Appendix A

Air Quality and Greenhouse Gas 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.

Wafi-Golpu Project

Air Quality and Greenhouse Gas Impact Assessment

Report Number 620.11677-R01

26 April 2018

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Wafi-Golpu Project

Air Quality and Greenhouse Gas Impact Assessment

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Executive Summary

BACKGROUND

Wafi Mining Limited and Newcrest PNG 2 Limited (hereafter WGJV Participants) are equal participants in the Wafi-Golpu Joint Venture (hereafter WGJV) and propose to construct, operate and (ultimately) close 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 (hereafter the "Project").

The Project is located in the Morobe Province of Papua New Guinea (PNG) approximately 300 kilometres (km) north-northwest of Port Moresby and 65 km southwest of Lae. The focus of the Project is the proposed development and operation of:

- An underground block cave mine located in the Watut River catchment near Mount Golpu;
- Ore processing and concentrate transport/handling facilities;
- A deep sea tailings placement (DSTP) system for tailings management in the Huon Gulf near Lae; and
- Related support services.

Coffey Environments Australia Pty Ltd (Coffey) contracted SLR Consulting Australia Pty Ltd (SLR) to prepare an air quality and greenhouse gas impact assessment (AQGGIA). This report will form part of an Environmental Impact Statement (EIS) for the Project.

AIR QUALITY ASSESSMENT

The potential air quality impacts associated with air emissions from the Project have been assessed using a mixture of quantitative and qualitative assessment techniques. Design data available for the Project was reviewed to identify the key Project activities that have the greatest potential for impacts on local air quality, which were then assessed quantitatively. These activities were identified as follows:

- Emissions of combustion products from the diesel generators during the construction phase and the intermediate fuel oil (IFO) power generation facilities during operational phase;
- Fugitive dust emissions from the operational mining activities (e.g. haulage, wind erosion and borrow pit activities);
- Dust emissions from the underground ventilation exhaust systems; and
- Fugitive dust emissions from the construction of the Mine Area infrastructure, including declines, quarry operations and ventilation shaft development.

The emissions to air from these activities were estimated using published emission factors for the following air pollutants:

- Particulate emissions, which have the potential to impact on:
  - human health due to elevated suspended particulate concentrations (i.e. concentrations of particulate matter less than 10 microns (PM_{10}) and particulate matter less than 2.5 microns ($PM_{2.5}$);
  - local amenity, visibility and aesthetic enjoyment due to elevated Total Suspended Particulate (TSP) concentrations and dust deposition levels; and
  - vegetation, due to elevated dust deposition levels.

Executive Summary

- Products of fossil fuel combustion (in particular oxides of nitrogen (NO_x) and sulphur dioxide (SO_2) which have the potential to impact on the health and well-being of humans.

Atmospheric dispersion modelling was performed using the CALPUFF dispersion model developed by the US Environmental Protection Agency (USEPA) to simulate the dispersion of these emissions downwind (taking into account the local topography and meteorology) in order to estimate maximum ground level concentrations at nearby sensitive receptors. The modelling outputs were assessed against relevant international air quality guidelines and standards to identify potential impacts. The findings were then used to inform the design of the Project and/or development of proposed management measures where appropriate.

Activities with a low potential for impacts on local air quality were assessed qualitatively. Such activities included:

- Emissions of volatile organic compounds (VOCs) from the storage and transfer of diesel and other fuels; and
- Emissions of odour and methane from sewage treatment facilities, the proposed process plant and from the storage, handling and disposal of municipal waste from the accommodation facilities.

These emissions are expected to be minor and provided the facilities are well managed and located with appropriate separation distances from nearby sensitive receptors, no adverse impacts would be anticipated. The potential for off-site impacts from these activities was therefore assessed based on a review of separation distances recommended by Australian regulatory agencies (in the absence of guidelines in PNG) for each relevant activity type.

Papua New Guinea (PNG) does not currently have specific statutory air quality requirements. Consistent with other air quality impact assessments performed for major projects in PNG, a review of relevant international guidelines and standards was therefore performed to identify appropriate criteria to use in the assessment, including:

- International Finance Corporation (IFC) guidelines;
- World Health organisation (WHO) Air Quality Guidelines;
- United States Environmental Protection Agency (US EPA) standards; and
- Australian regulations.

It is noted that while international guidelines to protect against adverse human health impacts are applicable to populated areas (i.e., villages) surrounding the Project, guidelines designed to address the potential for adverse amenity impacts may be less relevant. Guidelines for TSP concentrations and dust deposition designed for use in urban areas, for example, may be overly stringent for a sparsely populated area of PNG where the high rainfall will act to rapidly wash dust off surfaces and vegetation.

In addition to the above review of relevant international guidelines and standards, given preliminary SO_2 dispersion modelling results predicted exceedances of the 2005 WHO criteria due to emissions from the power generation facilities (in the assumed absence of mitigation measures which are intended to be applied as required, such as scrubbers), WGJV commissioned a health-risk assessment (HRA) to understand possible impacts on sensitive receptors. The HRA included a targeted evaluation of relevant literature, international and national guidelines for the protection of human health from SO_2 emissions, and derived a Project-specific SO_2 criterion based on US EPA methodology and the European Union Member States' air quality directive criteria of 350 µg/m^3 (as the 3-year average of the 99th percentile of the annual distribution of daily maximum 1-hour concentrations). This criterion is equivalent to the 1-hour average ambient air quality limit for SO_2 set by European Union Directive 2008/50/EC (EU, 2008) and has been used to assess the predicted SO_2 impacts from the Project.

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The key findings of the air quality impact assessment are summarised below.

Mine Area

- Fugitive dust emission factors for mining activities published by the US EPA were used to estimate emissions of particulate matter for the following scenarios:
  - Scenario 1 – Construction phase activities; and
  - Scenario 2 – A worst case operational scenario assuming highest throughput.

  These calculations indicate that during construction, hauling is estimated to be the major source of TSP and PM_{10} emissions in the Mine Area. The estimated $PM_{2.5}$ emissions are almost equally weighted between hauling, material handling, wind erosion and power generation operations, with a minor contribution from ventilation emissions. During the operational phase of the Project, the IFO power generation facilities are the major source of the estimated TSP, PM_{10} and $PM_{2.5}$ emissions.
- Maximum ground level suspended particulate concentrations (including the TSP, PM_{10} and $PM_{2.5}$ size fractions) and dust deposition rates were predicted by the modelling to comply with the adopted assessment criteria at all identified sensitive receptor locations in the vicinity of the Mine Area (i.e. surrounding villages) for both the construction and operational scenarios. Based on the results of the modelling, no health-related or nuisance (amenity) based impacts are therefore anticipated as a result of particulate emissions from the Mine Area.
- Modelling of emissions from the on-site diesel generators during the construction phase showed that predicted NO_2, SO_2 and CO concentrations would be below the adopted assessment criteria at the surrounding sensitive receptors. Provided the generators are installed, operated and maintained in accordance with the manufacturer's instructions and good engineering practice, no adverse air quality impacts are therefore anticipated as a result of these emissions.
- Modelling of emissions from the proposed IFO power generation facilities during the operational phase showed that:
  - The predicted CO concentrations were well below the relevant assessment criteria at all surrounding sensitive receptors.
  - The predicted NO_2 concentrations comply with the relevant ambient assessment criteria at all receptors, acknowledging that Ziriruk is fractionally below the 1-hour average WHO criterion of 200 µg/m^3, with a predicted maximum concentration of 199.8 µg/m^3.
  - The predicted 1-hour average SO_2 concentrations comply with the Project-specific criterion of 350 µg/m^3 derived from the HRA (Coffey, 2018) at all receptors with the exception of Ziriruk and Fly Camp. The predicted 1-hour average SO_2 concentration predicted at Ziriruk is 849 µg/m^3, which is approximately 2.4 times the Project-specific criterion of 350 µg/m^3. The concentration predicted at Fly Camp of 605 µg/m^3 is approximately 1.7 times the criterion. The sensitive receptor predicted to be exposed to the third highest 1-hour average NO_2 concentration is Hekeng, with a concentration of 226 µg/m^3, which is well below the Project-specific criterion of 350 µg/m^3.

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- The above results indicate that there is potential for adverse air quality impacts at Ziriruk and Fly Camp as a result of SO_2 emissions from the IFO power generation facilities during the operational phase, once it is operating at full load. The project power demand for the Project indicates that during the first three years of operations, the power generation capacity will be approximately 50% of the full capacity assumed in the emission estimation and modelling. Ambient monitoring at these locations could therefore be performed during the early stages of the operational phase (i.e. when the power demand is lower and prior to all 12 IFO generators coming on-line) to verify the results of the modelling. If the monitoring confirms that concentrations above the Project criteria could be expected at these locations once the power generation facilities are operating at full load, then further management measures could be implemented. 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.
- Emissions of combustion products from mobile plant and machinery will be emitted over a large area and will be well-diluted before they can travel off-site. The potential for elevated off-site concentrations as a result of these emissions is therefore considered to be negligible.

Infrastructure Corridor

The Infrastructure Corridor encompasses the Project infrastructure linking the Mine Area and the proposed Coastal Area, and includes the proposed concentrate pipeline, terrestrial tailings pipeline and fuel pipeline, as well as the Northern Access Road.

- Construction of the pipelines and access roads has the potential to generate dust from the excavation, stockpiling and handling of soils, as well as wheel-generated dust from the movement of trucks and other mobile plant. The potential risks associated with dust emissions from construction of the pipelines have been assessed qualitatively using the risk assessment procedure published by the Institute of Air Quality Management, UK (IAQM, 2014).
- The assessment of potential impacts due to dust emissions for pipeline construction works concluded that there is a 'low' risk of dust soiling impacts occurring at the nearest sensitive receptors even if no management measures were to be applied during the earthworks, and a 'negligible' risk of dust soiling impacts at other sensitive locations located further away. The risk of human health impacts is classified as 'low' or 'negligible' at all locations, even if no management measures were to be applied.
- Provided appropriate management measures are applied during the access road and pipelines' construction works, it is anticipated that the potential risks of dust deposition and human health impacts at sensitive receptors close to the Infrastructure Corridor due to dust emissions from construction activities can be reduced from 'low' risk to 'negligible' risk. In addition, the impacts in any given location will be short-term in nature as the works proceed along the corridor.
- Air emissions from the operation of the access roads and the concentrate, terrestrial tailings and fuel pipelines would be limited to emissions from mobile plant and vehicles used for maintenance activities. These emissions will be minimal and have not been considered further.

Coastal Area

- The potential risks associated with dust emissions from construction of the Port Facilities Area have been assessed qualitatively using the risk assessment procedure published by the Institute of Air Quality Management, UK (IAQM, 2014). This IAQM risk assessment identified that the closest sensitive receptors to the site are located well beyond the largest separation distance recommended for screening out projects requiring assessment, hence the risk of potential impacts can be expected to be negligible.

Executive Summary

- During operation, the only potential source of dust emissions would be the concentrate filter cake, which will be stockpiled in a covered area or semi-enclosed building before being loaded into ships via a covered conveyor for export. On this basis, fugitive dust emissions from concentrate storage and handling are expected to be minimal and the potential for adverse air quality impacts at sensitive receptors will be negligible.
- Exhaust emissions from mobile plant and machinery operating at the site (such as forklifts, light vehicles, etc.) will also be minimal and would not have the potential to impact on air quality at the nearest sensitive receptors.
- Construction activities associated with the Outfall Area have the potential to generate fugitive dust emissions. The potential risks associated with dust emissions from construction have been assessed qualitatively using the risk assessment procedure published by the Institute of Air Quality Management, UK (IAQM, 2014). This IAQM risk assessment identified that the closest sensitive receptor to the site (Wagang) is located well beyond the largest separation distance recommended for screening out projects requiring assessment, hence further assessment has not been performed and the risk of potential impacts can be expected to be negligible.
- Air emissions from the operation of the Outfall Area are predicted to be negligible and have not been considered further.

Other Impacts

- High levels of dust deposition may cause damage to vegetation by blocking leaf stomata or inhibiting photosynthesis due to smothered leaf surfaces. The very high rainfall in the Project Area, however, would minimise such impacts by washing away dust deposited on leaves. Additionally, the low wind speeds characteristic of the area would minimise the area potentially affected as the majority of the particulate would not travel far before settling out of the air. As a result, any damage to vegetation due to dust emissions is expected to be very localised and limited to less than a few hundred metres from the active work areas.
- Different plant species and varieties and even individuals of the same species may vary considerably in their sensitivity to SO_2. 'Critical levels' have been developed for a number of air pollutants by the United Nations Economic Commission for Europe (UN/ECE) for the protection of vegetation (ICP, August 2017). While there are likely to be limitations in the relevance of these European-based guidelines to the types of vegetation and the growing conditions that exist in the Mine Area (warm temperatures and high rainfall), in the absence of local guidelines or data they have been used to provide insight on the potential for adverse impacts on vegetation due to SO_2 emissions from the Project.
- The results of the modelling performed as part of this assessment indicates that:
  - During the construction phase, annual average SO_2 concentrations are predicted to be far below the UN/ECE guideline for vegetation impacts on forest ecosystems across the modelling domain.
  - During the operational phase there is an area surrounding the IFO power generation facilities that is predicted to be exposed to annual average SO_2 concentrations above the UN/ECE guideline for vegetation impacts on forest ecosystems of 20 µg/m^3. Therefore, as recommended for the predicted exceedances of the 1-hour average Project-specific SO_2 criterion, it is recommended that ambient monitoring and vegetation surveys be performed within this area during the early stages of the operational phase (i.e. when the power demand is lower and prior to all 12 IFO generators coming on-line) to verify the results of the modelling and to assess the sensitivity of local vegetation to SO_2. If the monitoring confirms that there is potential for vegetation impacts to occur (such as impacts on gardens utilised by villagers) once the power generation facilities are operating at full load, then ongoing monitoring programs and management measures should be developed and implemented to offset potential identified impacts.

Executive Summary

GREENHOUSE GAS ASSESSMENT

A quantitative greenhouse gas (GHG) assessment has been performed for the Project. The assessment was performed through a six stage process:

- definition of the Project boundary
- identification of emission sources within the Project boundary
- identification of activity data for each emission source
- identification of emission calculation methods for each source
- calculation of GHG emissions
- identification of potential GHG mitigation strategies to reduce the GHG impact of the Project

GHG sources have been identified through the examination of process descriptions and activity data for each source provided by WGJV. In the absence of PNG guidelines, internationally accepted GHG emission calculation methodologies were used (Intergovernmental Panel on Climate Change [IPCC] and Australian Government Department of the Environment and Energy [DEE]) to calculate GHG emissions attributable to Project construction and operation activities. The GHG emission inventory included estimates of:

- Scope 1 'direct' emissions - GHG emissions produced from sources within the boundary of an organisation and as a result of the organisation's activities;
- Scope 2 emissions - GHG emissions from the generation of purchased electricity consumed in owned or controlled equipment or operations; and

Scope 3, or 'indirect' emissions (i.e. project-related GHG emissions outside of the control of the organisation) were not included in the emission inventory. This includes the extraction and production of purchased materials and fuels, contractor activities, and transport of staff, materials, products or waste by third parties (including shipping of concentrate).

The total Scope 1 GHG emissions for the Project are estimated at 15,182 kt CO_2-e assuming a five year construction period, 27 year operation and a three year closure period. Averaged over the 35 year life span of the Project, this is equivalent to 433.8 kt CO_2-e/annum.

Taking into account both Scope 1 and Scope 2 emissions, total estimated GHG emissions for the Project are estimated at 15,354 kt CO_2-e. Averaged over the 35 year life span of the Project, this is equivalent to 438.7 kt CO_2-e/annum.

The main sources of GHG emissions are diesel combustion and land clearance during mine construction, and IFO and diesel combustion during mine operation.

The most recent total GHG emissions reported for Papua New Guinea was for 2013; with emissions of 70,855 kt CO_2-e including land use change and forestry (LUCF) and 16,434 kt CO_2-e excluding LUCF (FAO, 2014). Comparison of the estimated annual average Scope 1 and Scope 2 GHG emissions over the life of the Project of 438.7 kt CO_2-e/annum with the total national emissions (including LUCF) reported by the FAO indicates that over the life of the Project, it would result in a relatively minor (0.6%) increase in the national emissions. In addition to the modelled base case of IFO power generation, the project will continue to assess energy options on an ongoing basis, including possible future renewable energy options that could reduce this contribution to national emissions.

Executive Summary

The environmental value potentially impacted due to GHG emissions from the Project is defined as the maintenance of climatic systems to maintain the health, development and well-being of humans and the protection of ecosystems and biodiversity. The sensitivity of climatic systems is somewhat unknown as there are remaining scientific uncertainties about the magnitude of the positive and negative feedbacks in the climatic system. For the purposes of this study, the sensitivity of this value has been characterised as moderate. The magnitude of change related to GHG emissions from the Project is considered to be low due to the minimal contribution these emissions will have to the overall greenhouse gas emissions of PNG (<1% based on the most recent national inventory data available (FAO, 2014)). Regardless of the minimal contribution to national emissions however, the WGJV Participants are committed to minimising GHG emissions through a proactive approach to emissions control and reduction.

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ABBREVIATIONS

%	percent
°C	degrees Celsius
µg	microgram
µg/m^3	microgram per cubic metre
µg/Nm^3	microgram per normalised cubic metre (273K, 101.3kPa)
µm	micrometre or micron
AP-42	US EPA Compilation of Emission Factors
ARM	Ambient Ratio Method
AWS	automatic weather station
CDM	Clean Development Mechanism
CEMP	Construction Environmental Management Plan
CEPA	Conservation and Environment Protection Authority
CER	Certified Emission Reduction
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalent
DEC	Department of Environment and Conservation
EEO	Energy Efficiency Opportunities
EETM	Emission Estimation Technique Manual
EF	Emission Factor
EIS	Environmental Impact Statement
EHS	Environmental Health and Safety
EPFI	Equator Principle Financial Institution
g	gram
g/m^2/month	grams per square metre per month
GHG	Greenhouse Gas(es)
GJ	gigajoule: 1.0 x 10^9 J
GJ/s	gigajoule per second
GWP	Global Warming Potential
ha	hectares
HFC	Hydrofluorocarbons
IFO	Intermediate Fuel Oil
IFC	International Finance Corporation
IPCC	Inter-Governmental Panel on Climate Change
J	joule
K	degrees Kelvin
kg	kilogram
kg/hr	kilogram per hour
km	kilometre
km E	kilometres east
km N	kilometres north
kV	kilovolt
L	litre
LUCF	land use change and forestry
m	metre
M	million
m/s	metre per second
m^2	square metre
m^3	cubic metre

min	minute
mm	millimetre
Mt	million tonnes
Mtpa	million tonnes per annum
MW	megawatt
MWh	megawatt-hour: 1 MWh = 3,600 J
N_2O	nitrous oxide
NAF	Non-Acid Forming
NMVOC	Non Methane Volatile Organic Compounds
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	oxides of nitrogen
NPI	National Pollutant Inventory (Australia)
O_3	ozone
OLM	Ozone Limited Method
PAF	Potentially Acid-Forming
PFC s	Perfluorocarbons
PM	Particulate Matter
PM_{10}	particular matter with an equivalent aerodynamic diameter of 10 microns or less
$PM_{2.5}$	particular matter with an equivalent aerodynamic diameter of 2.5 microns or less
ppb	parts per billion (10^9)
ppm	parts per million (10^6)
SF_6	Sulphur hexafluoride
SO_2	sulphur dioxide
SO_X	oxides of sulphur
t	tonne
TJ	terajoule: 1.0 x 1012 J
tonne d m	tonne dry mass
tpa	tonnes per annum
TSP	total suspended particulate matter
UNFCC	United Nations Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
VOC	Volatile Organic Compounds
W	watt
WHO	World Health Organization

