e.g., a species) identified and declared under environmental regulations, policies or guidelines (e.g., International Union of Conservation of Nature (IUCN) Red List).
- A feature (e.g., a forest type) that is important to biodiversity that, while it may not be specifically mentioned in regulations or policies, is recognised as such by the technical specialists based on accepted practice (e.g., IUCN criteria for threatened ecosystems).

Values can be assessed spatially or by organisational structure (i.e., individual species' populations). Ecological values within this assessment were defined in two ways:

- Forest and habitat types. This definition uses a broad spatial scale and includes forest (and habitat) types and all the encompassing biodiversity within them.
- Species and populations. This definition focuses on the species or population level, primarily conservation-priority species.

Corresponding to the major landforms, terrestrial ecology habitat types were characterised as hill forest, alluvial forest (both floodplain forest and swamp forest and woodland), riparian and aquatic, grassland and disturbed anthropogenic, and coastal habitats. These have been based primarily on Forest Inventory Mapping System (FIMS) forest types. Given that FIMS was developed for assessment of commercial forestry resources, the mapping of forest boundaries is coarse, often consisting of 'forest complexes' containing a mixture of forest and other land types (Shearman and Bryan, 2011). During field surveys vegetation types were ground-truthed to verify and, if required, modified.

Habitat values are described in Table 14.16 along with an assessment of their ecological value (both flora and fauna), sensitivity and conservation status.

Table 14.16: Habitat ecological values and their sensitivity

Habitat value	Description	Sensitivity
Hill forest	Hill forest consists of lowland forest on low hills and slopes, and are the most abundant forest types that occur in PNG representing more than half of the nation's forests (excluding swamp forests). Hill forest habitat, broadly represented by the Medium Crowned Forest/Small Crowned Forest (Hm/Hs), occur on upland areas across the Lower Watut River alluvial plain with a relatively wide distribution across the terrestrial ecology study area. This community contains a suite of species associated with hill and montane habitats that do not occur on alluvial plains and supports diverse faunal communities. Generally hill forests have a high rate of natural disturbances due to tree-falls and landslips. As a result, this forest type has a moderate level of resilience with regeneration within these gaps occurring over decades. The clearing rates described in Shearman et al. (2009) and Bryan et al. (2015) estimate that 74% of the 1975 extent of mixed hill forest remained in 2017. As a consequence, this habitat is moderately susceptible to habitat loss as a result of forestry, and clearance for new houses and gardens, and other threatening processes such as fires, and invasion by weeds.	Medium
Alluvial forest – floodplain forest	Floodplain forest, represented by Large to Medium Crowned Forest (Pl) is poorly represented within the Morobe Province, being naturally restricted to floodplain areas with better drainage and also having been heavily harvested. Within the terrestrial ecology study area this habitat occurs on an alluvial terrace of the Lower Watut River, which stands a few metres above the active floodplain. Fauna within alluvial forests typically contain fewer endemic species compared to hill forest, with most species present in alluvial forest also occurring in hill forest. Despite this reduced endemism, the habitat is among the most productive habitats (in terms of biomass) and also contains a higher concentration of large, hollow-bearing trees and a higher diversity and abundance of fleshy-fruiting tree species than hill forest. Floodplain forest hosts the valued timber resources and due to its location on flat land, floodplain forest is more accessible to commercial logging operations. As such, this habitat is highly susceptible to clearance for timber and for gardens. It is also susceptible to altered hydrological regimes (e.g., flooding) that have caused areas of forest dieback. BAAM (see Appendix C, Terrestrial Ecology Characterisation – Mine Area to Markham River) considers the reduction in extent of floodplain forest 'substantial', having exceeded 30%, but less than 50% over the past 50 years. Since alluvial forest is the most heavily exploited tropical forest habitat in New Guinea, it is considered to have low resilience and limited replacement potential.	Very high
Alluvial forest – swamp forest and woodland	Mixed Swamp Forest (Fsw/FswC) covers extensive areas of the Lower Watut River and Markham River floodplains as well as near the mouth of the Busu River, often forming a transitional community between the well-developed Large to Medium Crowned Forest (Pl) and the permanently wet Swamp Woodlands (Wsw) dominated by sago palm (*Metroxylon sagu*). The characteristic feature of Mixed Swamp Forest (Fsw/FswC) is the semi-permanently 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. Swamp Woodland (Wsw) occurs in permanently saturated areas on the Lower Watut River floodplain, and mouth of the Markham River, and is generally occupied by extensive woodlands and forests dominated by sago palm.	Low
Riparian and aquatic habitats	Riparian and aquatic habitats occur on river banks and are an important landscape component providing specialised habitats for a range of fauna. Riparian and aquatic habitats vary from those on large turbid rivers, such as Riverine Mixed Successions (Fri), to small clear streams. Riparian and aquatic habitats also occur as a microhabitat within broad habitat types (e.g., hill forest and alluvial forest). A range of species are particularly abundant in these habitats, including birds and butterflies, which tend to congregate to mate in riverine areas. Riverine forest is most important in the lowlands where it supports a variety of large fruiting trees. Riparian habitats are relatively well represented in the terrestrial ecology study area and region. Their condition largely reflects levels of disturbance, which in turn is influenced by proximity to human settlement, distance from roads and terrain. These habitats have been defined based on their known disproportionate role in maintaining the associated terrestrial ecology values (including conservation significant species). This habitat is also more susceptible to altered hydrology and sediment deposition downstream of construction areas, particularly river crossings.	High

Habitat value	Description	Sensitivity
Grasslands and modified habitats	The eastern flanks of the Lower Watut River valley include a number of Grassland (G) areas. These occur mostly on the hills but extend onto the alluvial plain. They were created by clearing forest and have been maintained and gradually extended by regular burning practices. Areas of Scrub (Sc) form transitional vegetation, between regularly burned kunai grassland and forest. Swamp grassland (Gsw) 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. By comparison with the surrounding forests and wetland habitats, grassland habitats support a relatively species poor but distinct fauna. Areas cleared of vegetation generally occur in the urbanised areas around Lae city, along the Markham, Busu and Bumbu rivers and along the Highlands Highway. Here the vegetation is made up of a patchwork of grasslands, gardens, coconut and cocoa plantations and cattle farms. Anthropogenic habitats within the terrestrial ecology study area are varied and include grass patches, gardens, older regrowth, sea shore habitats and plantation habitats. An impoverished native faunal community, typically comprised of adaptable generalist species, occurs in this habitat type and it is considered to be of low ecological value in comparison to intact forest types.	Very low
Coastal habitats	Estuarine swamp and mangrove forests occur in isolated patches along the Huon Gulf within the terrestrial ecology study area. Forests here are comprised of sago, nipa and mangrove forests and are relatively wet and moist. Mangrove forests, such as those around the Labu Lakes, occur normally within the tidal range and are inundated daily. Beach vegetation ranges from pioneer herbaceous communities on sandy beaches to shrubberies and to tall littoral forest further away from the maximum high tide mark. Above the high tide mark, herbaceous communities comprise mainly creeping plants. These areas have been impacted by human activities within the terrestrial ecology study area. The strand vegetation has been heavily impacted by human activities, with most of the larger trees removed and exotic tree species introduced.	Low
Lower montane forest above 1,000m	The lower montane forest above 1,000m (L) has an even to undulating canopy 20 to 30m high and is very dense to almost closed. This forest is moist, and at the higher levels almost constantly dripping wet (Paijmans, 1976). Trees tend to be thin, and oaks (*Castanopis* and *Lithocarpus*) are common, dominating in some areas. The ground flora, mainly consisting of mosses, ferns, herbs, lycopods, and seedlings is variable in density (Paijmans, 1976). This forest type, while somewhat less diverse in tree species composition than other forests, can have a high diversity of smaller plants. This habitat occurs outside of the terrestrial ecology study area, at higher elevations of the Watut River catchment. The potential resettlement sites are in proximity to this vegetation community, as they are within 3 to 5km of its mapped extent.	High

Population level values are described in Table 14.17 along with an assessment of their conservation status and assessed sensitivity.

Table 14.17: Population level values and their sensitivity

Population level values	Sensitivity
IUCN Critically Endangered and Endangered species Four plants: • *Diospyros lolinopsis* recorded in alluvial forest near the Northern Access Road. • *Halfordia papuana* recorded in the Markham Gap Basin. • Two species that have the potential to occur in the terrestrial ecology study area based on their distribution and habitat requirements: *Calophyllum morobense* and *Helicia subcordata*. Three mammals: • Goodfellow's tree kangaroo (*Dendrolagus goodfellowi*) was recorded as a pet at Madzim. This animal was reported to have been captured as a juvenile in montane forest in the Upper Watut River valley. • Black-spotted cuscus (*Spilocuscus rufoniger*), may historically have occurred within the terrestrial ecology study area, as it is within its known range. • Eastern long-beaked echidna (*Zaglossus bartoni*), may historically have occurred within the terrestrial ecology study area as it is within its known range.	Very high
IUCN Endangered species One plant, *Flindersia pimenteliana*, recorded along the Watut Valley Road.	High

<table>
<tr><th>Population level values</th><th>Sensitivity</th></tr>
<tr><td>IUCN Vulnerable species
Twenty-one plants:
Aglaia brownii recorded in the Atzera Mountain Range.
Intsia bijuga (kwila) recorded in the Lower Watut River alluvial plain.
Myristica buchneriana recorded in hill forest near the Finchif area.
Pterocarpus indicus (New Guinea rosewood).
Another 17 species that 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.
Two birds:
Papuan eagle (Harpyopsis novaeguineae) inhabit primary forest landscapes in the terrestrial ecology study area.
Pesquet's parrot (Psittrichas fulgidus) recorded within the terrestrial ecology study area near the Atzera Mountain Range.
One mammal:
New Guinea pademelon (Thylogale browni) was recorded as a captive individual observed in Pekumbe.</td><td>Medium</td></tr>
<tr><td>IUCN Near Threatened species
Thirteen plants including:
Cycas schumanniana was recorded on a low ridgeline adjacent to the Markham River.
Cycas apoa was recorded in Medium Crowned Forest on hillslopes in a large number of localities in the Lower Watut River valley.
Myristica globosa was collected during field surveys in Medium Crowned Forest in the vicinity of the Northern Access Road Borrow Pit.
Aglaia silvestris was recorded commonly on ridges and occasionally on alluvial plains, and also recorded along the Watut Valley Road.
Aglaia euranthera was recorded along the Watut Valley Road.
Aglaia sexipetala was recorded in disturbed Large Crowned Forest on the margins of the Waime River.
Cycas campestris was recorded occasionally on ridges in hill forest and rarely on alluvial plains.
Cycas scratchleyana was recorded commonly in hill forest on ridges and occasionally on flats.
Flindersia amboinensis was in Medium Crowned Forest in the Buvu Creek valley and in the vicinity of the proposed Northern Access Road Borrow Pit.
Eight species that have the potential to occur in the terrestrial ecology study area based on their distribution and habitat requirements. These are: Cycas rumphii, Adinandra forbesii, Aglaia flavida, Aglaia lepidopetala, Aglaia rimosa, Aglaia subcuprea, Eucalyptopsis papuana, and Podocarpus rumphii.
Three birds:
Gurney's eagle (Aquila gurneyi) as at least one breeding pair appears to be resident in primary rainforest in the terrestrial ecology study area.
Forest bittern (Zonerodius heliosylus) has the potential to occur around streams, pools and swamps in alluvial and hill forest within the terrestrial ecology study area.
Doria's goshawk (Megatriorchis doriae) has the potential to occur in the terrestrial ecology study area based on its distribution and habitat requirements.
Two mammals:
New Guinea quoll (Dasyurus albopunctatus) has the potential to occur in the terrestrial ecology study area, based on its distribution and habitat preferences.
Small dorcopsis (Dorcopsulus vanheurni) while unlikely to occur in the Project Area, may occur at higher elevations of the terrestrial ecology study area.</td><td>Low</td></tr>
<tr><td>Protected under the Fauna (Protection and Control) Act 1966, IUCN Data Deficient and unnamed forest bats
Nine protected species including: raggiana bird-of-paradise (Paradisaea raggiana), king bird-of-paradise (Cicinnurus regius), crinkle-collared manucode (Manucodia chalybatus), glossy-mantled manucode (Manucodia ater), eastern osprey (Pandion cristatus), great egret (Ardea alba) intermediate egret (Ardea intermedia), palm cockatoo (Probosciger aterrimus) and Blyth's hornbill (Rhyticeros plicatus).
Two data deficient birds, the Papuan hawk-owl (Uroglaux dimorpha) and blue-black kingfisher (Todiramphus nigrocyaneus) recorded within complex mosaic of sago palm swamps and adjoining rainforest habitats and alluvial forest.
Two widespread, unnamed forest bats of the genus Nyctimene, and of the genus Macroglossus.</td><td>Very low</td></tr>
</table>

The sensitivity of ecological values was assessed after considering their:

- Status (and the underlying assessment of distribution, abundance and ecology).
- Rarity and current threatening processes. For species, a particular emphasis is placed on the degree of endemism.
- Vulnerability to disturbance or other threatening processes.

The criteria for sensitivity used in this assessment are provided in Table 14.18. These criteria have been developed based on various guidance documents including the IUCN Red List of Threatened Species (IUCN, 2017a) and the underlying criteria, principles supporting the IUCN Red List of Ecosystems (IUCN, 2017b), and Ecological Impact Assessment guidelines for use in New Zealand: terrestrial and freshwater ecosystems (EIANZ, 2015).

Table 14.18: Definitions for sensitivity of terrestrial ecology values

Sensitivity	Definition
Very high	• A forest type, habitat or species of at least national and possibly international importance. • An ecological value that has a very restricted distribution. • An ecological value that has very low resilience to adapt to changed environmental conditions (i.e., very limited or no capacity to adapt to change). • An ecological value that is fully intact and retains its intrinsic value prior to project development.
High	• A forest type, habitat or species having national importance. • An ecological value that has a restricted distribution. • An ecological value that has low resilience or ability to adapt to changed environmental conditions. • An ecological value that is intact and retains its intrinsic value prior to project development.
Medium	• A forest type, habitat or species having regional importance. • An ecological value that is limited in abundance and distribution. • An ecological value that has some resilience or ability to adapt to changed environmental conditions. • A site or ecological value that is in moderate to good condition prior to project development.
Low	• A forest type, habitat or species having local importance. • An ecological value that is abundant, widespread and numerous for which representative examples occur. • An ecological value that is resilient having a high ability to adapt to changed environmental conditions.
Very low	• Not vulnerable to changes in habitat structure or condition.

The magnitude of change was determined by a combination of the scale (temporal and spatial) and severity of change that will be caused to the ecological value. More specifically, the criteria to define the magnitude of change are:

- Geographic extent. The area over which an impact will be experienced; national (or international), regional, local extent.
- Temporal extent (duration). The timescale of the impact, i.e., temporary, short-term or long-term. Also accounts for the reversibility of the impact, where an irreversible impact is one where recovery on a reasonable timescale is not possible.
- Severity. The degree of change from the existing conditions as a result of the impact; severity can also be considered in terms of the intensity of the impact.

Criteria relating to magnitude of change are shown in Table 14.19.

Table 14.19: Definitions for the magnitude of potential impacts to terrestrial ecology

Rating	Criteria	Definition
Very high	Severity and intensity of impact	Total loss of, or severe alteration to ecological value, and/or loss of a high proportion of the known population or range of the value with a strong likelihood that the viability of the value will be severely reduced.
	Geographic extent	The effects on forest types/habitats extend beyond the study area at a regional level. Effect extends to >15% of the value's extent within the terrestrial ecology study area.
	Duration	Long-term or permanent; greater than 30 years.
High	Severity and intensity of impact	Major loss or alteration to ecological value and/or loss of a significant proportion of the known population or range of the value with the viability of the biological value reduced.
	Geographic extent	The effects extend across the study area, and immediately adjacent areas. Effect contained to 10 to 15% of the value's extent within the terrestrial ecology study area.
	Duration	Prolonged; 15 to 30 years.
Moderate	Severity and intensity of impact	Loss or alteration to ecological value that is readily detectible with respect to natural variability, and/or loss of a moderate proportion of the known population or range of the value with limited overall reduction in the viability of the value.
	Geographic extent	The effects are contained within the study area. Effect contained to 1 to 10% of the value's extent within the terrestrial ecology study area.
	Duration	Medium term; 5 to 15 years.
Low	Severity and intensity of impact	Minor effect from existing baseline conditions. Effects unlikely to reduce the overall viability of the ecological value
	Geographic extent	The effects contained within the Project disturbance area. Effect contained to <1% of the value's extent within the terrestrial ecology study area.
	Duration	Temporary or short term effects; less than 5 years.
Very low	Severity and intensity of impact	Effects likely to be very low or barely detectable and reduction in the viability of the ecological value is highly unlikely.
	Geographic extent	The effects are limited to areas within the Project footprint.
	Duration	Temporary or short term effects; less than 1 year.

14.4.2. Potential Impacts

A range of potential direct and indirect processes may impact terrestrial ecology values. These typically act interactively on flora and fauna populations and their habitats and may have multiple interrelated sources.

Processes that may lead to impacts on terrestrial ecology values either directly or indirectly are summarised in the following section. Their effects on ecological values are described and quantified in the assessment of residual impacts.

14.4.2.1. Physical Disturbance

Physical disturbance will be the most apparent process that would directly impact ecological values within the Project Area. Physical disturbance is defined as the vegetation clearance, excavation and earth movements (e.g., stockpiling or cut-and-fill) required to construct Project infrastructure. The shape, spatial extent and duration of vegetation clearance (i.e., temporary or permanent) is important in determining the degree to which vegetation communities may be impacted.

Physical disturbance will primarily occur during construction, although physical disturbance due to ground subsidence will occur during operations. A small amount of physical disturbance is expected during decommissioning of the Project.

Vegetation clearance for the development of Project infrastructure will result in the loss of vegetation and natural habitats, and this may cause direct mortality to individual plants and some less mobile animals during clearing activities. Following clearance of vegetation, earthworks will be required to create suitable surfaces for facilities and infrastructure, as well as access.

In addition to direct physical loss, vegetation clearance during construction of the Project may also result in some degradation of remaining habitats, through exposure of new forest edges leading to an ecological response described as an ‘edge effect’ (Saunders, et al., 1991). Edge effects include increased sunlight (causing drying of the forest understorey) and wind (causing drying and wind damage), and these disturbed conditions facilitate the invasion of introduced weed species and increase the susceptibility of the forest to fire. Primary edge effects identified include increased cover and abundance of disturbance-adapted plants including weeds, wiry lianas and early successional species, as well as increased levels of branch fall and tree mortality. These conditions change the structure and species composition of the forest and can alter species interactions that affect the overall ecology within areas affected by these changes, which typically extends up to 100m from the forest edge (Laurance et al., 2002). Laurance et al. (2009) describes the severity of edge effects as decreasing where the distance from cleared areas increases. Laurance et al. (2009) also describes the width of the gap as important, where narrow linear clearings are less vulnerable to wind disturbance and desiccation from edge effects. Edge effects decrease over time, as the forest edge regenerates, with impacts most pronounced during and immediately after clearance activities, and hence are typically largest during construction.

Vegetation clearance may also create barriers to the movement of flora (e.g., seed dispersal) and fauna. The Project will create gaps in intact habitats through clearing and constructing infrastructure. This results in barrier effects that split or fragment fauna populations by preventing fauna from moving across the gap. Animals with an aversion to crossing linear gaps, such as roads, include forest specialist terrestrial and arboreal marsupials and birds, as well as several reptiles and amphibians (Goosem, 2000; Laurance, 2002; 2004; Lehtinen et al., 2003). This barrier effect can also limit the dispersal of seeds and pollen (Goosem, 2007). Maintaining canopy connectivity is particularly important for rainforest ecology (Goosem et al., 2010). As large portions of the Project will be constructed within areas of largely intact forest (i.e., the Mine Area), ecological connectivity may continue to be maintained through the retained vegetation around the perimeter of Project infrastructure.

14.4.2.2. Altered Hydrology

The construction of roads and larger infrastructure has the potential to alter existing drainage patterns, leading to prolonged flooding and tree mortality (e.g., dryland forests can die if flooded), or conversely, desiccation and vegetation dieback (e.g., swamp forest and swamp woodland complexes can die if flooding and drying dynamics are altered). Prolonged changes to drainage patterns can lead to permanent changes to vegetation structure (e.g., conversion of swamp forest into drier forest) and may also impact fauna directly through effects on seasonal and breeding cycles and through habitat loss. Hydrological effects have the potential to occur over a large area, due to the nature of the shallow topographical relief of floodplain systems.

Drainage is the main factor that determines the community composition and structure of floodplain forest. Altered hydrological regimes have the potential to influence larger-scale processes. Hydrological changes have been shown to breach ecological tipping points (Scheffer et al., 2001). In such instances, there is little ecosystem change in response to steadily changing environmental conditions until a threshold is reached, at which point the system changes dramatically. For example, changes to flooding patterns (e.g., duration, frequency or depth of inundation) are known to cause large areas of floodplain forest die-back, as has happened in other parts of PNG. When a soil is flooded, gas exchange between the soil and air is drastically reduced, and exacerbated further by the consumption of oxygen by micro-organisms (Atwell, 1999). During prolonged floods, reduced aeration of root systems can cause extensive forest dieback, as increased river bed levels and floodplain inundation have caused in the Lower Ok Tedi and Middle Fly floodplains (Marshall and Rau, 1999).

Sediment-laden runoff can enter watercourses because of erosion, particularly where Project activities are close to watercourses. The increased sediment loads can affect the water quality in watercourses (greater turbidity) and lead to aggradation of sediment where it settles on the river or stream bed which can alter hydrological patterns and exacerbate flooding in low-lying areas. Microhabitats within the watercourse may be smothered from the settling of sediment and there is also potential to influence riparian habitats.

14.4.2.3. Erosion and Sedimentation

Disturbance and erosion of soils and subsequent loss or degradation of soil quality during earthworks or stockpiling of spoil may reduce the capacity of soils to support terrestrial ecosystems and may exacerbate the effects of habitat loss, edge and barrier effects. This can happen through the loss of topsoils or soil compaction, which reduces the capacity of plants to germinate affecting the structure and diversity of naturally regenerated forest, as well as through the smothering of understory vegetation and lower parts of tree stems, which has the potential to reduce tree root aeration leading to tree death.

Surface erosion is a natural process, but is exacerbated by ground disturbance which reduces the soil permeability and breaks down soil aggregates. Erosion of soils is likely to be highest on sedimentary and volcanic soils on undulating to steep slopes. Erosion can transport sediment some distance from the area of disturbance, potentially affecting vegetation and habitat beyond the extent of vegetation clearance.

While the impacts are difficult to predict, the most likely construction phase impacts may be localised dieback of vegetation through sedimentation of creek channels. This affects freshwater aquatic habitat values for frogs breeding in freshwater streams and birds and reptiles that feed on freshwater aquatic fauna. Crocodiles and turtles are not known to be highly sensitive to high sediment concentrations. However, both reptile groups may be indirectly affected by sediments because of habitat loss (sedimentation) or loss of food resources (e.g., invertebrates, fish). The impact of sediments on aquatic ecosystems and water quality, particularly in relation to construction phase impacts (where the level of impact will be greatest) is described in detail in Chapter 15, Freshwater Environment Impact Assessment.

14.4.2.4. Burial and Entrapment

Vegetation clearing and earthworks may bury or displace fauna, where they seek refuge in tree and log hollows or below ground to avoid construction activities. Reptiles, frogs and small terrestrial mammals are particularly susceptible.

Pipeline trenches will remain open during pipe stringing, welding and pipelaying along the Infrastructure Corridor. The trenches will be up to 2m deep and, during Project construction, fauna (especially frogs, reptiles and non-volant mammals) may fall in to and become trapped in open, steep-sided trenches unless escape options are provided.

14.4.2.5. Chemical Contamination and Waste Management

The use of chemicals in Project activities and the formation of AMD may impact on flora, fauna and vegetation if uncontrolled releases of such chemicals or AMD to the environment occur, or if the chemicals enter the environment, particularly watercourses, through spills, seepage or stormwater flows. Terrestrial species particularly susceptible to chemical contaminants include frogs, turtles, crocodiles, waterbirds, water rats (*Hydromys* spp.) and large-footed bats (*Myotis* spp.). Spills may occur during all Project phases, although the potential is greatest during construction. Fauna may come into contact with or ingest spilt materials, and hazardous contaminants may leach into the soil or be carried with runoff into waterways, impacting on water quality and riparian habitats.