GLOSSARY

air dispersion model	A computer-based software program which provides a mathematical prediction of how pollutants from a source will be distributed in the surrounding area under specific conditions of wind, temperature, humidity and other environmental factors
airshed	The geographical area associated with a given air supply
algorithms	A step-by-step problem-solving procedure, especially an established, recursive computational procedure for solving a problem in a finite number of steps
ambient	Pertaining to the surrounding environment or prevailing conditions
atmosphere	A gaseous mass surrounding the planet that is retained by Earth's gravity. It is divided into five layers, with most of the weather and clouds found in the first layer
atmospheric stability	The tendency of the atmosphere to resist or enhance vertical motion
atmospheric pressure	The force per unit area exerted against a surface by the weight of air above that surface in the Earth's atmosphere
background	The existing air quality in the Project Area excluding the impacts from the Project
baseline monitoring program	A monitoring program designed to measure the ambient concentration levels which currently exist prior to the Project
CALMET	A meteorological model that develops wind and temperature fields on a 3-dimensional gridded modelling domain
CALPOST	A post-processor used to process CALPUFF files, producing tabulations that summarise results for user-selected averaging periods
CALPUFF	A transport and dispersion model that advects “puffs” of material emitted from modelled sources, simulating dispersion and transformation processes
climatological	The science dealing with climate and climatic phenomena
combustion	The process of burning. A chemical change, especially oxidation, accompanied by the production of heat and light
dust deposition	Settling of particulate matter out of the air through gravitational effects (dry deposition) and scavenging by rain and snow (wet deposition)
dispersion	The spreading and dilution of substances emitted in a medium (e.g. air or water) through turbulence and mixing effects
diurnal	Relating to or occurring in a 24-hour period; daily
downwash	The grounding of an air pollution plume as it flows over nearby buildings or other structures due to turbulent eddies being formed in the downwind side of the building, resulting in elevated ground level concentrations.
downwind	The direction in which the wind is blowing

emission factor	A measure of the average amount of a specific pollutant or material emitted by a specific process, fuel, equipment, or source based on activity data such as the quantity of fuel burnt, hours of operation or quantity of raw material consumed.
emissions inventory	A database that lists, by source, the amount of air pollutants discharged into the atmosphere from a facility over a set period of time (e.g. per annum, per hour)
erodible	A term used to describe a soil that is vulnerable to erosion by the agents of wind, water, ice
epidemiological	The branch of medicine that deals with the study of the causes, distribution, and control of disease in populations
fossil fuel	A natural fuel such as coal, diesel or gas, formed in the geological past from the remains of living organisms
fugitive emissions	Pollutants which escape from an industrial process due to leakage, materials handling, transfer, or storage
global warming potential	A measure of how much a given mass of greenhouse gas is estimated to contribute to global warming using a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP is by convention equal to 1).
greenhouse gas	A gas that contributes to the greenhouse effect by absorbing infrared radiation, e.g. carbon dioxide
guideline	A general rule, principle, or piece of advice. A statement or other indication of policy or procedure by which to determine a course of action
materiality threshold	Represents the amount of insignificant emissions allowed which do not need to be quantified and accounted for
meteorological	The science that deals with the phenomena of the atmosphere, especially weather and weather conditions
mixing height	The height to which the lower atmosphere will undergo mechanical or turbulent mixing, producing a nearly homogeneous air mass
modelling domain	The area over which the model is making predictions
particulate	Of, relating to, or formed of minute separate particles. A minute separate particle, as of a granular substance or powder
plume	A space in air, water, or soil containing pollutants released from a point source
point source	A pollution source that is fixed and/or uniquely identifiable, such as a stack, chimney, outlet pipe or vent
pollutant	A substance or energy introduced into the environment that has undesired effects, or adversely affects the usefulness of a resource
prognostic	A prediction of the value of variables for some time in the future on the basis of the values at the current or previous times
qualitative assessment	An assessment of impacts based on a subjective, non-statistical oriented analysis

quantitative assessment	An assessment of impacts based on estimates of emission rates and air dispersion modelling techniques to provide estimate values of ground level pollutant concentrations.
receptor	Coordinate locations specified in an air dispersion model where ground level pollutant concentrations are calculated by the model
Scope 1	Direct emissions of greenhouse gases produced from sources within the boundary of an organisation and as a result of the organisation's activities
Scope 2	Indirect emissions of greenhouse gases produced from the generation of purchased electricity consumed in owned or controlled equipment or operations
Scope 3	Indirect emissions of greenhouse gases generated in the wider economy as a consequence of an organisation's activities but are physically produced by the activities of another organisation
sensitive receptor	Locations such as residential dwellings, hospitals, churches, schools, recreation areas etc., where people (particularly the young and elderly) may often be present
solar radiation	The total electromagnetic radiation emitted by the Sun
spatial variation	Pertaining to variations across an area
standard	The prescribed level of a pollutant in the outside air that should not be exceeded during a specific time period to protect public health
synoptic meteorological data	A surface weather observation, made at periodic times (usually at 3-hourly and 6-hourly intervals), of sky cover, state of the sky, cloud height, atmospheric pressure reduced to sea level, temperature, dew point, wind speed and direction, amount of precipitation, hydrometeors and lithometeors, and special phenomena that prevail at the time of the observation or have been observed since the previous specified observation
temporal variation	Pertaining to variations with time
topography	Detailed mapping or charting of the features of a relatively small area, district, or locality
volatile organic compounds	All organic compounds (substances made up of predominantly carbon and hydrogen) with boiling temperatures in the range of 50-260°C, excluding pesticides. This means that they are likely to be present as a vapour or gas in normal ambient temperatures
wind direction	The direction from which the wind is blowing
wind erosion	Detachment and transportation of loose topsoil or sand by the wind
wind rose	A meteorological diagram depicting the distribution of wind direction and speed at a location over a period of time

1 INTRODUCTION

Wafi Mining Limited and Newcrest PNG 2 Limited (WGJV Participants) are equal participants in the Wafi-Golpu Joint Venture (the WGJV). The WGJV is investigating the feasibility of constructing, operating and (ultimately) closing 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"), a proposed greenfield underground copper-gold mine located beneath Mt Golpu, approximately 300 kilometres (km) north-northwest of Port Moresby and 65km southwest of Lae in the Morobe Province of the Independent State of Papua New Guinea (PNG).

Coffey Environments Australia Pty Ltd (Coffey) contracted SLR Consulting Australia Pty Ltd (SLR) to prepare an Air Quality and Greenhouse Gas Impact Assessment (AQGGIA) for the Project. This report will form part of the environmental impact statement (EIS) for the Project.

The objective of the AQGGIA is to identify potential air pollutant emissions associated with the Project, and to assess the potential off-site impacts of those emissions on human health, amenity and ecological values based on relevant ambient air quality criteria. A quantitative greenhouse gas (GHG) assessment has also been performed to quantify the potential annual GHG emissions associated with the Project, with the potential significance of these emissions assessed based on the Project's estimated contribution to PNG's national GHG emissions.

1.1 Structure of this Report

This report describes the study methods used in the assessment, summarises the results of the assessment and describes the management measures proposed to mitigate the potential air quality impacts of the Project and the predicted residual impacts assuming these measures are implemented.

The structure of this report is outlined below.

- **Section 1** outlines the objectives of the AQGGIA and the report structure.
- **Section 2** provides a brief outline of the Project and identifies the proposed construction and operational activities with the potential to give rise to air emissions.
- **Section 3** identifies the pollutants of interest and provides an overview of the assessment methodologies used to assess potential off-site impacts.
- **Section 4** discusses the various air quality criteria (including PNG regulatory requirements and international standards) upon which this assessment is based.
- **Section 5** describes the study area with respect to the topography, land use, climate, sensitive receptors and existing air quality.
- **Section 6** describes the study methods used in the air quality impact assessment to assess the potential impacts on local air quality, including details of the meteorological and dispersion modelling approach used to quantitatively assess impacts associated with the Mine Area activities and the qualitative risk assessment approach used for construction activities.
- **Section 7** presents the assessment of local air quality impacts associated with the proposed construction and operational activities in the Mine Area.
- **Section 8** presents the assessment of local air quality impacts associated with the proposed construction and operational activities associated with the Infrastructure Corridor.
- **Section 9** presents the assessment of local air quality impacts associated with the proposed construction and operational activities in the Coastal Area.
- **Section 10** discusses the potential impacts of air emissions from the Project on surrounding vegetation.

- **Section 11** presents the study methods used to compile the GHG emissions inventory for the Project, assesses the GHG efficiency and significance of the Project in relation to national emissions and identifies appropriate GHG management and offset options.
- **Section 12** outlines the recommended management and monitoring measures.
- **Section 13** summarises the key findings of the air quality and GHG assessment.

2 PROJECT DESCRIPTION

2.1 Project Overview

The Project includes ore processing, concentrate transport and handling, power generation, water management, a deep sea tailings placement (DSTP) system for tailings management, access roads to the mine and related support facilities.

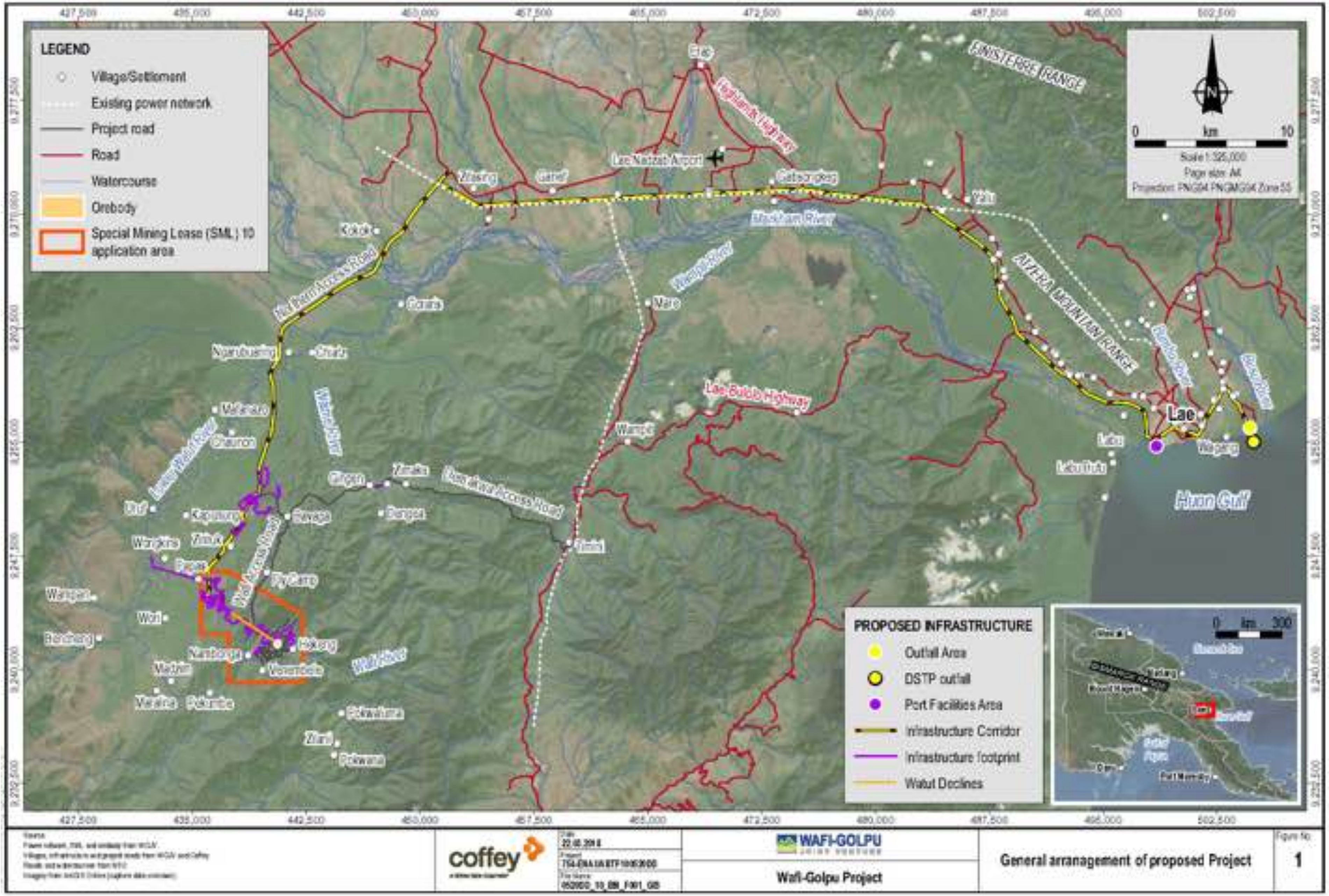
Geographically, the Project occupies a mine to port footprint that extends from the Mine Area to the Coastal Area with an Infrastructure Corridor that links the two areas. Together these discrete areas make up the proposed Project Area (**Figure 1**):

- **Mine Area.** The area encompassing the proposed block cave mine, underground access declines and nearby infrastructure, including a portal terrace and waste rock dump supporting each of the Watut and Nambonga declines, the Watut Process Plant, power generation facilities, laydown areas, water treatment facilities, quarries, wastewater discharge and raw water make-up pipelines, raw water dam, sediment control structures, roads and accommodation facilities for the construction and operations workforces.
- **Infrastructure Corridor.** The area encompassing the proposed Project infrastructure linking the Mine Area and the Coastal Area, being corridors for pipelines and roads and associated laydown areas. The proposed concentrate pipeline, terrestrial tailings pipeline and fuel pipeline will connect the Mine Area to the Coastal Area. A proposed Mine Access Road and Northern Access Road will connect the Mine Area to the Highlands Highway. New single-lane bridges are proposed over the Markham, Watut and Bavaga rivers. Laydown areas will be located at key staging areas.
- **Coastal Area.** The Coastal Area includes the proposed Port Facilities Area and the proposed Outfall Area:
  - Port Facilities Area. Located at, or in proximity to, the Port of Lae, with a site adjacent to Berth 6 (also known as Tanker Berth) nominated as the preferred option. The proposed facilities will include the concentrate filtration plant and materials handling, storage, ship loading facilities and filtrate discharge pipeline.
  - Outfall Area. Located approximately six kilometres east of the port. The proposed facilities will include the Outfall System comprising the mix/de-aeration tank and associated facilities, seawater intake pipelines and DSTP outfall pipelines, pipeline laydown area, choke station, access track and parking turnaround area.

The WGJV has commissioned a range of studies to inform the Project's Feasibility Study Update and to prepare an Environmental Impact Statement (EIS).

Future development of the Project remains subject to further deep orebody drilling and definition (after underground access has been achieved), technical studies, completion of statutory permitting processes and securing Government and WGJV Participants' approvals.

Engineering design and other studies, including environmental studies, are continuing and there is potential that aspects of the proposed Project design, layout and timetable may change.

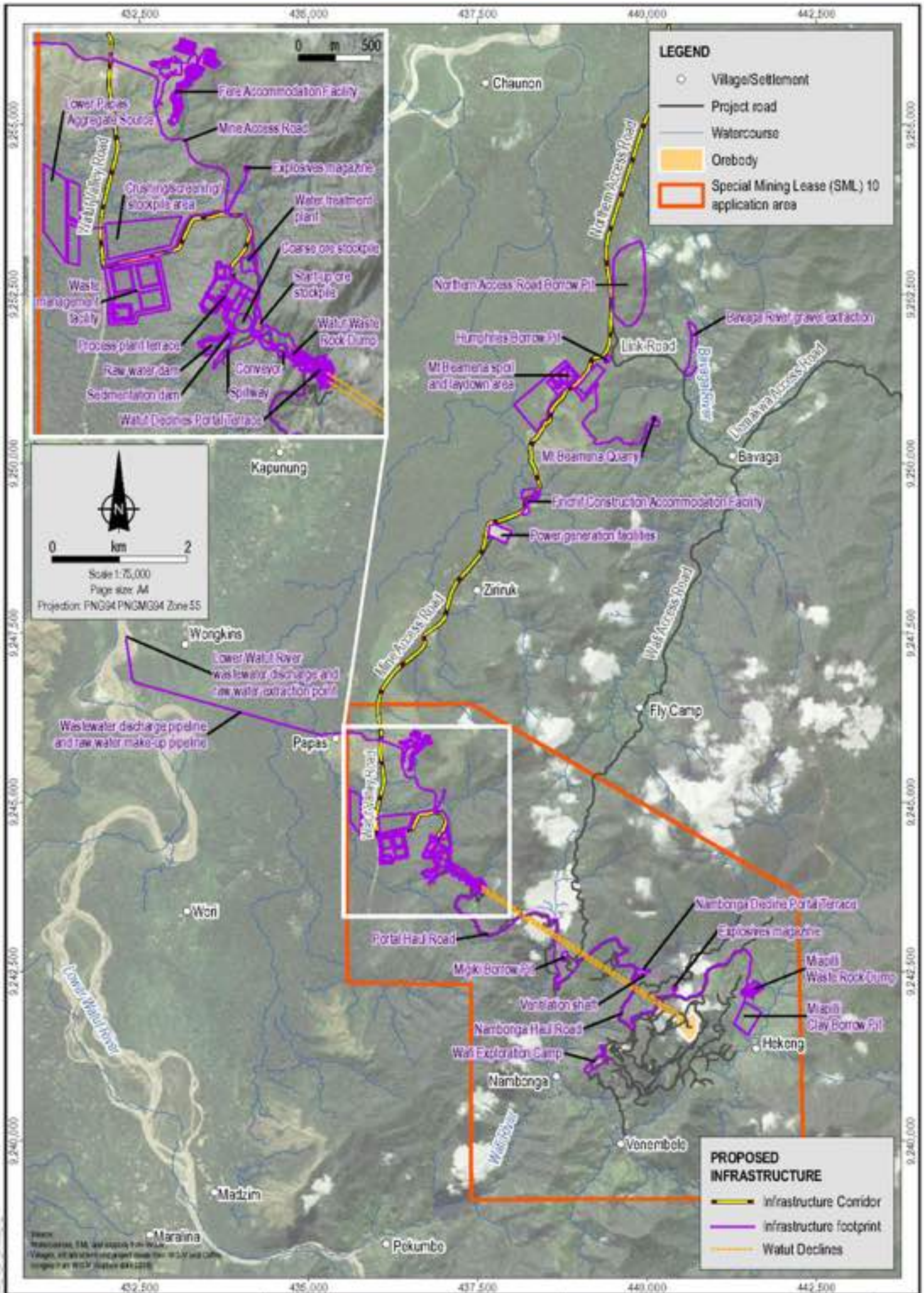

LEGEND
Village/Settlement
Existing power network
Project road
Road
Watercourse
Orebody
Special Mining Lease (SML) 10 application area
PROPOSED INFRASTRUCTURE
Outfall Area
DSTP outfall
Port Facilities Area
Infrastructure Corridor
Infrastructure footprint
Watut Declines
FINISTERRE RANGE
ATZERA MOUNTAIN RANGE
Highlands Highway
Lae-Bulolo Highway
Markham River
Lae Nadzab Airport
Lae
Huon Gulf
Wafi-Golpu Project
General arranagement of proposed Project
1

2.2 Proposed Activities with Potential for Air Emissions

Development of the Project will require significant infrastructure and facilities to operate. The principal components of the Project (see **Figure 2**) include:

- Underground mine comprising three block caves, to be developed in stages and located beneath Mt Golpu at Reduced Level (RL) 4,400 metres (m), 4,200 m and 4,000 m, respectively. Access to the orebody will be obtained via the twin Watut Declines (3.6 km long) and the Nambonga Decline.
- Ore processing and concentrate transport/handling facilities, including a pipeline to transport concentrate slurry from the Mine Area to the Port Facilities Area at the Port of Lae.
- A deep sea tailings placement (DSTP) system for tailings management into the Markham Canyon in the Huon Gulf near Lae, with tailings transported by pipeline from the Mine Area to the Outfall Area on the Huon Gulf coast.
- On-site power generation facilities located within the Mine Area, with IFO delivered via pipeline from a third-party supplier located at the Port of Lae.
- The Watut and Miapilli waste rock dumps to store non-acid forming (NAF) and potentially acid-forming (PAF) rock generated during the development of the declines and ventilation shaft.
- Water and waste management facilities, including water treatment facilities, wastewater discharge and raw water make-up pipelines and raw water and sedimentation dams.

Further details of specific activities with potential to generate air emissions (including emissions of GHG) are provided in the following sections.



coffey

Date: 22.03.2018

Project: 754-ENAUABTF100520DD

File Name: 05200D_18_BM_F002_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

General arrangement of proposed Mine Area

Figure No: 2

2.2.1 Mine Construction and Operation

It is anticipated that both PAF and NAF waste rock will be excavated from the declines. Waste rock dumps will be constructed to accommodate this waste rock. The NAF rock will be encountered in the initial portion of decline development and used in construction to provide fill for portal and process plant platforms and access roads.

During mining operations, ore from the block cave draw points will be delivered by diesel load-haul-dump (LHD) vehicles to an underground jaw crusher. The crushed ore will then be conveyed to the surface. The ore conveyor emerging at the Watut Decline Portal Terrace will continue overland to discharge onto a coarse ore stockpile adjacent to the Watut Process Plant.

The underground air ventilation system will connect the block caves to the ventilation shaft used to expel air from the mine, with fresh air drawn into the mine via the declines. Ventilation air will also be exhausted via the Watut Decline during the operational phase.

2.2.2 Borrow Pits and Quarry

Four borrow pits and one quarry are proposed for the Project: Migiki, Humphries, Miapilli clay, and the Northern Access Road borrow pits and Mt Beamena Quarry (see **Figure 2**). Gravel will also be sourced from the Bavaga and Waime River beds and the Lower Papas aggregate source.

2.2.3 Electricity Generation

Forecast demand for electricity during construction is 20 MW. It is assumed this will be met by multiple (20 units) small and geographically diverse diesel generators. Each generator is expected to have an output of approximately 1 MW and will be provided by the construction contractors.

During the operational phase, the forecast demand for electricity for the Project is 100 MW. The AQGGIA is based on the installation of fourteen (14) Wartsila 20V32 reciprocating engine generation units burning intermediate fuel oil (IFO-160), with twelve (12) units operating at any one time to supply power for ore production at a 16.8 Mtpa throughput, and two (2) on standby.

2.2.4 Pipelines

Concentrate will be transported from the Watut Process Plant to the Port Facilities Area by a buried pipeline (see **Figure 1**). The steel concentrate pipeline will be lined with high density polyethylene (HDPE) and operate at high pressure (approximately 200 bar) to transport the concentrate.

Tailings will be transported from the Watut Process Plant to the Outfall Area by a buried, steel pipeline that will be constructed adjacent to the concentrate pipeline to the Port of Lae, and then will extend further east to the Huon Gulf coast (see **Figure 1**). This pipeline will be lined with HDPE and operate at high pressure (approximately 200 bar).

Fuel will be transported to the Mine Area from the Port of Lae by a buried, steel pipeline, which will also be constructed adjacent to the concentrate pipeline and will operate at high pressure (approximately 200 bar).

2.2.5 Port Facilities Area

The Port Facilities Area will be constructed at the Port of Lae. The concentrate will be dewatered using a pressure filter and the filtrate treated prior to discharge into the marine environment. The concentrate filter cake will be stockpiled in a covered area or semi-enclosed building before being loaded into ships via a covered conveyor for export. The proposed location of the plant site is shown in **Figure 1**.

2.2.6 Outfall Area

The Outfall Area will be constructed approximately 100 m inshore of the beach, and approximately 1.5 km west of the Busu River. The Outfall System will comprise a mix/de-aeration tank located in a dry moat, a facility building and generators, a pipe and choke station area, laydown and storage area, and parking and turnaround area. Dual outfall pipelines, to deposit the tailings, and seawater intake pipelines, to supply water to the mix/de-aeration tank, will be constructed along the seafloor. The location of the Outfall Area is shown in **Figure 1**.

3 IDENTIFIED SOURCES OF AIR EMISSIONS & ASSESSMENT APPROACH

3.1 Sources of Emissions

Based upon a review of the Project information provided, potential air emission sources associated with the construction and operation of the Project have been identified as detailed in **Table 1**.

3.2 Pollutants of Interest

The key air pollutants requiring assessment are:

- Fugitive particulate emissions from construction and operational activities which have the potential to affect:
  - human health due to elevated suspended particulate concentrations (i.e. concentrations of particulate matter less than 10 microns (PM_{10}) or less than 2.5 microns ($PM_{2.5}$));
  - local amenity, visibility and aesthetic enjoyment due to elevated Total Suspended Particulate (TSP) concentrations and dust deposition levels; and
  - health of other forms of life, including the protection of ecosystems and biodiversity, due to increased rates of dust deposition.
- Products of fossil fuel combustion (in particular, carbon monoxide (CO), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2)) which have the potential to impact on the life, health and well-being of humans.

3.3 Assessment Approach

The greatest amount of land disturbance/earthworks and fuel consumption associated with the Project will occur within the Mine Area. Therefore the most significant sources of air emissions associated with the Project will arise from construction and operational activities in the Mine Area. A detailed quantitative assessment of these emissions has been performed using atmospheric dispersion modelling techniques, as detailed in **Section 7**, which covers:

- Emissions of combustion products from the diesel generators during the construction phase and the IFO power generation facilities during operational phase;
- Fugitive dust emissions from the operational mining activities;
- Dust emissions from the underground ventilation exhaust systems; and
- Fugitive dust emissions from the construction of the Mine Area infrastructure, including declines, quarry operations and ventilation shaft.

Fugitive dust emissions from the construction of the pipelines and access roads have been assessed qualitatively (refer **Section 8**). Due to the moving focal point of construction activities along the length of the Infrastructure Corridor, no single geographic setting could be used to characterise the site. Similarly, changes in the surrounding land use and distance to sensitive receptors (which all have the potential to affect the level of potential air quality impacts that could occur) varies along the length of the corridor. Modelling of these activities will therefore have a high level of uncertainty as the actual impacts could vary significantly depending on the time of year when the works occur in each area, as well as any deviations in the pipeline route within the proposed corridor.

Similarly, fugitive dust emissions from the construction of the Port Facilities Area and Outfall Area have also been assessed qualitatively in **Section 9**.

Air emissions from the operation of the concentrate, tailings and fuel pipelines, Port Facilities Area and Outfall Area will be minimal. These emissions would be limited to products of fuel combustion from vehicles and equipment operating in these areas. For example, vehicles and trucks transporting staff and equipment during inspections and maintenance of the pipelines, chainsaws/brush cutters used to cut back vegetation within the Infrastructure Corridor, and forklifts operating at the Port Facilities Area. These emissions do not have any potential to adversely impact on off-site sensitive receptors and have not been considered further.

Section 11 presents an assessment of the potential emissions of GHGs from fuel combustion and other activities associated with the Project (e.g., leakage of refrigerants from refrigeration units and SF_6 leakage from switchgear), which have the potential to impact on climatic systems.

Table 1 Potential Sources of Air Emissions Identified for the Project

Project Location	Construction	Operation	Closure
Mine Area	• Fugitive particulate matter from earthworks associated with the construction of the Project infrastructure, borrow pit activities (including drilling and blasting) and development of the declines and ventilation shaft. • Dust and fugitive gases from blasting during the development of the declines. • Fugitive particulate matter from the handling, transport and disposal of waste rock at the waste rock dumps. • Particulate matter from wind erosion of open areas, waste rock dumps, borrow pits and stockpiles. • Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from diesel-powered equipment, e.g. trucks, excavators, bulldozers etc. • Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from diesel-powered generators. • Products of combustion from the waste incinerator at the Watut industrial area. • Emissions of VOCs from the storage and transfer of diesel and other fuels. • Emissions of odour and methane from sewage treatment facilities and from the storage, handling and disposal of municipal waste from the accommodation facilities. • Emissions of dust and fumes from workshops (e.g. from sanding, welding and the use of solvents for cleaning equipment parts).	• Fugitive particulate matter from ore handling and processing. • Emissions of dust and fumes from the declines and ventilation shaft. • Particulate matter from wind erosion of open areas and stockpiles. • Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from on-site diesel-powered equipment such as trucks, excavators, bulldozers etc. • Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from IFO power generation facilities. • Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from the transport of workers (aircraft, passenger buses and light vehicles). • Products of combustion from the waste incinerator at the Watut industrial area. • Emissions of VOCs from the storage and transfer of diesel and other fuels. • Emissions of odour and methane from sewage treatment facilities, process plant and from the storage, handling and disposal of municipal waste from the accommodation facilities. • Emissions of dust and fumes from the storage, handling and disposal of mine waste and municipal waste from the accommodation facilities. • Emissions of dust and fumes from workshops (e.g. from sanding, welding and the use of solvents for cleaning equipment parts).	• Fugitive particulate matter from earthworks and demolition activities. • Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from on-site diesel-powered equipment such as trucks, excavators, bulldozers etc.
Infrastructure Corridor	• Fugitive particulate matter from earthworks during construction of the pipelines. • Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from diesel-powered equipment, e.g. trucks, excavators, bulldozers etc.	• Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from vehicles, truck and other diesel-powered equipment used for maintenance.	No impacts expected.
Port Facilities Area	• Fugitive particulate matter from earthworks during construction at the port. • Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from diesel-powered equipment, e.g. trucks, cranes etc.	• Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from diesel-powered equipment, e.g. front-end loaders, forklifts etc. • Particulate emissions from storage and handling of concentrate. • Emissions from shipping are assumed to be the responsibility of the carrier and are beyond the scope of this assessment.	No impacts expected.
Outfall Area	• Fugitive particulate matter from earthworks associated with construction activities. • Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from diesel-powered equipment, e.g. trucks, excavators, bulldozers etc.	• Products of combustion (NO_x, CO, CO_2, SO_2, VOCs and particulate) from diesel-powered equipment, e.g. vehicles etc.	No impacts expected.

4 IMPACT ASSESSMENT CRITERIA

Assessment criteria for particulate and products of combustion are reviewed below. Emissions of CO_2 and other GHG are addressed in **Section 11**.

4.1 Defining Biophysical Environmental Values

The following impact assessment criteria have been identified for use in this AQGGIA to assess the Project's potential impacts on biophysical environmental values. A biophysical environmental value is generally defined as a quality or physical characteristic of the environment that is important to ecological health or public amenity. Based on this definition, the key environmental values relating to air and GHG emissions include:

- Health of humans;
- Health of other forms of life, including the protection of ecosystems and biodiversity;
- Local amenity and aesthetic enjoyment;
- Visibility;
- The useful life and aesthetic appearance of buildings, structures, property and materials; and
- Climatic systems (GHG emissions only).

4.2 Types of Air Quality Criteria

Regulatory authorities manage air quality through a range of mechanisms, including ambient air quality guidelines and source emission limits.

Ambient air quality guidelines or standards relate to the maximum downwind, ground level concentrations that may occur as a result of the emissions and are the maximum concentrations to which the public may be exposed. These criteria are normally based on the results of epidemiological or other health-based studies and are generally designed to protect sensitive populations from adverse health effects, or to prevent damage to sensitive vegetation and crops. When assessing compliance with ambient air quality criteria it is necessary to account for other sources in the area so that the total cumulative impact of all sources is considered. Ambient air quality criteria relevant to the Project are presented and discussed in **Section 4.3**.

Source emissions limits are maximum allowable emission concentrations or emission rates which relate to in-stack concentrations at the point of discharge. Emission limits are normally specified for particular source types, such as SO_2 emission rates for sulphuric acid plants or NO_X emission concentrations for gas-fired combustion sources, and are generally based on the current best available technology for the relevant equipment.

The vast majority of sources associated with the Project are fugitive in nature. The only potentially significant point sources of emissions would be:

- Emissions from the construction phase diesel generators (20 units, each approximately 1 MW in size);
- Emissions from the IFO-fired Wartsila 20V32 reciprocating engine power generation units (12 operating and 2 in standby) during the operational phase (total operational capacity of 100 MW); and
- Emissions from the declines and ventilation shaft discharging dust and fumes from the underground workings.

Air quality at locations where people are present in the underground workings must comply with occupational exposure criteria, and there are no additional stack emission limits that would be relevant to the ventilation exhaust system. Source emission limits relevant to the diesel generators and IFO power generation facilities are presented and discussed in **Section 4.3**.

4.3 Overview of Relevant Legislation and Guidelines

4.3.1 PNG Environmental Legislation

The Conservation and Environment Protection Authority (CEPA) is the government agency responsible for administering the *Environment Act 2000*. It replaces the former Department of Environment and Conservation (DEC).

The *Environment Act 2000* (Environment Act) is the primary legislation in PNG which regulates the environmental impact of development activities and how adverse effects of such activities should be avoided, remedied or mitigated. The Environment Act caters for the sustainable management of the biological and physical components of the land, air and water resources of the country.

Several guidelines have also been published by CEPA (then DEC), including:

- *Guideline for submission of an application for an environmental permit to discharge waste*. GL-Env/03/2004, including the following Technical Guidelines:
    - Noise discharges. IB-ENV/03/2004
    - Air discharges. IB-ENV/02/2004
    - Water and Land Discharges. IB-ENV/04/2004.

The Technical Guideline (Additional Information) for air discharges (DEC, 2004) sets out the information that should be provided as part of an application for an Environment (Waste Discharge) Permit where air emissions may be generated. This includes:

- Details of the source, nature, composition and rate of air emissions;
- Information on emissions control equipment and proposed methods to minimise air discharges (specific information for fabric filters, afterburners and wet scrubbers is requested);
- Maintenance procedures and contingency procedures to avoid air discharges from process failure and shut down;
- Stack emission details;
- Calculated ground level concentrations of pollutants proposed to be discharged to air under normal and maximum operating conditions and start up and shutdown conditions; and
- An assessment of the impact of the proposal on the environment.

The State of PNG does not currently have any statutory ambient air quality standards or stack emission limits, nor are any specified in the Technical Guideline (Additional Information) for air discharges. A review of relevant air quality criteria and guidelines set by other agencies has been therefore performed in the follow sections, including:

- International Finance Corporation (IFC) Environmental, Health and Safety Guidelines (EHS);
- World Health Organization (WHO) Air Quality Guidelines;
- United State Environmental Protection Agency (US EPA) standards; and
- Australian regulations.

The objective of this review was to identify appropriate criteria to use in the assessment in the absence of PNG-specific guidelines or similar. The guidelines used are presented in **Section 4.4**, while details of the review performed are provided in **Section 4.3.2** to **Section 4.3.5**.

4.3.2 IFC Assessment Requirements

4.3.2.1 Environmental, Health and Safety Guidelines – Air Emissions and Ambient Air Quality

The International Finance Corporation (IFC) *Environmental, Health and Safety Guidelines – Air Emissions and Ambient Air Quality* (IFC, 2007) provides an approach to the management of significant sources of air emissions, including specific guidance for assessment and monitoring of impacts. This guideline states that:

> *"Where possible, facilities and projects should avoid, minimize, and control adverse impacts to human health, safety, and the environment from emissions to air. Where this is not possible, the generation and release of emissions of any type should be managed through a combination of:*
>
> - *Energy use efficiency*
> - *Process modification*
> - *Selection of fuels or other materials, the processing of which may result in less polluting emissions*
> - *Application of emissions control techniques"*

The IFC air quality guidelines require that impacts on air quality of a proposed development be estimated through qualitative or quantitative assessments by the use of baseline air quality assessments and atmospheric dispersion models to assess potential ground level concentrations. Local atmospheric, climatic, and air quality data should be applied when modelling plume dispersion, taking into account atmospheric downwash, wakes, or eddy effects of the source, nearby structures and terrain features.

In addition, projects with significant sources of air emissions, and potential for significant impacts to ambient air quality, should prevent or minimise impacts by ensuring that:

- Emissions do not result in pollutant concentrations that reach or exceed relevant ambient quality guidelines and standards by applying national legislated standards or, in their absence, the current WHO Air Quality Guidelines, or other internationally recognised sources.
- Emissions do not contribute a significant portion to the attainment of relevant ambient air quality guidelines or standards (as a general rule, the guideline suggests 25% of the applicable air quality standards to allow additional, future sustainable development in the same airshed).

Given the above, and in the absence of PNG standards, this assessment has largely adopted the WHO Air Quality Guidelines as Project criteria for off-site ground level concentrations. Where guidelines are not set by WHO for relevant pollutants or averaging periods, other internationally recognised sources have been referenced.

4.3.2.2 Environmental, Health and Safety Guidelines for Mining

The IFC industry sector EHS guideline document for mining (IFC, 2007) is designed to be used together with the General EHS Guidelines document and provide general and industry-specific examples of Good International Industry Practice.

This guideline notes that principal air emissions sources from mining projects include fugitive dust from blasting, exposed surfaces such as tailings facilities, stockpiles, waste dumps, haul roads and infrastructure, and to a lesser extent, gases from combustion of fuels in stationary and mobile equipment. It provides guidance on recommended fugitive dust mitigation strategies and refers to the IFC's General EHS guidelines for recommended emissions reduction and control strategies for stationary steam and power generation activities from sources with a capacity equal to or lower than 50 MW and from mobile sources.

4.3.2.3 Environmental, Health and Safety Guidelines for Thermal Power Plants

The IFC industry sector EHS guideline document for thermal power plants (IFC, 2008) is applicable to processes associated with the generation of mechanical or electrical power, steam or heat (or any combination of those) through combustion of gaseous, liquid or solid fossil fuels or biomass, with a total rated heat input capacity greater than 50 MW. This document is therefore relevant to the 100 MW IFO-fired power generation facilities proposed for the operational phase of the Project.

The document notes that principal air emissions sources from the combustion of fossil fuels are sulphur dioxide (SO_2), oxides of nitrogen (NO_X), particulate matter (PM), carbon monoxide (CO) and greenhouse gases such as carbon dioxide (CO_2). The amount and nature of air emissions depends on the fuel type, the type and design of the combustion unit, operating practices, emissions control measures and the overall system efficiency.

A range of management measures to minimise emissions of air pollutants are provided in the document. Table 6(A) also presents the following Emissions Guidelines (i.e. maximum in-stack concentrations) for reciprocating engines:

- For a plant burning liquid fuels with capacity between 50 MW and 300 MW and located in a non-degraded airshed:
  - PM: 50 mg/Nm^3 (dry gas, 15% O_2);
  - SO_2: 1,170 mg/Nm^3 (dry gas, 15% O_2), or use of 2% or less sulphur fuel; and
  - NO_X: 1,460 mg/Nm^3 (dry gas, 15% O_2)[1].

4.3.3 World Health Organization

The first edition of the WHO air quality guidelines was issued in 1987 and was intended for European countries. By 2000, research concerning health effects of air pollution had significantly advanced to enable the WHO to update its guideline resulting in the publication of *Air Quality Guidelines for Europe, Second Edition* (World Health Organisation, 2000). In this edition the guidelines were no longer presented as European-specific, but applied to all countries.

In 2005, WHO issued the *Air Quality Guideline - Global Update – Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide* (World Health Organisation, 2005), which updated the recommended ambient air quality guidelines for PM_{10} (particulate matter less than 10 microns in aerodynamic diameter) and SO_2 based on further research. Interim targets were also provided by the WHO in recognition of the need for a staged approach to achieving the new recommended guidelines in areas where the recommended guidelines are currently exceeded. The updated guidelines and interim targets are presented in **Table 2**. The carbon monoxide (CO) guidelines shown in **Table 2** are from the WHO Air Quality Guidelines for Europe, 2nd Edition, 2000 as they were not included in the 2005 update.

[1] Compression ignition, bore size diameter less than 400 mm.

Table 2 WHO Air Quality Guidelines

Pollutant	Averaging Time	Interim Target 3 (µg/Nm³)	Interim Target 2 (µg/Nm³)	Interim Target 1 (µg/Nm³)	Guideline Value (µg/Nm³)
Carbon monoxide	1-hour	-	-	-	30,000
	24-hours	-	-	-	10,000
Nitrogen dioxide	1-hour	-	-	-	200
	1-Year	-	-	-	40
Sulphur dioxide	10-minutes	-	-	-	500
	24-hours	-	125	50	20
PM_{10}	24-hours	150	100	75	50
	1-Year	70	50	30	20
$PM_{2.5}$	24-hours	75	50	37.5	25
	1-Year	35	25	15	10

4.3.4 US Environmental Protection Agency

The US EPA Office of Air Quality Planning and Standards (OAQPS) has set National Ambient Air Quality Standards for seven criteria pollutants: PM_{10}, $PM_{2.5}$, ground level ozone (O_3), CO, SO_2, NO_2 and lead (Pb). These standards are applicable throughout the USA, and while individual states may have stronger air pollution laws or regulate additional pollutants, they cannot have less stringent pollution limits than those set by the US EPA.

US EPA standards are often adopted in the absence of local guidelines as they are designed to apply for a variety of populations and industry types through a well-regulated process of formulation and review. The current US EPA primary standards (US EPA, 2016) are presented in **Table 3**.

It is noted that a guideline value for Total Suspended Particulate (TSP) is no longer published, but since TSP concentrations can be used to assess nuisance effects, it is useful to refer to the 1987 guideline values and these are listed in **Table 3** with the guidelines for PM_{10} and $PM_{2.5}$. In June 2010, the US EPA set a new 1-hour average primary standard for SO_2 of 75 ppb and revoked the two existing primary standards of 140 ppb as a 24-hour average, and 30 ppb as an annual average (US EPA, 2010b).

The primary standards are set to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. The secondary standards, which are set to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation and buildings, are either equal to or higher than the primary standards shown in **Table 3**.

Table 3 US EPA National Primary Ambient Air Quality Standards (US EPA, 2016)

Pollutant	ppb	µg/m³	Averaging Time
Carbon monoxide	9,000	10,000	8-hour
	35,000	40,000	1-hour [1]
Lead	-	0.15	Rolling 3-Month Average
Nitrogen dioxide	53	100	Annual [2]
	100	190	1-hour [3]
PM_{10}	-	150	24-hour [4]
$PM_{2.5}$	-	12	Annual [5]
	-	35	24-hour [6]
Ozone	70	140	8-hour [7]
Sulphur dioxide	75	200	1-hour [8]
TSP	-	75	Annual [9]
	-	150	24-hour [9]

1 Not to be exceeded more than once per year.
2 As an arithmetic average.
3 3-year average of the 98th percentile of the daily maximum 1-hour average.
4 Not to be exceeded more than once per year on average over 3 years.
5 Annual mean averaged over 3 years.
6 98th percentile of 24-hour concentrations averaged over 3 years.
7 3-year average of the 4th highest daily maximum 8-hour average ozone concentrations measured over each year.
8 3-year average of the 99th percentile of the daily maximum 1-hour average.
9 Replaced by PM_{10} standards in 1987 – included here to assess nuisance effects.

4.3.5 Australian Regulatory Requirements

Dust deposition guidelines are relatively uncommon and were not available for any of the jurisdictions reviewed above.

New South Wales (NSW EPA, 2016) has long-established guidelines for dust deposition rates of:

- 2 g/m²/month for the incremental impact above background; and
- 4 g/m²/month for total cumulative impact.

These guidelines have been adopted for use by other States and Territories and are widely used throughout Australia, to assess the potential for nuisance impacts due to dust emissions from projects of this type.

4.4 SO_2 Health Risk Assessment

Following review of the preliminary SO_2 dispersion modelling results, which predicted exceedances of the 2005 WHO criteria due to emissions from the IFO power generation facilities, additional modelling was performed to optimise the height of the stacks to maximise dispersion of the emissions. Further to this, a targeted evaluation of relevant literature and international and national guidelines for the protection of human health from SO_2 emissions was undertaken, to understand possible impacts on sensitive receptors.

This assessment and its outcomes are described in detail in the Health Risk Assessment (Coffey, 2018) which is included in this EIS as Appendix W. It includes the derivation of proposed Project-specific criteria developed from US EPA methodology and the European Union Member States' air quality directive criteria.

The proposed Project criterion for SO_2 to achieve protection of human health is 350 µg/m^3 based on a 3-year average of the 99th percentile of the annual distribution of daily maximum 1-hour concentrations. This criterion is equivalent to the 1-hour average ambient air quality limit for SO_2 set by European Union Directive 2008/50/EC (EU, 2008).

It is noted that the air dispersion modelling study performed for the Project uses a one-year meteorological data file (based on 2016 data) whereas the HRA criterion is based on a three-year average. This is discussed further in **Section 7.4.5**.

4.5 Ambient Air Quality Criteria Adopted for this Assessment

The ambient air quality criteria adopted for use in this study are summarised below in **Table 4**. In selecting the criteria, priority has been given to those set by the WHO in line with the IFC *Environmental, Health and Safety Guidelines – Air Emissions and Ambient Air Quality* (IFC, 2007). For SO_2, the Project-specific criterion derived from the HRA (Coffey, 2018) has been used, and for TSP (which does not have guidelines set by WHO), guidelines set by the US EPA have been used. Where guidelines are not available from either WHO or the US EPA (i.e. deposited dust), Australian guidelines have been used.

Table 4 Ambient Air Quality Criteria Adopted for this Assessment

Pollutants	Averaging Period	Limit [1] (µg/m^3)	Reference	Notes
NO_2	1-hour	200	(WHO, 2005)	
	Annual	40	(WHO, 2005)	
SO_2	1-hour	350	(Coffey, 2018), equivalent to (EU, 2008) [2]	3-year average of the 99th percentile of the annual distribution of daily maximum 1-hour concentrations
CO	1-hour	30,000	(WHO, 2005)	
	24-hours	10,000	(WHO, 2005)	
TSP	24-hours	150	(US EPA, 2012)	pre-1987 Secondary Standard
	Annual	75	(US EPA, 2012)	pre-1987 Primary Standard
PM_{10}	24-hours	50	(WHO, 2005)	
	Annual	20	(WHO, 2005)	
$PM_{2.5}$	24-hours	25	(WHO, 2005)	
	Annual	10	(WHO, 2005)	
Dust deposition	Annual	2 g/m^2/month	(NSW EPA, 2016)	Incremental Impact

[1] All limits are in µg/m^3 unless noted otherwise.