14.4.2.6. Air Emissions

During the construction, operations and closure phases of the Project, air emissions that may impact on terrestrial ecology values will include fugitive dust and sulphur dioxide (SO_2) (see Section 14.5). Dust may be generated during dry periods by earthmoving machinery during site clearing, construction and operational activities such as drilling and blasting, from crushing and screening machinery and conveyor belts, traffic, and wind erosion of open areas and stockpiles. The greatest source of sulphur dioxide emissions will be from the on-site power generation facilities during operations (see Section 14.5).

Fugitive dust has the potential to reduce the photosynthetic efficiency of vegetation by blocking leaf stomata or smothering leaf surfaces leading to compromised vegetation condition, and reducing fruit yields through reduced pollination success of dust-affected flowers. The high, year-round rainfall will likely mitigate the effects of dust on vegetation given the rain will regularly and frequently wash away dust from leaves. Furthermore, the low wind speeds characteristic of the Project Area will minimise the area potentially affected, as the majority of dust particles will not travel far before settling out of the air. Impacts of dust on vegetation will therefore be localised, limited to less than a few hundred metres from active work areas, and will be only of short duration (Appendix A, Air Quality and Greenhouse Gas Impact Assessment). The impacts of dust on terrestrial vertebrate fauna will manifest through highly localised impacts on habitat condition and possibly reduced fruit yields. Given the high rainfall setting and highly localised potential impacts, impacts from dust deposition are not considered further.

Sulphur dioxide can have negative direct and indirect impacts on plants. Direct impacts include inhibition of photosynthesis by disrupting the photosynthetic mechanism, while indirect impacts result from acid rain that leaches out nutrients from the plant canopy and soil (Varshney, et al., 1979). Plants vary widely in their tolerance to SO_2, with lichens and bryophytes being particularly sensitive.

'Critical levels' for the protection of vegetation have been developed for a number of air pollutants including SO_2 by the United Nations Economic Commission for Europe (UN/ECE). There are limitations of the applicability of these European-based guidelines to tropical forests in the Project Area, particularly given the fact that SO_2 impacts on vegetation are exacerbated by cold temperatures. Nonetheless these provide a conservative assessment for the effects of SO_2 on vegetation.

The results of SO_2 modelling against the critical level guideline for forests (described in Appendix A, Air Quality and Greenhouse Gas Impact Assessment) indicates that during construction, annual average SO_2 concentrations are predicted to be well below the UN/ECE guideline. During operations there is an area covering approximately 1,600ha (predominantly Medium Crowned Forest/Small Crowned Forest) surrounding the power generation facilities predicted to be exposed to annual average SO_2 concentrations above the UN/ECE guideline for vegetation impacts on forest ecosystems of $20 \mu g/m^3$.

14.4.2.7. Lighting and Noise

Temporary and permanent sources of light may affect the behaviour of animals, both for diurnal and nocturnal species. Lighting can interfere with nocturnal birds and birds that migrate at night, alter the reproductive behaviour of frogs, focus the foraging activities of insectivores such as micro-bats, increase the likelihood of predation for some species (e.g., insects attracted to lights) and affect foraging activities of prey species. The impacts of extended periods of lighting are not detrimental to all species and some, particularly insectivorous predators (e.g., micro-bats that feed on insects attracted to lights), may derive a benefit.

Project-related activities will generate noise from a number of sources (see Section 14.7). Blasting will generate high levels of instantaneous sound and pressure waves. Excessive noise emissions have the potential to adversely affect some fauna species. The severity of the impact will vary depending on the proximity to the activities, individual species sensitivity (and their ability to habituate), and the efficacy of proposed avoidance and management measures. There is limited documentation of the effects of noise on fauna assemblages or populations. While noise can cause increased stress hormones and interfere with breeding communications and predator avoidance (Rabin, et al., 2003; Barber, et al., 2010), many species habituate to noise (Bomford and O'Brien, 1990). Noise levels in excess of 100dBA over extensive periods may cause physical damage or injury but, this is unlikely and, where blasting at surface does occur (such as initial decline development and hard rock quarrying), it will typically occur at most, twice a day. Further, it is unlikely that any terrestrial fauna would remain in an area affected by noise levels of this magnitude. Construction and operation will not include plant and equipment capable of generating noise levels required to cause such damage. Sensitive fauna species can be expected to be displaced from areas in close proximity to Project activities generating high noise levels (Appendix B, Noise and Vibration Impact Assessment). Given this, potential impacts to terrestrial ecology from lighting and noise are not considered further.

14.4.2.8. Traffic

The Project will increase road traffic in the local region, particularly along the Mine Access Road, Link Road, Northern Access Road, Watut Valley Road and other access roads, which in turn will increase the risk of direct mortality of slow-moving fauna through vehicle strike. Most vertebrate fauna are mobile and move away from construction sites or attempt to avoid vehicles. Frogs and reptiles are more susceptible to vehicle strike, whereas birds are generally only impacted at relatively fast vehicle speeds. Most traffic will occur during the day, whereas many amphibian and reptile species are more active at night. Furthermore, the low speed limits for WGJV vehicles in the Mine Area (of 40km/h) and the relatively low number of roads in the local region means the rate of vehicle strike mortality is likely to be very low in the broader context. Given this, potential impacts to terrestrial ecology from road traffic are not considered further.

14.4.2.9. Introduction and/or Spread of Weeds, Pests and Pathogens

Invasive exotic (i.e., non-native) species pose a serious threat to terrestrial ecology values especially in lowland rainforest areas where canopy disturbance provides ideal growth conditions for tropical weeds.

The potential exists for exotic species to be introduced, for example, as a result of Project vehicles and equipment carrying invasive weed species' seeds or spores. Invasive pests may out-compete local biota and lead to degradation of the quality and condition of habitat. Establishment of invasive species can cause permanent changes in the structure and function of ecosystems as a result of competition or directly mortality. Weeds, pests and pathogens may be introduced directly or indirectly through anthropogenic alteration of natural habitat.

Based on the findings of technical ecological investigations (see Appendix C, Terrestrial Ecology Characterisation - Mine Area to Markham River and Appendix D, Terrestrial Ecology Characterisation - Markham River to Wagang), invasive weeds are prevalent in foothill and lowland habitats throughout the Infrastructure Corridor with infestations of siam weed (*Chromolaena odorata*), giant sensitive weed (*Mimosa diplotricha*), bamboo piper (*Piper aduncum*), leucaena (*Leucaena leucocephala*) and tropical kudzu (*Pueraria phaseoloides*). Therefore, vehicle and equipment movements along the Infrastructure Corridor have the potential to spread these species to areas that are presently free of these weed species.

Plant pathogens can cause large areas of forest dieback. Like invasive flora, pathogens can be transmitted through the movement of personnel and materials. One invasive plant pathogen known to infect trees and cause large areas of dieback is the *Phytophthora cinnamomi* fungus. No records of *P. cinnamomi* have been reported in or around the Project Area.

Exotic fauna once introduced (either intentionally or accidentally) can become established in the wild. Invasive fauna present in the Project Area are generally restricted to human modified environments, principally in and around villages. Food scraps at camps and landfill refuse may attract pest animals, increasing the risk of the establishment and spread of invasive species.

Six exotic fauna species have been recorded within the terrestrial ecology study area, comprising: four mammals, water buffalo (*Bubalus bubalis*), feral pig (*Sus scrofa*), feral cat (*Felis catus*) and polynesian rat (*Rattus exulans*); one reptile, common house gecko (*Hemidactylus frenatus*) that is restricted to human settlements; and one amphibian, cane toad (*Bufo marinus*), that is widely distributed but more common in disturbed areas.

The likelihood of such introductions is influenced by the effectiveness of hygiene and quarantine practices, the number of vehicles and machinery moving through the Project Area, and supply lines to and from other parts of PNG and internationally.

14.4.2.10. Increased Susceptibility to Fire

The clearing of forest creates a boundary or edge, and may exacerbate drying of forest edge vegetation and the establishment of fire-prone vegetation in disturbed areas. These changes allow fires to penetrate into tropical forests, particularly during periods of severe drought that accompany El Niño events, and can precipitate the rapid conversion of tropical rainforest to grassland (Shearman et al., 2008). Forest gaps are often expanded for gardens through burning practices.

Uncontrolled fires may result from the Project during construction and operation, primarily because of accidental industrial fires but also indirectly through the expansion of local populations. Repeated burning practices have converted much forested land to 'permanent' grasslands and this is particularly evident in the Lae–Wau–Bulolo Valley and the Markham Valley.

The most sensitive forests to fire are lower montane forests on high ridges, and those forests affected negatively by edge effects.

14.4.2.11. Infrastructure for Community Purposes

The WGJV proposes to construct two roads for community purposes: the Watut Services Road and Resettlement Road. The roads will provide communities in the Mine Area with access to the Northern Access Road and to new village locations agreed in relation to the resettlement program. They will also facilitate daily travel to the Mine Area for local villagers who are employed on the Project.

The Watut Services Road is intended to diverge from the southern end of the Northern Access Road to provide road access to Babuaf villages including Papas, Wongkins, Wori and Madzim.

An alignment is presently being investigated for the Resettlement Road, which is envisaged to commence at Madzim and continue east along valleys past the existing villages of Pekumbe and Pokwaluma to the Old Hengambu resettlement site (see Figure 6.3).

As with the establishment of the Northern Access Road, the construction of the Watut Services and Resettlement roads may increase the exploitation of natural resources by landholders (e.g., logging), and also facilitate access to the area by in-migrants with the potential for increased hunting pressure, clearing of land for gardens and the increased risk of the spread of pests and weed species. Both have potential impacts to terrestrial ecology.

The construction and maintenance of roads and other linear infrastructure in tropical forests around the world has shown that long term uncontrolled access can lead to increased forest clearing and degradation, and hunting, which may extend beyond the Project Area affecting habitat integrity (e.g., Trombulak and Frissell 2000; Laurance et al. 2009). Small-scale logging routinely follows road construction projects in rural PNG, particularly when roads are built in previously remote areas of intact lowland alluvial forest that supports a high density of mature trees of valuable timber species. Impacts may extend well beyond the road corridors, with the opening of feeder roads splintering out into surrounding forest. In PNG, typical impact buffers around constructed roads range from 10km to 50km or more depending on the general accessibility of the landscape (Cannon, 2007).

14.4.2.12. Altered Land Use

Indirect processes linked to social change may have effects on terrestrial ecology values. The discussion presented here solely relates to how these processes affect ecological values; the potential impacts of these processes to people and local communities are described in detail in Chapter 18, Socioeconomic Impact Assessment.

The construction and operations phases of the Project are expected to increase economic activity in the local area, and the construction of new roads to service the Project is expected to facilitate access to previously remote areas. Based on recent experience elsewhere in PNG, these factors can be expected to result in the in-migration of people into the area (see Chapter 18, Socioeconomic Impact Assessment), thereby leading to increased impacts to terrestrial ecology values from forest clearing for building and shifting cultivation, and an increased frequency of patch-burning for shifting cultivation, firewood collection, small-scale logging and hunting. Often the initial impact of increased in-migration is the thinning of the understory through the removal of timber for building and structural purposes. Understory thinning is apparent close to villages and existing accommodation facilities, most prominently along walking and access tracks with impacts generally decreasing rapidly with increasing distance from access points.

The pattern of subsistence agriculture practiced within the region is one where forest is cleared for cultivation at intervals of at least 10 years and multiple patches of forest fallows or areas of secondary forest are rotated (Filer et al., 2009). Habitats most at risk are those most suitable for settlement, agriculture and natural resource harvesting.

The opening up of forests by clearing may facilitate the expansion of shifting cultivation and the establishment of new settlements that cause additional and longer-lasting or permanent impacts through further clearing and degradation of intact forest.

Forest clearance for the purposes of firewood collection and sale in Lae could also have an impact on the rate of forest clearance, particularly along the Northern Access Road.

14.4.2.13. Increased Hunting Pressure

Hunting is an important part of the food supply for villages in the proximity of the Mine Area (see Chapter 12, Socioeconomic Environment Characterisation, and Woxvold and Aplin, 2013). Hunting is also a major contributor to the rarity and decline of larger mammals and birds in New Guinea (Mack and West, 2005; Cuthbert, 2010; Woxvold and Aplin, 2013). The increased accessibility of previously remote areas together with increased local population densities and opportunities to sell hunted animals may increase hunting pressure in the terrestrial ecology study area, as has been documented in similar situations elsewhere (Suarez et al., 2009; Pangau-Adam et al., 2012).

The Project is proposing to resettle Nambonga, Venembele and Hekeng (approximately 800 people) to sites Nongokwa, Tivgi, Kwepkwep and Old Hengambu (see Figure 6.3). The closest village to these new sites is Pokwaluma, where approximately 143 people currently reside. The resettlement sites are closer to areas of higher elevation (up to approximately 1,000mASL) making higher elevation habitats more accessible to villagers. Additional species not recorded within the terrestrial ecology study area may be present within these higher elevation habitats. Potential species of high conservation significance include Goodfellow's tree kangaroo (*D. goodfellowi*), New Guinea pademelon (*T. browni*) and eastern long-beaked echidna (*Z. bartoni*), and if present, will experience increased hunting pressure as a result of the increased accessibility.

14.4.3. Proposed Management Measures

The primary mitigation to limit impacts on terrestrial ecology values was through assessment of Project alternatives and siting of Project infrastructure. Examples include avoidance of high-value areas, such as the Markham Gap and Watut River floodplain. Conceptual planning and early engineering identified design and siting alternatives, which underwent multi-criteria assessment of environmental, social, cultural heritage and technical constraints to identify feasible options that minimised environmental, social and cultural heritage impacts. Chapter 7, Assessment of Alternatives, provides further detail in this regard.

Proposed management measures that are fundamental to reducing the significance of impacts on the terrestrial ecology values are presented in this section. The Project EMP (Attachment 3) presents the comprehensive set of proposed management measures that address all identified impacts to terrestrial ecology values, including those that are standard practice on any mine site and those listed below. The residual impact assessment was prepared on the basis that all proposed management measures presented within the Project EMP (Attachment 3) will be implemented.

General measures that are also relevant to terrestrial ecology are provided in the Project EMP (Attachment 3), these include measures to manage altered hydrology, water quality and erosion; accidental spills and waste; emissions of dust and SO_2 to air, and the generation of noise and lighting.

14.4.3.1. Land Clearing

A priority management measure to minimise impacts on terrestrial ecology values involves minimising the extent of land clearing and maximising the likelihood of rehabilitation success. To achieve this, the following management measures are proposed:

- Obtain approval from the WGJV Environment Department prior to clearing vegetation in defined areas of relevant mining leases.
- Plan the area to be cleared to be the minimum required to undertake works safely.
- Minimise vegetation clearing by using previously disturbed or degraded areas (e.g., existing access tracks or disturbed kunai grasslands, co-location of linear infrastructure such as the concentrate pipeline, power lines and access roads) as a first preference.
- Minimise the creation and extent of new access corridors in undisturbed catchments.
- Demarcate areas to be protected with boundaries clearly communicated.

14.4.3.2. Edge Effects, Barrier Effects and Habitat Fragmentation

To minimise impacts from habitat fragmentation, edge effects and barrier effects that arise through the clearing of natural habitats, the following management measures are proposed:

- Maintain hydraulic connectivity along linear infrastructure corridors for pipelines and roads (e.g. install culverts and drains where required).
- Minimise the length of time that disturbed areas are exposed through planning progressive clearing and progressive rehabilitation of disturbed areas, unless areas are planned for additional disturbance at a later date.
- Decommission and revegetate temporary infrastructure footprints and access routes.

14.4.3.3. Invasive Weeds and Pest Fauna

To minimise Project-related impacts from invasive weeds and pest fauna, the following management measures are proposed:

- Implement risk-based control of weeds and plant pathogens, for example:
  - Weed and plant pathogen identification manual for contractors and personnel, and training in its use
  - Visual inspection of vehicles, plant and equipment for soil, seeds and weed material
  - Risk-based wash down of vehicles, plant and equipment before arrival at site
  - Removal of weeds using appropriate methods

- Conduct pre-construction surveys of weeds and potential vegetation dieback, and record the location and extent of infestations for inclusion in GIS database.
- Monitor and manage washdown areas to avoid weed establishment.

14.4.3.4. Fauna Management

To minimise potential impacts on fauna, the following management measures are proposed:

- Undertake preconstruction ecological clearance surveys in high conservation value areas, including areas around the proposed re-settlement village locations.
- Check excavations and trenches daily for trapped animals.
- Implement an access protocol for Project-controlled roads.
- Prohibit Project personnel and contractors from hunting, harassing, capturing and keeping wildlife or gathering, possessing or selling wildlife products.

14.4.3.5. Fire

To minimise potential impacts from uncontrolled fires, the following management measures are proposed:

- Prohibit unauthorised lighting of fires by Project personnel and contractors.
- Avoid burning cleared or standing vegetation, wherever practicable.
- Install appropriate fire detection and suppression systems.
- Maintain surface and underground firefighting equipment with rescue capability.
- Manage response to natural disaster (such as tsunami, flood, bushfire, or earthquake) in accordance with WGJV Crisis, Emergency and Incident Management Plan.

14.4.3.6. Summary of Processes Causing Impacts to Terrestrial Ecology Values

Table 14.20 presents a summary of processes that may affect terrestrial ecology values during construction, operation and decommissioning of the Project. The issue and impact are described, as well as the project phase in which it occurs (X) is concentrated (X_C), or is ameliorating throughout (X_A).

Table 14.20: Summary of potential issues and impacts during Project construction, operation and decommissioning

Processes Causing Impacts to Terrestrial Ecology Values	Project Phase		
	Construction	Operations	Decommissioning
Physical disturbance leading to vegetation clearance and associated edge and barrier effects.	X_C	X_A	X_A
Physical disturbance leading to sedimentation or altered hydrology and subsequent vegetation loss or degradation.	X_C	X_A	X_C
Physical disturbance leading to fauna entrapment or displacement, or the burial of refuges and habitat.	X_C	-	X_C
Accidental spills of hazardous materials or wastes with exposure of fauna.	X_C	X	-
Emissions of dust from disturbed areas leading to reduced vegetation condition.	X_C	X	X
Emissions of SO_2 from Project facilities reducing vegetation condition.	-	X_C	-
Emissions of noise and light causing disturbance to fauna.	X	X_A	X

Processes Causing Impacts to Terrestrial Ecology Values	Project Phase		
	Construction	Operations	Decommissioning
Traffic movements leading to collisions with fauna by Project vehicles or machinery.	X	X	X
Introduction and/or spread of invasive weeds and pests.	X	X	X
Increased risk of fire, particularly during drought years.	X	X	X
In-migration and improved access leading to altered land-use with consequent impacts to terrestrial ecology.	X_C	X_A	X
In-migration and improved access leading to increased hunting by non-Project personnel with consequent impacts to terrestrial ecology.	X	X_A	X_C

14.4.4. Residual Impact Assessment

The impact assessment approach focuses on credible impacts, i.e., those that could be reasonably expected during one or more phases of the Project in the context of the existing conditions. Predicted residual impacts to terrestrial ecology values have been assessed assuming mitigation measures are successfully implemented.

In this section, the residual impacts that are expected to occur if the Project proceeds are defined as direct, indirect and cumulative impacts, more specifically:

- Direct impacts are those effects on terrestrial ecology that are directly caused by Project activities (i.e., there is a direct cause-and-effect relationship between them).
- Indirect impacts are those effects on terrestrial ecology that are related to Project activities but are not directly caused by them (i.e., there is not a direct cause-and-effect relationship between them).
- Cumulative impacts are those incremental effects on terrestrial ecology (whether positive or negative) resulting from the interaction of Project activities and non-Project activities occurring simultaneously or subsequently. Cumulative impacts are assessed in Chapter 22, Cumulative Impact Assessment.

Predicted residual impacts to terrestrial ecology values (both habitat and populations) have been grouped into three broad types:

- Habitat loss as a result of vegetation clearance and earthworks. These impacts can be exacerbated indirectly by increased human populations (through in-migration and improved access to Project areas).
- Habitat degradation resulting from edge effects, barrier effects, deposition of eroded sediments, colonisation by invasive species or from contamination caused by accidental spills of hazardous materials. Degradation may also occur indirectly as a result of increased use of natural resources, as a result of increased populations through in-migration and improved access to Project areas.
- Reduced abundance of flora and fauna populations as a consequence of:
    - Changes to available habitat (including food sources, shelter and nesting or roosting sites) due to habitat loss and degradation (described above).
    - Injury, death or displacement of flora and fauna from vegetation clearing and earthworks, collision with vehicles, predation by exotic species, or increased hunting in previously difficult to access areas or indirectly through increased

hunting pressure from increased human populations (through in-migration and improved access to Project areas).

Residual impacts (both direct and indirect) were assessed on two scales: broad scale habitat ecological values; and population scale ecological values for conservation significant species.

The areas of disturbance by the Project were calculated using a conservative approach. Buffers to the areas of disturbance for construction of Project infrastructure were applied to allow for refinement during detailed design and to ensure impacts were not under-represented. These included adding a:

- 30m-buffer around infrastructure in areas of very steep slopes (i.e., greater than 30° slope).
- 20m-buffer around infrastructure in areas of steep slopes (i.e., 20 to 30° slope).
- 15m-buffer either side of the proposed 40-m-wide Infrastructure Corridor.
- 10m-buffer around infrastructure located in flat areas (i.e., less than 2° slope).

The area that will be directly disturbed during the construction phase (including temporary laydown areas) of the Project was estimated to be 1,405 hectares (ha), comprising approximately:

- 374ha in the Mine Area
- 708ha in the Infrastructure Corridor
- 8ha in the Coastal Area
- 316ha for community infrastructure development

Chapter 6, Project Description provides a full breakdown of disturbance areas by infrastructure type.

Direct disturbance will mostly occur in previously disturbed areas, primarily for the Infrastructure Corridor, and hill forest habitat, primarily in the Mine Area. Almost one half (48%; 677ha) of all disturbance will affect land categorised as Other Non-Forest Areas Dominated by Land-use (O), which consists of various land uses such as gardens or regrowth and assigned to the ‘highly modified’ condition category. A total of 295ha (21% of all disturbance) of direct disturbance will affect hill forest habitat represented by Medium Crowned Forest/Small Crowned Forest (Hm/Hs), with the majority of this disturbance to intact vegetation (87%), and the rest to moderately disturbed vegetation. A total of 121ha (9% of all disturbance) of direct disturbance will affect Large to Medium Crowned Forest (Pl), with 92% of this disturbed vegetation being intact, and the rest moderately disturbed vegetation. A breakdown of direct disturbance by vegetation type is shown in Table 14.21.

The extent of edge effects around Project sites was estimated by applying a 100m-wide buffer to the area of direct disturbance (which include buffers of between 10 m and 30 m around Project infrastructure). In terms of edge effects due to forest disturbance, 561ha is estimated to occur in Medium Crowned Forest/Small Crowned Forest (Hm/Hs), 225ha is estimated to occur in Large to Medium Crown Forest (Pl), and 162ha is estimated to occur in Mixed Swamp Forest (Fsw/FswC). Table 14.21 provides the complete breakdown of disturbance predicted for each vegetation community.

Table 14.21: Terrestrial ecology impact areas by vegetation type

Vegetation Community (FIMS)	Direct Impact Area (ha)	Proportion of Total Direct Impact Area (%)	Edge Effects Area (ha)	Proportion of Total Edge Effects (%)
Grassland (G)	90.5	6.4	-	-
Large to Medium Crown Forest (Pl)	120.7	8.6	225.3	17.3
Littoral (Beach) Communities (B)	13.6	1.0	-	-
Medium Crowned Forest/Small Crowned Forest (Hm/Hs)	295.3	21.0	560.6	43.1
Mixed Swamp Forest (Fsw/FswC)	71.1	5.1	161.5	12.4
Other Non-Forest Areas Dominated by Land-use (O)	676.9	48.2	-	-
Riverine Mixed Successions (Fri)	66.7	4.7	195.0	15.0
Swamp Woodland (Wsw)	70.5	5.0	158.9	12.2
Scrub (Sc)	0	0	0.1	0.0
Total	**1405.2**	**100%**	**1,301.4**	**100%**

Note (-) results denote vegetation communities of such degraded and highly modified condition, they are not expected to experience edge effects.

A breakdown of direct disturbance by vegetation condition is shown in Table 14.22.

Table 14.22: Terrestrial ecology impact areas by vegetation condition

Vegetation Condition	Direct Impact Area (ha)	Proportion of Total Direct Impact Area (%)	Edge Effects Area (ha)	Proportion of Total Edge Effects (%)
Intact	484.9	34.5	896.4	68.9
Moderately disturbed	57.9	4.1	152.8	11.7
Degraded	381.2	27.1	244.2	18.8
Highly modified	481.1	34.2	8.1	0.6
Total	**1,405.2**	**100%**	**1,301.4**	**100%**

An assessment of predicted residual impacts on terrestrial ecology values was made following application of the proposed management measures outlined in Section 14.4.3. Potential impacts effecting each identified value are described below and summarised in Table 14.23.

14.4.4.1. Residual Impacts on Habitat Values

This section describes the predicted residual impacts on broad scale habitat ecological values, with a focus on the potential for effects to the composition, structure and function of the biodiversity across the terrestrial ecology study area.

14.4.4.1.1. Hill Forest

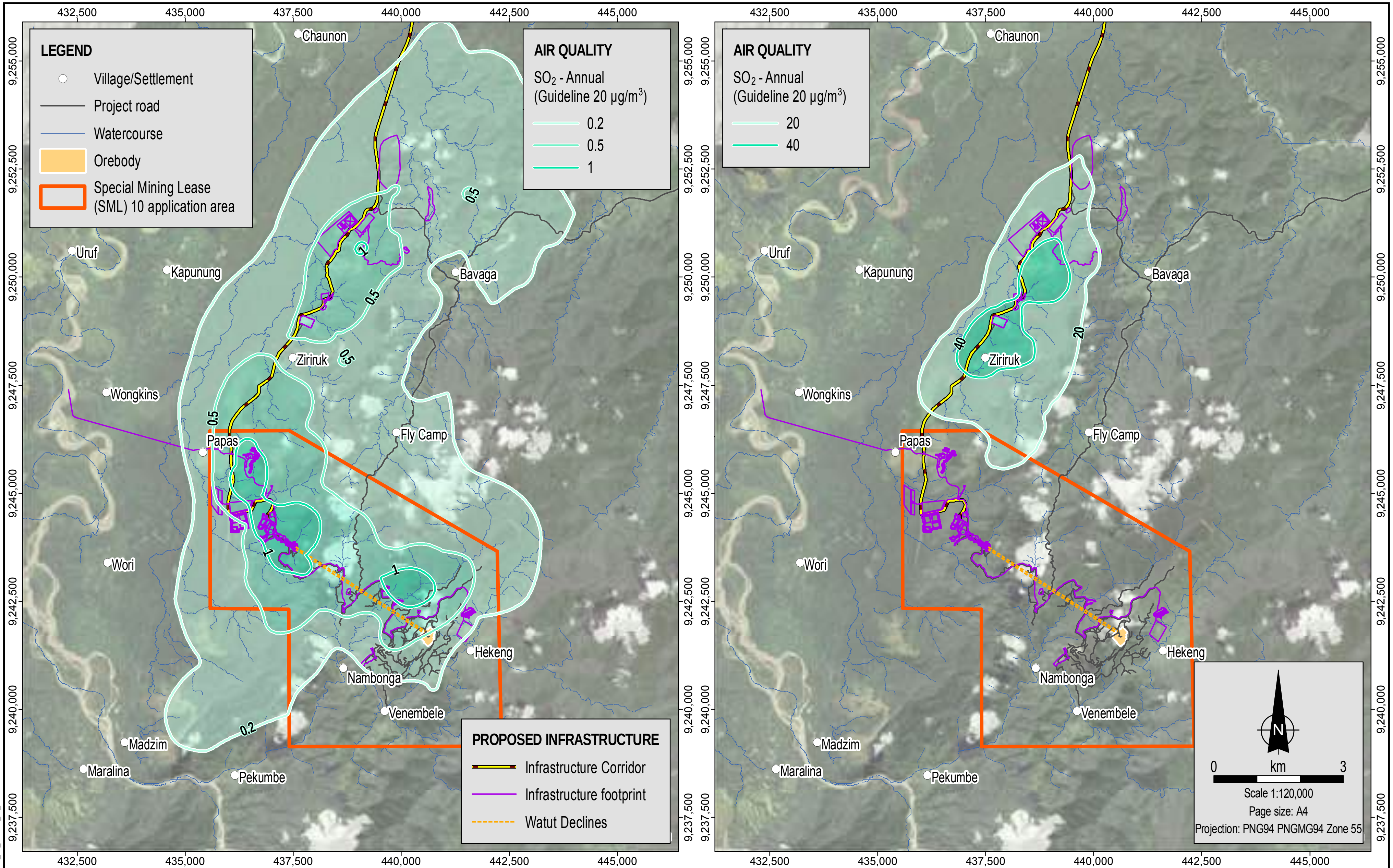
Hill forest habitats support diverse flora and fauna communities including the majority of conservation-significant species that were recorded in the terrestrial ecology study area including *F. pimenteliana* (Endangered), *I. bijuga* (kwila; Vulnerable), *M. buchneriana* (Vulnerable) and Pesquet's parrot (*P. fulgidus*; Vulnerable).

Physical disturbance of hill forest habitat as a direct result of the Project equates to a loss of 295ha (21% of all disturbance) of Medium Crowned Forest/Small Crowned Forest (Hm/Hs). The condition of this habitat type is primarily intact (undisturbed) and therefore of good condition from an ecological perspective. This disturbance will result in the loss of vegetation and natural habitats and cause direct mortality to individual plants and some less mobile animals. The majority of this area will be permanently converted to Project infrastructure or is within the mine subsidence zone.

Physical disturbance also leads to edge effects that cause changes in the abiotic and biotic environment along the boundary between intact natural habitat and a clearing resulting in habitat degradation (see Section 14.4.2.1). Generalist forest species and grassland species adapted to drier, more open habitats including many species of grasses, butterflies, birds and bats are likely to prefer these forest edges and increase in abundance. It was estimated that 561ha will be degraded from edge effects as a consequence of physical disturbance of hill forest.

Overall, direct habitat loss and degradation through edge effects (856ha) represents approximately 5% of hill forest vegetation types of the terrestrial ecology study area and 0.1% at the provincial scale. The magnitude of this change to hill forest was assessed to be readily detectible with respect to natural variability on a local scale. Generally, hill forests have a naturally high rate of natural disturbances due to tree-falls and landslips, due to their occurrence on steep slopes with shallow soils. As a result of this natural pattern of disturbance, this forest type has a moderate level of resilience, with regeneration within these gaps occurring over decades. Therefore, some recovery and regeneration of hill forest following construction of the Project, for example on temporary construction working spaces, is expected.

Direct impacts from sulphur dioxide emissions for example disrupting photosynthesis of plants may further degrade forest habitats (see Section 14.4.2.6). Figure 14.4 shows average SO_2 concentrations during construction (left hand side) and operation (right hand side) of the Project based on modelling described in Appendix A, Air Quality and Greenhouse Gas Impact Assessment. This figure shows that annual SO_2 emissions during construction are predicted to be two orders of magnitude lower than the UN/ECE annual SO_2 guideline for forest health of 20µg/m^3. During operations, emissions of SO_2 from the power generation facilities are predicted to exceed the UN/ECE annual SO_2 guideline in an area covering approximately 1,600ha of predominately hill forest habitats. This area is shown on the right hand panel on Figure 14.4 and stretches along the ridgeline and Lower Watut River eastern floodplain in a generally north-south direction from the Northern Access Road Borrow Pit in the north to the northern boundary of Special Mining Lease (SML) 10 application area in the south. The hill forest habitat within this area is predominantly intact with only small areas of degraded vegetation. Impacts to vegetation in this area due to SO_2 may be difficult to discern from other Project-related impacts, such as degradation through direct physical disturbance during the construction of Project infrastructure, and indirect impacts such as edge effects from the construction of the Infrastructure Corridor, laydown areas, Mt Beamena Quarry Access Road and power generation facilities. The predicted SO_2 emission concentrations will be verified, and potential impacts to vegetation quality confirmed through implementation of a targeted SO_2 monitoring program, described in Section 14.4.5.



Source:
Air quality from SLR.
Watercourses, 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: 20.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.04_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Annual average SO_2 concentrations during construction (left) and operations (right)

Figure No: 14.4

Hill forest that will be directly impacted as a result of construction activities is relatively free of weeds and pests. Therefore, accidental introduction of an invasive species will introduce weeds, pests and pathogens into new areas further degrading hill forests. If these become established in an area, invasive species can cause permanent changes in the structure and function of ecosystems. Unlike direct habitat loss, these changes could occur in areas outside the Project Area. Highly invasive weed species are capable of smothering and/or out competing native shrubs and trees due to their dominance in the seed bank and high rates of biomass accumulation (Rogers and Hartemink, 2000). Movement of vehicles and goods along the Infrastructure Corridor, in particular, pose a risk to the spread of highly invasive species that are already well established in areas the Infrastructure Corridor will traverse. These species include siam weed, giant sensitive weed, piper, leucaena and tropical kudzu.

The risk of introducing a weed, pest or pathogen to the Project Area, and it spreading, will depend on the effectiveness of quarantine measures, and to a lesser extent education and control of the workforce, and the subsequent timeliness and effectiveness of control measures should an introduction be detected.

As described in sections 14.4.2.11 and 14.4.2.12, the construction and maintenance of roads combined with increased population density can indirectly lead to increased forest clearing and degradation through increased clearing for houses and gardens, and increased land clearing for small-scale agriculture. In their assessment of threats to PNG forests, Shearman et al. (2009) estimated that approximately 42% of remaining lowland hill forest was accessible to commercial logging. As described above, a substantial proportion of hill forests occur on steep slopes with poor soils with a lower proportion of large (straight boled) trees. As such, this habitat was assessed to be moderately susceptible to indirect habitat loss as a result of changes in natural resource use, e.g., from increased access and population density.

The impacts to terrestrial ecology from the resettlement of Nambonga, Venembele and Hekeng to higher elevations of the Wafi River catchment in intact hill forests is likely to be of greater magnitude both in terms of direct impacts from constructing the access roads and clearing new village areas, and indirectly through the use of natural resources around the new villages, including forest clearance for shifting cultivation and hunting.

Proposed management measures to reduce Project-related impacts on hill forest aim to:

- Limit the Project footprint, habitat loss and disturbance.
- Avoid the introduction and spread of weeds, plant pathogens and pests.
- Prevent uncontrolled fires from starting.

Following implementation of proposed management measures, the magnitude of direct impacts around the Mine Area was predicted to be **low** during construction and **very low** during operation. Impacts are predicted to be localised at Project sites and temporary in nature, and are predicted to affect only a very small proportion of hill forest habitats locally. This is not expected to reduce the viability of hill forest habitat with the Project Area.

Subsistence use of natural resources surrounding the resettlement sites, such as clearance for gardens, will result in continuing clearance of the primarily intact forests, further impacting on hill forest habitat. Potential indirect impacts are closely linked to changes in natural resource use (e.g., clearance for gardens, and timber extraction) and the introduction/spread of invasive species such as weeds. The magnitude of the combined indirect impact was assessed as **moderate** during construction and operation following the implementation of proposed management measures.

While hill forests are ecologically important, they are also the most abundant forest type in PNG. Hill forests are also more resilient than alluvial forest both in terms of small scale disturbance – being adapted to gap phase dynamics from treefalls and landslips – and occur on less amenable geomorphology and slope characteristics for large-scale forestry.

Based on the magnitude of direct and indirect impacts on hill forest habitat and the **medium** sensitivity of hill forest, the level of significance of residual impacts on this habitat was assessed to be **moderate** during construction and operation, primarily as a result of indirect processes.

14.4.4.1.2. Alluvial Forest

Within the alluvial forest habitats, two main variations have been defined:

- Floodplain forest represented by Large to Medium Crowned Forest (Pl) vegetation type.
- Swamp forest and woodlands represented by Mixed Swamp Forest (Fsw/Fswc) and Swamp Woodland (Wsw) vegetation types.

Due to ecological differences corresponding to geomorphologic and drainage patterns, the sensitivities of these habitats have been assessed separately.

14.4.4.1.2.1. Floodplain Forest

Within the Project Area, floodplain forest is associated with an alluvial terrace of the Lower Watut River. It is notable that the main channel of the river stands a few metres above the surrounding floodplain on the eastern side- a contributing factor to the frequent and widespread flooding.

Stands of floodplain forest are poorly represented in Morobe Province, with most having been harvested for timber. However, BAAM (see Appendix C, Terrestrial Ecology Characterisation – Mine Area to Markham River) concluded that the forests of the Lower Watut River alluvial plain and surrounding foot-slopes appear to have been protected from broad scale logging due to their relative geographical isolation.

Vertebrate fauna within alluvial forests typically contain fewer endemic species compared to hill forest, with most species also occurring in hill forest. Despite having reduced endemism, floodplain forest on alluvial plains are among the most productive habitats (in terms of biomass). Typically, these forests have a higher concentration of large, hollow-bearing trees and a higher diversity and abundance of fleshy-fruiting tree species than hill forest.

Physical disturbance as a direct result of the Project on floodplain forest habitat represented by Large to Medium Crown Forest (Pl) equates to 121ha (9% of all disturbance). The clearing of land will result in the loss of vegetation and natural habitats, and cause direct mortality to individual plants and some less mobile fauna during clearing activities. The condition of this habitat is primarily intact with smaller areas of moderately disturbed vegetation. Approximately half of this area along the Infrastructure Corridor is expected to regenerate over time to some degree as the right of way verges regenerate. This regenerated habitat, however, is unlikely to represent intact Large to Medium Crown Forest (Pl) given it will experience edge effects, estimated to equate to 225ha.

With respect to the Infrastructure Corridor, the cleared area may create a barrier and limit the movement of fauna, and to a lesser extent, the dispersal of seeds and pollen. Barrier effects have been demonstrated for a wide range of animals. In extreme cases barrier effects can split a population into subpopulations, with consequential loss of gene flow. The degree to which barrier effects operate is dependent on the behaviour and biology of flora and fauna, as well as road design features and landscape aspects. The construction of the Northern Access Road and community infrastructure development will fragment a number of patches of Large to Medium Crown Forest (Pl), thereby reducing the integrity of the separated patches.

Overall direct disturbance and associated edge effects equates to 346ha. This represents approximately 6% of Large to Medium Crown Forest (Pl) vegetation type in the terrestrial ecology study area and 1% at the provincial scale.

Hydrological changes in floodplains within the Project Area could be affected through two main processes, direct alteration (e.g., barriers to flow) or via alteration of stream bed levels, which may influence hydrological patterns such as overbank flooding. This is further described in Chapter 15, Freshwater Environment Impact Assessment. Instances of forest dieback adjacent to the Lower Watut River have occurred within the past 10 years and are likely to have been due to an altered flood regime, partly due to episodic increases in sedimentation of the river, resulting in tree mortality (Booyong, 2013).

During Project construction, bulk earthworks will increase the rate of both soil erosion and sediment mobilisation downstream of disturbed areas. Exposed areas, particularly in steep slopes and disturbed and/or displaced soils, are prone to erosion by high-intensity and short-duration rainfall events. This in turn leads to increased suspended solids loads comprised of fine-grained sediments, and watercourse bed aggradation and bed sediment transport. It is likely that the majority of sediment deposition associated with construction will be highly localised and restricted to the eastern Lower Watut River floodplain sub-catchment areas and floodplain creeks, and particularly the Boganchong, Womul and Chaunong creeks and the Bavaga and Waime rivers.

On this local scale, sediment loads generated in the vicinity of key construction activities were predicted to be many times higher than the existing natural loads in Boganchong and Womul creeks and the Bavaga River. For the modelled construction period, these activities (if unmanaged) will result in an increase to the natural sediment loads in Boganchong and Womul creeks by approximately 50 to 60 times during the wet season and between approximately 200 and 250 times during the dry season (described further in Chapter 15, Freshwater Environment Impact Assessment). Construction of a sedimentation pond downstream of the Watut Declines Portal and Process plant terraces' facilities prior to any works taking place on these terraces is likely to limit sediment reporting to downstream reaches of these creeks. The small amount of sediment that is not captured by the sedimentation pond or raw water dam once constructed (downstream of the process plant terrace) is likely to be deposited on the floodplain once gradients flatten and velocities slow. Based on this, significant impacts on floodplain forest habitat, as a result of Project derived sediment, are not expected.

Indirect impacts are likely to be greater in scale and severity in comparison to direct impacts, with these linked to changes in natural resource use, e.g., timber extraction and clearance for gardens. In their assessment of population growth and agricultural land use in the Morobe Province, Ningal et al. (2008) found that population change and total land use change were strongly correlated, and most new agricultural land is taken from primary forest. Further, they found that the district that had the largest change (Huon), in both population growth and agricultural land use, was likely due to increased access to transport and agro-ecological conditions.

The construction and maintenance of roads in tropical forests around the world has shown that long term uncontrolled access generally leads to increased forest clearing and degradation (see Laurance et al., 2009; Trombulak and Frissell 2000). Due to the abundance of harvestable timber species, amendable topography, productive soils and access to transport through newly created roads (primarily the Northern Access Road), Large to Medium Crown Forest (Pl) is likely to be targeted for timber extraction and creation of new gardens. These indirect impacts may be more widespread, and could lead to changes at a broader scale that continue over a longer time frame. The magnitude of these indirect impacts is likely to exceed the direct losses through construction of Project infrastructure.

Proposed management measures to reduce impacts on the floodplain forest aim to:

- Reduce the Project footprint, habitat loss and disturbance.
- Maintain hydrological connectivity of floodplains.
- Limit erosion and capture mobilised sediments.
- Limit the introduction and spread of weeds, plant pathogens and pests.
- Implement access protocols for Project-related roads.

Following implementation of proposed management measures, the magnitude of direct impacts to floodplain forest was assessed to be **moderate** during construction and **low** during operation. Such impacts are predicted to be localised around Projects sites, but represent approximately 6% of this habitat within the terrestrial ecology study area. The greatest uncertainty relates to potential changes to floodplain flooding dynamics, which are highly sensitive to change. Any alterations to floodplain dynamics, for example, as a result of increased sediment deposition, could increase the magnitude of direct impacts by triggering broad-scale habitat changes.

Indirect impacts are likely to be greater in magnitude since these habitats contain valuable resources (timber) and are preferable for agriculture and will be more easily accessible via the Northern Access Road. As noted by BAAM (see Appendix C, Terrestrial Ecology Characterisation – Mine Area to Markham River), the recent construction of access roads for the Project has already contributed to localised disturbance through the influx of portable logging and milling operations in alluvial forest adjacent to access roads. These impacts are expected to occur over a longer period than the Project life. Indeed, in the long term (i.e., post mine closure), it is likely these habitats will be severely reduced if not completely lost or degraded, with incremental losses over the preceding decades. The magnitude of the indirect impacts was assessed as **moderate** during construction increasing to **high** during operation following the implementation of proposed management measures.

Given the magnitude of impacts on floodplain forest, and the **very high** sensitivity rating for this habitat, the level of significance of residual impacts was assessed to be **high** during construction and **major** during operation, primarily as a result of indirect processes.

14.4.4.1.2.2. Swamp Forest and Woodland

Swamp forest and woodlands represented by Mixed Swamp Forest (Fsw/FswC) and Swamp Woodland (Wsw) vegetation types cover extensive areas of the Lower Watut River and Markham River floodplains, often forming a transitional community between the well-developed Large to Medium Crowned Forest (Pl) and the permanently wet Swamp Woodlands (Wsw) dominated by sago palm.

Physical disturbance as a direct result of the Project of swamp forest and woodland habitat equates to 142ha (or 10% of all disturbance) with approximately 50/50 split between Mixed Swamp Forest (Fsw/FswC) and Swamp Woodland (Wsw). This will primarily occur as a result of construction of the Infrastructure Corridor. A further 320ha is expected to have edge effects. To put these losses into context, these represent approximately 4% of these habitats within the terrestrial ecology study area or less than one percent of these types at the provincial level.

Like floodplain forests, altered drainage (and flooding) patterns are key processes likely to influence broader losses of these habitats. Altered drainage, for example creating barriers to the movement of water through these habitats, can result in drying and changes to community composition to a dry forest system. However, this habitat is likely to be less sensitive to hydrological changes, such as an increase in the duration and/or depth of floods, as a consequence of the Project in comparison to floodplain forest.

Proposed management measures to reduce impacts on the swamp forest and woodland aim to:

- Reduce the Project footprint, habitat loss and disturbance.
- Maintain hydrological connectivity of floodplains.
- Limit erosion and capture mobilised sediments during construction.
- Limit the introduction and spread of weeds, plant pathogens and pests.

The magnitude of the direct impacts (primarily during construction) from habitat loss and edge effects are not predicted to cause a detectible change with respect to natural variability or viability of the habitat. Such impacts would be localised around Project sites and represent roughly 4% of this habitat within the terrestrial ecology study area. As for floodplain forest, the greatest uncertainty relates to potential changes to floodplain flooding dynamics, which are highly sensitive to change, and the potential for introduction of an invasive species. Any alterations to floodplain dynamics, e.g., as a result of increased sediment deposition, could increase the magnitude of direct impacts by triggering broad-scale habitat changes. Similarly, accidental introduction of an invasive weed species may reduce the quality of habitat in the Project Area. Following implementation of proposed management measures, the magnitude of direct impacts to floodplain forest was assessed to be **moderate** during construction and operations.

Unlike Large to Medium Crowned Forest (Pl), swamp forest and woodland habitats are less likely to experience indirect clearance and degradation as a result of the Project. These habitats are less accessible, contain limited valuable timber species and are less suitable for agricultural use. Nonetheless, areas of swamp forest surrounding Lae have been heavily impacted by people. Therefore, population growth near these habitats would be expected to have some effect on habitat quality.

Shearman et al. (2008) mapped 3,409,018ha of swamp forest at a national level in 2002, and noted that swamp forests are difficult to access and largely undisturbed. Based on this evidence, swamp forest types are not considered to be threatened by forest clearance. As such the magnitude of indirect impacts to floodplain forest was assessed to be **low** during construction and operations.

Given the magnitude of impacts on the swamp habitats, and the **low** sensitivity of swamp forest and woodland, the level of significance of residual impacts on this habitat was assessed to be **low** during construction and operation.

14.4.4.1.3. Riparian and Semi Aquatic Habitats

Riparian and aquatic habitats occur on river and stream banks and are an important landscape component providing specialised habitats for a range of fauna. Riparian and aquatic habitats vary from those on large turbid rivers, such as Riverine Mixed Successions (Fri), to small clear streams. Across the floodplain of the Lower Watut River, numerous oxbow lakes and wetlands have been formed and isolated due to the ongoing migration of the river's broad meanders. These swamplands form a mosaic of open wetlands, swamp grasslands dominated by forbs and swamp tolerant grasses and *Pandanus* spp. forests.

Riparian and aquatic habitats also occur as a microhabitat within broad habitat types (e.g., hill forest and alluvial forest). These habitats have been defined based on their known disproportionate role in maintaining the associated terrestrial ecology values, including conservation significant species. This value is also more susceptible (i.e., it has lower resilience) to altered hydrology and sediment deposition downstream of construction areas, particularly river crossings.

Riparian habitats are relatively well represented in the terrestrial ecology study area and in the region more generally. Their condition largely reflects levels of disturbance, which in turn is influenced by proximity to human settlement and roads, and terrain.

Direct impacts on watercourses and riparian forest are predicted to occur during construction of watercourse crossings for roads and pipelines, from sediment-laden runoff to watercourses and from accidental spills of hazardous materials in or nearby watercourses (see Chapter 15, Freshwater Environment Impact Assessment). These impacts are expected to be localised and temporary in nature, and to be concentrated in the construction phase. For example, the Infrastructure Corridor crosses three major watercourses (Bavaga, Watut and Markham rivers) and multiple minor watercourses along its alignment. Watercourse crossings require additional workspace to accommodate the necessary handling and storage of materials excavated from the river bed and banks. Vegetation clearing at watercourse crossings will be determined by the watercourse size.

Increased sediment loads caused by erosion and sediment-laden runoff from disturbed areas could degrade riparian habitat immediately downstream of the source and impact terrestrial fauna that rely on watercourses for feeding. Accidental release of hazardous materials or wastes at Project sites could also contaminate the local environment and nearby watercourse and threaten terrestrial fauna that specialises in feeding on aquatic fauna (for example, kingfishers and water rats). Amphibians are particularly sensitive to exposure to organic and inorganic contaminants. Tadpoles are highly susceptible to pollution of freshwater habitats.