[2] The 1-hour average ambient air quality limit for SO_2 set by European Union Directive 2008/50/EC.

5 EXISTING ENVIRONMENT

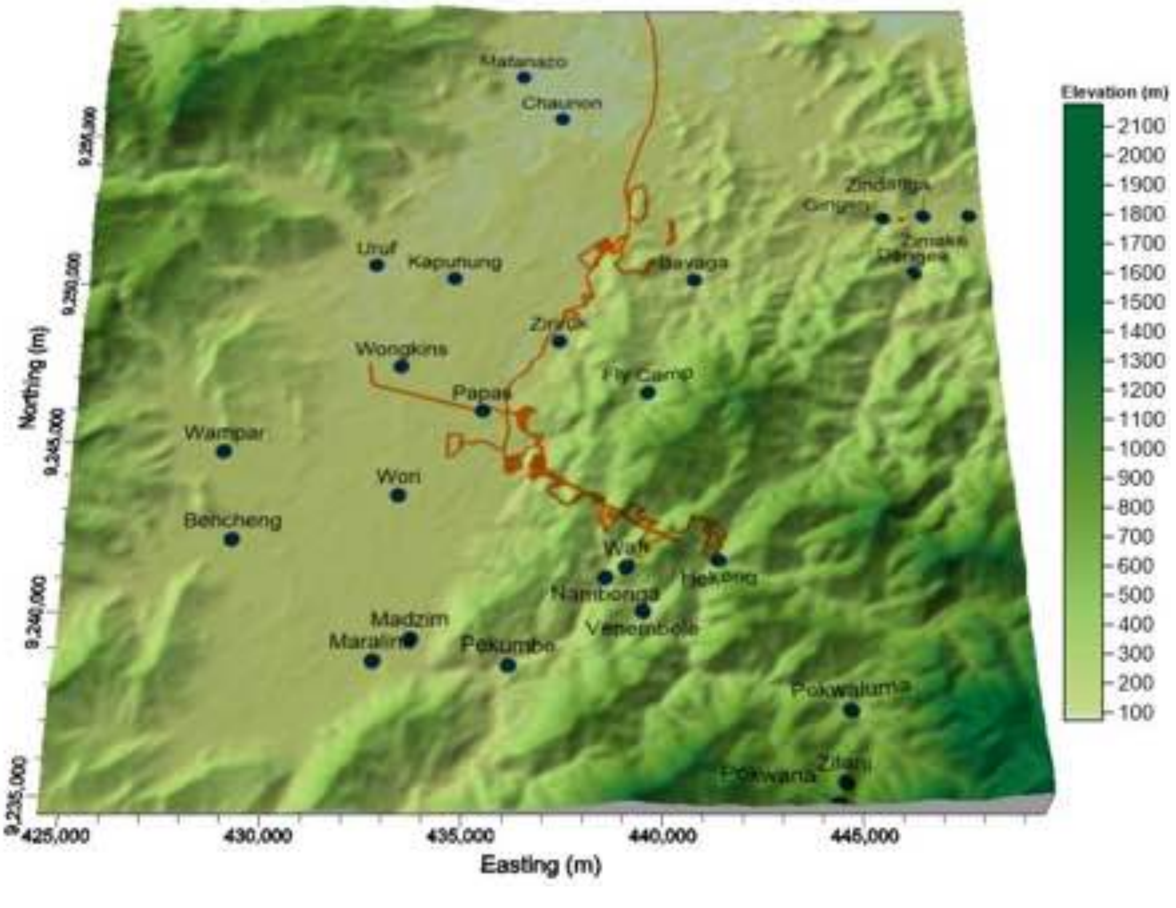
5.1 Mine Area

5.1.1 Local Topography and Land Use

The Mine Area is located on the northern side of the main dividing range of PNG. The majority of the area surrounding the Mine Area is rugged, steep, mountainous and densely forested. The western edge of the Mine Area is situated on the alluvial plains along the Lower Watut River valley. The topography surrounding the Mine Area is shown in **Figure 3**.

The vegetation found within the surrounds of the Mine Area varies with altitude, topography, climate and substrate. Much of the surrounding area is dominated by steep, hilly terrain intersected with steep valleys and waterways. Areas of disturbed grassland (kunai grassland) occur along the boundary of the Watut plains and Watut hills. These areas have been previously cleared of forest by local residents and are maintained and gradually extended by regular burning practices. Detailed vegetation description of the Mine Area is provided in the flora study undertaken by Biodiversity Assessment and Management Pty Ltd (BAAM, 2017).

Figure 3 Local Topography – Mine Area



Note: Outline of proposed Project infrastructure (quarries, pits declines and roads etc.) shown in orange.

5.1.2 Climate and Meteorology

PNG has a tropical climate. The coastal and islands regions tend to be hot and humid, with temperature averages ranging between 20°C and 32°C. Some areas in the south have a distinct rainy and dry season, such as Port Moresby, where the dry season typically runs from June to September brought on by the southeasterlies, and the rainy season typically occurs during December to March brought on by the northwesterlies. Other coastal areas have a wet season (Madang and Morobe), but it is not as clearly defined as in the south. Relative humidity levels are relatively high, ranging between 70% and 90%. Temperature is altitude dependent, with hot and humid conditions associated with lower altitudes and cooler conditions at higher altitudes.

The primary rainfall gauge for the Project is installed at Wafi Camp. This gauge has a rainfall record starting in January 1990 with recordings continuing to date. Additional rainfall records are also available from various gauges that are associated with both meteorological stations and hydrological stations. A review of this baseline information, including monthly rainfall and evaporation data from various sources in and around the proposed Project Area, was performed in 2015 which identified that many of the datasets were limited by both missing data as well as short record lengths. It was concluded however that while rainfall in the region is variable, some correlation does exist between the average monthly rainfall of the Bavaga, Hekeng, Nambonga and Wafi Camp rainfall gauges.

Based on the findings of the review, baseline rainfall for the Project Area was assessed using data from rain gauges within the Project Area supported by Climate Forecast System Reanalysis (CFSR) and annual Worldclim data to infill data gaps. This infilled Wafi Camp record has been used as the primary daily rainfall dataset for the Project and the monthly average rainfall records are summarised in **Table 5**. These data demonstrate the high rainfall experienced in the Project Area, with lower average rainfalls during the dry season (June to September) and higher average rainfalls during the rainy season (December to March).

Table 5 Average Monthly Rainfall for Wafi Camp (infilled)

Month	Wafi Infilled (mm)
January	323
February	298
March	335
April	290
May	213
June	154
July	131
August	150
September	132
October	203
November	247
December	358
Annual	**2,836**

SOURCE: Rainfall-Runoff Response Preliminary Technical Memorandum Wafi Golpu (WorleyParsons, 2015).

Meteorological data for 2016/17 was provided by WGJV from monitoring stations located at Mt Golpu, Papas and the Watut Portal. A summary of the wind data provided (Mt Golpu and Papas monitoring sites only, no data available from the Watut Portal site) is presented as wind roses in **Figure 4**. Time series plots of the temperature and humidity data provided are presented in **Figure 5** and **Figure 6**.

The wind roses for Mt Golpu and Papas show that very different wind patterns were recorded at each site. This is expected given the complex topography in the region which will act to channel wind flows. The Mt Golpu weather station is located at a higher altitude, in a densely vegetated area while the Papas weather station shows the channelling of winds along a north-south direction in line with the flood plain. It is noted that both stations are only 3 m above ground level, and the data from the Papas weather station only covers a five month period, which may also contribute to the differences.

Overall, the wind roses and temperature and humidity plots indicate that the climate at the Mine Area is characterised by low wind speeds, high humidity and warm temperatures. Meteorological modelling has been performed for the Mine Area as part of this AQGGIA and further details on the predominant wind patterns and atmospheric stability characteristics of the area are presented and discussed in **Section 6.1.2**.

Figure 4 Wind Roses – Mt Golpu and Papas Weather Stations

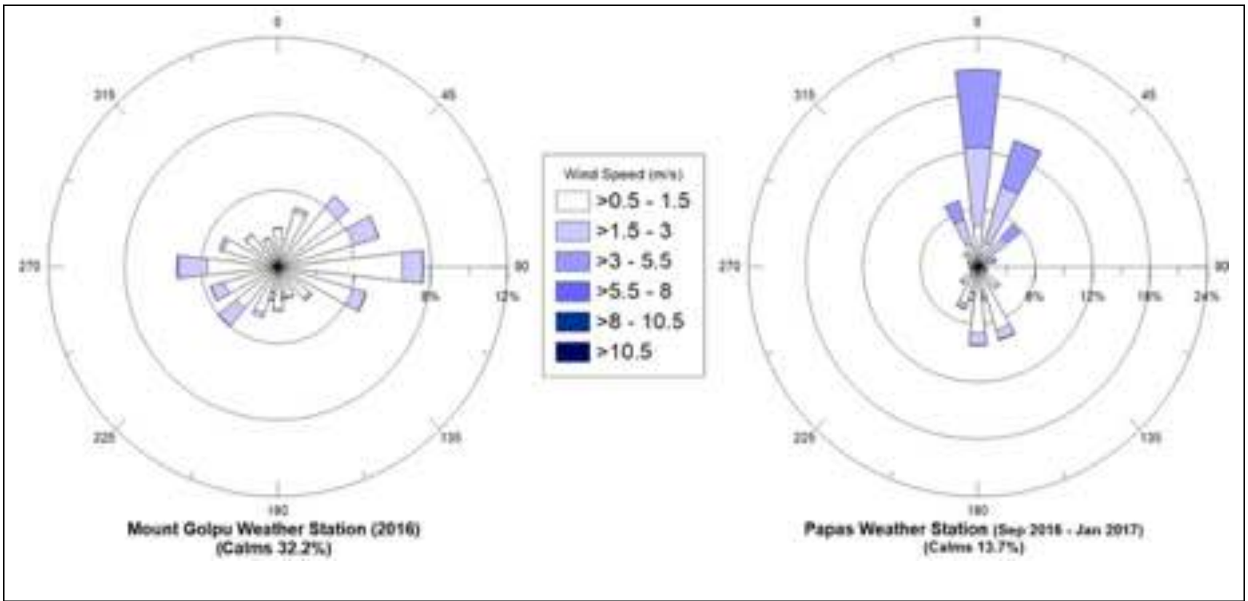


Figure 5 Temperature Data - Mt Golpu, Portal and Papas Weather Stations (2016)

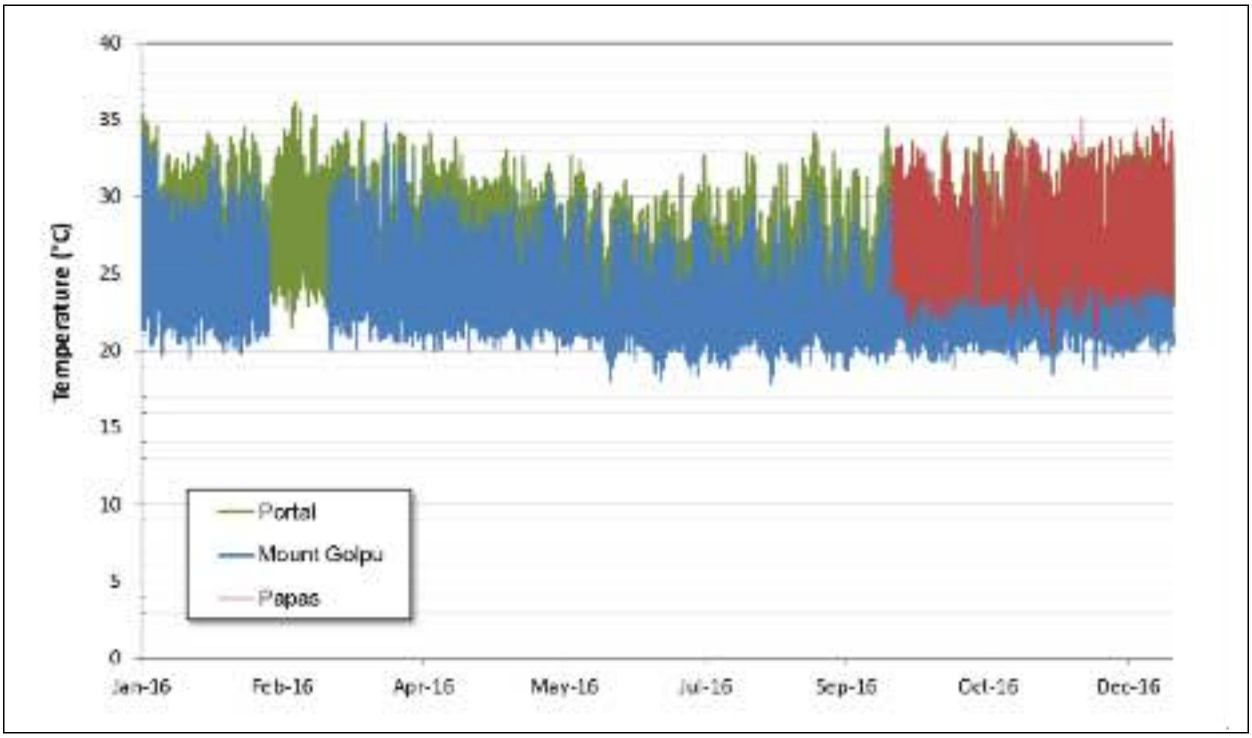
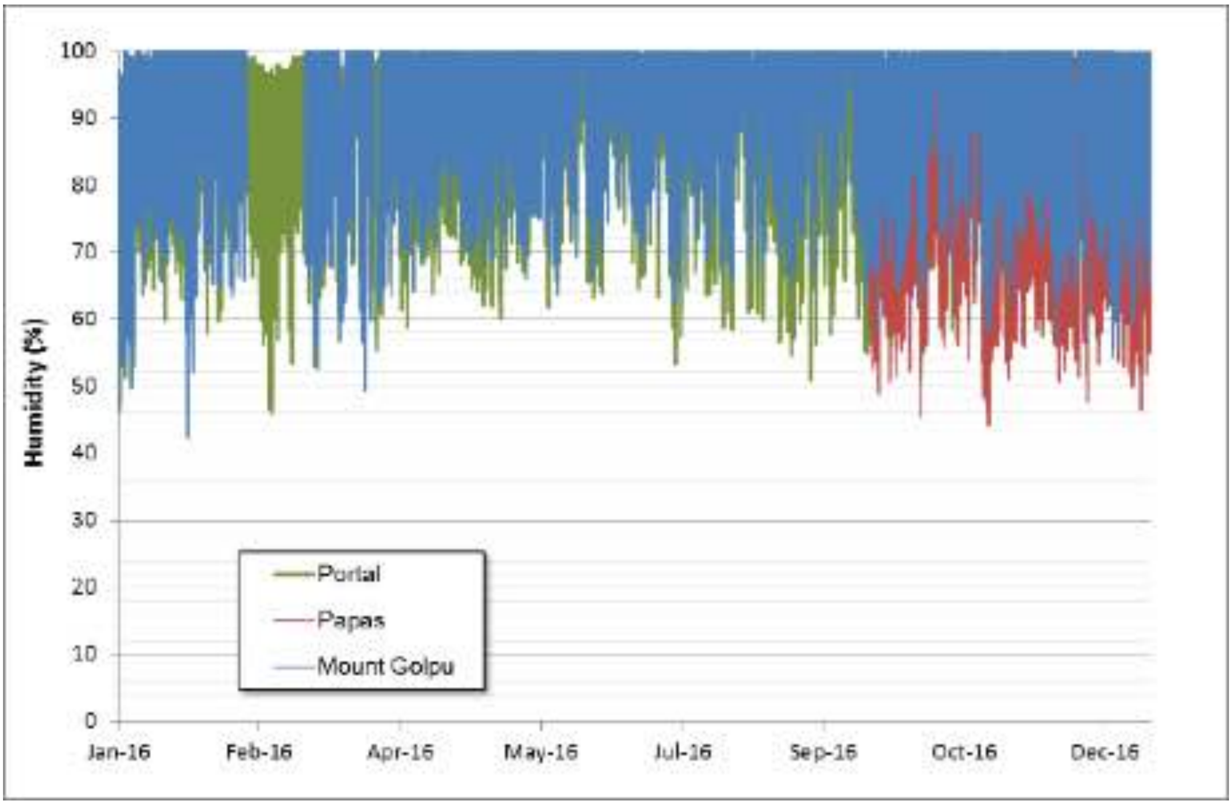


Figure 6 Humidity Data - Mt Golpu, Portal and Papas Weather Stations (2016)



5.1.3 Sensitive Receptors

The Mine Area is situated in a remote location with a number of villages located in the surrounding area. These villages have been identified as sensitive receptors for the purposes of this AQIA as people will be present at these locations for extended periods of time.

The locations of the closest sensitive receptors identified in proximity to the Mine Area are listed in **Table 6** and shown in **Figure 7**. These receptors were entered into the air quality dispersion model as discrete receptor locations and the assessment of impacts has focussed on these locations.

Table 6 Sensitive Receptors Located Close to the Mine Area

ID	Name	Easting (m)	Northing (m)
1	Bavaga	441,257	9,250,113
2	Kapunung	434,578	9,250,166
3	Gingen	446,645	9,252,153
4	Wori	433,201	9,243,395
5	Wongkins	433,173	9,247,336
6	Uruf	432,378	9,250,610
7	Madzim	433,602	9,239,237
8	Wampar	428,487	9,244,704
10	Bencheng	428,849	9,242,088
11	Maralina	432,650	9,238,615
12	Ziriruk	437,492	9,248,134
13	Mafanazo	436,476	9,257,118
15	Papas	435,404	9,245,949
16	Pokwana	444,322	9,234,501
17	Zilani	444,539	9,235,108
18	Hekeng	441,610	9,241,364
20	Dengea	447,400	9,250,308
21	Zimake	449,081	9,252,213
22	Pokwaluma	444,822	9,237,128
23	Venembele	439,612	9,239,958
24	Pekumbe	436,148	9,238,475
25	Fly Camp	439,891	9,246,407
26	Nambonga	438,662	9,240,951
29	Chaunon	437,612	9,255,629
39	Zindanga	447,803	9,252,234

Figure 7 Sensitive Receptors – Mine Area

5.1.4 Existing Air Quality

Given the remote location of the Mine Area, background concentrations of gaseous pollutants are expected to be negligible. Background concentrations of particulate matter are also expected to be low, particularly given the high rainfall, low wind speeds and dense vegetation characteristics of the area. Exceptions to this would be areas in close proximity to existing exploration and construction operations and during times of burning of the kunai grassland, or during regionally significant events such as a volcanic eruption.

A monitoring program to characterise existing air quality for the Project was conducted in May 2011 (Coffey, 2011). As there has been no significant change in the local land use since this time, with modest population growth and no other major air emission sources being developed in the region in the intervening period, the data collected by this baseline monitoring program will still be representative of current conditions.

Four of the closest villages to the underground exploration and associated activities were selected for the characterisation survey of dust deposition rates and PM_{10} concentrations. These monitoring sites were:

- Wongkins (R5) - located approximately 5.7 km northwest of the Watut Decline Portal Terrace;
- Wori (R4) - located approximately 4.3 km west of the Watut Decline Portal Terrace;
- Bavaga (R1) - located approximately 7.5 km northeast of the Watut Decline Portal Terrace and adjacent to the junction of the existing Wafi Road and the Northern Access Road; and
- Madzim (R7) - located approximately 5.9 km southwest of the Watut Decline Portal Terrace.

Within each village, the air quality monitoring equipment was placed in a central location to ensure that the data is representative of normal village conditions. The PM_{10} and dust deposition monitoring locations are shown in **Figure 8** and coordinates are provided in **Table 7** and **Table 8**.

The dust deposition gauges have been maintained by WGJV since their installation in May 2011, with an additional gauge added at Hekeng village in 2015.