During construction, a 20m-wide vegetation buffer zone from watercourses will be maintained where practicable. The clearing of riparian vegetation will be reduced to a width required to safely accommodate pipeline right-of-way, access roads or tracks and watercourse crossings. Implementation of these proposed management measures as well as other erosion and sediment controls, spill prevention measures, and quarantine and weed management will reduce the magnitude of potential impacts on watercourses and riparian forest. Stream bank reinstatement using riprap and other stabilising methods are known to be successful in reducing soil loss and adverse effects on water quality, and will ameliorate these impacts on riparian habitats.

Following implementation of proposed management measures, the magnitude of direct impacts was predicted to be **low** during construction and reduce to **very low** during operation. Such impacts will be localised at Project sites and temporary in nature, affecting only a small proportion of riparian and semi-aquatic habitats locally. This is not expected to reduce the viability of watercourse and riparian habitats.

Indirect impacts are closely linked to changes in natural resource use, e.g., clearance for gardens and housing, and timber extraction. These could increase fugitive sediments and subsequent degradation of riparian habitat. These impacts are expected to occur over a longer period associated with increased access along maintained roads. The magnitude of this indirect impact was assessed as **very low** during construction and operations.

Given the magnitude of impacts on the watercourses and riparian habitats, and the **high** sensitivity of riparian and semi aquatic habitats, the level of significance of residual impacts on this habitat was assessed to be **moderate** during construction and **low** during operations.

14.4.4.1.4. Grasslands and Modified Habitats

The eastern flanks of the Lower Watut River valley include a number of large islands of grassland. The Grasslands (G) occur mostly on the hills but extend onto the alluvial plain. They were created by clearing forest and have been maintained and gradually extended by regular burning practices. These areas are fringed by Scrub (Sc). Swamp Grassland (Gsw) occurs where oxbow lakes and wetlands have isolated due to meanders of the Lower Watut River. By comparison with the surrounding forests, grassland habitats are relatively species poor and are dominated by generalist species.

Areas cleared of vegetation generally occur along the Highlands Highway, along the Markham, Busu and Bumbu rivers and around Lae city. Here the vegetation is made up of a patchwork of grasslands, gardens, older regrowth, coconut and cocoa plantations and cattle farms. An impoverished native flora and fauna community, typically comprised of adaptable generalist species, occurs in this habitat type and it is considered to be of low ecological value in comparison to intact forest types.

Direct disturbance from the Project will mostly occur in these previously disturbed areas with over half (55%; 767ha) of all disturbance affecting land categorised as Grassland (G) of the 'degraded' condition category, and Other Non-Forest Areas Dominated by Land-use (O) of the 'highly modified' condition category. While the scale of this loss is large, and there is potential to impact some flora and fauna populations, from an ecological perspective the magnitude of impact following implementation of proposed management measures was assessed to be **very low** during construction and operation.

Given the magnitude of impact on grasslands and modified habitats, and the **very low** sensitivity, the level of significance of residual impacts on this habitat was assessed to be **very low** during construction and operations.

14.4.4.1.5. Coastal Habitats

Estuarine swamp and mangrove forests occur in isolated patches on the Huon Gulf within the terrestrial ecology study area. These forests are comprised of sago, nipa and Mangrove Forests (M) and are relatively wet and moist. Along the sandy coastline, Littoral Beach Communities (B) consist of pioneer herbaceous communities, to scrub and tall littoral forest further away from the maximum high tide mark. Above the high tide mark, herbaceous communities comprise mainly creeping plants. Within the terrestrial ecology study area these areas have been impacted by human activities, with most of the larger trees removed and exotic tree species introduced.

Direct habitat loss and/or degradation will occur for the construction of the Infrastructure Corridor and the Outfall Area. This will impact roughly 14ha (1.0% of all disturbance). From an ecological perspective, the magnitude of impact following implementation of proposed management measures was assessed to be **very low** during construction and operation based on both their existing condition (e.g., degraded) and the scale of loss.

Given the magnitude of impact on coastal habitats, and the **low** sensitivity, the level of significance of residual impacts on this habitat was assessed to be **low** during construction and operations.

14.4.4.1.6. Lower Montane Forest Above 1,000m

There will be no direct impact during the construction and operations of the Project in the Mine Area on Lower Montane Forest above 1,000m (L), as all Project components are situated well below this elevation. However, the currently-proposed location of the resettlement village sites and the Resettlement Road to be constructed to them, will provide increased access to the relatively-intact Lower Montane Forest (L) on the southern side of the Wafi River and Hekeng River. As described in Chapter 12, Socioeconomic Environment Characterisation, Tier 1 villages typically establish gardens within a 3km radius of the village, with the majority of hunting reported to be within 5km of the village.

Figure 14.5 shows the indicative alignment of the Resettlement Road and the currently-proposed location of the resettlement villages, with the FIMS vegetation mapping for 3km and 5km radius from the villages. On the basis that it is reasonable to assume both the resettled villagers and in-migrants to the villages will establish gardens within a 3km radius of each proposed site (over an area of 2,102ha), this habitat will be indirectly impacted. In addition, based on current reported natural resource uses (Chapter 12, Socioeconomic Environment Characterisation), resettled villagers and in-migrants are likely to also hunt (particularly larger mammals) within a 5km radius of each proposed resettlement site. Increased hunting pressure on larger species residing in this area (5,202ha) is expected, and these larger target hunting species will be indirectly impacted as a result of the Project.

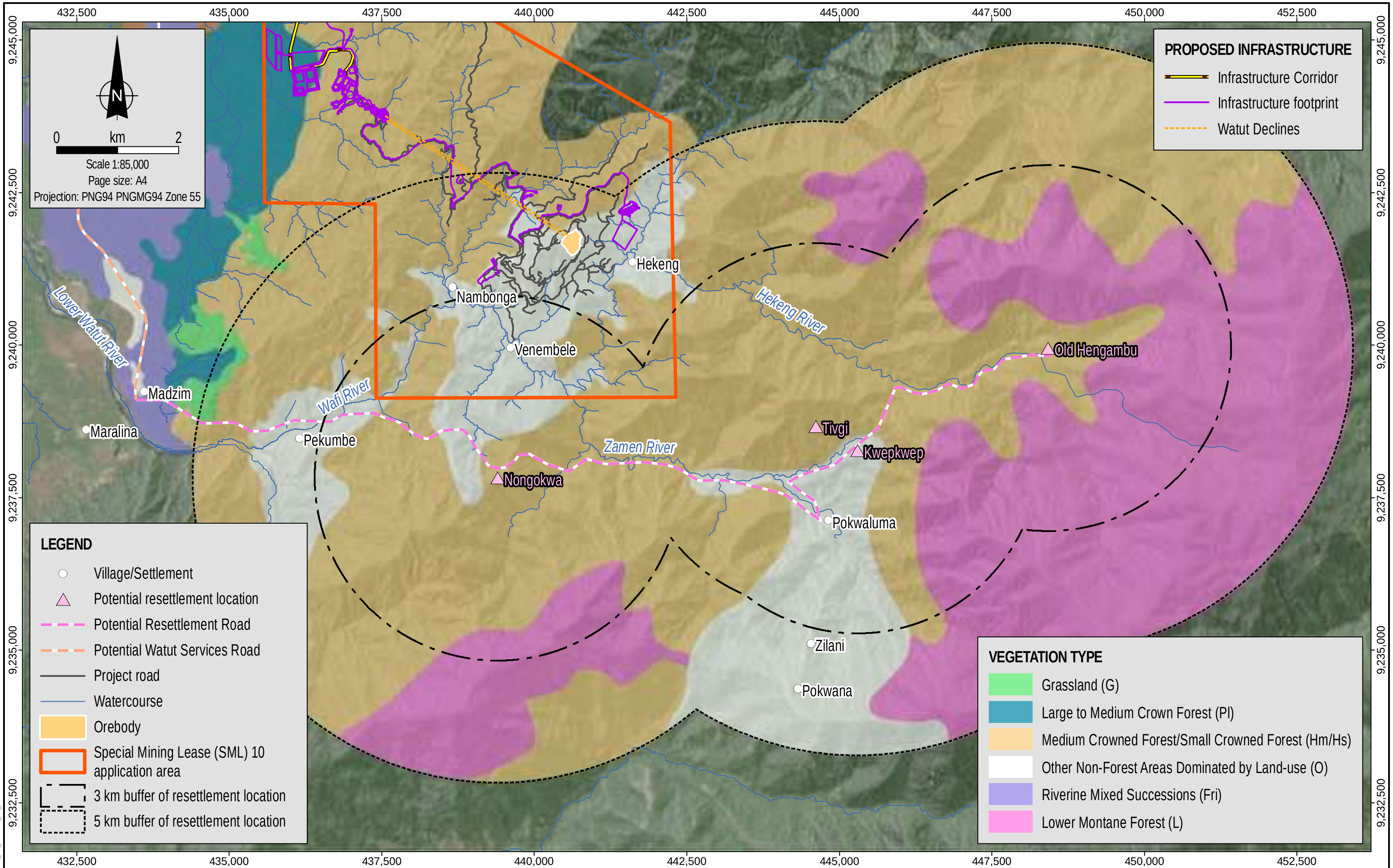
These indirect impacts will be of the same nature as those described for Hill Forest in Section 14.4.4.1.1 above. There is little the Project can do to limit indirect impacts to Lower Montane Forest in proximity to newly established villages, as villagers will garden and hunt where they choose.

The montane mammal community in Lower Montane Forest (L) is particularly significant because these species have suffered decline through the greater part of their distribution along the Central Cordilleran ranges of PNG due to overhunting and habitat modification. Species such as Goodfellow’s tree kangaroo, long-beaked echidna, small dorcopsis, bandicoots and cuscus are typically the targets of hunting. Because Lower Montane Forest (L) has a restricted distribution and because there has been no survey work to date in the areas to be indirectly impacted (to confirm the presence/absence of species likely to be the target of hunting), it has conservatively been assigned a **high** sensitivity, with **moderate** magnitude of impact and therefore the level of significance of residual impacts on this habitat was assessed to be **high**.

14.4.4.2. Residual Impacts on Flora and Fauna Populations

The extent to which flora and fauna populations would be impacted by the Project (either directly or indirectly) depends on their abundance and distribution, demographics, and ecology and how this relates to processes effected by the Project. For example, the degree to which flora and fauna populations can tolerate habitat loss or degradation varies. Species that prefer forest interiors and mature forest or those with restricted habitat requirements are most likely to be affected by habitat losses from physical disturbances.

The potential impacts on broad scale habitats (assessed above) would affect flora and fauna species which inhabit these areas to varying degrees. This assessment of population level values focuses on the population dynamics, how they interact with the environment and whether the Project (either directly or indirectly) will impact these.



Source:
Vegetation mapping from Coffey and BAAM.
Potential resettlement locations and roads, watercourses, SML and orebody from WGJV.
Villages, infrastructure and project roads from WGJV and Coffey.
Imagery from ArcGIS Online (capture date unknown).

coffey
A TETRA TECH COMPANY

Date: 12.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.05_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Resettlement sites and surrounding vegetation

Figure No: 14.5

MXD Reference: 0520DD_10_GIS047_v0_4

Impact analysis for species of conservation-significance was conducted by grouping species to reflect similar ecologies and sensitivities and by taking a conservative approach by assuming presence based on known habitats and distributions, rather than simply whether they were recorded during surveys. Most species in each group require similar proposed management measures to reduce potential impacts.

14.4.4.2.1. Flora

Residual impacts on flora populations as a direct result of habitat loss are most influenced by the spatial extent and severity of the habitat loss and the nature of the population. Some plant species are relatively continuous and widespread and occupy 'matrix habitats'. Others have specific habitat requirements (such as specific soil types) and occur in 'island habitats' that occur in more or less isolated patches within the matrix (Ashton, 2008). A major residual impact could be expected if the Project disturbance area overlaps with a population's range and thus would be subjected to range reduction and reduced overall abundance. For this to occur, their distributions would need to be restricted and coincide with an area that will be impacted by Project-related activities.

In many instances in PNG, the distributions of flora is poorly known; however, this is partly a reflection of the limited scientific research focus on these taxa, rather than the actual distribution of these species. Previous experience has shown that the ranges of poorly known (or newly discovered species) generally expand with increased survey effort in similar environments. Recent history of biodiversity surveys associated with resource projects in New Guinea has been one of continuing discoveries that gradually increase knowledge of these species.

Diospyros lolinopsis was listed as Critically Endangered in 1998 due to very few known localities. Since that time further records of the species have shown a significantly broader distribution and this species therefore requires re-assessment. Direct disturbance (and degradation) to approximately 346ha of Large to Medium Crowned Forest (Pl) on alluvial plains (described above) is likely to result in the clearance of individual plants. Like *D. lolinopsis, C. morobense* (listed as Endangered) also has the potential to be impacted by physical disturbance and degradation of Large to Medium Crowned Forest (Pl) on alluvial plains, its preferred habitat. While not recorded during field surveys, the species is endemic to the Morobe Province (Lae district).

For *D. lolinopsis*, the magnitude of the direct impact of the Project within the terrestrial ecology study area was conservatively rated as **moderate** during construction reducing to **low** during operations, based on effects to a moderate proportion of the known population and their currently known distribution and presence outside the Project disturbance area. The magnitude of direct impacts to *C. morobense* as a result of the Project (should it occur in the Project Area) was conservatively predicted to be **low** during construction and operation. Indirect impacts associated with increased access from the Northern Access Road and associated habitat loss (e.g., from small scale logging) are likely to be more significant. These impacts may have a noticeable effect on this habitat within the region and therefore the local populations of *D. lolinopsis* and *C. morobense*. Such losses are predicted to occur over a longer duration following construction of the Northern Access Road. Therefore, the magnitude of indirect impacts to these species was assessed to be **low** during construction increasing to **moderate** during operations. Given the magnitude of impact on these species, and the **very high** sensitivity, the level of significance of residual impacts on *D. lolinopsis* was assessed to be **high** during construction and operations, and on *C. morobense* was assessed to be **moderate** during construction and **high** during operations.

While *H. papuana* (Endangered) was recorded in Mixed Swamp Forest (Fsw/FswC) in the Markham Gap Basin area during field surveys, the species is generally a submontane and montane forest species. Therefore, the terrestrial ecology study area provides sub-optimal habitat and is unlikely to support an important population of this species. Any losses of individuals are likely to be barely detectable with respect to natural variability. Like *H. papuana*, *H. subcordata* (Critically Endangered) is a mid-montane forest species that has the possibility (albeit low) of occurring within hill forests but the species was not recorded during surveys. Based on its known typical locality at higher elevation (1,350m ASL), hill forests within the Project Area are likely to represent suboptimal habitat. As a result, the residual magnitude of any impact (direct or indirect) to these species from the Project was assessed to be **very low** during construction and operations. Given the magnitude of impact on these species, and the **very high** sensitivity, the level of significance of residual impacts was assessed to be **moderate** during construction and operations.

Flindersia pimenteliana (Endangered), *A. brownii* (Vulnerable) and *M. buchneriana* (Vulnerable) are rare trees threatened primarily from habitat loss; they are not harvested for timber. These inhabit foothill forests and therefore there will be direct impacts to their potential habitat (i.e., Medium Crowned Forest/Small Crowned Forest (Hm/Hs)) and potentially localised losses of individuals. Considering the scale of habitat loss, the distribution of the species and the amount of remaining habitat available, the magnitude of impact to the species within the terrestrial ecology study area was assessed to be **very low** during construction and operations. Given the magnitude of impact on these species, and their **medium** to **high** sensitivities, the level of significance of residual impacts was assessed to be **low** during construction and operations.

Kwila (*I. bijuga;* Vulnerable), New Guinea rosewood (*P. indicus;* Vulnerable) and *M. altissima* (Vulnerable) are lowland forest species distributed throughout South East Asia and Melanesia. These species are threatened from overharvesting as they are highly valued for their hardwood timber. Direct impacts to potential habitat for these species would result in localised impacts (i.e., losses of individual trees). Indirect impacts associated with increased access from the Northern Access Road would be more significant considering their value as timber and the increased access. Considering the scale of habitat loss, the distribution of the species and the amount of remaining habitat available, the magnitude of direct impact to the species within the terrestrial ecology study area was assessed to be **low** during construction and operations. Potential indirect impacts to the species within the terrestrial ecology study area was assessed to be **moderate**, which will primarily occur during operations. Given the magnitude of impact on these species, and the **medium** sensitivity, the level of significance of residual impacts was assessed to be **moderate** during construction and operations.

Another 17 species (16 trees and one herb) listed as Vulnerable by the IUCN may occur within habitats in the Project Area, based on their known distribution and habitat requirements. Physical disturbance will result in a localised, permanent loss of habitat and likely losses of individuals within these areas. Further, indirectly influenced habitat loss is likely to result in additional habitat loss and impacts to these species. However, considering these species all have broad distributions, the magnitude of impacts was assessed to be **low** during construction and operations. Given the magnitude of impact on these species, and the **medium** sensitivity, the level of significance of residual impacts was assessed to be **low** during construction and operations.

Residual impacts to Near Threatened plant species (nine recorded and eight that may occur) are expected to be similar in magnitude with localised losses of habitat and individuals. As these species were assessed to be of **low** sensitivity, the level of significance of residual impacts was assessed to be **low** during construction and operations.

14.4.4.2.2. Fauna

Fauna species vary in the degree to which they can tolerate loss of forest habitats within their range. Fauna that prefer forest interiors, specific habitat features and mature forest elements, and taxa that are subject to other threatening processes are most likely to suffer population declines (Munks and Watling, 2013).

The majority of research investigating the effects of disturbance or loss of tropical forest on fauna has focussed on birds. Species with larger or heavier bodies and those foraging on insects, or fruits, are particularly prone to declines as they often occur at low densities making them more vulnerable to habitat alterations (Sodhi et al., 2004). These findings were supported by Tvardíková (2010), who demonstrated that the main differences in the bird assemblage in small-scale secondary forest plots and in adjacent primary forest in the Wanang Conservation Area of Madang Province, was the presence or absence of canopy frugivores. Mammals appear to show some similar trends. For example, in their review of the sensitivity of forest mammals to the effects of timber harvesting in Borneo, Meijaard et al. (2008) found that intolerant species were characterised by narrow ecological niches and strict feeding habits (frugivorous, carnivorous or insectivorous) and were restricted to particular forest strata (ground or upper canopy). Reptiles are highly sensitive species compared to other fauna species, i.e., they become more vulnerable due to habitat alteration (Zakaria et al., 2016). This might be because they have a small home range, which is adversely affected by habitat loss and degradation.

A number of species are also tolerant, and indeed may benefit from creation of clearings. For example, many species of bats and birds may benefit as a result of increased habitat diversity and potential food resources.

Populations of fauna species of conservation significance with the potential to be impacted by the Project are discussed in the following section.

14.4.4.2.2.1. Canopy Birds

Five canopy birds of conservation significance were either recorded or are likely to occur in the terrestrial ecology study area, including four raptors. The Papuan eagle (*H. novaeguineae*; Vulnerable) and Gurney's eagle (*A. gurneyi*; Near Threatened) inhabit primary forest landscapes in the terrestrial ecology study area. Likewise, the eastern osprey (*P. cristatus;* Protected under the *Fauna (Protection and Control) Act 1966*) was observed along the Waime River in the terrestrial ecology study area and forages for fish in larger areas of open water. A more cryptic canopy raptor, Doria's goshawk (*M. doriae;* Near Threatened), is likely to occur in lowland forest and adjoining hill forest foothills with its range extending to lowland habitat northwest of Lae although it was not recorded during field surveys. The palm cockatoo (*P. aterrimus*) and Blyth's hornbill (*R. plicatus*), both Protected under the *Fauna (Protection and Control) Act 1966* and recorded within the terrestrial ecology study area, are common within the broader area and occupy wide ranges across PNG. Finally, the large colourful parrot, Pesquet's parrot (*P. fulgidus*; Vulnerable), was recorded at the limits of the terrestrial ecology study area, near the Atzera Mountain Range. This highly distinctive species is unlikely to occur within any areas of Project disturbance (direct or indirect), and multiple surveys at the Mine Area have shown no evidence of occurrence.

With the exception of Pesquet's parrot, these conservation priority canopy bird species are threatened from habitat loss. Pesquet's parrot is also threatened from hunting for its feathers. The Project will directly impact approximately 485ha of intact vegetation or 1,381ha including edge effects. Therefore, this may impact a number of individuals of this species from the terrestrial ecology study area, primarily during construction. These losses may be exacerbated by indirectly influenced forest loss, particularly floodplain forest (described above). The magnitude of these impacts was assessed to be **low** with a minor effect from existing baseline conditions that is unlikely to reduce the overall viability of these populations.

Given the magnitude of impact on these species, and the **very low** to **medium** sensitivities, the level of significance of residual impacts on these species was assessed to be **low** during construction and operations.

14.4.4.2.2.2. Interior Forest Birds

The primary, intact forests support birds that are specialist feeders, particularly frugivores, nectarivores and branch gleaners. As discussed above, due to their specialist ecological niches, populations of these species may experience greater change as opposed to generalist species.

Interior forest birds either recorded or likely to occur in the terrestrial ecology study area include:

- Papuan hawk-owl (*U. dimorpha;* Data Deficient) occurs in lowland rainforest or gallery forest and is a resident in hill forest in the terrestrial ecology study area and possibly also alluvial forest. While this species has a wide distribution across New Guinea, it is rare throughout its range.
- Blue-black kingfisher (*T. nigrocyaneus*; Data Deficient) is very rare throughout its range, being known from a few scattered records from streams, swamps and ponds in forest up to 600mASL. The species was recorded in a complex mosaic of Sago Palm swamps and adjoining rainforest habitats in alluvial forest.
- Forest bittern (*Z. heliosylus*; Near Threatened) has the potential to occur around streams, pools and swamps in alluvial and hill forest within the terrestrial ecology study area. This species is widely distributed, but reclusive and rarely seen.

These interior forest bird species are threatened from habitat loss and degradation. The Project will directly impact (clearance and degradation) roughly 1,381ha of intact vegetation. Therefore, this may impact a number of individuals from the terrestrial ecology study area, primarily during construction. The magnitude of these impacts was assessed to be **low** with a minor effect from existing baseline conditions that is unlikely to reduce the overall viability of these populations.

Given the magnitude of impact on these species, and the **very low** to **low** sensitivities, the level of significance of residual impacts on these species was assessed to be **low** during construction and operations.

14.4.4.2.2.3. Birds-of-Paradise

All but two birds-of-paradise and satinbirds are endemic to New Guinea and are Protected under the *Fauna (Protection and Control) Act 1966*. Within this group males are characterised by spectacular plumage while the females are duller plain brown. Most have communal display grounds (leks) where males compete for females. Four bird-of-paradise species were recorded in the terrestrial ecology study area: raggiana bird-of-paradise (*P. raggiana*); king bird-of-paradise (*C. regius*); crinkle-collared manucode (*M. chalybatus*); and glossy-mantled manucode (*M. ater*). All four species are widely distributed across PNG and not considered threatened. Both raggiana and king bird-of-paradise were common species in both hill and alluvial forests, whereas the single observations of the two manucode species suggest they are uncommon in the terrestrial ecology study area.

For populations of these species, even though some habitat will be lost, all can occupy disturbed habitat mosaics so the Project is unlikely to significantly impact local populations. The magnitude of residual direct impacts was predicted to be **very low** for all species. Hunting, primarily from increased access and in-migration associated population increase, is likely the most significant threatening process for all except the duller manucodes. The magnitude of residual indirect impacts was assessed as **low** for the decorative species that may be hunted for their plumage.

Given the magnitude of impact on these species, and the **very low** sensitivity, the level of significance of residual impacts on these species was assessed to be **low** during construction and operations (largely due to indirect impacts).

14.4.4.2.2.4. Waterbirds

A range of waterbirds was recorded within the terrestrial ecology study area. These include a number of ducks, cormorants and a range of other species. Two of these, the great egret (*A. alba*) and intermediate egret (*A. intermedia*), are Protected under the *Fauna (Protection and Control) Act 1966*. However, both species are wide spread, abundant and not of conservation significance.

Sedimentation, pollution and contamination of local watercourses has the potential to result in the mortality of individuals. This mortality would be expected to be highly localised and there is unlikely to be any long-term loss of viability of these populations as a result of the Project. Therefore, a **very low** impact magnitude was predicted, and the level of significance of residual impacts on these species was assessed to be **very low** during construction and operations.