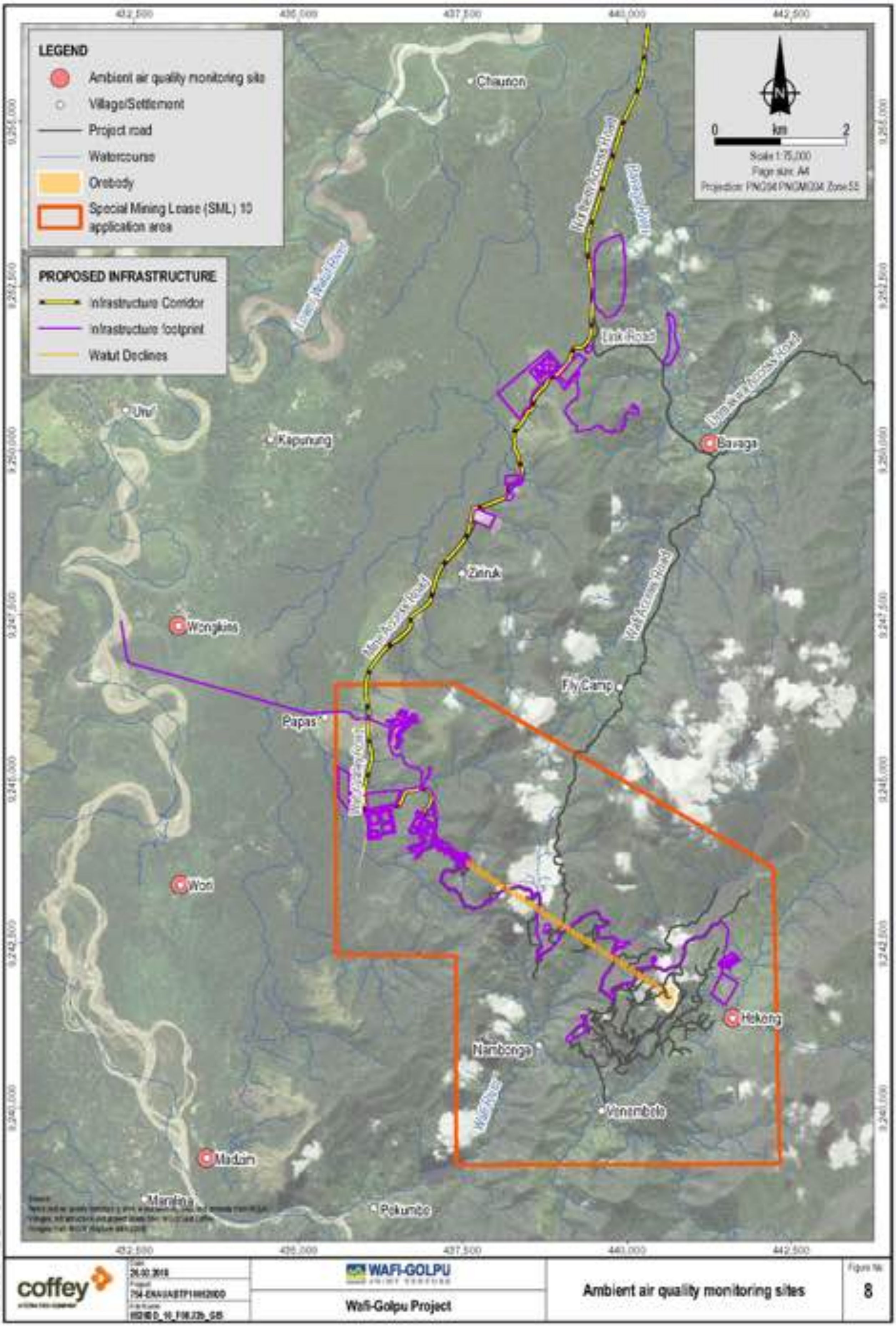
Table 7 PM_{10} Monitoring Locations and Sampling Periods

Village	Approximate Location		Monitoring Period (2011)		
	Latitude	Longitude	Start	End	Duration (HH:MM)
Wongkins	-6° 48' 29.568"	146° 23' 46.038"	11 May, 10:40	12 May, 12:02	25:22
Wori	-6° 50' 46.806"	146° 23' 40.110"	11 May, 14:47	12 May, 14:54	24:07
Bavaga	-6° 47' 5.154"	146° 28' 4.584"	13 May, 12:00	14 May, 16:46	28:45
Madzim	-6° 52' 52.380"	146° 23' 52.920"	13 May, 15:31	14 May, 16:13	24:41

Table 8 Dust Deposition Monitoring Locations

Village	Approximate Location of Dust Deposition Gauge	
	Latitude	Longitude
Wongkins	-6° 48' 21.882"	146° 23' 44.550"
Wori	-6° 50' 46.098"	146° 23' 42.318"
Bavaga	-6° 47' 5.154"	146° 28' 4.584"
Madzim	-6° 52' 52.380"	146° 23' 52.920"
Hekeng	-6° 51' 46.790"	146° 28' 17.430"

Figure 8 Baseline Air Quality Monitoring Locations



The monitoring results are summarised in **Table 9** and **Table 10**.

Table 9 PM_{10} Monitoring Data

	24-Hour Average PM_{10} Concentration (µg/m^3)	Averaging Period
Wongkins	33	24 hour period ending 11:00 AM 12 May 2011
Wori	4	24 hour period ending 2:50 PM 12 May 2011
Bavaga	26	24 hour period ending 12 noon 14 May 2011
Madzim	5	24 hour period ending 4:00 PM 14 May 2011

Table 10 Dust Deposition Monitoring Data

Parameter / Year	Total Insoluble Matter Deposition Rate (g/m^2/month)				
	Wongkins ***DDG01***	**Wori** ***DDG02***	**Madzim[2]** ***DDG03***	**Bavaga** ***DDG04***	**Hekeng** **DDG05**
Range (Number of Samples)					
2013	0.5 - 2.4 (9)	0.9 - 3.9 (9)	0.3 - 3.3 (9)	1.1 - 3.2 (9)	-
2014	0.7 - 2.4 (12)	0.8 - 5.2 (12)	-	0.5 - 3.5 (12)	-
2015	0.8 - 2.7 (10)	0.8 - 2.7 (10)	1.1 - 2.8 (5)	0.4 - 3.0 (10)	0.8 - 2.3 (6)
2016	0.2 - 1.3 (11)	0.3 - 1.4 (10)	0.3 - 3.0 (11)	0.2 - 6.9 (10)	0.1 - 1.0 (11)
2017	0.2 - 3.2 (6)	0.3 - 1.0 (6)	0.3 - 0.5 (6)	0.3 - 0.7 (6)	0.2 - 3.5 (6)
Average					
2013	1.6	2.0	1.6	1.7	-
2014	1.6	2.4	-	1.7	-
2015	1.7	1.6	1.9	1.6	1.4
2016	0.9	0.9	0.9	1.8	0.5
2017	1.0	0.7	0.4	0.5	0.9
Criterion [1]	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**

Notes: 1. Annual average criterion of 4 g/m^2/month widely used in Australia to protect against nuisance dust impacts.
2. The Madzim Village DDG was relocated in January 2014 to enable background data collection in the vicinity of the (then) proposed Exploration Shaft at the Golpu Drillers Facility to commence.

Table 9 indicates that ambient PM_{10} concentrations are highest at Wongkins and Bavaga and very low at Wori and Madzim. These measurements took place during May, which is the start of the dry season. The available data are limited and it is not possible to draw any firm conclusions as to the typical ambient PM_{10} levels in these locations, which will vary seasonally (due to pollen levels, rainfall etc.) and will also be dependent on the activities occurring in and around the villages (e.g. construction of new dwellings, burning of vegetation, land clearance etc.). However, the results indicate compliance with the WHO 24-hour average guideline of 50 µg/m^3 for PM_{10} and therefore are as expected in a rural PNG setting.

Table 10 indicates that monthly dust deposition rates at all locations being monitored are generally low, with the annual average dust deposition rates below the cumulative nuisance-based criterion of 4 g/m^2/month adopted for the Project (see **Section 4.3.5**). Slightly elevated dust deposition rates have been measured at Wori and Bavaga on occasion, however they are atypical for the area based on the long term averages.

Details of how the available ambient air quality data has been used to estimate background concentrations of particulate matter for use in the dispersion modelling study are provided in **Section 6.1.3**.

5.2 Infrastructure Corridor

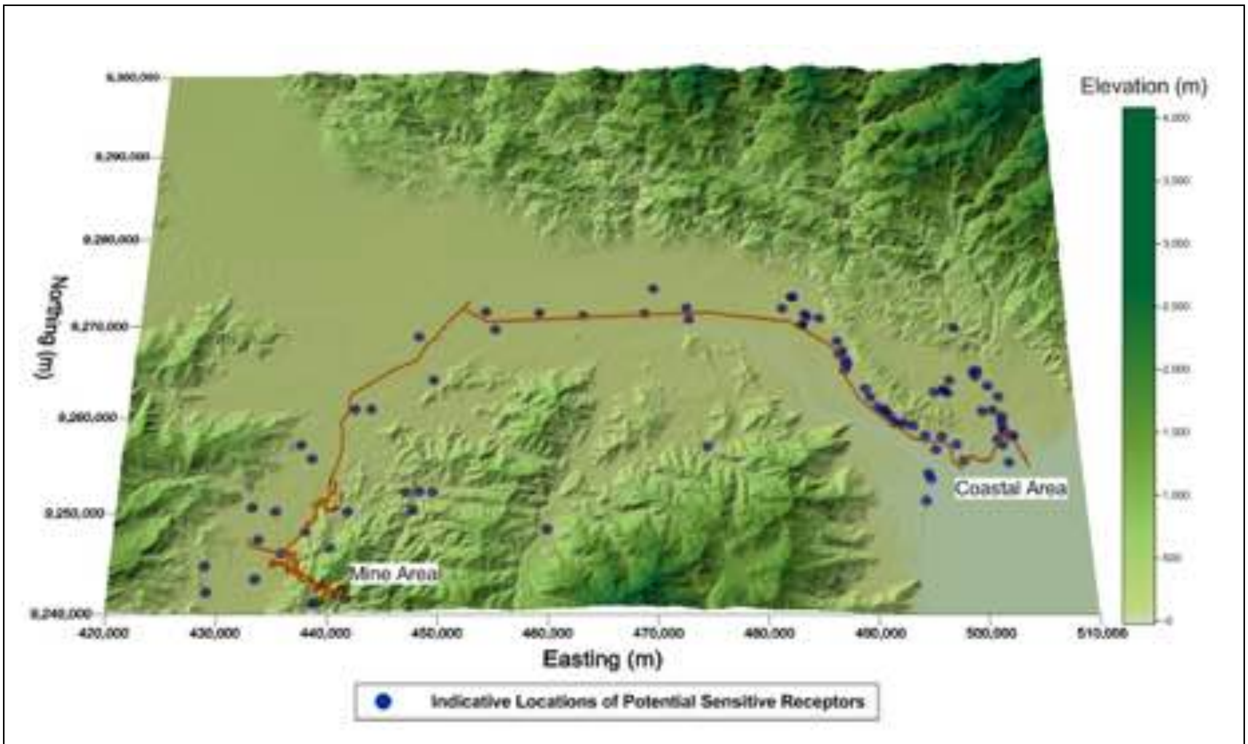
5.2.1 Local Topography and Land Use

The concentrate, tailings and fuel pipelines, collectively located within the Infrastructure Corridor, extend from the Mine Area to the Port Facilities Area, with the tailings pipeline continuing further east to the Outfall Area on the Huon Gulf coast (see **Figure 9**).

The topography surrounding the proposed pipeline route is shown in **Figure 9**. The surrounding area at the western end of the pipeline corridor is dominated by steep, hilly terrain intersected with steep valleys and waterways. In the middle of the corridor, the pipelines will be constructed on the floodplain located between the main dividing range of PNG and the mountainous area to the north of Port Lae.

The locations of sensitive receptors identified along the concentrate pipeline corridor are shown in **Figure 9**. Remote villages are sparsely distributed along the western end of the pipeline with relatively high density dwellings at the eastern end of the pipeline located at Lae (**Figure 9**).

Figure 9 Local Topography – Infrastructure Corridor



5.2.2 Climate and Meteorology

No reliable wind speed and wind direction data are available for locations along the Infrastructure Corridor. Observational data from Lae Nadzab Airport, which is located approximately 16 km east of Zifasing, was obtained for the period 2009-2014, however the data capture rate over this period was less than 15%.

Climatological conditions along the Infrastructure Corridor are expected to be similar to those experienced at Lae, although predominant wind directions would potentially vary along the route depending on channelling and blocking effects from surrounding terrain, as well as the increasing influence of coastal sea breezes closer to Lae. Given the low potential for air quality impacts from activities within the Infrastructure Corridor (limited to short-term dust impacts from construction activities) meteorological modelling of the area was not performed.

5.2.3 Existing Air Quality

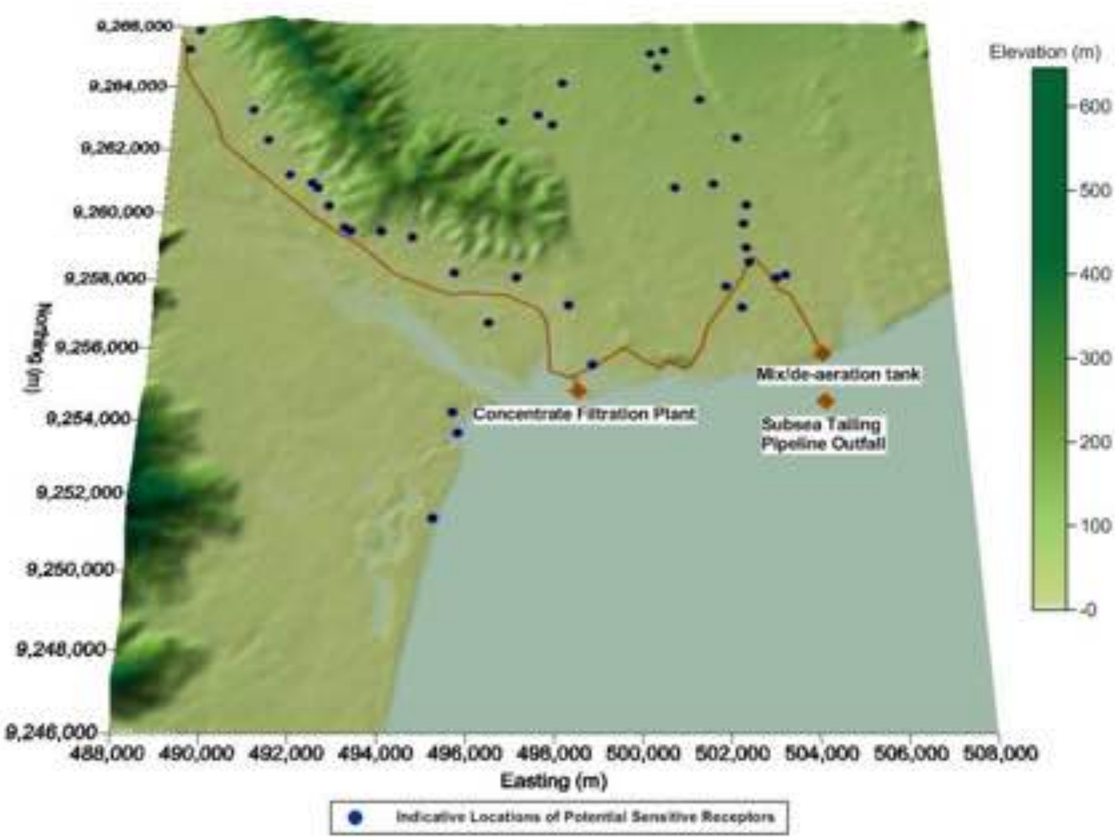
Air quality along the majority of the pipeline corridor would be expected to be similar to that surrounding the Mine Area (refer **Section 5.1.4**). However, at the Lae end of the concentrate pipeline, the existing air quality will be influenced by air emissions from the current port activities (e.g. shipping emissions), as well as other commercial, industrial and residential air emissions sources located within Lae, such as vehicle emissions from local traffic. This is discussed further in **Section 5.3.3**.

5.3 Coastal Area

5.3.1 Local Topography and Land Use

The topography surrounding the Port of Lae area is relatively flat, as shown in **Figure 10**. Rugged and mountainous terrain is located further to the southwest and north of the site. Identified representative sensitive receptors in the vicinity of the proposed infrastructure are also presented in **Figure 10**.

Figure 10 Local Topography and Sensitive Receptors – Port of Lae



5.3.2 Climate and Meteorology

Lae experiences two distinct seasons: a southeast monsoon from mid-May to October and a northwest monsoon from mid-November to the end of March, with the intervening periods experiencing light variable winds.

During the southeast monsoon the trade winds are moderate, typically around 4 m/s at Lae, and rainfall is high. The city of Lae receives between 3,900 mm to 4,500 mm of rain per annum (Embassy of Papua New Guinea to the Americas, 2004) with rainfall peaking during the period May to August. Humidity exceeds 90% during the wet season.

From December to April, major influences are from the northwest monsoon originating in Asia. Coupled with the warm sea temperatures of the Southern Hemisphere during this period, this is also the cyclone season, when cyclones in the Coral Sea may from time to time influence conditions around Lae.

5.3.3 Existing Air Quality

No baseline air quality monitoring data is available for the Port of Lae or the Outfall Area. However, given the coastal location of these sites and absence of major industry, the existing air quality is anticipated to be generally good. There is potential for localised areas of elevated concentrations of air pollutants in Lae close to power generation units and industrial sites. Emissions from ships entering and berthed at the Port of Lae also have the potential to result in localised elevated concentrations of NO_2, SO_2 and particulates under the predominant (on-shore) wind direction.

As air emissions from the Port Facilities Area and the Outfall Area will be limited to dust emissions during the construction period, baseline air quality monitoring for these sites is not warranted.

6 IMPACT ASSESSMENT METHODS

6.1 Quantitative Impact Assessment

As stated in **Section 3.2**, air emissions from the Project are associated mainly with the construction and mining activities and diesel/IFO power generators at the Mine Area. Air emissions from the pipelines and operational activities at the Port Facilities Area and Outfall Area would be minimal and unlikely to have any measurable impact on air quality surrounding these sites.

Based on the above, a detailed quantitative air quality impact assessment has been carried out for the activities associated with the construction and mining operation at the Mine Area using the assessment methods presented below. Potential air quality impacts from construction and operational activities within the Infrastructure Corridor and at the Coastal Area has been assessed using a risk-based qualitative assessment approach (refer **Section 6.2**). Only if the risk assessment identified a significant risk of potential adverse air quality impacts would a quantitative modelling assessment be warranted.

6.1.1 Dispersion Models Used

6.1.1.1 CALPUFF

Air emissions from the construction and mining operations have been modelled using the US EPA's CALPUFF (Version 6) modelling system. CALPUFF is a transport and dispersion model that ejects "puffs" of material emitted from modelled sources, simulating dispersion and transformation processes along the way. In doing so it typically uses the fields generated by a meteorological pre-processor CALMET, discussed further below. Temporal and spatial variations in the meteorological fields selected are explicitly incorporated in the resulting distribution of puffs throughout a simulation period. The primary output files from CALPUFF contain either hourly concentration or hourly deposition fluxes evaluated at selected receptor locations. The CALPOST post-processor is then used to process these files, producing tabulations that summarise results of the simulation for user-selected averaging periods.

The advantages of using CALPUFF (rather than using a steady state dispersion model such as AERMOD) is its ability to handle calm wind speeds (<0.5 m/s) and complicated terrain. Steady state models assume that meteorology is unchanged by topography over the modelling domain and may result in significant over or under estimation of air quality impacts. CALPUFF is appropriate for use in PNG and in the Project Area and has previously been used for similar assessments in PNG.

6.1.1.2 Weather Research and Forecast (WRF) model

The Weather Research and Forecast (WRF) model is a next generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. It features two dynamical cores; a data assimilation system and a software architecture facilitating parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometres.

For this assessment, the WRF modelling system was used to produce the meteorological field required as input for the outer domain of the CALMET meteorological model. Parameters used in the WRF model for this assessment are presented in **Table 11**. Modelling was performed for the 2016 calendar year.

Table 11 Meteorological Parameters – WRF Modelling

Parameter	Domain 1	Domain 2
Modelling domain	2,100 km × 2,100 km	310 km × 310 km
Grid resolution	30 km	10 km
Number of vertical levels	30	30
Microphysics	WSM6	WSM6
Cumulus parametrization	Kain-Fritsch	Kain-Fritsch
Shortwave radiation physics	Dudhia	Dudhia
Longwave radiation physics	RRTM	RRTM
Planetary boundary layer	YSU	YSU

6.1.1.3 CALMET

CALMET is a diagnostic meteorological model that develops wind and temperature fields on a 3-dimensional gridded modelling domain. Associated 2-dimensional fields such as mixing height, surface characteristics, and dispersion properties are also included in the file produced by CALMET. The interpolated wind field is then modified within the model to account for the influences of topography, as well as differential heating and surface roughness associated with different land uses across the modelling domain. These modifications are applied to the winds at each grid point to develop a final wind field. The final wind field thus reflects the influences of local topography and land uses.

In this assessment, CALMET was run using WRF model output (see **Section 6.1.1.2**). No surface, upper air or buoy observations were used ('No-Obs Mode' hereafter). This approach is recommended by Scire et al (2011) as:

- No-Obs mode allows the important benefits of the non-steady-state approach in CALPUFF to be included in the dispersion modelling (e.g. spatially varying meteorology and dispersion, causality, recirculation, stagnation, pollutant build-up, fumigation, etc.).
- No-Obs mode makes use of 3-dimensional, hourly prognostic meteorological data often available at high resolution to drive CALMET and CALPUFF.
- No-Obs mode greatly simplifies the preparation of the CALMET inputs because a large number of input variables dealing with observational data are not required and the difficulties of dealing with potentially incomplete observational datasets are eliminated.
- No-Obs mode provides a relatively straightforward approach that facilitates agency review and approval of the CALMET/CALPUFF simulations.

CALMET modelling was conducted using the nested CALMET approach, where the final results from a coarse-grid run were used as the initial guess of a fine-grid run. This has the advantage that off-domain terrain features including slope flows, blocking effect can be allowed to take effect and the larger-scale wind flow provides a better start in the fine-grid run.

The outer domain was modelled with a resolution of 3 km. WRF-generated 3-dimensional meteorological data were used as the initial-guess wind field and local topography and land use information were used to refine the wind field predetermined by the WRF data.

The output from the outer domain CALMET modelling was then used as the initial-guess field for the mid and inner domain CALMET modelling. Horizontal grid spacings of 1 km and 0.25 km were used in the mid and inner domain respectively, to adequately represent the important local terrain features and land use. Fine scale local topography and land use information were used in the inner domain run to refine the wind field parameters predetermined by the coarse CALMET runs.

Table 12 details the parameters used in the meteorological modelling to drive the CALMET model and the spatial extent of the meteorological modelling domains are presented in **Figure 11**.

Figure 11 Meteorological Modelling Domains

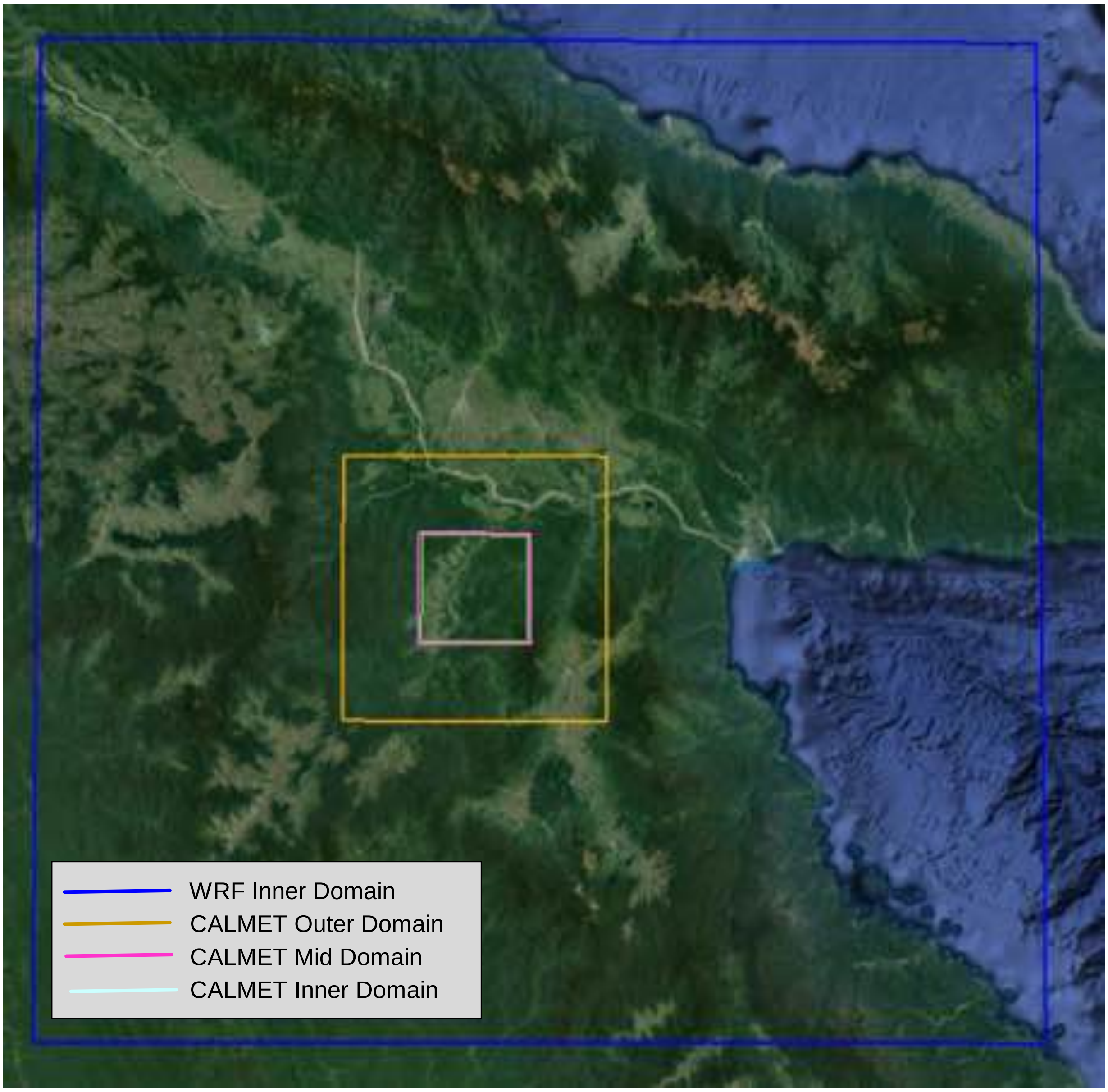


Table 12 CALMET Configuration Used for this Study

Outer Domain	Data
Meteorological grid	60 km × 60 km
Meteorological grid resolution	3 km
Initial guess filed	3D output from WRF model
Mid Domain	
Meteorological grid	30 km × 30 km
Meteorological grid resolution	1 km
Initial guess field	3D output from outer domain modelling
Inner Domain	
Meteorological grid	25 km × 25 km
Meteorological grid resolution	0.25 km
Initial guess field	3D output from mid domain modelling

6.1.2 Meteorological Data Used in Dispersion Modelling

This section presents a summary of the meteorological data used in the dispersion modelling study based on the results of the meteorological modelling process described above. The results of the meteorological modelling have been compared against the observational data presented in **Section 5.1.2**, where available.

In reviewing the following information, it is important to note that the data presented are based on the results of the meteorological modelling given for a single location at the centre of the Mine Area. The meteorological data file used in the modelling study for the Mine Area consists of a 3-dimensional dataset, and the hourly wind speeds, wind directions, ambient temperatures, degree of atmospheric turbulence and other parameters will vary across the 25 km x 25 km modelling domain, depending on variations in the topography and other local features. Key meteorological patterns, such as predominant wind directions, may therefore be quite different at other locations compared to those presented below.

Wind Speed and Direction

A summary of the annual wind behaviour predicted by CALMET for the Mine Area is presented as wind roses in **Figure 12** and as a wind speed frequency chart in **Figure 13**.

Figure 12 indicates that winds at the Mine Area predominantly blow from the north and southeast. There is little difference between the wind patterns experienced during the wet season (October - April inclusive) and dry season (May - September inclusive), aside from wind speeds being slightly lower and southeasterly winds occurring more frequently during the dry season. As shown in **Figure 13**, calm wind conditions (less than 0.5 m/s) were predicted to occur approximately 6% of the time throughout 2016. The modelled wind speeds are relatively low, consistent with the on-site meteorological data presented in **Section 5.1.2**.

It is noted that due to the complex topography surrounding the Mine Area, wind speed and direction varies significantly. The typical spatial variation of day time and night time winds is presented in **Appendix A**.

Figure 12 Annual and Seasonal Wind Roses for Mine Area, as Predicted by CALMET (2016)

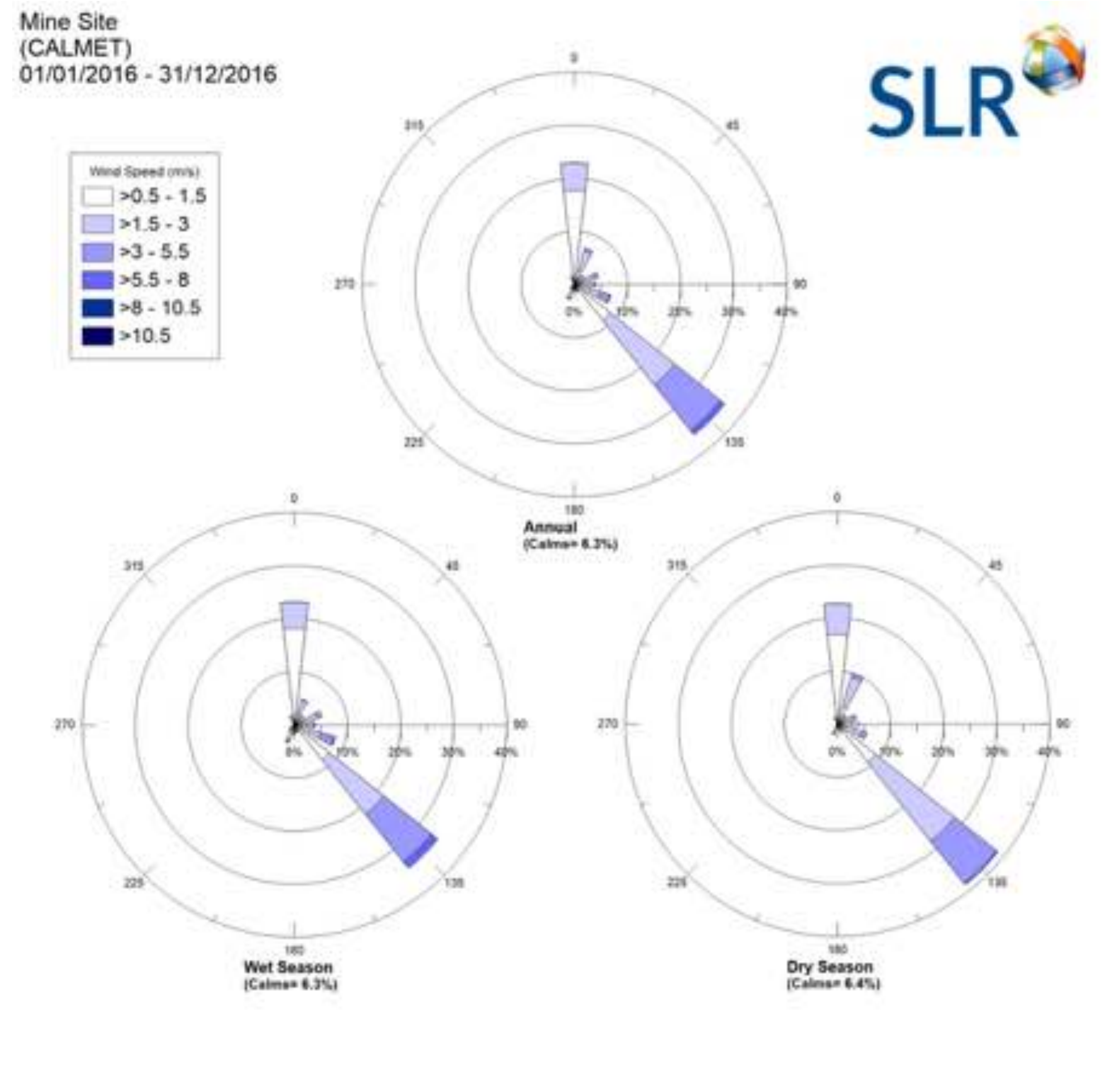
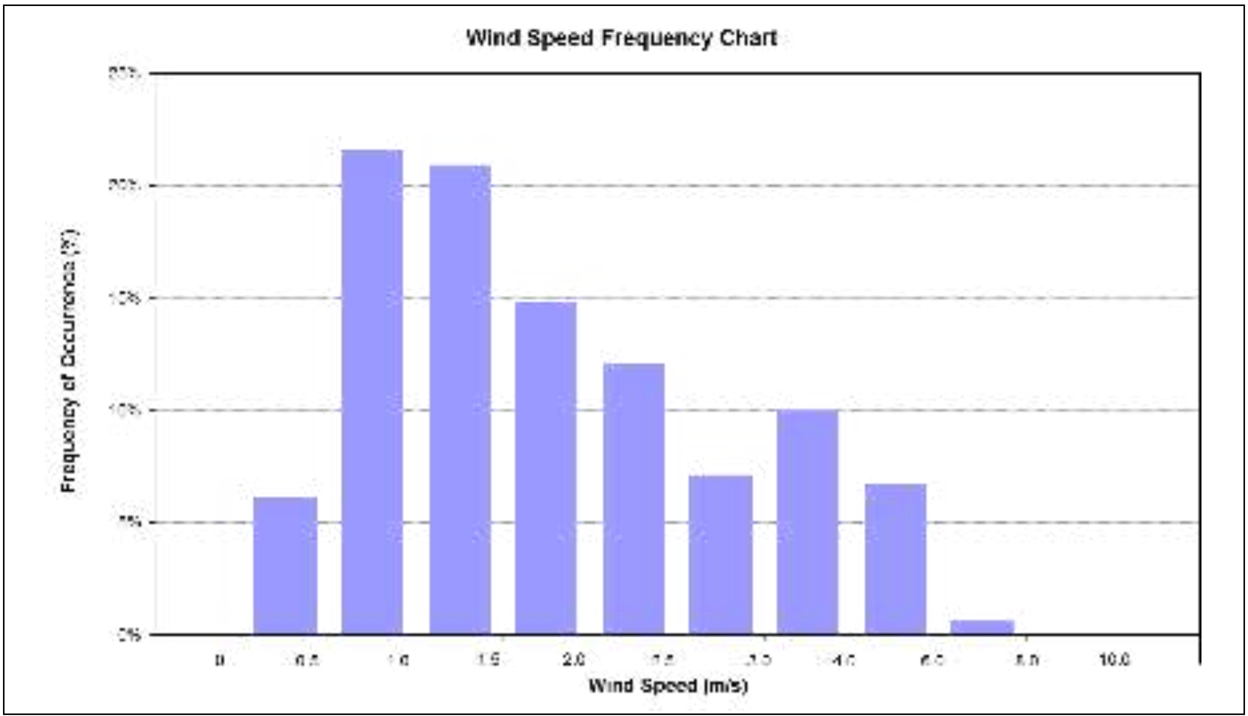


Figure 13 Wind Speed Frequency Chart, as Predicted by CALMET (2016)



Atmospheric Stability

Atmospheric stability refers to the tendency of the atmosphere to resist or enhance vertical motion. The Pasquill-Turner assignment scheme (Turner, 1994) identifies six Stability Classes, A to F, to categorize the degree of atmospheric stability as follows:

- A = Extremely unstable conditions
- B = Moderately unstable conditions
- C = Slightly unstable conditions
- D = Neutral conditions
- E = Slightly stable conditions
- F = Moderately stable conditions

The meteorological conditions defining each Pasquill stability class are shown in **Table 13**.

Figure 14 shows the predicted atmospheric stability class frequencies for the Mine Area. The results indicate high frequencies of conditions typical to Stability Classes F. Stability Class F occurs during still clear nights and is associated with a low level of atmospheric turbulence and limited dispersion. Considering the inland location of the Mine Area, the combined percentage of E and F conditions is considered reasonable, and the high proportion of F Class stabilities is reflective of the low wind speeds in the area.

Table 13 Meteorological Conditions Defining Pasquill Stability Classes

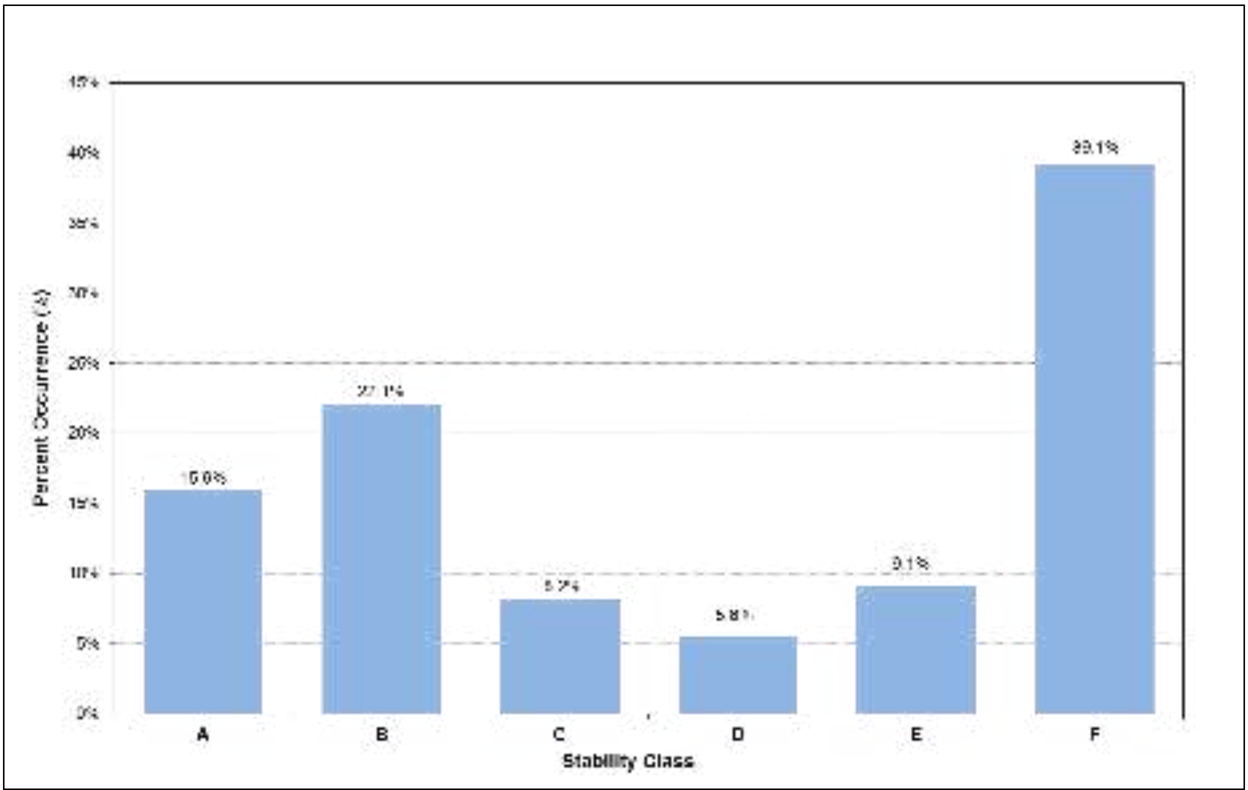
Surface wind speed (m/s)	Daytime insolation			Night-time conditions	
	Strong	Moderate	Slight	Thin overcast or > 4/8 low cloud	<= 4/8 cloudiness
< 2	A	A - B	B	E	F
2 - 3	A – B	B	C	E	F
3 - 5	B	B - C	C	D	E
5 - 6	C	C - D	D	D	D
> 6	C	D	D	D	D

(Source: (Pasquill, 1961))

Notes:

1. Strong insolation corresponds to sunny midday in midsummer in England; slight insolation to similar conditions in midwinter.
2. Night refers to the period from 1 hour before sunset to 1 hour after sunrise.
3. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night and for any sky conditions during the hour preceding or following night as defined above.

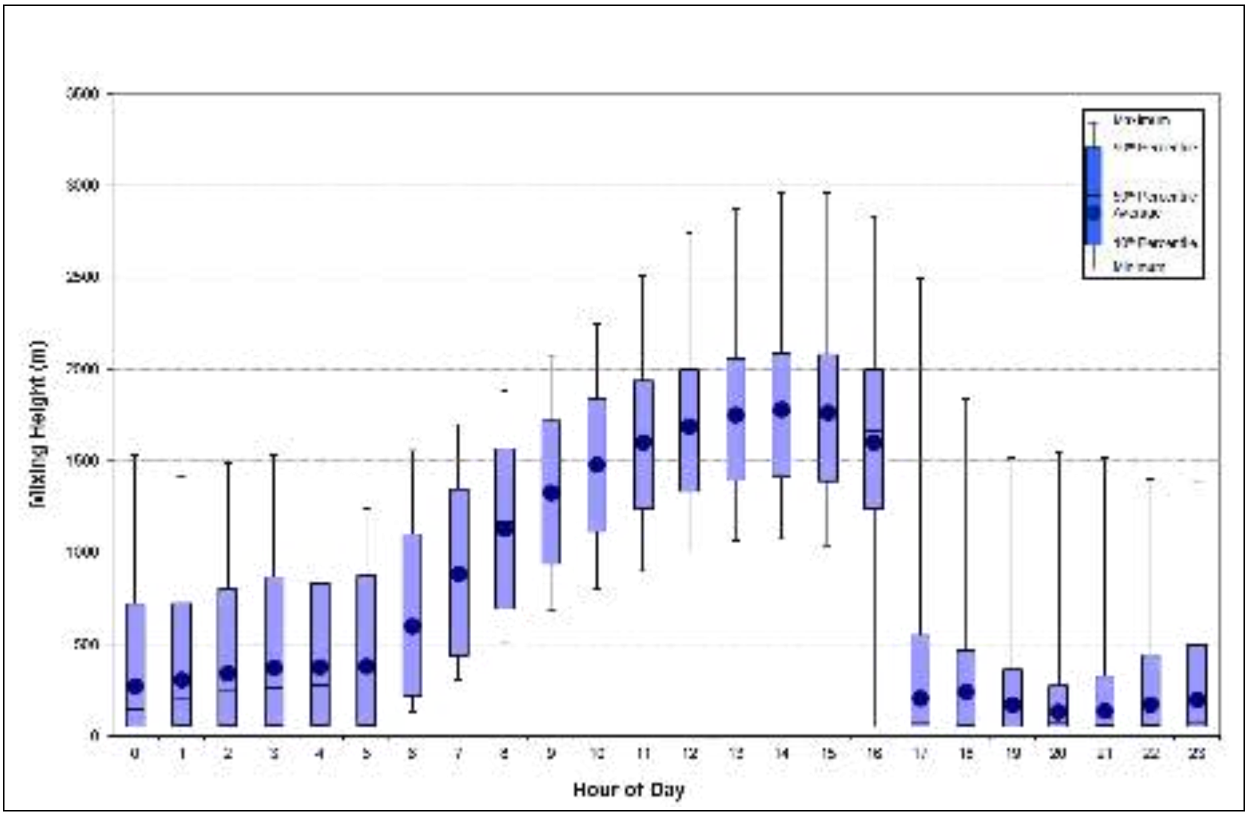
Figure 14 Atmospheric Stability Class Frequencies, as Predicted by CALMET (2016)



Mixing Height

Diurnal variations in maximum and average mixing heights predicted by CALMET at the Mine Area during 2016 are illustrated in **Figure 15**. As would be expected, an increase in the mixing height during the morning is apparent, due to the onset of vertical mixing following sunrise. Maximum mixing heights occur in the mid to late afternoon, due to the dissipation of ground-based temperature inversions and the growth of the convective mixing layer.

Figure 15 Diurnal Variation in Mixing Heights, as Predicted by CALMET (2016)



6.1.3 Background Concentrations Used in Dispersion Modelling

To provide an assessment of potential cumulative pollutant concentrations at surrounding sensitive receptors, measured long term (≥1 year) ambient air quality data are required. However, as stated above, no long term ambient monitoring data for suspended particulate are available in the vicinity of the Project Area.

In the absence of any measured long term ambient air quality data in the local area, which is not unusual for a development proposed in remote areas like PNG, background air pollution levels for cumulative impact assessment purposes have been estimated based on the measured short term air quality data presented in **Table 9**. To provide a conservative estimate of background 24-hour average PM_{10} concentrations, the measurements recorded at the Wori and Madzim monitoring sites, which reported relatively low concentrations, were not considered further in this analysis. Thus, based on the Wongkins and Bavaga measurements, annual average background PM_{10} and TSP concentrations were estimated as presented in **Table 14**. Given that there are no significant potential dust emission sources in the local area and the region is sparsely populated, use of the background levels presented in **Table 14** are expected to provide a conservative estimate of the existing ambient background levels.

Given the undeveloped nature of the surrounding area and the absence of any significant industry or other sources of combustion products, background concentrations of oxides of nitrogen (NO_X), sulphur dioxide (SO_2) and carbon monoxide (CO) have been assumed to be negligible.