14.4.4.2.2.5. Medium to Large Mammals

A number of medium to large mammals are of elevated conservation significance within PNG. A number of these species were recorded in the terrestrial ecology study area, or have the potential to occur.

Goodfellow's tree kangaroo (*D. goodfellowi;* Critically Endangered) was recorded as a pet at Madzim. This animal was reported to have been captured as a juvenile in montane forest in the Upper Watut River valley. The species is known to local residents who reported it being restricted to the most remote parts of the local region. While this species is likely to have occurred historically, it is highly sensitive to hunting and the proximity of local settlements means the species has likely been hunted to local extinction in the terrestrial ecology study area (which does not extend south of the Wafi River into the Lower Montane Forest above 1,000m which will be indirectly impacted by the resettlement villages). Similarly, the New Guinea pademelon (*Thylogale Browni;* Vulnerable) was recorded as a captive individual observed in Pekumbe. This species was considered unlikely to be resident in the terrestrial ecology study area (Woxvold, 2011, 2012; Woxvold and Aplin, 2013), in large part due to the heavy hunting pressure. The species may rarely move down from higher elevations. Another species that may have historically occurred in the terrestrial ecology study area is the eastern long-beaked echidna (*Z. bartoni*; Critically Endangered). Like Goodfellow's tree kangaroo and New Guinea pademelon, this species is highly sensitive to hunting pressure and the proximity of local settlements means the species has likely been hunted to local extinction in the terrestrial ecology study area.

Three smaller mammals have the potential to occur in the terrestrial ecology study area, based on their distribution and habitat preferences. These are New Guinea quoll (*D. albopunctatus;* Near Threatened), black-spotted cuscus (*S. rufoniger;* Critically Endangered), and small dorcopsis (*D. vanheurni;* Near Threatened). The New Guinea quoll

(*D. albopunctatus*) was either not recognised or said to be absent by local residents during community interviews, and the black-spotted cuscus and small dorcopsis are sensitive to hunting pressure and unlikely to occur in the terrestrial ecology study area due to proximity of settlements.

Direct impacts on these threatened mammal species are not predicted based on their predicted absence from the terrestrial ecology study area.

Indirect impacts are more difficult to predict, but it is possible that these species may occur in the upper reaches of the Wafi River catchment in less populated and therefore less disturbed and hunted habitat. The resettlement of Nambonga, Venembele and Hekeng will bring a population influx into higher elevations, specifically at:

- Nongokwa, the proposed site is situated at approximately 800mASL, with elevations up to 1,000mASL within 5km.
- Tivgi, the proposed site is situated at approximately 800mASL, with elevations up to 1,000mASL within 5km.
- Kwepkwep, the proposed site is situated at approximately 700mASL, with elevations up to 1,200mASL within 5km.
- Old Hengambu, the proposed site is situated at approximately 850mASL, with elevations up to 1,600mASL within 5km.

These species may be present at higher elevations, where access has traditionally been limited due to the difficulty in access. Increased hunting pressure surrounding these villages is likely to impact these species. With the exception of the New Guinea pademelon, the indirect impacts for these species are expected to be in the more remote parts of the local region, where populations would persist, resulting in **low** magnitude of impact. A **moderate** magnitude of impact is predicted for the New Guinea pademelon as the increased hunting pressure may threaten the viability of a local study area population, though this is unlikely across the broader local region.

Given the magnitude of impact on the Goodfellow's tree kangaroo, New Guinea pademelon, eastern long-beaked echidna and black-spotted cuscus, and their **medium** to **very high** sensitivities, the level of significance of residual impacts on these species was assessed to be **moderate** due to indirect impacts. The magnitude of impact on the New Guinea quoll and small dorcopsis, with their **low** sensitivity, resulted in a **low** significance of residual impact.

14.4.4.2.2.6. Interior Forest Bats

Two interior forest bats trapped during the 2012 survey currently lack scientific names (Woxvold and Aplin, 2013). These are a tube-nosed bat of the genus *Nyctimene*, and a blossom bat of the genus *Macroglossus*. Both are known to occur widely in PNG and to be locally common at other localities.

The Project may impact a number of individuals from within the terrestrial ecology study area, primarily during construction. Given the wide-spread nature and commonality of these species, the magnitude of these impacts was assessed to be **low** with a minor effect from existing baseline conditions that is unlikely to reduce the overall viability of these populations.

Given the magnitude of impact on these species, and the **very low** sensitivity, the level of significance of residual impacts on these species was assessed to be **low** during construction and operations.

Table 14.23 Summary of terrestrial ecology residual impact assessment

Terrestrial Ecology Value	Potential Impact	Impact Type	Management Objective Proposed	Residual Impact Assessment*		
				Sensitivity	Magnitude	Residual Impact Significance
Ecological Habitats						
Hill Forest	Habitat loss and/or degradation as a result of: • Physical disturbance • Invasive weeds and pests • Increased fire risk • Altered land use	Direct	• Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Prevent uncontrolled fires from starting. • Maintain canopy connectivity and progressively rehabilitate sites as practicable.	Medium	C - Low O - Very low	C / O - Moderate
		Indirect			C / O - Moderate	
Alluvial Forest (Floodplain Forest)	Habitat loss and/or degradation as a result of: • Physical disturbance • Invasive weeds and pests • Altered hydrology • Erosion and sedimentation • Altered land use, including logging	Direct	• Reduce the Project footprint, habitat loss and disturbance. • Maintain hydrological connectivity of floodplains. • Limit erosion and capture mobilised sediments. • Avoid the introduction and spread of weeds, plant pathogens and pests. • Implement access protocols for Project-related roads. • Maintain canopy connectivity and progressively rehabilitate sites as practicable. • Maintain existing drainage patterns.	Very high	C - Moderate O - Low	C - High O - Major
		Indirect			C - Moderate O - High	
Alluvial Forest (Swamp Forest and Swamp Woodland)	Habitat loss and/or degradation as a result of: • Physical disturbance • Invasive weeds and pests • Altered hydrology • Erosion and sedimentation	Direct	• Reduce the Project footprint, habitat loss and disturbance. • Maintain hydrological connectivity of floodplains. • Limit erosion and capture mobilised sediments. • Limit the introduction and spread of weeds, plant pathogens and pests. • Maintain canopy connectivity and progressively rehabilitate sites as practicable. • Maintain existing drainage patterns.	Low	C / O - Moderate	C / O - Low
		Indirect			C / O - Low	
Riparian and Semi Aquatic Habitats	Habitat loss and/or degradation as a result of: • Physical disturbance • Altered hydrology • Erosion and sedimentation • Chemical contamination • Invasive weeds and pests	Direct	• Reduce the Project footprint, habitat loss and disturbance. • Maintain hydrological connectivity of floodplains. • Limit erosion and capture mobilised sediments. • Limit the introduction and spread of weeds, plant pathogens and pests. • Maintain canopy connectivity and progressively rehabilitate sites as practicable. • Maintain existing drainage patterns.	High	C - Low O - Very low	C - Moderate O - Low
		Indirect			C / O - Very low	
Grasslands and Modified Habitats	Habitat loss degradation as a result of: • Physical disturbance	Direct	• Reduce the Project footprint, habitat loss and disturbance.	Very low	C / O - Very low	C / O - Very low

Terrestrial Ecology Value	Potential Impact	Impact Type	Management Objective Proposed	Residual Impact Assessment*		
				Sensitivity	Magnitude	Residual Impact Significance
Coastal Habitats	Habitat loss as a result of: • Physical disturbance	Direct	• Reduce the Project footprint, habitat loss and disturbance.	Low	C / O - Very low	C / O - Low
Lower Montane Forest above 1,000m	Habitat loss and/or degradation as a result of: • Physical disturbance • Invasive weeds and pests • Increased fire risk • Altered land use	Indirect	• Implement access protocols for Project-related roads.	High	O - Moderate	O - High
Flora						
D. lolinopsis	Individual, and habitat loss and/or degradation as a result of: • Physical disturbance • Increased fire risk • Altered land use	Direct Indirect	• Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Implement access protocols for Project-related roads. • Maintain canopy connectivity and progressively rehabilitate sites as practicable.	Very high	C - Moderate O - Low C - Low O - Moderate	C / O – High
C. morobense	ndividual, and habitat loss and/or degradation as a result of: • Physical disturbance • Increased fire risk • Altered land use	Direct Indirect	• Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Implement access protocols for Project-related roads. • Maintain canopy connectivity and progressively rehabilitate sites as practicable.	Very high	C / O - Low C - Low O - Moderate	C - Moderate O - High
H. papuana	Individual, and habitat loss and/or degradation as a result of: • Physical disturbance • Increased fire risk • Altered land use	Direct Indirect	• Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Implement access protocols for Project-related roads. • Maintain canopy connectivity and progressively rehabilitate sites as practicable.	Very high	C / O - Very low	C / O - Moderate
H. subcordata	Individual, and habitat loss and/or degradation as a result of: • Physical disturbance • Increased fire risk • Altered land use	Direct Indirect	• Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Implement access protocols for Project-related roads. • Maintain canopy connectivity and progressively rehabilitate sites as practicable.	Very high	C / O - Very low	C / O - Moderate

<table>
<tr><th rowspan="2">Terrestrial Ecology Value</th><th rowspan="2">Potential Impact</th><th rowspan="2">Impact Type</th><th rowspan="2">Management Objective Proposed</th><th colspan="3">Residual Impact Assessment*</th></tr>
<tr><th>Sensitivity</th><th>Magnitude</th><th>Residual Impact Significance</th></tr>
<tr><td rowspan="2">F. pimenteliana</td><td rowspan="2">Individual, and habitat loss and/or degradation as a result of:
• Physical disturbance
• Increased fire risk
• Altered land use</td><td>Direct</td><td rowspan="2">• Reduce the Project footprint, habitat loss and disturbance.
• Limit the introduction and spread of weeds, plant pathogens and pests.
• Implement access protocols for Project-related roads.
• Maintain canopy connectivity and progressively rehabilitate sites as practicable.</td><td rowspan="2">High</td><td rowspan="2">C / O - Very low</td><td rowspan="2">C / O - Low</td></tr>
<tr><td>Indirect</td></tr>
<tr><td rowspan="2">A. brownii</td><td rowspan="2">Individual, and habitat loss and/or degradation as a result of:
• Physical disturbance
• Increased fire risk
• Altered land use</td><td>Direct</td><td rowspan="2">• Reduce the Project footprint, habitat loss and disturbance.
• Limit the introduction and spread of weeds, plant pathogens and pests.
• Implement access protocols for Project-related roads.
• Maintain canopy connectivity and progressively rehabilitate sites as practicable.</td><td rowspan="2">Medium</td><td rowspan="2">C / O - Very low</td><td rowspan="2">C / O - Low</td></tr>
<tr><td>Indirect</td></tr>
<tr><td rowspan="2">M. buchneriana</td><td rowspan="2">Individual, and habitat loss and/or degradation as a result of:
• Physical disturbance
• Increased fire risk
• Altered land use</td><td>Direct</td><td rowspan="2">• Reduce the Project footprint, habitat loss and disturbance.
• Limit the introduction and spread of weeds, plant pathogens and pests.
• Implement access protocols for Project-related roads.
• Maintain canopy connectivity and progressively rehabilitate sites as practicable.</td><td rowspan="2">Medium</td><td rowspan="2">C / O - Very low</td><td rowspan="2">C / O - Low</td></tr>
<tr><td>Indirect</td></tr>
<tr><td rowspan="2">Kwila (I. bijuga)</td><td rowspan="2">Individual, and habitat loss and/or degradation as a result of:
• Physical disturbance
• Increased fire risk
• Altered land use, including logging</td><td>Direct</td><td rowspan="2">• Reduce the Project footprint, habitat loss and disturbance.
• Limit the introduction and spread of weeds, plant pathogens and pests.
• Implement access protocols for Project-related roads.
• Maintain canopy connectivity and progressively rehabilitate sites as practicable.</td><td rowspan="2">Medium</td><td>C / O - Low</td><td rowspan="2">C / O - Moderate</td></tr>
<tr><td>Indirect</td><td>C / O - Moderate</td></tr>
<tr><td rowspan="2">New Guinea rosewood (P. indicus)</td><td rowspan="2">Individual, and habitat loss and/or degradation as a result of:
• Physical disturbance
• Increased fire risk
• Altered land use, including logging</td><td>Direct</td><td rowspan="2">• Reduce the Project footprint, habitat loss and disturbance.
• Limit the introduction and spread of weeds, plant pathogens and pests.
• Implement access protocols for Project-related roads.
• Maintain canopy connectivity and progressively rehabilitate sites as practicable.</td><td rowspan="2">Medium</td><td>C / O - Low</td><td rowspan="2">C / O - Moderate</td></tr>
<tr><td>Indirect</td><td>C / O - Moderate</td></tr>
</table>

Terrestrial Ecology Value	Potential Impact	Impact Type	Management Objective Proposed	Residual Impact Assessment*		
				Sensitivity	Magnitude	Residual Impact Significance
M. altissima	Individual, and habitat loss and/or degradation as a result of: • Physical disturbance • Increased fire risk • Altered land use, including logging	Direct	• Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Implement access protocols for Project-related roads. • Maintain canopy connectivity and progressively rehabilitate sites as practicable.	Medium	C / O - Low	C / O - Moderate
		Indirect			C / O - Moderate	
Seventeen IUCN vulnerable species; *A. flavescens, A. lepiorrhachis, P. prolifera, C. robustum, G. papuana, A. brassii, A. cremea, C. bullata, G. unguiculata, H. clavata, M. papyracea, M. altissima, M. pygmaea, M. schlechteri, M. sinclairii, C. stellatus, P. papilionaceum*	Individual, and habitat loss and/or degradation as a result of: • Physical disturbance • Increased fire risk • Altered land use	Direct	• Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Implement access protocols for Project-related roads. • Maintain canopy connectivity and progressively rehabilitate sites as practicable.	Medium	C / O - Low	C / O - Low
		Indirect				
Fauna						
Canopy Birds	Individual, and habitat loss and/or degradation as a result of: • Physical disturbance • Invasive weeds and pests • Altered land use • Hunting pressures	Direct	• Prohibit disturbance or harassment of wildlife, including hunting, by project personnel. • Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Implement access protocols for Project-related roads.	Very low to Medium	C / O - Low	C / O - Low
		Indirect				
Interior Forest Birds	Individual, and habitat loss and/or degradation as a result of: • Physical disturbance • Invasive weeds and pests • Altered land use	Direct	• Prohibit disturbance or harassment of wildlife by project personnel. • Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests.	Very low to Low	C / O - Low	C / O - Low
		Indirect				
Birds-of-Paradise	Individual, and habitat loss and/or degradation as a result of: • Physical disturbance • Hunting pressures	Direct	• Prohibit disturbance or harassment of wildlife, including hunting, by project personnel. • Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Implement access protocols for Project-related roads.	Very low	C / O - Very low	C / O - Low
		Indirect			C / O - Low	

Terrestrial Ecology Value	Potential Impact	Impact Type	Management Objective Proposed	Residual Impact Assessment*		
				Sensitivity	Magnitude	Residual Impact Significance
Waterbirds	Individual, and habitat loss and/or degradation as a result of: • Altered hydrology • Erosion and sedimentation • Chemical contamination	Direct Indirect	• Reduce the Project footprint, habitat loss and disturbance. • Maintain hydrological connectivity of floodplains. • Limit erosion and capture mobilised sediments.	Very low	C / O - Very low	C / O - Very low
Medium to Large Mammals (Goodfellow's tree kangaroo, eastern long-beaked echidna, black-spotted cuscus)	Individual, and habitat loss and/or degradation as a result of: • Altered land use • Hunting pressures	Indirect	• Prohibit disturbance or harassment of wildlife, including hunting, by project personnel. • Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests. • Prevent accidental trapping of fauna, e.g., ensure trenches have escape routes. • Implement access protocols for Project-related roads.	Very high	O - Low	O - Moderate
Medium to Large Mammals (New Guinea pademelon)				Medium	O - Moderate	O - Moderate
Medium to Large Mammals (New Guinea quoll, small dorcopsis)				Low	O - Low	O - Low
Interior Forest Bats	Individual, and habitat loss and/or degradation as a result of: • Physical disturbance • Invasive weeds and pests • Altered land use	Direct Indirect	• Prohibit disturbance or harassment of wildlife, including hunting, by project personnel. • Reduce the Project footprint, habitat loss and disturbance. • Limit the introduction and spread of weeds, plant pathogens and pests.	Very low	C / O - Low	C / O - Low

* Note 'C' denotes construction phase and 'O' denotes operations phase.

14.4.5. Monitoring

Monitoring of the impacts of the Project on terrestrial ecology values and the performance of the proposed management measures is proposed to include the following:

- Vegetation monitoring to enable comparison of quantitative data collected over time and identification of trends. Sites will be visually inspected by suitably qualified personnel noting the changes in abundance, composition and condition of vegetation communities. A particular focus will be on threatened vegetation communities. Vegetation monitoring will also include impact and control sites to assess potential effects of SO_2.
- Fauna monitoring to enable comparison of quantitative data collected over time and identification of trends. Monitoring will be undertaken by suitably qualified personnel, and will include targeted counts of threatened species and noting the changes in abundance, composition and condition of fauna species.
- Regular monitoring of areas considered to possess high potential for, or likelihood to, exhibit infestation from exotic species, both flora and fauna. This may include areas of cleared vegetation, along roads or near Project facilities (particularly waste storage areas and around water sources).
- Maintaining a record of the timing and extent of rehabilitation of temporarily cleared areas, and monitoring the success of rehabilitation by recording the canopy height of rehabilitation, percentage native plant species cover and percentage weed species cover every two years.
- Weed and pest monitoring of Project disturbance areas focussing on areas with high susceptibility to weed and pest invasion, including along roadsides, watercourse crossing, recently cleared areas and newly rehabilitated areas.

14.5. Air Quality

This section describes the air quality impacts of the Project, based on the assessment conducted by SLR Consulting Australia (SLR) and presented in Appendix A, Air Quality and Greenhouse Gas Impact Assessment.

14.5.1. Assessment Method Inputs

Environmental values to be protected from an air quality perspective are:

- Good quality and visibility of air to support human health and wellbeing.
- Health of animals and plants to support ecosystems, crops and gardens. Impacts to this value is assessed in Section 14.4.
- Amenity of the ambient environment and the useful life and aesthetic appearance of buildings, structures, property and materials. The impact assessment depends on how any changes in the value are perceived by people. Consequently, impacts on amenity are assessed in Chapter 18, Socioeconomic Impact Assessment.

Air emissions from key Project activities were modelled to simulate dispersion of the emissions in the atmosphere. The predicted ground level concentrations of air pollutants were compared against Project air quality criteria. This approach was applied to emissions from the Project activities listed in Table 14.24. Details of emission rates and assumptions used in the modelling for each of these activities are provided in Appendix A, Air Quality and Greenhouse Gas Impact Assessment.

Table 14.24: Modelled emission sources

Activity	Potential Emissions Sources
Construction	
Construction of the mine site infrastructure including Watut and Nambonga declines and ventilation shaft, process plant and portal terraces and associated infrastructure, Watut and Miapilli waste rock dumps, accommodation camp, electricity generation facilities, borrow pits, quarry and gravel extraction operations	• Particulate matter from earthworks. • Particulate matter and gases from blasting. • Particulate matter from handling, transport and disposal of waste rock at the waste rock dumps. • Particulate matter from wind erosion of open areas, the waste rock dumps, borrow pits, quarry and stockpiles. • Exhaust emissions from diesel powered equipment such as trucks, excavators and bulldozers. • Particulate matter and gaseous emissions from Watut and Nambonga declines and the ventilation shaft.
On-site diesel generators	• Combustion emissions and particulate matter.
Operation	
Mine operation	• Particulate matter from ore handling and processing. • Particulate matter from wind erosion of disturbed areas and stockpiles. • Exhaust emissions from diesel powered equipment such as trucks, excavators and bulldozers.
Operation of declines and ventilation shaft	• Particulate matter and gaseous emissions from Watut Declines and the ventilation shaft.
Operation of power generation facilities	• Combustion emissions and particulate matter.

Air emissions from these sources were modelled using CALPUFF, the United States Environmental Protection Agency's (US EPA) modelling system. CALPUFF uses topography and meteorological data, measured background levels of pollutants (described in Chapter 8, Physical and Biological Environment Characterisation) and estimated emission rates, to simulate the dispersion of air emissions from construction and operation of the Project.

The model predicted ground level concentrations for key air pollutants at nominated sensitive receptors, which were then compared against adopted Project air quality criteria. The sensitive receptors relevant to the air quality assessment are the villages that may be impacted by air emissions. These are described in Chapter 8, Physical and Biological Environment Characterisation.

State of Papua New Guinea regulations do not include specific air quality criteria. Therefore Project-specific criteria, based on international standards, have been adopted to determine compliance. The air quality criteria adopted have been taken from World Health Organisation (WHO), US EPA and Australian guidelines. These criteria are based on acceptable limits to protect human health, biodiversity and local amenity. In addition, due to potential human health effects from SO_2 emissions from the power generation facilities, a targeted review of relevant literature, and international and national guidelines for the protection of human health was undertaken. This assessment and its outcomes are described in Appendix W, Human Health Risk Assessment.

The Project assessment criteria for ambient air quality are provided in Table 14.25.

Table 14.25: Adopted Ambient Air Quality Criteria

Type of Emissions	Pollutant	Averaging Period	Limit	Reference
Combustion emissions	NO_2	1 hour	200µg/m^3	World Health Organisation, 2005
		Annual	40µg/m^3	World Health Organisation, 2005
	SO_2	1 hour	350µg/m^3	Project site-specific assessment (Appendix W)
	CO	1 hour	30,000µg/m^3	World Health Organisation, 2000
		24 hours	10,000µg/m^3	World Health Organisation, 2000
Particulate emissions	Total Suspended Particulate matter	24 hours	150µg/m^3	US EPA, 2012
		Annual	75µg/m^3	US EPA, 2012
	PM_{10}	24 hours	50µg/m^3	World Health Organisation, 2005
		Annual	20µg/m^3	World Health Organisation, 2005
	$PM_{2.5}$	24 hours	25µg/m^3	World Health Organisation, 2005
		Annual	10µg/m^3	World Health Organisation, 2005
	Dust deposition	Annual (incremental impact)	2g/m^2/month	NSW EPA, 2016
		Annual (cumulative impact)	4g/m^2/month	NSW EPA, 2016

It is difficult to model emissions for some Project activities due to the short timeframe of activities, changes in location of emission sources and inconsistent rate of emissions. This includes activities such as construction of the trench for the concentrate, terrestrial tailings and fuel pipelines, and construction of the Northern Access Road. For these activities, the risk assessment method set out in *IAQM Guidance on the Assessment of Dust from Demolition and Construction* (IAQM, 2014), a guideline developed in the United Kingdom by the Institute of Air Quality Management, was adopted.

The assessment method in IAQM (2014) assesses the risk of sensitive receptors to adverse health and amenity impacts from temporal impacts of dust, based on their proximity to construction activities and the scale and intensity of the activities. Separation of activities from sensitive receptors is the key mitigation for reducing risk. Further details of this approach are provided in Appendix A, Air Quality and Greenhouse Gas Impact Assessment.

This approach was applied to particulate emissions from the sources set out in Table 14.26.

Table 14.26: Emissions sources informing separation distance assessment

Activity	Potential Emissions Sources
Construction of access roads and pipelines	• Particulate matter from earthworks.
Construction of Port Facilities Area and Outfall Area	• Particulate matter from earthworks.

A number of emission sources were not subject to detailed assessment as those emissions are expected to be negligible. Due to the nature of operational activities, air emissions from the operation of the Northern Access Road, pipelines, Port Facilities Area and Outfall Area are predicted to be minimal and are unlikely to impact on the environment. The concentrate storage shed and ship loading conveyors at the Port Facilities Area have been designed to limit fugitive concentrate dust emissions (see Chapter 6, Project Description) and the Outfall Area is a gravity fed pumping system. On this basis, emissions are predicted to be negligible and a detailed assessment has not been completed.

14.5.2. Potential Impacts

Air emissions from Project sources listed in Table 14.24 have the potential to impact on sensitive receptors including human health and wellbeing, amenity and the health of ecosystems.

14.5.3. Proposed Management Measures

This section presents an overview of the proposed management measures to reduce the air quality impacts of the Project. Specific measures are detailed in the Project EMP (Attachment 3). Proposed key measures include:

- Apply dust suppression in the vicinity of sensitive receptors (e.g., villages, schools, churches), as required during extended dry periods.
- Prohibit unauthorised lighting of fires by Project personnel and contractors.
- Maintain site access roads.
- Cover the concentrate storage area and ship loading conveyors in order to contain concentrate dust and equip conveyors with rain/dust covers and suitable drip/spillage trays.