Table 14 Background Particulate Concentrations Adopted in Dispersion Modelling Study

Pollutant	Averaging Period	Background Concentration (µg/m³)	Basis
$PM_{2.5}$	24-hour	14.8	$PM_{2.5}$ assumed to be 50% of PM_{10} [a]
	Annual	5.9	$PM_{2.5}$ assumed to be 50% of PM_{10} [a]
PM_{10}	24-hour	29.5	Average of Wongkins and Bavaga readings
	Annual	11.8	Scaled based from the 24-hour average using a factor of 0.4 as per the WHO 24-hour and annual average guidelines
TSP	24-hour	41.3	Assumed PM_{10}:TSP ratio of 50:70 [b]
	Annual	29.5	Assumed PM_{10}:TSP ratio of 20:50 [b]

[a] The WHO particulate matter guidelines are based on studies that use $PM_{2.5}$ as an indicator and that the PM_{10} guidelines have been derived using a ratio of 1:2 for $PM_{2.5}$:PM_{10} concentrations, on the basis that 0.5 is the typical ratio that applies in urban areas in developing countries. Given the Project is located in a non-urban area, this is considered a conservative approach for estimating background $PM_{2.5}$ concentrations.

[b] Using the same approach as (a), the 24-hour average TSP background concentration has been scaled from the 24-hour average PM_{10} concentration based on the ratio of the 24-hour average guidelines set by WHO for these indicators. Similarly, the annual average TSP background concentration has been scaled from the annual average PM_{10} concentration based on the ratio of the annual average guidelines set by WHO.

6.1.4 Modelling of NO_X Chemistry

NO_X emissions from fossil fuel combustion are primarily NO, with only a few volume percent as NO_2. However, once the gases are discharged into the atmosphere, chemical reactions take place which result in the transformation of NO in the plume to NO_2.

There are various methods for estimating NO_2 concentrations from model predictions of NO_X as the plume is emitted from the emission point. These include:

- **Total Conversion Method (Tier 1 or screening):** In this conservative screening approach, predicted ground-level concentrations of total NO_X are simply assumed to exist as 100% NO_2. This is an extremely conservative approach and not likely to occur in reality.
- **US EPA Tier 2 analysis**: This method assumes a 75% conversion of NO_X to NO_2 and is to be used when the NO_2 concentration exceeds guidelines when determined through the total conversion method above (US EPA, 2003).
- **Ozone Limiting Method (OLM):** The OLM is based on the assumption that approximately 10% of the NO_X emissions are generated as NO_2 (Alberta Environment, 2003). If the ozone (O_3) concentration is greater than 90% of the predicted NO_X concentrations, all the NO_X is assumed to be converted to NO_2, otherwise $NO_2 = 0.1 \times NOx + \min(0.9 \times NOx, 46/48 \times O_3)$.
- **Ambient Ratio Method (ARM):** If there is at least one year of monitoring data available for NO_X and NO_2 within the airshed, an empirical NO_2:NO_X: relationship can be derived and used as an alternative to the ozone limiting method (Alberta Environment, 2003) (US EPA, 2003).
- **Reactive Plume Modelling**: This approach requires detailed data inputs for regional emissions and is usually used for regional inventory modelling.

For this assessment, maximum off-site ground level NO_2 concentrations were estimated from the downwind NO_X predictions given by CALPUFF using the Ozone Limiting Method. This approach enables the existing air quality environment to be considered, while not requiring hourly varying background ozone data or regional modelling studies. A background ozone concentration of 40 ppb (86 µg/m³) was used in the calculations based on studies that have shown that ambient ozone concentrations in remote tropical rainforest locations typically range from 20-40 ppb (CGER, 1991).

6.1.5 Accuracy of Modelling

Atmospheric dispersion models all represent a simplification of the many complex processes involved in the dispersion of pollutants in the atmosphere.

The main sources of uncertainty in dispersion models, and their effects, are discussed below.

- **Oversimplification of physics:** This can lead to both under-prediction and over-prediction of ground level pollutant concentrations. Errors are smaller in puff models such as CALPUFF, which include the effects of non-steady-state meteorology (i.e., spatially- and temporally-varying meteorology).
- **Errors in emission rates:** Ground level concentrations are proportional to the pollutant emission rate. In this study, the modelling is based on emission estimates derived from the use of published emission factors and estimated activity levels for worst case operational activities. In order to address the uncertainty associated with these estimates, conservative assumptions have been made so that the emissions are not under-predicted.
- **Errors in source parameters:** Plume rise is affected by source dimensions, temperature and exit velocity. Inaccuracies in these values will contribute to errors in the predicted height of the plume centreline and thus ground level pollutant concentrations.
- **Errors in wind direction and wind speed**: Wind direction affects the direction of plume travel, while wind speed affects plume rise and dilution of plume. Errors in these parameters can result in errors in the predicted distance from the source of the plume impact, and magnitude of that impact. In addition, aloft wind directions commonly differ from surface wind directions (referred to as "wind shear"). The preference to use rugged meteorological instruments to reduce maintenance requirements also means that light winds are often not well characterised.
- **Errors in mixing height:** If the plume elevation reaches 80% or more of the mixing height, more interaction will occur, and it becomes increasingly important to properly characterize the depth of the mixed layer as well as the strength of the upper air inversion. For ground-level fugitive sources such as those associated with this study, mixing height is not a significant factor.
- **Errors in temperature:** Ambient temperature affects plume buoyancy, so inaccuracies in the temperature data can result in potential errors in the predicted distance from the source of the plume impact, and magnitude of that impact.
- **Errors in stability estimates:** Gaussian plume models use estimates of stability class, and 3D models use explicit vertical profiles of temperature and wind (which are used directly or indirectly to estimate stability class for Gaussian models). In either case, errors in these parameters can cause either under-prediction or over-prediction of ground level concentrations. For example, if an error is made of one stability class, then the computed concentrations can be off by 50% or more.

The US EPA makes the following statement in its Modelling Guideline (US EPA, 2005) on the relative accuracy of models:

> *"Models are more reliable for estimating longer time-averaged concentrations than for estimating short-term concentrations at specific locations; and the models are reasonably reliable in estimating the magnitude of highest concentrations occurring sometime, somewhere within an area. For example, errors in highest estimated concentrations of ±10 to 40% are found to be typical, i.e., certainly well within the often quoted factor-of-two accuracy that has long been recognized for these models. However estimates of concentrations that occur at a specific time and site, are poorly correlated with actually observed concentrations and are much less reliable."*

In summary, modelling of air emissions is subject to a number of sources of uncertainty.

The main source of uncertainty for the air dispersion modelling study performed for the mining operation relates to the pollutant emission rates, which are based on published emission factors and estimated activity data such as annual quantities of waste rock moved and annual diesel consumption figures. There will be a large degree of variation in the activity levels that will occur during the Project – with regards to both location and time – which will affect the actual short-term hourly emission rates that will occur in any given location. For this reason, care has been taken to use conservative assumptions in estimating the emission rates hence the predicted off-site impacts should be conservative overestimates of the actual levels likely to be experienced.

In addition, the effects of the high rainfall and dense vegetation which are characteristic of the area (which would both act to filter dust out of the air) have not been factored into the modelling. The inclusion of wet deposition (rain scavenging) is extremely computationally intensive and it is not standard practice to include it in modelling for air quality impact assessments. There are also no control factors available in the literature to be able to quantify the effects of vegetation (in particular the types of vegetation present in the study area) in reducing ambient particulate concentrations. Excluding wet deposition and vegetative screening effects from the modelling will also ensure that the modelling results will be conservative overestimates of the actual levels likely to be experienced.

6.2 Qualitative Impact Assessment

Potential air quality impact associated with the construction of the access roads, concentrate, fuel and tailings pipelines, Port Facilities Area and the Outfall Area have been assessed qualitatively. Fugitive dust emissions from construction activities, such as vegetation clearance, bulk earthworks and truck movements, have the potential to result in elevated TSP, PM_{10} and $PM_{2.5}$ concentrations and dust deposition rates in the vicinity of the works.

The use of diesel-powered mobile machinery, diesel generators and vehicles at these construction sites also have the potential to result in minor, localised elevations in ambient concentrations of combustion-related pollutants, but as they are emitted over a wide area they are well dispersed and would not have any potential to result in exceedances of relevant ambient air quality criteria at the nearest sensitive receptor locations. Fugitive dust emissions have the greatest potential to give rise to downwind air quality impacts in the vicinity of construction projects.

The following sections describe the methodology used to perform a qualitative assessment of the potential risks to air quality associated with dust from activities associated with the construction of the access roads, concentrate, fuel and tailings pipelines, Port Facilities Area and the Outfall Area.

6.2.1 Construction Dust Risk Assessment Method

For this assessment, the *IAQM Guidance on the Assessment of Dust from Demolition and Construction* (IAQM, 2014) developed in the United Kingdom by the Institute of Air Quality Management (IAQM) has been used to provide a qualitative assessment method. The IAQM method uses a five-step process for assessing dust impacts from construction activities:

- **Step 1**: Screening based on distance to the nearest sensitive receptor; whereby the sensitivity to dust deposition and human health impacts of the identified sensitive receptors is determined.
- **Step 2**: Assess risk of dust effects from activities based on:
    a. the scale and nature of the works, which determines the potential dust emission magnitude
    b. the sensitivity of the area surrounding dust-generating activities
- **Step 3**: Determine site-specific mitigation for remaining activities with greater than negligible effects.
- **Step 4**: Assess significance of remaining activities after management measures have been considered.

There are some limitations in applying the IAQM construction dust assessment methodology to the Project. The IAQM methodology has been developed in the UK for the assessment of dust impacts from construction sites in urban areas with much higher population densities and (potentially) different community expectations regarding amenity levels in relation to dust emissions. Rainfalls in PNG are also much higher than in the UK, construction practices are likely to be different and the local infrastructure (roads, housing etc.) will also be very different. However, use of the IAQM methodology provides a structured approach to the assessment of dust emissions from construction activities, and it is expected to provide a conservative assessment of the potential risk of off-site health and amenity impacts from the proposed Project. The main objective of the IAQM methodology is to identify potentially high risk activities so that appropriate management measures are identified and implemented during the works to manage the risks, and that is the intent of using this methodology for assessing potential impacts from the Project.

Step 1 – Screening Based on Separation Distance

The Step 1 screening criteria provided by the IAQM guidance suggests screening out any assessment of impacts from construction activities where sensitive receptors are located more than 350 m from the boundary of the site, more than 50 m from the route used by construction vehicles on public roads and more than 500 m from the site entrance. This step is noted in the IAQM document as having deliberately been chosen to be conservative.

Step 2a – Assessment of Scale and Nature of the Works

Step 2a of the assessment provides "dust emissions magnitudes" for each of four dust generating activities; demolition, earthworks, construction, and track-out (the movement of site material onto public roads by vehicles). The magnitudes are: *Large*; *Medium*; or *Small*, with suggested definitions for each category. The definitions given in the IAQM guidance for demolition, earthworks and construction activities, which are most relevant to this Project, are as follows:

- Demolition:
    - ***Large***: Total building volume greater than 50,000 m^3, demolition activities greater than 20 m above ground, on-site crushing and screening activities or demolition of potentially dusty construction materials
    - ***Medium***: Total building volume between 20,000 m^3 and 50,000 m^3, demolition activities between 10 m and 20 m above ground or demolition of potentially dusty construction materials
    - ***Small***: Total building volume less than 10,000 m^3, demolition activities lower than 10 m above ground, demolition performed during wetter months or demolition of construction materials with low potential for dust release
- Earthworks:
    - ***Large***: Total site area greater than 10,000 m^2, potentially dusty soil type (e.g., clay, which will be prone to suspension when dry due to small particle size), more than 10 heavy earth moving vehicles active at any one time, formation of bunds greater than 8 m in height, total material moved more than 100,000 t
    - ***Medium***: Total site area 2,500 m^2 to 10,000 m^2, moderately dusty soil type (e.g., silt), 5 to 10 heavy earth moving vehicles active at any one time, formation of bunds 4 m to 8 m in height, total material moved 20,000 t to 100,000 t
    - ***Small***: Total site area less than 2,500 m^2, soil type with large grain size (e.g., sand), less than five heavy earth moving vehicles active at any one time, formation of bunds less than 4 m in height, total material moved less than 20,000 t, earthworks during wetter months
- Construction:
    - ***Large***: Total building volume greater than 100,000 m^3, piling, on site concrete batching; sandblasting
    - ***Medium***: Total building volume 25,000 m^3 to 100,000 m^3, potentially dusty construction material (e.g., concrete), piling, on site concrete batching

- ***Small***: Total building volume less than 25,000 m^3, construction material with low potential for dust release (e.g., metal cladding or timber)

In order to provide a conservative assessment of potential impacts, it has been assumed that if at least one of the parameters specified in the 'large' definition is satisfied, the works are classified as large, and so on.

Step 2b – Assessment of the Sensitivity of the Area

Step 2b of the assessment process requires the sensitivity of the area to be defined. The sensitivity of the area takes into account:

- The specific sensitivities that identified sensitive receptors have to dust deposition and human health impacts
- The proximity and number of those receptors
- In the case of PM_{10}, the local background concentration
- Other site-specific factors, such as whether there are natural shelters such as trees to reduce the risk of wind-blown dust

Individual receptors are classified as having *high*, *medium* or *low* sensitivity to dust deposition and human health impacts (ecological receptors are not addressed using this approach). The IAQM method provides guidance on the sensitivity of different receptor types to dust soiling and health effects as summarised in **Table 15** (IAQM, 2014). It is noted that user expectations of amenity levels (dust soiling) is dependent on existing deposition levels.

Table 15 IAQM Guidance for Categorising Receptor Sensitivity

Value	High Sensitivity Receptor	Medium Sensitivity Receptor	Low Sensitivity Receptor
Dust soiling	• Users can reasonably expect a high level of amenity; or • The appearance, aesthetics or value of their property would be diminished by soiling, and the people or property would reasonably be expected to be present continuously, or at least regularly for extended periods as part of the normal pattern of use of the land.	• Users would expect to enjoy a reasonable level of amenity, but would not reasonably expect to enjoy the same level of amenity as in their home; or • The appearance, aesthetics or value of their property could be diminished by soiling; or • The people or property wouldn't reasonably be expected to be present here continuously or regularly for extended periods as part of the normal pattern of use of the land.	• The enjoyment of amenity would not reasonably be expected; or • Property would not reasonably be expected to be diminished in appearance, aesthetics or value by soiling; or • There is transient exposure, where the people or property would reasonably be expected to be present only for limited periods of time as part of the normal pattern of use of the land.
Health effects	• Locations where the public are exposed over a time period relevant to the air quality objective for PM_{10} (in the case of the 24-hour objectives, a relevant location would be one where individuals may be exposed for eight hours or more in a day).	• Locations where the people exposed are workers, and exposure is over a time period relevant to the air quality objective for PM_{10} (in the case of the 24-hour objectives, a relevant location would be one where individuals may be exposed for eight hours or more in a day).	• Locations where human exposure is transient.

According to the IAQM methods, the sensitivity of the identified individual receptors (as described above) is then used to assess the *sensitivity of the area* surrounding the active construction area, taking into account the proximity and number of those receptors, and the local background PM_{10} concentration (in the case of potential health impacts) and other site-specific factors. Additional factors to consider when determining the sensitivity of the area include:

- any history of dust generating activities in the area.
- the likelihood of concurrent dust generating activity on nearby sites.
- any pre-existing screening between the source and the receptors (e.g. dense vegetation surrounding the Mine Area and sections of the pipeline corridor).
- any conclusions drawn from analysing local meteorological data which accurately represent the area; and if relevant, the season during which the works will take place.
- any conclusions drawn from local topography.
- the duration of the potential impact (as a receptor may be willing to accept elevated dust levels for a known short duration, or may become more sensitive or less sensitive (acclimatised) over time for long-term impacts).
- any known specific receptor sensitivities which go beyond the classifications given in the IAQM document.

The IAQM guidance for assessing the sensitivity of an area to dust soiling is shown in **Table 16**. The sensitivity of the area should be derived for each activity relevant to the Project (i.e. demolition, construction and/or earthworks).

Table 16 IAQM Guidance for Categorising the Sensitivity of an Area to Dust Soiling Effects

Receptor sensitivity	Number of receptors	Distance from the source (m)			
		<20	<50	<100	<350
High	>100	High	High	Medium	Low
	10-100	High	Medium	Low	Low
	1-10	Medium	Low	Low	Low
Medium	>1	Medium	Low	Low	Low
Low	>1	Low	Low	Low	Low

Note: Estimate the total number of receptors within the stated distance. Only the *highest level* of area sensitivity from the table needs to be considered. For example, if there are 7 high sensitivity receptors < 20m of the source and 95 high sensitivity receptors between 20 and 50 m, then the total of number of receptors < 50 m is 102. The sensitivity of the area in this case would be high.

A modified version of the IAQM guidance for assessing the *sensitivity of an area* to health impacts is shown in **Table 17**. For high sensitivity receptors, the IAQM methods takes the existing background concentrations of PM_{10} (as an annual average) experienced in the area of interest into account and is based on the air quality objectives for PM_{10} in the UK. As these objectives differ from the ambient air quality criteria adopted for use in this assessment (i.e. an annual average of 20 µg/m^3 for PM_{10}), and given that limited site-specific background monitoring data are available for the sensitive receptors considered in this assessment, the IAQM method has been modified slightly.

This approach is consistent with the IAQM guidance, which notes that in using the tables to define the *sensitivity of an area*, professional judgement may be used to determine alternative sensitivity categories, taking into account the following factors:

- Any history of dust generating activities in the area
- The likelihood of concurrent dust generating activity on nearby sites
- Any pre-existing screening between the source and the receptors

- Any conclusions drawn from analysing local meteorological data which accurately represent the area, and if relevant the season during which the works will take place
- Any conclusions drawn from local topography
- Duration of the potential impact
- Any known specific receptor sensitivities which go beyond the classifications given in this document

Table 17 IAQM Guidance for Categorising the Sensitivity of an Area to Dust Health Effects

Receptor Sensitivity	Annual Mean PM_{10} Concentration (µg/m^3)	Number of Receptors[a]	Distance from the Source (m) <20	<50	<100	<200	<350
High	>20	>100	High	High	High	Medium	Low
		10-100	High	High	Medium	Low	Low
		1-10	High	Medium	Low	Low	Low
	18 – 20	>100	High	High	Medium	Low	Low
		10-100	High	Medium	Low	Low	Low
		1-10	High	Medium	Low	Low	Low
	16 – 18	>100	High	Medium	Low	Low	Low
		10-100	High	Medium	Low	Low	Low
		1-10	Medium	Low	Low	Low	Low
	≤16	>100	Medium	Low	Low	Low	Low
		10-100	Low	Low	Low	Low	Low
		1-10	Low	Low	Low	Low	Low
Medium	>20	>10	High	Medium	Low	Low	Low
		1-10	Medium	Low	Low	Low	Low
	18 - 20	>10	Medium	Low	Low	Low	Low
		1-10	Low	Low	Low	Low	Low
	<18	>1	Low	Low	Low	Low	Low
Low	-	>1	Low	Low	Low	Low	Low

Note: (a) Estimate the total within the stated distance (e.g. the total within 350 m and not the number between 200 and 350 m), noting that only the highest level of area sensitivity from the table needs to be considered. In the case of high sensitivity receptors with high occupancy (such as schools or hospitals) approximate the number of people likely to be present. In the case of residential dwellings, just include the number of properties.

Given the above, for the purposes of this study, all receptors have been classified based on the sensitivity classifications for a background annual average PM_{10} concentration of 11.8 µg/m^3, as outlined in **Section 6.1.3**.

The dust emission magnitude from Step 2a and the receptor sensitivity from Step 2b are then used in the matrices shown in **Table 18** (earthworks and construction) and **Table 19** (demolition) to determine the risk category with no mitigation applied.

Table 18 Risk Category from Earthworks and Construction Activities

Sensitivity of Area	Dust Emission Magnitude		
	Large	Medium	Small
High	High Risk	Medium Risk	Low Risk
Medium	Medium Risk	Medium Risk	Low Risk
Low	Low Risk	Low Risk	Negligible

Table 19 Risk Category from Demolition Activities

Sensitivity of Area	Dust Emission Magnitude		
	Large	Medium	Small
High	High Risk	Medium Risk	Medium Risk
Medium	High Risk	Medium Risk	Low Risk
Low	Medium Risk	Low Risk	Negligible

Step 3 - Site-Specific Mitigation

Once the risk categories are determined for each of the relevant activities, site-specific management measures can be identified based on whether the site is a low, medium or high risk site.

Step 4 – Residual Impacts

Following Step 3, the residual impact is then determined after management measures have been considered.

7 AIR QUALITY IMPACT ASSESSMENT – MINE AREA

7.1 Assessment Scenarios

Based on a review of the Project information relating to the proposed construction activities and mining operations, the following construction and operational scenarios were identified to represent the potential worst case assessment scenarios for the Mine Area:

- **Scenario 1 – Construction**: including extraction and hauling of materials from borrow pits, quarries, on-site diesel power generation, and construction of the declines, ventilation shaft, Watut Decline Portal Terrace, process plant terrace and other Mine Area infrastructure.
- **Scenario 2 – Operation**: Ore extraction, handling and milling at the maximum throughput of 16.84 Mtpa, ventilation emissions and the power generation facilities.

7.2 Estimation of Fugitive Particulate Emissions

7.2.1 Emission Sources

Based on the available information for the Project, the activities listed in **Table 20** have been identified as potentially significant fugitive dust emission sources for the construction phase of the Project. These sources were included in the dispersion model to predict the potential worst case impacts at sensitive receptors surrounding the Mine Area during the construction phase of the Project.

The potential fugitive dust emission sources identified for the Mine Area during the operational phase of the Project are presented in **Table 21**.

The methods used to estimate emissions from the identified construction-phase and operational-phase fugitive dust emission sources are detailed in **Section 0**.