14.5.4. Residual Impact Assessment

The air quality assessment completed by SLR (Appendix A, Air Quality and Greenhouse Gas Impact Assessment) demonstrated that ambient air quality criteria are predicted to be met during construction and operation of the Project for the majority of pollutants.

Emissions from operation of the power generation facilities may impact on human health and the environment due to emissions of SO_2. The potential impacts on human health are discussed in Chapter 19, Health Risk Assessment. The potential impacts on vegetation are discussed in Section 14.4.4.

This section summarises the results of the air quality assessment. The assessment has been completed using the compliance standard assessment method, i.e., the predicted emissions are predicted to either comply with the adopted Project air quality criteria or not.

14.5.4.1. Construction Impacts

The majority of particulate emissions during construction in the Mine Area will be from dust created from haulage of material from borrow pits, the quarry and gravel extraction, haulage of material to the waste rock dumps, and from exhaust discharges from the declines. The predicted concentrations of $PM_{2.5}$, PM_{10} and total suspended particulate matter at sensitive receptors are below the adopted Project air quality criteria for both the maximum 24-hour and annual average concentrations. The predicted dust deposition rates from construction activities are also well below the air quality criteria at sensitive receptors and it is predicted that there will be no noticeable change in the rate of dust deposition due to construction at these locations.

The majority of combustion emissions during construction within the Mine Area will be from on-site diesel generators used to provide power until the power generation facilities are operational. The predicted concentrations of SO_2, nitrogen dioxide (NO_2) and carbon monoxide (CO) at sensitive receptors during construction are well below the adopted Project air quality criteria.

As discussed above, because of the temporal nature of dust emissions from construction activities for the Infrastructure Corridor, Port Facilities Area and Outfall Area (from earthworks and vegetation clearing), the air quality assessment consisted of a risk assessment of the sensitivity of receptors and type of activity.

For construction of the Infrastructure Corridor, the majority of sensitive receptors are currently situated more than 350m from construction activities, which is the recommended distance for no adverse health or amenity impacts from dust for that type and scale of construction activity. The exceptions are:

- Papas, which is currently located approximately 300m from construction activities.
- Zirriuk, which is currently located approximately 300m from construction activities.
- Durung Farm, which is currently less than 20m from construction activities.
- Markham Farm, which is currently approximately 200m from construction activities.
- Residences in northern Lae that are currently within approximately 20m of construction activities.

The assessment concluded that while Durung Farm and northern Lae are highly sensitive to impacts, due to the small magnitude of dust emissions, there is a low risk of dust soiling impacts at these receptors at their current location. This risk can be mitigated through implementation of proposed management measures set out in Section 14.5.3 as well as the additional measures presented in the Project EMP (Attachment 3). All other risks, including the risk of human health impacts, were assessed as being either low or negligible.

While not modelled by SLR, the proposed Watut Services Road and Resettlement Road will be constructed within 350m of Kapunung, Wori, Madzim, Pekumbe and Pokwaluma villages. This is to be expected given that the purpose of the roads is to provide road access to the villages. Nevertheless, the risk of dust soiling or human health impacts due to air quality at these villages is expected to be similar to those described for the Infrastructure Corridor, i.e., low to negligible.

The closest sensitive receptors to the Port Facilities Area and Coastal Area are currently approximately 1km and 1.6km away from construction activities, respectively. These distances are further than the recommended distance of 500m, so the risk of dust spoiling or impacts to human health from the Port Facilities Area or Coastal Area was assessed as negligible.

The assessment of air quality impacts during construction of the Project demonstrated that predicted pollutant concentrations at sensitive receptors would be below the air quality criteria adopted for the Project. These criteria are based on internationally-recognised limits to protect human health, biodiversity and local amenity (see Table 14.25). Achieving these limits means that the impacts of dust and combustion emissions during construction would not adversely affect human heath, biodiversity and local amenity.

14.5.4.2. Mine Area Operations Impacts

During operations there will be particulate and combustion emissions generated at the Mine Area. The majority of emissions will be from the power generation facilities, with some combustion emissions from vehicles, mobile plant and particulate emissions from material handling, bulldozer operation, ventilation and wind erosion.

Emissions from the waste incinerator have not been modelled, as currently sensitive receptors are located beyond the 500m buffer distance recommended by EPAV (1990) to prevent air quality and odour nuisance impacts due to solid waste management activities.

Modelling of particulate concentrations during mine operations predicted that air quality criteria will be met at the current locations of all sensitive receptors for $PM_{2.5}$, PM_{10}, total suspended particulate matter and dust deposition. These modelled emissions are presented in Figure 14.6 and Figure 14.7.

Modelling of combustion emissions predicted that CO and NO_2 concentrations at the current locations of sensitive receptors will be within adopted Project air quality criteria. Predicted emissions of NO_2 at Ziriruk, however, were only slightly below the criteria for one hour and annual average concentrations, with predictions of 199.8µg/m^3 and 39.2µg/m^3 respectively.

The predicted one hour average concentrations of SO_2 comply with the air quality criteria at all receptors with the exception of Ziriruk and Fly Camp. The predicted concentration at Ziriruk is 849 µg/m^3, and at Fly Camp is 605 µg/m^3. These predictions use only one year of site-representative meteorological conditions, while the Project criterion is based on a three-year average. A three-year average tends to flatten out peaks from unusual weather patterns or climate variations from year to year, or emission surges due to short-term technical problems in one year. These exceedances are described further with respect to human health impacts in Chapter 19, Health Risk Assessment.

The one hour average predicted combustion emissions for mine operations are presented in Figure 14.8.

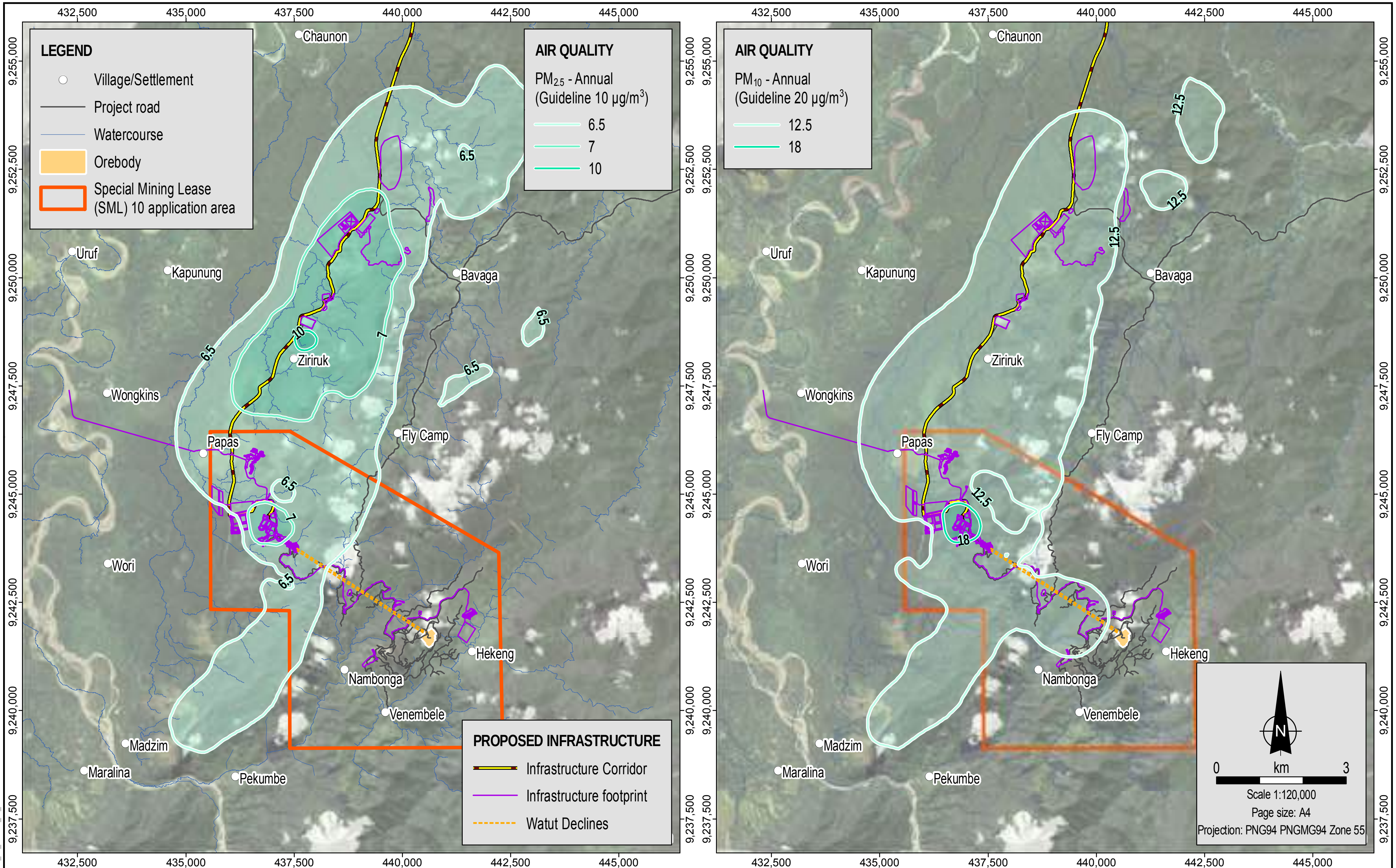
14.5.5. Monitoring

Monitoring of emissions from the on-site diesel generators (during construction) and the power generation facilities and waste incinerators (during operations) will be performed to confirm actual emissions are within estimates predicted in this EIS. The proposed monitoring program would include consideration of:

- Oxides of nitrogen (NO, NO_2 and NO_X)
- Sulphur dioxide (SO_2)
- Carbon monoxide (CO)
- Particulate matter
- Metals
- Volatile organic compounds
- Exhaust gas conditions from the power generation facilities (e.g., temperature, exit velocity, oxygen and moisture contents)

In conjunction, the existing dust deposition monitoring program would continue to provide monitoring data on dust deposition levels as the Project progresses.

Furthermore, targeted monitoring of ambient SO_2 at Ziriruk and Fly Camp will be performed during the early stages of the operations phase, when the Project power demand and corresponding emissions from the power generation facilities is lower, to verify the modelling predictions. Additional management measures will be required if monitoring confirms that exceedances of the Project air quality criteria are expected once the power generation facilities are operating at full capacity. Management measures such as scrubbers on the power generation facilities' stacks or increasing the exhaust gas exit velocity will be implemented as required, with the WGJV committed to achieving compliance with adopted air quality criteria.



Source:
Air quality from SLR.
Watercourses, 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

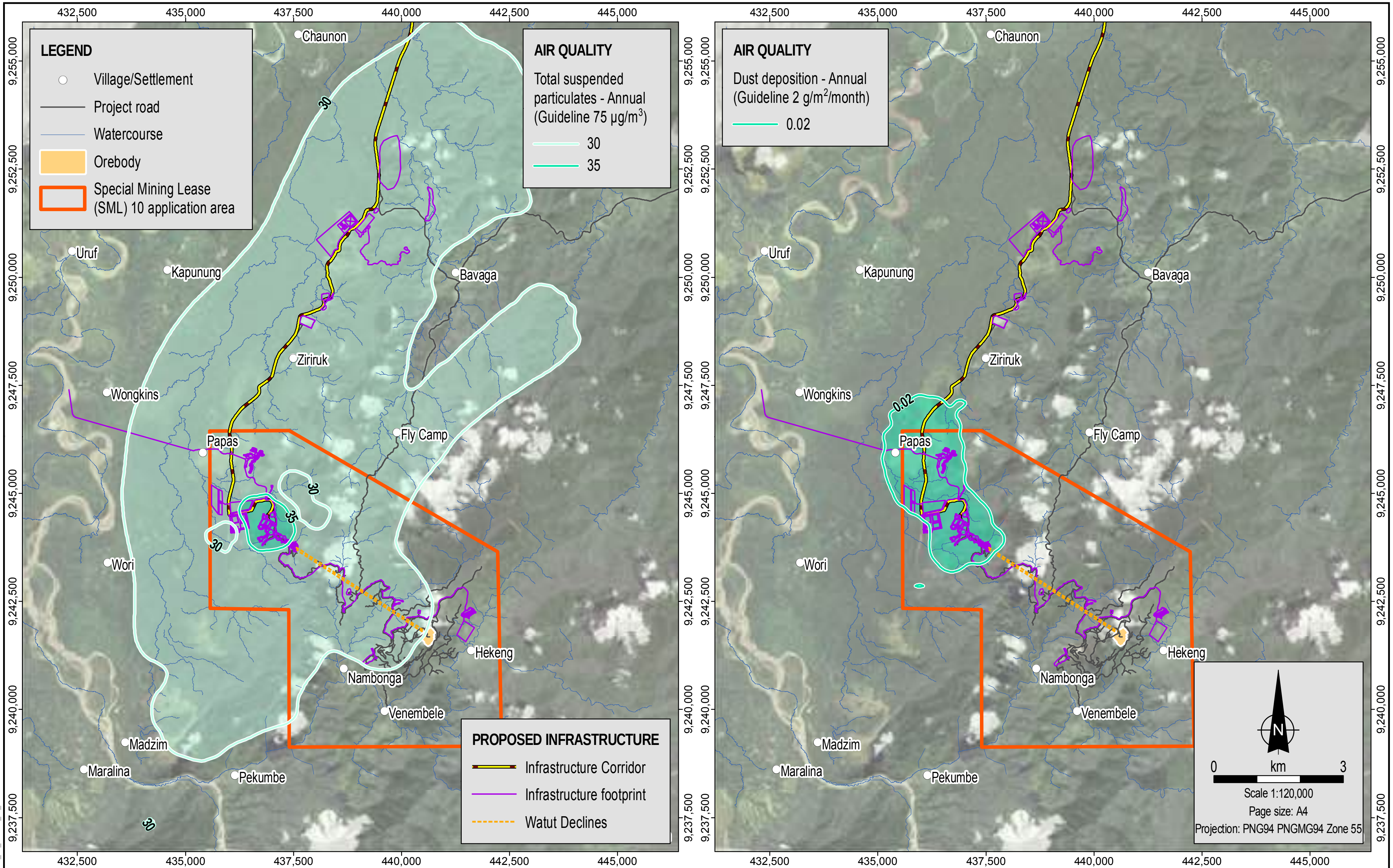
Date: 24.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.06_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Annual average $PM_{2.5}$ and PM_{10} concentrations during operations

Figure No: 14.6



MXD Reference: 0520DD_10_GIS055_v0_4

Source:
Air quality from SLR.
Watercourses, 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

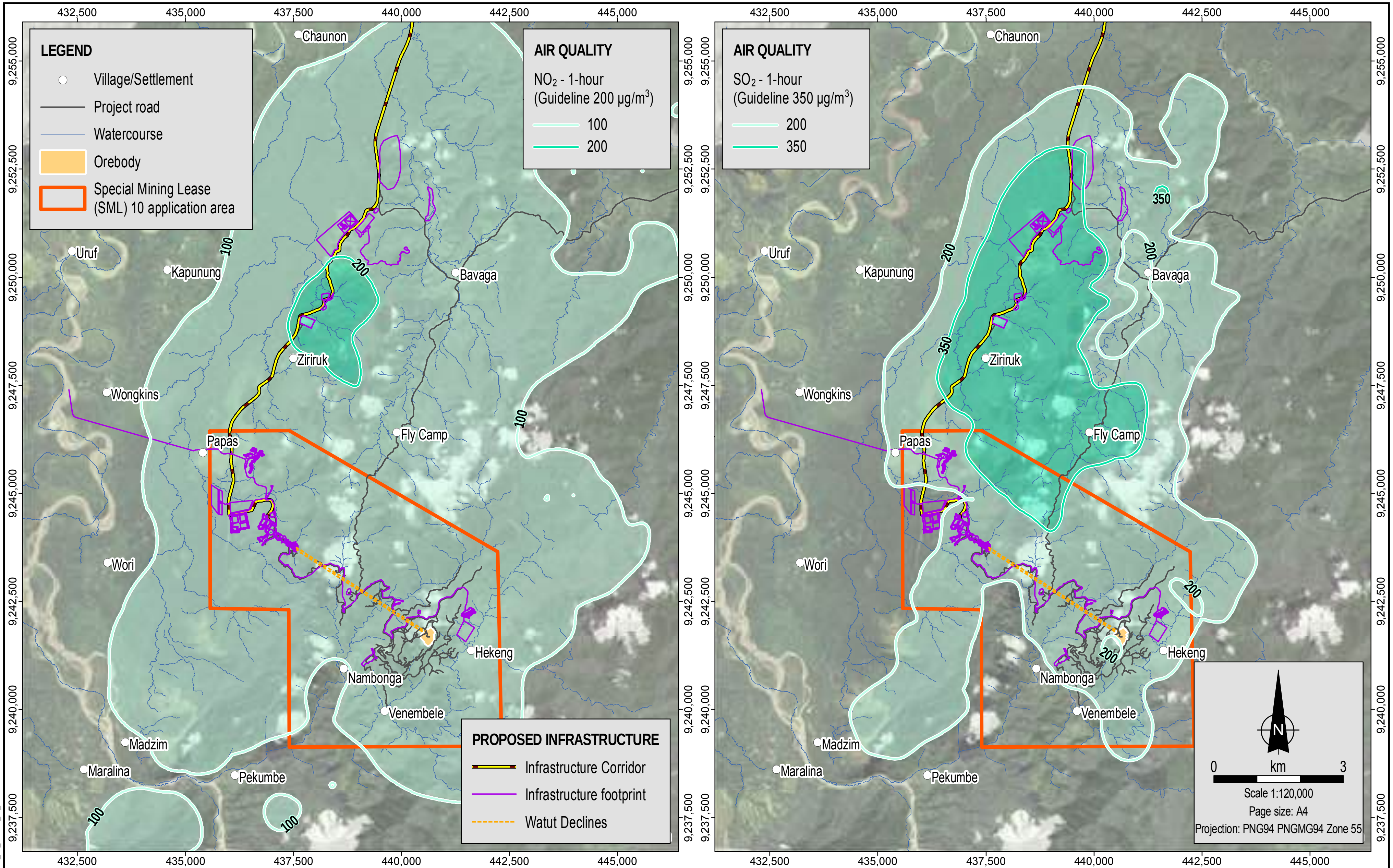
Date: 24.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.07_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Annual average total suspended particulates concentrations and dust deposition rates during operations

Figure No: **14.7**



Source:
Air quality from SLR.
Watercourses, 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: 24.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.08_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

1-hour average NO_2 and SO_2 concentrations during operations

Figure No: 14.8

MXD Reference: 0520DD_10_GIS056_v0_4

All monitoring will be conducted annually during construction and operations, and until closure criteria are met post mine closure.

14.6. Greenhouse Gas Assessment

This section describes the greenhouse gas emissions of the Project, based on the assessment conducted by SLR and presented in Appendix A, Air Quality and Greenhouse Gas Impact Assessment.

The operations phase for the Project, including commissioning, ramp-up and production, will continue for some 28 years as described in Chapter 6, Project Description. For consistency with the technical reports (which were based on an earlier Project description) that informed the impact assessment in this section, however, the duration of the operations phase is referred to as 27 years. This discrepancy is immaterial to the assessments and conclusions presented in this section.

14.6.1. Assessment Method Inputs

The greenhouse effect is a naturally occurring process that aids in heating the earth's surface and atmosphere (Pidwirny, 2006). It results from the fact that certain atmospheric gases, such as carbon dioxide (CO_2), water vapour (H_2O) and methane (CH_4) are able to change the energy balance of the planet by absorbing longwave radiation emitted from the earth's surface (Pidwirny, 2006).

The impact of greenhouse gas emissions from the Project was assessed by calculating the Project greenhouse gas emissions using an internationally recognised calculation method (IPCC, 2013), consisting of the following stages:

- Defining the Project boundary.
- Identifying emission sources within the Project boundary.
- Identifying activity data for each emission source.
- Identifying the appropriate emission calculation method for each source based on international standards.
- Calculating greenhouse gas emissions.

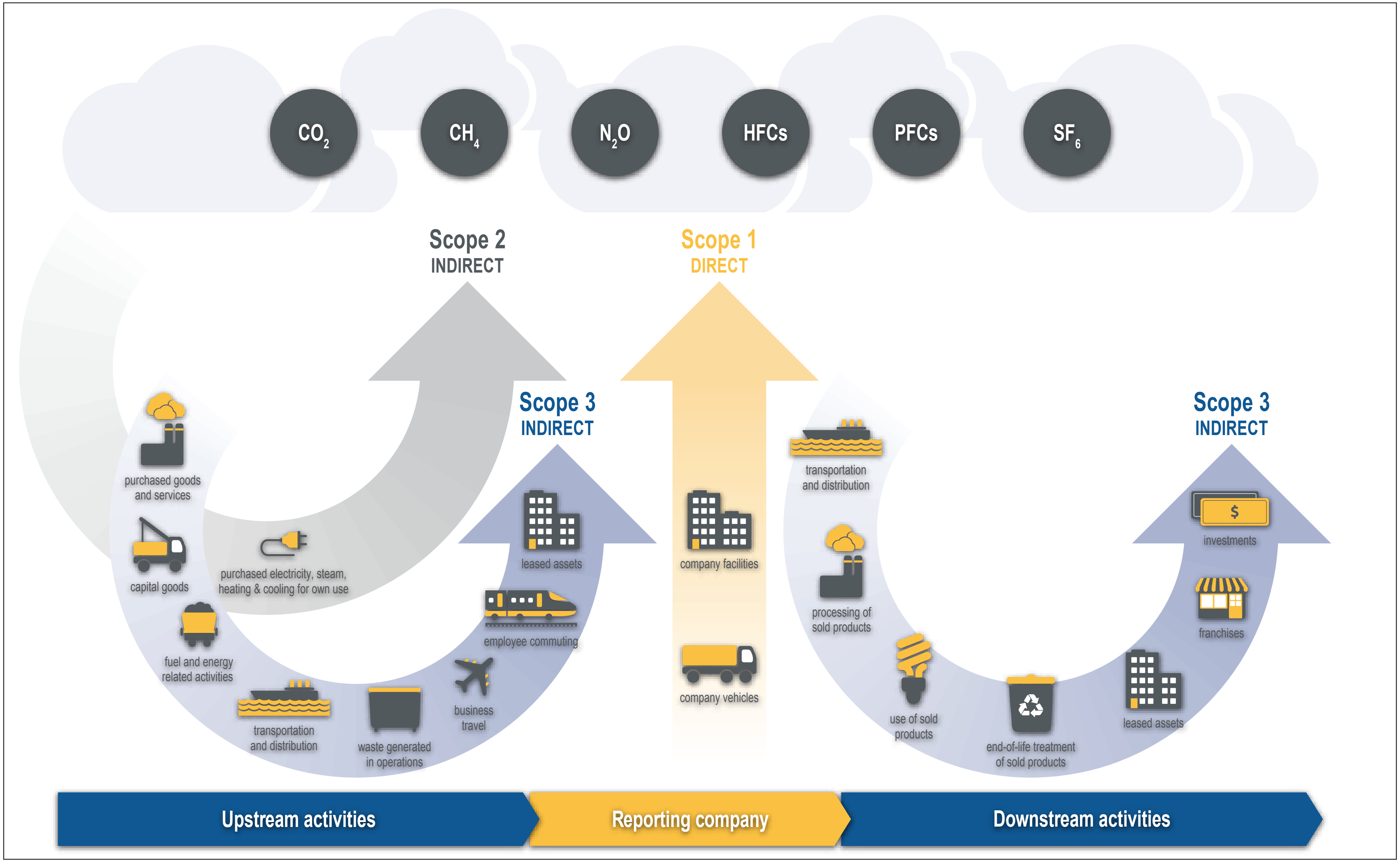
The calculated emissions were then benchmarked against PNG annual emissions.

Greenhouse gas emissions are categorised as either Scope 1, Scope 2 or Scope 3 depending on whether they are ‘direct’ (Scope 1) or ‘indirect’ (Scope 2 and Scope 3). Figure 14.9 illustrates the difference in the nature of these emissions.

Scope 1 and 2 emissions have been calculated based on the average fuel consumption and activities for the Project in any one year. The Intergovernmental Panel on Climate Change does not provide calculation methodologies for Scope 3 emissions, and they are not required to be reported as part of a GHG emissions assessment. As such, Scope 3 emissions are not included in this assessment.

14.6.2. Potential Impacts

The boundary for the Project has been defined as the Project Area, including the footprint of Project infrastructure and emissions associated with Project construction, operation and closure. Table 14.27 describes typical activities within each scope, and sets out the emissions sources included in the calculation of predicted greenhouse gas emissions from the Project. The transportation of materials and workforce to the Project Area has been excluded from the calculation of greenhouse gas emissions.



coffey
A TETRA TECH COMPANY

Date: 24.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.09_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Scope 1, 2 and 3 GHG emissions as defined in the GHG protocol initiative

Figure No: 14.9

INDD Reference: 0520DD_10_GRA018.indd_2

Table 14.27: Emissions sources

Emissions Category	Examples of Scope Activities	Calculated Project Emissions Sources
Scope 1 – direct emissions from sources within the boundary of an organisation and as a result of the organisation's activities	• Transportation of material, products, waste or people, i.e., use of diesel. • Generation of electricity, heat and/or steam. • Fugitive emissions. • Onsite waste management.	Construction: • Land clearing. • Diesel fuel consumption from construction equipment. • Diesel fuel consumption from generators. • Use of explosives. • Fuel consumption in transport of materials within the Project Area boundary. • Management of solid waste and wastewater. Operation: • Power generation facilities' fuel consumption. • Use of explosives. • Management of solid waste and wastewater. • Use of sulphur hexafluoride (SF_6) in switchgear. Closure: • Management of solid waste and wastewater. • Diesel consumption from earthworks, demolition and reinstatement works.
Scope 2 – indirect emissions from consumption of purchased electricity	• Purchased electricity.	• Electricity purchased for construction and operation of the pipelines, Port Facilities Area and Outfall Area.
Scope 3 – indirect emissions from outsourced activities	• Extraction and production of materials. • Transport related activities such as business travel • Use of sold products	• Scope 3 emissions not calculated.

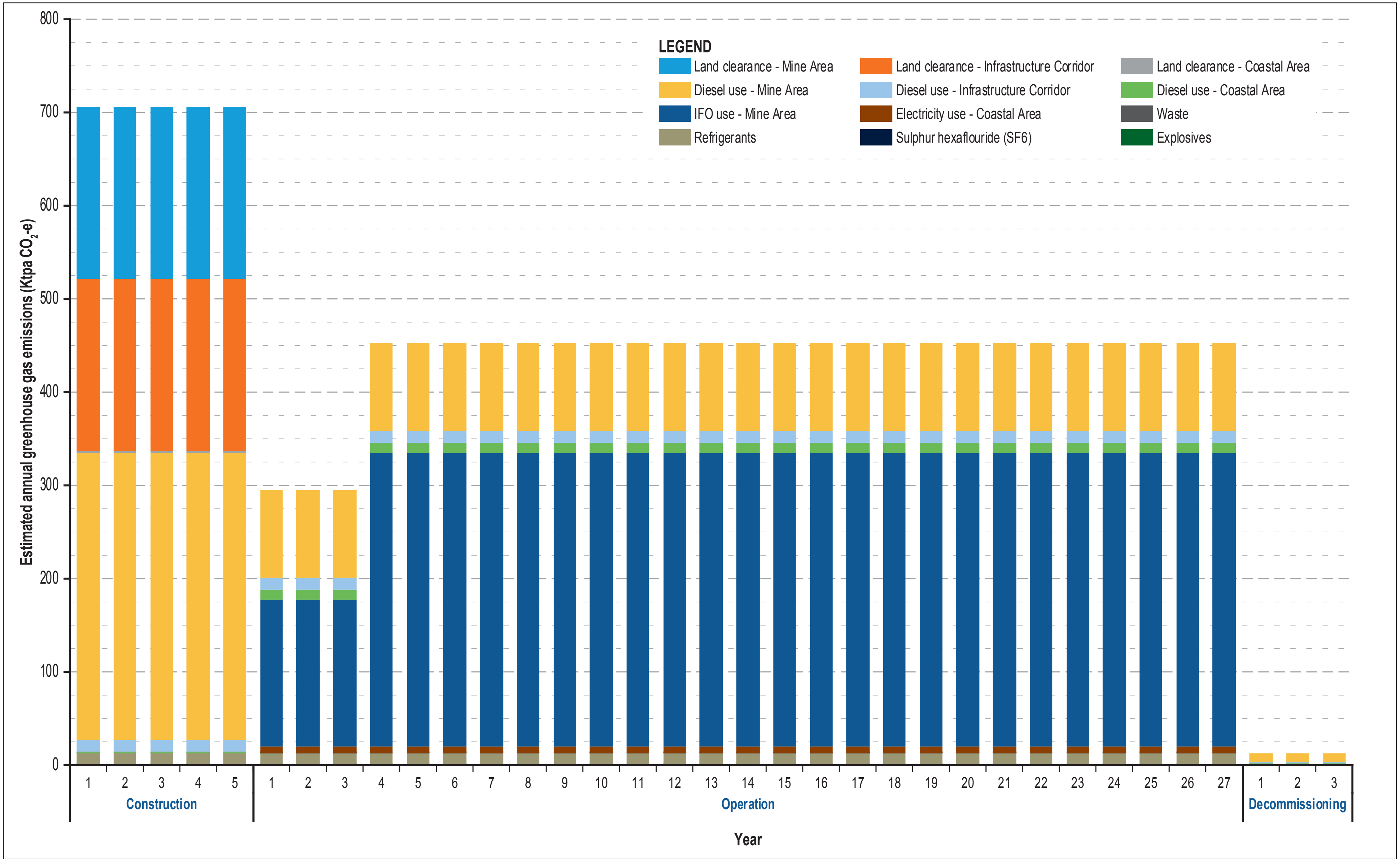
14.6.3. Proposed Management Measures

This section presents an overview of the proposed management measures to reduce the greenhouse gas emissions from the Project. Specific measures are detailed in the Project EMP (Attachment 3). The key measures proposed include:

- Maintain an inventory of greenhouse gas emissions and report in accordance with the State of PNG requirements.
- Implement mechanisms to promote review of energy efficiency during operations, with opportunities for efficiency improvements identified and implemented as appropriate.

14.6.4. Residual Impact Assessment

The predicted greenhouse gas emissions from the Project are presented in Table 14.28. The contribution of Project activities to the total predicted emissions is shown in Figure 14.10. The total predicted Scope 1 and Scope 2 greenhouse gas emissions from the Project have been calculated at 15,354 kilo tonnes (kt) carbon dioxide equivalent (CO_{2-e}), assuming a five year construction period, 27 year operations period and three year closure period. Averaged over the life of the Project, this is equivalent to 438.7ktpa CO_{2-e}.



INDD Reference:0520DD_10_GRA104.indd_3

coffey A TETRA TECH COMPANY

Date: 24.04.2018

Project: 754-ENAUABTF100520DD

File Name: 0520DD_10_F14.10_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Summary of predicted greenhouse gas emissions

Figure No: 14.10

The main sources of greenhouse gas emissions from the Project will be from land clearance during construction and fuel and diesel consumption during operations (largely by the power generation facilities).

Table 14.28: Calculated annual greenhouse gas emissions

Source	Emissions (ktpa CO_2-e)		
	Scope 1	Scope 2	Total
Mine Area			
Construction	507.27	0	**507.27**
Operation	423.48	0	**423.48**
Closure	10.61	0	**10.61**
Infrastructure Corridor			
Construction	196.42	0	**196.42**
Operation	11.96	0	**11.96**
Closure	1.38	0	**1.38**
Coastal Area			
Construction	3.16	0	**3.16**
Operation	11.96	6.36	**18.33**
Closure	1.33	0	**1.33**
Total Project			
Construction	706.85	0	**706.85**
Operation	447.40	6.36	**453.77**
Closure	13.32	0	**13.32**

To put these emissions into context, and allow for comparison, the total greenhouse gas emissions for the State of PNG reported for 2013 (the most recent year available) were 70,855kt CO_2-e including land use change and forestry and 16,434kt CO_2-e excluding land use change and forestry (FAO, 2014). Comparison of the predicted annual average Scope 1 and 2 greenhouse gas emissions over the life of the Project of 438.7ktpa CO_2-e with the total national emissions (including land use change and forestry) reported by the Food and Agriculture Organization of the United Nations (2014) indicates that over the life of the Project, it will result in a relatively minor (0.6%) increase in the national emissions.

14.7. Noise and Vibration

This section describes the noise and vibration impacts of the Project, based on the assessment conducted by SLR and presented in Appendix B, Noise and Vibration Impact Assessment.

14.7.1. Assessment Method Inputs

Environmental values to be protected from a noise and vibration perspective are:

- Good quality acoustic environment in which people can sleep, learn and enjoy recreational activities in support of human health and wellbeing
- Amenity of the ambient environment and the useful life and structural integrity of buildings, structures, property and materials.

The following sections describe the approach to the noise and vibration impact assessments.

14.7.1.1. Noise

Noise emissions from key Project activities were modelled to simulate noise emissions from the Project during construction and operation. Noise emissions during closure are expected to be similar to, and no worse than, during construction, and as such predicted emissions during construction are considered representative of closure. The modelled noise levels at sensitive receptors were compared to international noise guidelines and standards that have been adopted as Project noise criteria.

Table 14.29 summarises the key sources of noise emissions from the Project used in the modelling (see Appendix B, Noise and Vibration Impact Assessment for the exhaustive list).

Table 14.29: Modelled noise emission sources

Project Aspect	Construction Emission Sources	Operational Emission Sources
Mine Area	Noise emissions associated with the construction of: • Process plant terrace and infrastructure • Portal terrace and infrastructure • Watut Declines • Ventilation shaft • Nambonga Decline • Power generation facilities • Watut and Miapilli waste rock dumps • Migiki Borrow Pit • Supporting facilities and infrastructure Temporary power generation from on-site diesel generators.	Noise emissions associated with operation of: • Process plant • Power generation facilities • Overland conveyors • Batch plants • Ventilation fans and refrigeration • Migiki Borrow Pit • Accommodation camps

SoundPLAN was used to model noise emissions from these sources, calculating predicted noise levels at the sensitive receptors described in Chapter 8, Physical and Biological Environment Characterisation. The sensitive receptors identified are the villages in proximity to the Project.

The modelling takes into account factors such as distance attenuation, ground hardness, air absorption, barrier shielding effects and meteorological conditions to calculate noise levels. SoundPLAN is considered to be the best practice approach for modelling noise emissions for mining and industrial facilities and has been used for similar projects in PNG. Further details on the approach to modelling and the assumptions and inputs used are provided in Appendix B, Noise and Vibration Impact Assessment.

Modelling was completed for neutral and enhanced weather conditions. Enhanced weather conditions represent the worst-case scenario for noise transmission, and includes temperature inversions. Temperature inversions have the potential to occur up to 40% of the year at the Mine Area, however only typically during the early morning or evening (i.e., periods where the day time criterion is more applicable), and are not generally present for long periods.

The noise criteria adopted for the Project are set out in Table 14.30. State of Papua New Guinea regulations do not include specific noise criteria, so the criteria adopted for the Project were derived from international and Australian guidelines. The criteria are taken from the World Health Organisation (WHO) Guidelines for Community Noise (WHO, 1999), International Finance Corporation (IFC) and World Bank General Environmental, Health and Safety Guidelines: Environmental Noise Management (IFC, 2007) and the NSW Department of Environment and Climate Change (NSW DECC, 2016).

Table 14.30: Adopted Noise Level Criteria

Activity	Source	Time	Noise Criteria/Goals	Reference
Normal operations and construction periods longer than three months	Continuous	Night	45 dBA $L_{eq,\ 1\ hour}$	IFC, 2007
		Day	55 dBA $L_{eq,\ 1\ hour}$	WHO, 1999; IFC, 2007
	Single events	Night	60 dBA $L_{A\ max}$	WHO, 1999
Construction periods less than three months	Continuous	Night	45 dBA $L_{eq,\ 1\ hour}$	IFC, 2007
		Day	75 dBA $L_{eq,\ 1\ hour}$	NSW DECC, 2009
	Single events	Night	60 dBA $L_{A\ max}$	WHO, 1999
Vehicle movements on existing main roads	Intermittent	Day	No numerical limit	
		Night	60 dBA $L_{A\ max}$	WHO, 1999

The assessment of noise impacts from construction and operation of the Infrastructure Corridor, Port Facilities Area and Outfall Area was based on an assessment of the distance between the activity and sensitive receptors. Assuming flat, open ground between the noise sources and sensitive receptors (i.e., the worst-case scenario) the predicted offset distance needed to achieve the Project noise criteria was calculated. This was then compared to the distance proposed noise generating activities are from sensitive receptors to determine compliance.

14.7.1.2. Vibration

The vibration assessment considered potential impacts on sensitive receptors from ground vibrations and airblast emissions during construction and operation of the Project. Airblast is the pressure wave that is produced by blasting, which is transmitted through the air.

The activities that are likely to produce the greatest vibration and airblast emissions that have the potential to impact on sensitive receptors are:

- Blasting during construction and operation, i.e., at the quarry or borrow pits.
- Rock breaking and heavy vehicle movement during construction and operation, i.e., at the quarry or borrow pits.
- Compaction from vibratory rollers during construction, i.e., at waste rock dumps and terraces.

State of Papua New Guinea regulations do not include specific vibration and airblast criteria, so the criteria adopted for the Project were derived from international guidelines. These are set out in Table 14.31.

Table 14.31: Project vibration and airblast criteria

Source	Aspect	Criteria	Reference
Blasting vibrations	Blasting ground vibration	95% compliance 5mm/s Maximum 10mm/s	USBM RI 8507 (Siskind, 1980) AS2187.2 (Australian Standards, 2006)
	Airblast	95% 115dBL Maximum 120dBL	AS2187.2 (Australian Standards, 2006)
Non-blasting vibrations	Human comfort	0.2mm/s	British Standard, 2008
	Structural damage	12.5mm/s	British Standard, 2008

Ground vibration and airblast levels from blasting were calculated based on the method set out in Australian Standard AS2187.2, Explosives–Storage and use Part 2: Use of explosives, and compared against the relevant adopted Project criteria.

The assessment of vibration impacts from construction and operation was based on an assessment of the distance between the activity and sensitive receptors. The predicted offset distance needed to achieve the adopted Project noise criteria was calculated. This was then compared to the distance proposed noise generating activities are from sensitive receptors to determine compliance.

14.7.2. Potential Impacts

The potential noise and vibration impacts to the values of human health and wellbeing may result from excessive noise which has the potential to cause nuisance, sleep deprivation, stress and increased blood pressure. Noise criteria have been determined for the Project based on levels that prevent these impacts occurring.

The potential impacts of vibration on human health and wellbeing vary from person to person. The assessment of vibration impacts has considered the potential to impact both the amenity value through damage to structures and utilities, and the human health and wellbeing value in terms of its effects on human comfort.

14.7.3. Proposed Management Measures

14.7.3.1. Noise Management Measures

The following section provides a summary of measures that WGJV proposes to implement to minimise the potential for adverse impacts related to noise amenity. Detailed management measures proposed to be implemented during various phases of the Project are listed in the Project EMP (Attachment 3).

In addition to the measures noted below, for village locations where predicted exceedances of the adopted Project noise criteria are confirmed, i.e., through monitoring (see Section 14.7.4), additional proposed management measures would be considered including:

- Maximise the distance between noisy plant items and noise sensitive receptors, where practicable.
- Where practicable, limit the hours of operation of high noise or vibration activities, especially vehicles, plant and equipment operating near sensitive receptors.
- Where practicable, provide advanced notice of high noise activities to local communities.

- Where practicable, avoid or minimise heavy vehicle traffic near villages during the night.
- Limit machinery and vehicle movements, where possible, to defined work areas and designated roads.
- Maintain site access roads.
- Where safe, minimise exhaust braking in the vicinity of villages.

14.7.3.2. Vibration Management Measures

Due to the buffer distances between the majority of blasting and/or construction activities and the nearest sensitive receptors, minimal vibration impacts are predicted for the identified sensitive receptors. The WGJV proposes to implement the following standard good industry practice management measures:

- Restrict surface blasting to daylight hours.
- Inform potentially affected communities of planned surface blasting events.
- Optimise surface blast design to reduce noise and vibration, where safe and practicable.

14.7.4. Residual Impact Assessment

This section summarises the results of the noise and vibration impact assessment. The assessment has been completed using the compliance standard assessment method, i.e., the predicted emissions either comply with the adopted Project noise and vibration criteria or not.

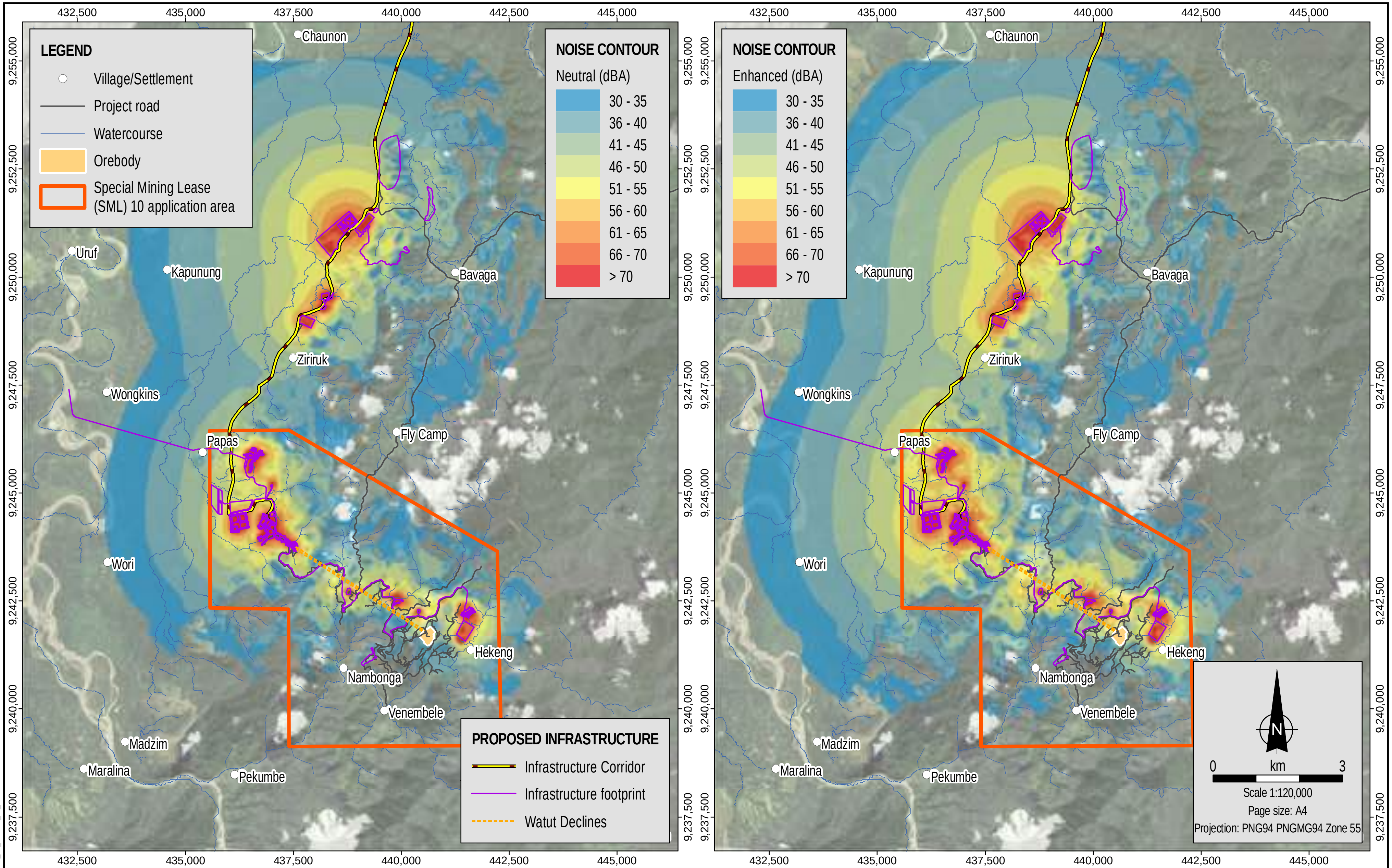
The assessment of noise emissions from the Mine Area against the adopted Project criteria concluded that daytime noise criteria will be met for construction and operation of the Project. However, there will be some exceedances of night time criteria during both construction and operation. These are discussed further below.

The assessment of predicted noise emissions from construction and operation of the Infrastructure Corridor, Port Facilities Area and Outfall Area demonstrated that the distance between the noise generating activities and the sensitive receptors is far enough for noise to attenuate to below the adopted Project criteria.

As mentioned above, due to the buffer distances between the blasting and/or construction activities and the nearest sensitive receptors, SLR predicted minimal vibration impacts to the identified sensitive receptors.

14.7.4.1. Mine Area Construction

Predicted Project contribution to background noise levels from construction of the Mine Area are provided in Table 14.32 and presented as noise contour plots (Figure 14.11). The assessment shows that the adopted Project noise criteria are predicted to be achieved during the day and night under both neutral and enhanced (i.e., worst case) weather conditions with the exception of Hekeng (night time criterion under neutral and enhanced conditions), and Papas and Ziriruk (night time criterion under enhanced conditions). Predicted exceedances are shown in bold.



MXD Reference: 0520DD_10_GIS057_v0_4

Source:
Noise data from SLR.
Watercourses, 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: 24.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.11_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Mine Area construction noise emissions with neutral and enhanced meteorological conditions

Figure No: 14.11

Table 14.32: Mine construction noise predictions

Village	Meteorological Conditions		Adopted Project Noise Criteria (dBA)	
	Neutral (dBA)	Enhanced (dBA)	Day	Night
Bavaga	22	23	55	45
Bencheng	<15	<15	55	45
Dengea	<15	<15	55	45
Fly Camp	15	20	55	45
Gingen	<15	<15	55	45
Hekeng	**47**	**50**	55	45
Kapunung	35	37	55	45
Madzim	<15	<15	55	45
Maralina	<15	<15	55	45
Nambonga	<15	20	55	45
Papas	42	**48**	55	45
Pekumbe	<15	<15	55	45
Pokwaluma	<15	<15	55	45
Uruf	<15	<15	55	45
Venembele	<15	19	55	45
Wafi	34	40	55	45
Wongkins	28	33	55	45
Wori	30	35	55	45
Zindanga	<15	<15	55	45
Ziriruk	44	**48**	55	45

14.7.4.2. Infrastructure Corridor Construction

Table 14.33 sets out the predicted offset distance required to achieve noise criteria from construction of the Infrastructure Corridor. Only short-term (i.e., less than three months), day time noise criteria have been considered, as the scheduling of works for construction of the Infrastructure Corridor will be adapted as needed based on the area under construction. This will include for example, construction only during the day when in proximity to villages, however through Lae, despite the associated noise emissions, night-works may be preferential to minimise the disturbance to users of existing road infrastructure.

While the overall period of construction for the Infrastructure Corridor will exceed three months, the transient nature of the moving works front means sensitive receptors are not exposed to potential impacts for longer than this time period and hence this criterion is applied (see Table 14.30).

Table 14.33: Infrastructure Corridor compliance assessment

Village	Approximate Distance to Infrastructure Corridor Construction	Recommended Offset Distance	Compliance?
Ziriruk	300m	30m	Yes
Papas	600m	30m	Yes
Nambonga	1,300m	30m	Yes
Hekeng	1,200m	30m	Yes
Bavaga	1,100m	30m	Yes
Kokok	1,400m	30m	Yes
Zifasing	800m	30m	Yes
Ngarubuaring	530m	30m	Yes
Durung Farm	<20m	30m	Potential exceedance
Gabsongkeg	600m	30m	Yes
Yalu	700m	30m	Yes
Lae	Through town	30m	Potential exceedance
Bowali	100m	30m	Yes
Malahang	300m	30m	Yes
Yanga	350m	30m	Yes

The section of the Infrastructure Corridor alignment parallel to the Highlands Highway predominantly consists of flat, open ground between the noise sources and sensitive receptors, and is therefore consistent with the worst-case scenario for noise impacts. In the area southwest of the Highlands Highway towards the Mine Area, however, greater acoustic shielding will be afforded by both dense vegetation and topography, so the assessment is conservative and presents a worst-case prediction of noise impacts.

While the construction of the Infrastructure Corridor will occur within the vicinity of villages, elevated noise levels will be short-term and the highest noise levels are likely to last for only a few days as the construction front passes.

In addition, under normal meteorological conditions the offset distance predicted to be required for compliance would be less, as the assessment conservatively assumes meteorological conditions are optimised to carry the sound of construction to the nearest village (i.e., worst case conditions).

While the offset distance between the Infrastructure Corridor and identified villages may be greater than the required distance to achieve compliance, the village locations generally represent the geographical centre of the village and may not account for scattered dwellings, which could potentially be located closer to the works (or the potential for the village to expand towards Project infrastructure, such as roads). Where such outlying dwellings are within the offset distances presented, reduced noise amenity may be experienced.

While not modelled by SLR, the proposed Watut Services Road and Resettlement Road will be constructed at greater than the recommended offset distances from all villages, and therefore Project noise criteria are expected to be met in these villages.

14.7.4.3. Port Facilities Area and Outfall Area Construction

The offset distances required to achieve compliance with the adopted Project noise criteria for construction of the Port Facilities Area and Outfall Area for day time construction is predicted to be:

- 20m in neutral weather conditions and 25m for enhanced weather conditions for construction activities less than three months.
- 140m in neutral weather conditions and 200m in enhanced weather conditions for construction activities greater than three months.

The closest sensitive receptor to the Port Facilities Area is currently approximately 1,000m away, and to the Outfall Area is currently approximately 1,350m away, therefore both areas have further separation than the recommended offset distance.

On this basis, SLR concluded that the adopted Project noise criteria is predicted to be achieved during construction of the Port Facilities Area and Outfall Area.

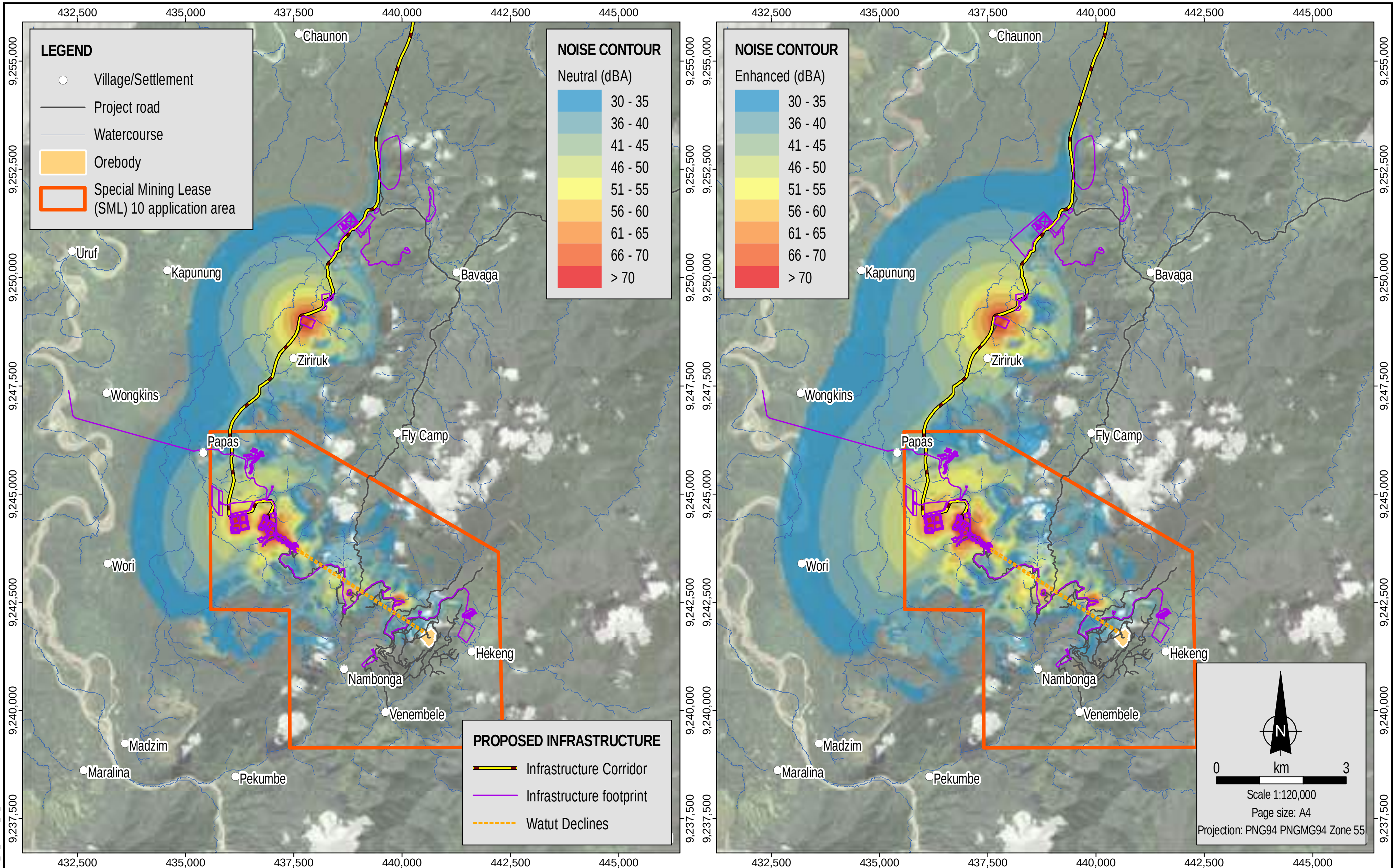
14.7.4.4. Mine Area Operation

Predicted noise levels associated with the Mine Area operations were calculated and are presented as noise contour plots (Figure 14.12). Both neutral and enhanced (i.e., worst case) weather conditions are presented.

A summary of the predicted noise levels is provided in Table 14.34 for the nearest sensitive receptors. Predicted exceedances are shown in bold.

Table 14.34: Mine Area operation noise predictions

Village	Power generation facilities only (dBA)		Mine Operation (dBA)		Noise Criteria (dBA)	
	Neutral	Enhanced	Neutral	Enhanced	Day	Night
Bavaga	<15	<15	<15	<15	55	45
Bencheng	<15	<15	<15	<15	55	45
Dengea	<15	<15	<15	<15	55	45
Fly Camp	<15	<15	<15	<15	55	45
Gingen	<15	<15	<15	<15	55	45
Hekeng	<15	<15	<15	<15	55	45
Kapunung	25	30	25	30	55	45
Madzim	<15	<15	<15	<15	55	45
Nambonga	<15	<15	<15	15	55	45
Papas	23	27	29	34	55	45
Pekumbe	<15	<15	<15	<15	55	45
Pokwaluma	<15	<15	<15	<15	55	45
Uruf	<15	<15	<15	<15	55	45
Venembele	<15	<15	<15	<15	55	45
Wongkins	18	23	23	29	55	45
Wori	<15	<15	27	32	55	45
Zindanga	<15	<15	<15	<15	55	45
Ziriruk	**48**	**51**	**48**	**51**	55	45



MXD Reference: 0520DD_10_GIS058_v0_4

Source:
Noise data from SLR.
Watercourses, 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: 24.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F14.12_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Mine Area operation noise emissions with neutral and enhanced meteorological conditions

Figure No: 14.12

Exceedances of the adopted Project noise criteria are predicted at Ziriruk during the night under both neutral and enhanced (i.e., worst case) meteorological conditions. This is due to operation of the power generation facilities, which is located approximately 800m north of Ziriruk.

Project noise criteria are predicted to be met at all other sensitive receptors during day time and night time, under neutral and enhanced (i.e., worst case) weather conditions.

14.7.4.4.1. Borrow Pit Operation

The required offset distance to achieve compliance with the adopted Project noise criteria for operation of the borrow pits, quarry and gravel extraction sites is predicted to be 800m.

Table 14.35 sets out the compliance assessment results assuming enhanced (i.e., worst case) conditions. Based on these results, SLR has predicted that the operation of the borrow pits, quarry and gravel extraction sites will meet the adopted Project noise criteria except at Hekeng. However, Hekeng is proposed for resettlement, and potential exceedances will only be experienced prior to resettlement being completed.

Table 14.35: Borrow Pits, Quarry and Gravel Extraction Operation Compliance Assessment

Village	Approximate Distance to infrastructure	Recommended Offset Distance	Compliance?
Migiki Borrow Pit			
Nambonga	1,700m	800m	Yes
Venembele	2,800m	800m	Yes
Hekeng	3,080m	800m	Yes
Pekumbe	4,925m	800m	Yes
Fly Camp	3,770m	800m	Yes
Humphries Borrow Pit			
Bavaga	2,305m	800m	Yes
Ziriruk	3,870m	800m	Yes
Chaunon	4,422m	800m	Yes
Kapunung	4,970m	800m	Yes
Miapilli Clay Borrow Pit			
Hekeng	400m	800m	Potential exceedance
Venembele	2,500m	800m	Yes
Nambonga	2,700m	800m	Yes
Northern Access Road Borrow Pit			
Bavaga	2,400m	800m	Yes
Kapunung	5,400m	800m	Yes
Ziriruk	4,500m	800m	Yes
Mount Beamena Quarry			
Kapunung	5,290m	800m	Yes
Bavaga	1,390m	800m	Yes
Fly Camp	4,090m	800m	Yes

Village	Approximate Distance to infrastructure	Recommended Offset Distance	Compliance?
Uruf	7,500m	800m	Yes
Wongkins	7,400m	800m	Yes
Gingen	6,890m	800m	Yes
Dengea	7,500m	800m	Yes
Bavaga River Gravel Extraction			
Bavaga	1,300m	800m	Yes
Gingen	6,070m	800m	Yes
Dengea	6,500m	800m	Yes
Lower Papas Aggregate Source			
Papas	1,200m	800m	Yes
Wori	2,100m	800m	Yes
Wongkins	2,800m	800m	Yes

14.7.4.4.2. Mine Access Road and Northern Access Road Operations Transportation Noise

The Project-related vehicle fleet will deliver fuel, food, materials and supplies and during construction, the traffic volume is estimated to be 30 vehicles per travelling direction per day. During the operations phase of the mine, traffic movements will be approximately five trucks per travelling direction per day, seven days a week.

These traffic numbers are well below those required to accurately predict ‘continuous’ noise levels using standard road noise prediction modelling. Therefore, noise impacts from heavy vehicle movements have been assessed by predicting maximum pass-by noise levels at offset distances from the Mine Access Road and the Northern Access Road. In particular, the night period pass-bys are the most critical, as they may cause sleep disturbance.

The approximate noise levels for a slow-moving 20t truck pass-by (being the loudest of the potential sources assessed) are:

- 75dBA at 15m
- 60dBA at 80m
- 58dBA at 100m
- 52dBA at 200m

For night time, in order to minimise sleep disturbance, a criterion of 60dBA L_{max} was adopted, which would be achieved at a buffer distance of approximately 80m. For the day, the adopted criteria for infrequent short-term pass-by noise levels is 75dBA L_{eq}. This is predicted to be achieved at a buffer distance of approximately 15m. As all villages are currently located more than 15m from the routes of the Mine Access Road and Northern Access Road, it is predicted that the adopted Project day noise criteria will be achieved.

Compliance with the sleep disturbance criterion of 60dBA L_{max} is predicted to be achieved even if 24 hour road usage were planned due to the current distances between villages and the Mine Access Road and Northern Access Road. The only after-dark road use planned will be commuter buses for Project personnel that live locally, or otherwise in exceptional or emergency situations.

14.7.4.5. Port Facilities Area and Outfall Area Operation

The required distance from operations at the Port Facilities Area to meet the adopted Project noise criteria are predicted to be:

- In the day time, 240m in neutral weather conditions and 300m in enhanced weather conditions.
- In the night time, 520m in neutral weather conditions and 730m in enhanced weather conditions.

The closest sensitive receptor to the Port Facilities Area is currently approximately 1,000m away. In addition, the Port Facilities Area is located within the Port of Lae, in the second largest city in PNG, where it can be expected that noise levels are higher than areas without industry. Operation of the Port Facilities Area is predicted to meet the Project noise criteria.

The required distance from the choke station at the Outfall Area predicted to meet the adopted Project noise criteria is 1,000m without an acoustic enclosure. The closest sensitive receptor to the Outfall Area is currently approximately 1,300m away, so the Project noise criteria are therefore predicted to be met.

14.7.4.6. Blasting Vibration

With respect to borrow pits and the quarry, the nearest village is located at a distance of more than 1,300m from where blasting will occur (Hekeng is 400m from the Miapilli Clay Borrow Pit, however blasting is not proposed at this borrow pit). Blasting vibration and airblast overpressure levels at these villages are predicted to be well below the adopted Project criteria.

The distance between blasting required for the Infrastructure Corridor construction and any sensitive receptor is expected to be typically greater than the 415m distance for avoidance of vibration and airblast impacts. In the event that these activities are proposed with a separation distance of less than 415m, the need for additional measures will be considered.

14.7.4.7. Non-blasting Vibration

For daytime construction activity, predicted vibration levels will meet the adopted Project vibration guideline for human comfort at distances greater than 15m from heavy rock-breaking and heavy vehicle movements and 55m from heavy vibratory roller activity. There are no identified sensitive receptors currently within 55m of the Northern Access Road, however Durung Farm is within 55m of the Infrastructure Corridor, and the Infrastructure Corridor continues on to pass through Lae. As such, perceptible vibration levels may be noticed where heavy vibratory roller activity is undertaken during the construction at these locations.

Due to the distances between the Project construction sites and the nearest villages, compliance with the structural damage vibration criterion will be readily achieved at the current location of all sensitive receptors.

14.7.5. Monitoring

Monitoring of noise emissions in the Mine Area, during operations, will be performed to confirm actual emissions are within the estimates predicted in this EIS.

If construction activities that generate vibration (such as vibratory rolling) are to be carried out within 55m of villages, vibration monitoring will be implemented to assess and demonstrate compliance with the adopted Project vibration guideline levels.

Monitoring of blasting activities may be required at sensitive receptors in the vicinity of blasting activities required for construction of the Infrastructure Corridor. The monitoring program and locations will be determined upon review of the blasting locations and blast design parameters.

14.8. References

Ashton. P.A. 2008. Changing values of Malaysian forests: the challenge of biodiversity and its sustainable management. Journal of Tropical Forest Science 20: 282-291

Atwell, B.J. 1999. Plants in Action: Adaption in Nature, Performance in Cultivation. MacMillan Education Australia Pty Ltd. Victoria, Australia.

Australian Standard. 2006. AS 2187.2 Explosives- Storage and Use Part 2: Use of Explosives. Published by Standards Australia. NSW, Australia.

Barber, J. R., Crooks, K. R. and Fristrup, K. M. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution 25: 180-189.

Bayne, E.M., Habib, L., and Boutin, S. 2008. Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. Integrated Landscape Management Group, Department of Biological Sciences. Alberta, Canada.

British Standard. 2008. BS 6472-1: 2008 Guide to Evaluation of Human Exposure to Vibration in Buildings.

Bomford, M., and O'Brien, P. H. 1990. Sonic deterrents in animal damage control: a review of device tests and effectiveness. Wildlife Society Bulletin 18: 411-422.

Booyong. 2013. Terrestrial Flora Survey for the Wafi Golpu Advanced Exploration Project. Report prepared for Wafi-Golpu Joint Venture by Booyong Forest Science. Queensland, Australia.

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

Cannon, J. B. 2007. Natural Resource Economics of Papua. In: A.J. Marshall & B.M. Beehler (eds) The ecology of Papua. Part one, pp. 564-616. Periplus Editions, Singapore.

CIEEM. 2016. Guidelines for Ecological Impact Assessment in the UK and Ireland: Terrestrial, Freshwater and Coastal, 2nd edition. Chartered Institute of Ecology and Environmental Management, Winchester.

Cuthbert, R. 2010. Sustainability of hunting, population densities, intrinsic rates of increase and conservation of Papua New Guinean mammals: a quantitative review. Biological Conservation 143: 1850-1859.

EIANZ. 2015. Ecological Impact Assessment: EIANZ guidelines for use in New Zealand: terrestrial and freshwater ecosystems. Published by Environment Institute of Australia and New Zealand, Melbourne, Australia.

FAO. 2014. FAOSTAT Emissions Database. (http://cait.wri.org). Washington DC, USA: Food and Agriculture Organization of the United Nations.

Filer, C., Keenan, R. J., Allen, B. J., and Mcalpine, J. R. 2009. Deforestation and forest degradation in Papua New Guinea. Annals of Forest Science 66: 813. Springer. Berlin.

Goosem, M. 2000. Effects of tropical rainforest roads on small mammals: edge changes in community composition. Wildlife Research 27: 151-163, CSIRO Publishing. Melbourne, Victoria

Goosem, M. 2007. Fragmentation impacts caused by roads through rainforests. December. Current Science 93 1587-1595. Bengaluru, India

Goosem, M., Harding, E. K., Chester, G., Tucker, N. and Harriss, C. 2010. Roads in Rainforest: Science Behind the Guidelines. Guidelines prepared for the Queensland Department of Transport and Main Roads and the Australian Government's Marine and Tropical Sciences Research Facility. Published by the Reef and Rainforest Research Centre Limited, Cairns (76pp.).

Hardner, J., R.E. Gullison, S. Anstee, M. Meyer. 2015. Good Practices for Biodiversity Inclusive Impact Assessment and Management Planning. Prepared for the Multilateral Financing Institutions Biodiversity Working Group.

IAQM. 2014. IAQM Guidance on the assessment of dust from demolition and construction. London: Institute of Air Quality Management.

IPCC. 2013. Chapter 8 - Anthropogenic and Natural Radiative Forcing, from: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IUCN. 2017a. The IUCN Red List of Threatened Species. Version 2016-3. A WWW resource by The International Union for the Conservation of Nature accessed on 15 March 2017 at www.iucnredlist.org.

IUCN. 2017b. IUCN Red List of Ecosystems. A WWW resource accessed on 22 December 2017 at https://iucnrle.org.

Laurance, S. G., Stouffer, P. C., and Laurance, W. F. 2004. Effects of Road Clearings on Movement Patterns of Understory Rainforest Birds in Central Amazonia. Conservation Biology 18: 1099-1109. Wiley. New York.

Laurance, W. F., Goosem, M., and Laurance, S. G. 2009. Impacts of roads and linear clearings on tropical forests. Trends in Ecology & Evolution 24: 659-669. Elsevier. London

Laurance, W. F., Lovejoy, T. E., Vasconcelos, H. L., Bruna, E. M., Didham, R. K., Stouffer, P. C., Gascon, C., Bierregaard, R.O., Laurance, S. G., and Sampaio, E. 2002. Ecosystem Decay of Amazonian Forest Fragments: a 22 Year Investigation. Conservation Biology 16: 605-618. Wiley. New York.

Lehtinen, R. M., Ramanamanjato, J. B., and Raveloarison, J. G. 2003. Edge effects and extinction proneness in a herpetofauna from Madagascar. Biodiversity & Conservation 12: 1357-1370. Springer. Berlin.

Mack, A. L., and West, P. 2005. Ten thousand tonnes of small animals: wildlife consumption in Papua New Guinea, a vital resource in need of management. Resource Management in Asia-Pacific Project Working Paper No. 61, Australian National University.

Marshall, A. R., and Rau, M. T. 1999. Lower Ok Tedi and Middle Fly - Estimate of current vegetation dieback and classification of floodplain vegetation. Report prepared for, Ok Tedi Mining Limited Environment Department. Tabubil, Papua New Guinea.

Meijaard, E., and Sheil, D. 2008. The persistence and conservation of Borneo's mammals in lowland rain forests managed for timber: observations, overviews and opportunities. Ecological Research 23: 21-34. Springer. Berlin.

Munks, S. A. and Watling, D. 2013. A review of information on the impact of forestry operations on the biodiversity of PNG's forests. A report under Project GCP/PNG/003/AUL for the PNG Forest Authority, the Food and Agriculture Organisation of the United Nations and the Australian Government Department of Agriculture, Fisheries and Forestry

Ningal, T., Hartemink, A.E. and Bregt, A.K., 2008. Land use change and population growth in the Morobe Province of Papua New Guinea between 1975 and 2000. Journal of Environmental Management, 87(1), pp.117-124.

NSW DECC. 2009. Interim Construction Noise Guidelines. Sydney, NSW Department of Environment and Climate Change.

NSW EPA. 2016. Approved Methods for the Modelling and Assessment of Air Pollutants in NSW. Sydney: New South Wales Environment Protection Authority.

Paijmans, K. 1976. New Guinea Vegetation. Report prepared for the Commonwealth Scientific and Industrial Research Organisation in association with Australian National University Press. Canberra, Australian Capital Territory

Pangau-Adam, M., Noske, R., & Muehlenberg, M. 2012. Wildmeat or bushmeat? Subsistence hunting and commercial harvesting in Papua (West New Guinea), Indonesia. Human Ecology 40(4): 611-621.

Pidwirny, M. 2006. The Greenhouse Effect. Fundamentals of Physical Geography, 2nd Edition. Accessed 2 March 2018. http://www.physicalgeography.net/fundamentals/7h.html

Pohlman, C. L., Turton, S. M., and Goosem, M. 2009. Temporal variation in microclimatic edge effects near powerlines, highways and streams in Australian tropical rainforest. Agricultural and forest meteorology 149: 84-95. Elsevier. London

Rabin, L. A., McCowan, B., Hooper, S. L. and Owings, D. H. 2003. Anthropogenic noise and its effect on animal communication: an interface between comparative psychology and conservation biology. International Journal of Comparative Psychology 16: 172-192.

Regini, K. 2000. Guidelines for ecological evaluation and impact assessment. Practice, Bulletin of the Institute of Ecology and Environmental Management 29.

Rogers, H. M., and Hartemink, A. E. 2000. Soil seed bank and growth rates of an invasive species, Piper aduncum, in the lowlands of Papua New Guinea. Journal of Tropical Ecology 16: 243-251. Cambridge University Press. Cambridge.

Saunders, D. A., Hobbs, R. J. and Margules, C. R. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5(1): 18-32.

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: 379-390. Wiley. New York

Shearman, P., and Bryan, J. 2011. A bioregional analysis of the distribution of rainforest cover, deforestation and degradation in Papua New Guinea. Austral Ecology 36: 9-34. Wiley. New York

Siskind, D. E. 1980. RI 8507 Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting. United States Bureau of Mines. Report of investigations 8507.

SNH. 2002. Environmental Assessment Handbook: Guidance on the Environmental Impact Assessment Process. Prepared by the Scottish Natural Heritage.

Sodhi, N. S. Liow, L.H. and Bazzaz F.A. 2004. Avian extinctions from tropical and subtropical forests. Annual Review of Ecology Evolution Systematics 35: 323-345

Suarez, E., Morales, M., Cueva, R., UtrerasBucheli, V., Zapata?Ríos, G., Toral, E., & Vargas Olalla, J. 2009. Oil industry, wild meat trade and roads: indirect effects of oil extraction activities in a protected area in north?eastern Ecuador. Animal Conservation 12(4): 364-373.

Trombulak, S. C., and Frissell, C. A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14: 18-30. Wiley. New York.

Tvardíková, K. 2010. Bird abundances in primary and secondary growths in Papua New Guinea: a preliminary assessment. Tropical Conservation Science 3: 373-388.

US EPA. 2010. National Ambient Air Quality Standards. US EPA Office of Air Quality Planning and Standards.

US EPA. 2012. History of the National Ambient Air Quality Standards for Particulate Matter During the Period 1971-2012. Retrieved from Technology Transfer Network National Ambient Air Quality Standards (NAAQS): http://www.epa.gov/ttnnaaqs/standards/pm/s_pm_history.html, Last updated on Saturday, 15 December 2012

Varshney, C. K., Garg, J. K., Lauenroth, W. K., & Heitschmidt, R. K. 1979. Plant responses to sulfur dioxide pollution. Critical Reviews in Environmental Science and Technology 9: 27-49.

World Health Organisation. 2000. Air Quality Guidelines for Europe: Second Edition. Copenhagen.

World Health Organisation. 2005. Air Quality Guideline: Global Update – Particulate Matter, Ozone, Nitrogen Dioxide and Sulphur Dioxide. Copenhagen.

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

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

Woxvold, I., and Aplin, K. 2013. Terrestrial fauna study and impact assessment of the Wafi-Golpu Advanced Exploration Project. Report prepared for Coffey Environments.

Zakaria, M., Rajpar, M.N., Ozdemir, I. and Rosli, Z., 2016. Fauna Diversity in Tropical Rainforest: Threats from Land-Use Change. In Tropical Forests-The Challenges of Maintaining Ecosystem Services while Managing the Landscape. InTech.