Table 20 Potential Fugitive Particulate Emission Sources – Construction

Source	Activities
Borrow Pits (Mt Beamena, Migiki, Northern Access Road, Miapilli clay and Humphries)	Drilling and blasting Crushing Material handling Hauling of quarry materials Diesel generators Wind erosion from disturbed areas
Gravel Extraction (Watut River floodplain, Waime River and Lower Papas aggregate source)	Hauling of quarry materials Diesel generators
Watut Decline and Portal Terrace	Bulldozer Concrete batching plant Diesel generators Drilling Blasting Wind erosion Ventilation system exhaust from Watut Decline
Nambonga Decline	Drilling Blasting Wind erosion Ventilation system exhaust
Miapilli Waste Rock Dump	Material handling Hauling of materials Wind erosion
Ventilation shaft	Drilling Blasting Wind erosion Ventilation system exhaust
Plant Terrace Fere Accommodation Facility Finchif Construction Accommodation Facility Power Generation Facilities Waste Management Facility	Detailed information for these activities is not available. Potential emissions were estimated using the default USEPA AP42 emission factor for heavy construction.

Table 21 Potential Fugitive Particulate Emission Sources – Operation

Source	Activities
Plant terrace	Material handling Bulldozer Wind erosion (stockpiles and disturbed areas)
Ventilation shaft	Ventilation system exhaust
Watut Decline	Ventilation system exhaust
Watut Decline Portal Terrace	Concrete batching plant Wind erosion
IFO power generation facilities	Generators

7.2.2 Activity Data and Assumptions

Fugitive particulate emissions from the Project were estimated based on the *Compilation of Air Pollutant Emission Factors AP-42* (US EPA, 1998) and emission estimation techniques listed in the *NPI Emission Estimation Technique Manual for Mining* (DSEWPC, 2012). Details of the emission factors used in estimating emissions are presented in **Appendix B**.

Construction

The activity data and site parameters used in the fugitive dust emission calculations for the construction activities are summarised in **Table 22**.

Table 22 Activity Data used to Estimate Fugitive Particulate Emissions - Construction

Parameter	Intensity	Basis
Quarries*		
Bulldozer	6,570 hrs/year/quarry	Assumed 18 hrs/day (9hrs per shift)
Number of drill holes	30 holes per blast	Assumed
Number of blasts	1 per 3 days per quarry	Assumed
Average area of blast	150 m^2	Assumed
Material moved	175,200 tonnes/year/quarry	Assumed
Rock crushing	175,200 tonnes/year/quarry	Assumed
Waste rock moisture content	7.9%	(US EPA, 1998)
Waste rock silt content	6.9%	(US EPA, 1998)
Haul road silt content	1.5%	(US EPA, 1998)
Haul Truck	CAT 740	Assumed
Haul road length - Mt Beamena	13.7 km	Mine layout
Haul road length - Migiki	4.7 km	Mine layout
Haul road length - Northern Access Road	20 km	Mine layout
Haul road length - Humphries	2 km	Mine layout
Haul road length – Miapilli clay	0.5 km	Mine layout
Haul road length – Miapilli WRD	3.6 km	Mine layout
Wind erosion – Mt Beamena	0.5 ha	Assumed to be overall footprint
Wind erosion – Migiki	1.2 ha	Assumed to be overall footprint
Wind erosion – Northern Access Road	51.5 ha	Assumed to be overall footprint
Wind erosion – Humphries	0.8 ha	Assumed to be overall footprint
Wind erosion – Miapilli clay	8 ha	Mine layout
Wind erosion – Miapilli WRD	5 ha	Assumed
Wind erosion – Quarry material stockpiles	10.6 ha	Assumed to be overall footprint
Gravel Extraction		
Haul road length – Watut Floodplain	20 km	Mine layout
Haul road length – Waime River	17.4 km	Mine layout
Haul road length – Lower Papas	3.5 km	Mine layout
Haul truck	CAT 740	Assumed
Number of trips	10 trips per day each	Assumed
Watut Decline Portal Terrace		

Parameter	Intensity	Basis
Bulldozer	2,920 hrs/year	Assumed 2 bulldozers at 4 hrs/day
Drilling	30 holes per blast	Assumed
Blasting	1 blast per day	Assumed
Concrete batching plant	152 tonnes/year	Based on 100 m³/hr throughput
Ventilation exhaust	160 m³/s	Provided by WGJV
Wind erosion	3.5 ha	Assumed to be overall footprint
Ventilation Shaft		
Drilling	30 holes per blast	Assumed
Blasting	1 blast per day	Assumed
Wind erosion	1.1 ha	Assumed to be overall footprint
Nambonga Decline		
Drilling	30 holes per blast	Assumed
Blasting	1 blast per day	Assumed
Ventilation Exhaust	370 m³/s	Provided by WGJV
Wind erosion	0.26 ha	Assumed to be overall footprint
Other		
Construction area – Plant terrace	27.8 ha	Assumed to be site area
Construction area - Fere Accommodation Facility	3.08 ha	Overall footprint from infrastructure layer
Concrete batching plant – Finchif construction accommodation facility	152 tonnes/year	Based on 100 m³/hr throughput
Construction area – Power generation facilities	7.34 ha	Overall footprint from infrastructure layer
Number of diesel generators	20	

* In the absence of detailed data on the throughput of each quarry, the same extraction rate, drilling and blasting parameters were assumed for each quarry as a conservative approach. Due to this assumption, predicted impacts for some quarries may be significantly overestimated.

Operation

The activity data and site parameters used in the fugitive dust emission calculations are summarised in **Table 23**.

Table 23 Activity Data used to Estimate Fugitive Particulate Emissions – Operation

Parameter	Units	Data
Plant Terrace		
Ore throughput	Mtpa	16.84
Silt content – haul roads	%	1.5
Bulldozer - stockpiles	hrs/year	3,546
Moisture content of rock and ore	%	7.9
Exposed area – start up ore stockpile	ha	0.8
Exposed area – coarse ore stockpile	ha	1.2
Exposed area – Process plant	ha	2.8
Ventilation Shaft		
Ventilation system exhaust	m^3/s	450
Watut Decline		
Ventilation system exhaust	m^3/s	225
Watut Decline Portal Terrace		
Concrete batching plant	tonnes/year	152
Exposed area	ha	0.4
Power Generation Facilities		
Number of operational IFO power generators		12
Number of standby IFO power generators		2

For the purpose of developing the emission inventories, the following assumptions have also been applied:

- Water is applied to haul roads at a rate greater than 2 litres/m^2/hour (this is referred to by US EPA as Level 2 watering) during any extended dry periods;
- During construction, wind erosion occurs from all exposed areas of the site including ventilation pad, portal and plant terraces area, declines, and waste rock dumps;
- During operation, wind erosion occurs from the portal and plant terrace areas, with other areas assumed to be rehabilitated; and
- During high wind events and extended dry periods, water is applied to exposed areas at a rate greater than 2 litres/m^2/hour.

7.2.3 Estimated Fugitive Particulate Emissions

Construction

Dust emissions from the construction activities were estimated based on the activity data and assumptions presented in the previous sections and are summarised in **Table 24**. Further details of the calculations are presented in **Appendix B**. The particulate emissions presented in **Table 24** include the estimated annual emissions from the diesel generators for completeness, and further details of the estimated emissions from this source are presented in **Section 7.3.1**.

Table 24 Estimated Particulate Emission Rates - Construction

Activity	Estimated Emissions (kg/annum)		
	TSP	PM_{10}	$PM_{2.5}$
Mt Beamena Quarry			
Removing overburden (bulldozers)	11,810	2,226	1,240
Drilling	2,154	1,119	102
Blasting	49	26	1
Rock crushing	473	210	21
Wind erosion - Quarry area	788	394	37
Wind erosion - stockpile	18,571	9,286	869
Loading materials to truck	21	10	2
Hauling materials from quarry	74,375	15,021	1,502
Loading/Unloading materials at stockpile	42	20	3
Unloading materials at Watut Decline Portal Terrace	21	10	2
Migiki Borrow Pit			
Removing overburden (bulldozers)	11,810	2,226	1,240
Drilling	2,154	1,120	101
Blasting	49	26	1
Rock crushing	473	210	21
Wind erosion - Quarry area	2,067	1,034	97
Loading materials to truck	21	10	2
Hauling materials from borrow pit	25,407	5,131	513
Unloading materials at portal terrace	21	10	2
Northern Access Road Borrow Pit			
Removing overburden (bulldozers)	11,810	2,226	1,240
Drilling	2,154	1,120	101
Blasting	49	26	1
Rock crushing	473	210	21
Wind erosion - Quarry area	90,228	45,114	4,223
Loading materials to truck	21	10	2
Hauling materials from borrow pit	108,577	21,929	2,193
Unloading materials	21	10	2
Humphries Borrow Pit			
Removing overburden (bulldozers)	11,810	2,226	1,240
Drilling	2,154	1,120	101
Blasting	49	26	1
Rock crushing	473	210	21
Wind erosion - Quarry area	1,367	683	64
Loading materials to truck	21	10	2
Hauling materials from borrow pit	10,858	2,193	219
Unloading materials at Process Plant terrace	21	10	2
Miapilli Clay Borrow Pit			
Removing overburden (bulldozers)	11,810	2,226	1,240
Rock crushing	473	210	21
Wind erosion - Quarry area	14,244	7,122	667

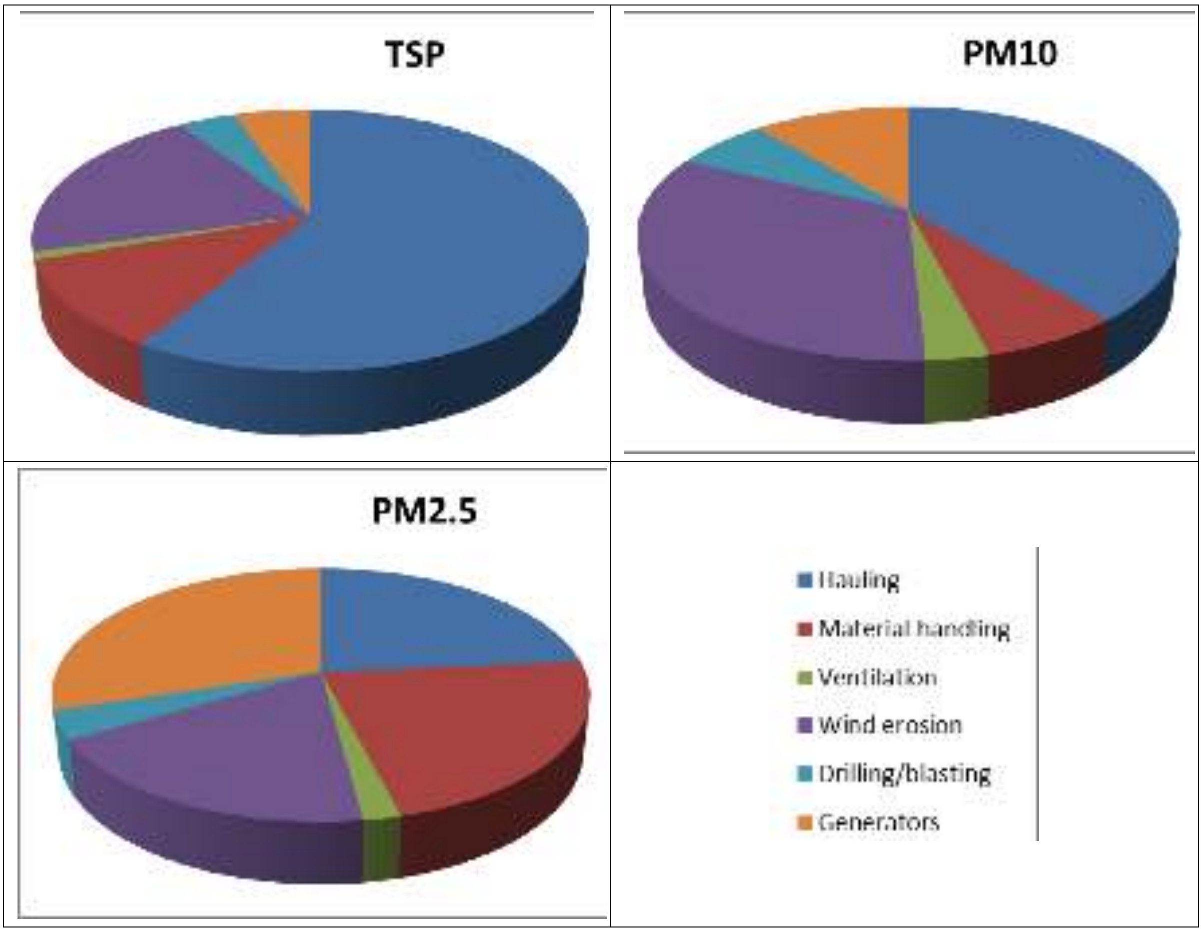
Activity	Estimated Emissions (kg/annum)		
	TSP	PM_{10}	$PM_{2.5}$
Loading materials to truck	21	10	2
Hauling materials from borrow pit	2,714	548	55
Unloading at WRD	21	10	2
Bavaga and Waime River Gravel Extraction			
Hauling materials from Bavaga River	75,172	15,182	1,518
Hauling materials from Waime River	65,212	13,171	1,317
Lower Papas Aggregate Source			
Hauling materials	13,155	2,657	266
Miapilli Waste Rock Dump			
Loading materials – Miapilli Decline	53	25	4
Hauling materials to WRD	48,876	9,871	987
Unloading materials at WRD	53	25	4
Reshaping WRD (bulldozers)	11,810	2,226	1,240
Wind erosion	8,760	4,380	410
Portal Terrace			
Spreading material with bulldozers	5,249	989	551
Drilling	6,461	3,359	302
Blasting	148	77	4
Wind erosion of waste rock dump	6,167	3,084	289
Concrete Batching Plant	8	8	1
Ventilation system exhaust	2,119	2,119	212
Ventilation Shaft			
Drilling	6,461	3,359	302
Blasting	148	77	4
Wind erosion	1,857	929	87
Nambonga Decline			
Drilling	6,461	3,359	302
Blasting	148	77	4
Wind erosion	457	228	21
Ventilation system exhaust	4,901	4,901	490
Plant Terrace			
Construction activities	449	224	22
Fere Accommodation			
Construction activities	50	25	2
Finchif Construction Accommodation			
Concrete Batching Plant	8	8	1
Power Generation Facilities			
Construction activities	118	59	6
Waste Management Facility			
Construction activities	261	131	13
Power Supply			
Diesel generators	9,461	9,461	9,461
Total (kg/yr)	**693,695**	**205,346**	**34,993**

The estimated particulate emissions were classified into the following groups to present the contribution from each type of activity:

- Hauling waste rock;
- Waste rock handling (includes emissions from drilling, blasting, loading and unloading);
- Ventilation;
- Wind erosion; and
- Other (including emissions from concrete batching plant and crushing).

The contributions of each source group to the total estimated emissions for the construction phase of the Project are presented graphically in **Figure 16**. It can be observed from **Figure 16** that hauling is estimated to be the major source of TSP and PM_{10} emissions in the Mine Area. The estimated $PM_{2.5}$ emissions are almost equally weighted between hauling, material handling, wind erosion and power generation operations, with a minor contribution from ventilation emissions.

Figure 16 Particulate Emissions Source Contribution – Construction Phase



Operation

Dust emissions from the Mine Area operations were estimated based on the activity data and assumptions presented in the previous sections and are presented in **Table 25**. The particulate emissions presented in **Table 25** include the estimated annual emissions from the IFO power generation facilities for completeness, and further details of the estimated emissions from this source are presented in **Section 7.3.2**.

Table 25 Estimated Particulate Emission Rates - Operation

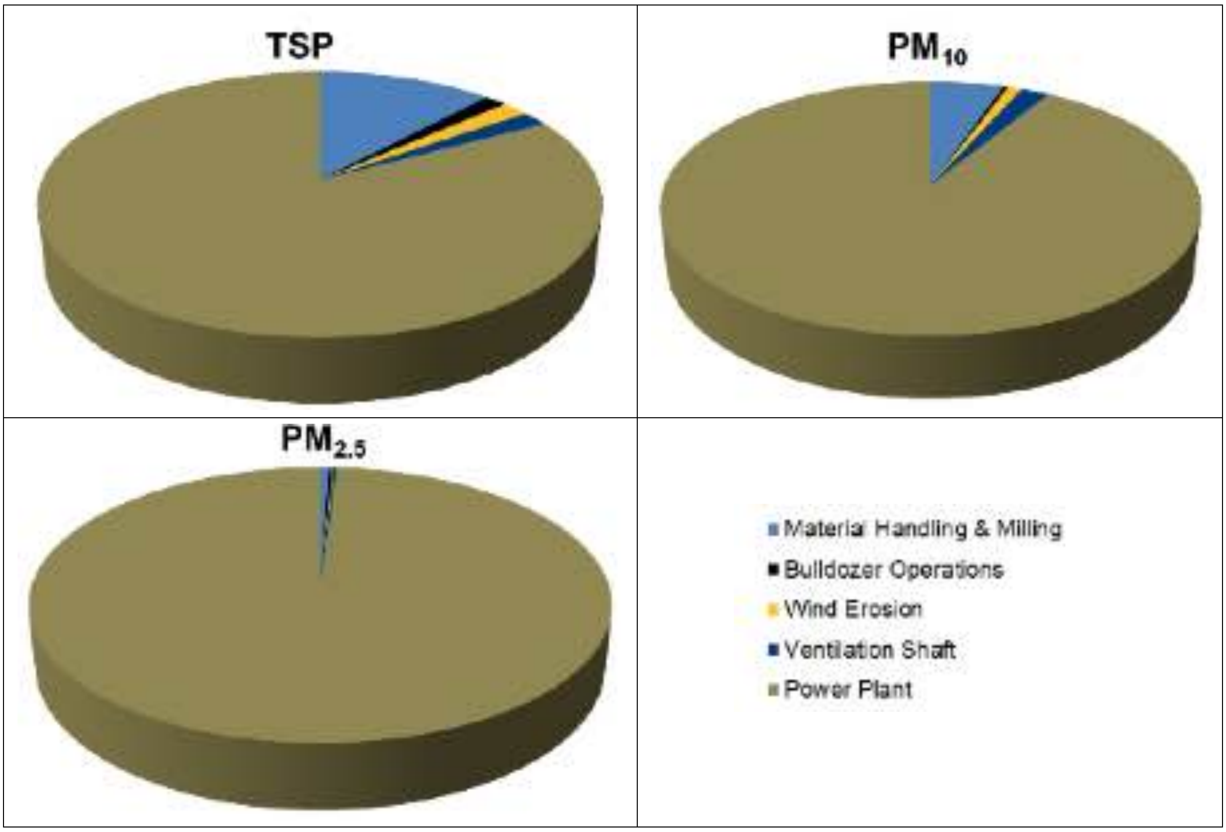
Activity	Estimated Emissions (kg/annum)		
	TSP	PM_{10}	$PM_{2.5}$
Plant Terrace			
Unloading ore from conveyor at coarse ore stockpile	58,940	23,576	2,358
Bulldozer working on stockpiles	7,366	1,388	773
Wind erosion of start-up ore stockpile	1,472	736	69
Wind erosion of coarse ore stockpile	2,150	1,075	101
Wind erosion of process plant terraces	4,871	2,435	228
Ventilation Shaft			
Ventilation system exhaust (dust particulates)	5,960	5,960	596
Portal Terraces			
Concrete batching plant	8	8	1
Wind erosion of portal terraces	617	308	29
Ventilation system exhaust (dust particulates)	2,980	2,980	298
Power Generation Facilities			
Operation of power generation facilities	408,707	408,707	408,707
Total	**493,070**	**447,173**	**408,707**

The estimated particulate emissions for the operational scenario have been classified into the following groups to present the contribution from each type of activity:

- material handling (includes emissions from milling, crushing, loading and unloading);
- bulldozer operation;
- wind erosion;
- ventilation; and
- power generation facilities.

The contributions of each source group to the total estimated emissions are presented graphically in **Figure 17**. **Figure 17** shows that the IFO power generation facilities are anticipated to be the major source of TSP, PM_{10} and $PM_{2.5}$ emissions during the operational phase of the Project.

Figure 17 Particulate Emissions Source Contribution – Operational Phase



7.3 Estimation of Combustion Emissions

7.3.1 Construction Phase Diesel Generators

Emissions from the on-site diesel generators have been estimated based on specifications for a Cummins C1250 D2R PowerBox 20X unit and emission factors published for large stationary diesel combustion engines in the National Pollutant Inventory (NPI) *Estimation Technique Manual for Combustion Engines* (DSEWPC, 2008). These emission factors are based on the US EPA's AP-42 Emission Factor Handbook, and in the absence of manufacturer specifications for maximum pollutant emission rates, they will provide a conservative estimate of potential pollutant emissions from this source.

The manufacturer data and emission factors used in the emission estimates are shown in **Table 26**.

Table 26 Estimation of Emissions from Diesel Generators

Parameter	Construction	Basis/Source
Size	1.25 MW	WGJV
Number of generators	20	
Fuel consumption	625 L/hr	Cummins C1250 D2R PowerBox 20X Specifications
Fuel consumption	520 kg/hr	Calculated from L/hr based on density of diesel of 0.832 kg/L
Exhaust temperature	520°C	Cummins C1250 D2R PowerBox 20X Specifications
Exhaust gas flow	3.73 m^3/s	Cummins C1250 D2R PowerBox 20X Specifications
Stack height	7.5 m	Cummins C1250 D2R PowerBox 20X Specifications
Stack diameter	0.35 m	Estimated from Cummins C1250 D2R PowerBox 20X Specifications
Exit velocity	39 m/s	Calculated based on exhaust flow and stack diameter
Sulphur content of fuel	500 ppm	Sulphur content of diesel in PNG is reported as being between 50-500ppm (ACFA, 2013)
NO_x emission rate	18.75 kg/hr	Emission Factor of 0.015 kg/kWh *
PM emission rate	0.54 kg/hr	Emission Factor of 0.00043 kg/kWh *
SO_2 emission rate	0.52 kg/hr	Calculated based on fuel sulphur content and consumption rate
CO emission rate	4.125 kg/hr	Emission Factor of 0.0033 kg/kWh *

* Table 42, (DSEWPC, 2008)

7.3.2 Operational Phase IFO Power Generation Facilities

Stack and emission data for the IFO-fired power generators to be installed to provide electricity for the operational phase of the Project were provided by WGJV and are summarised in **Table 27**.

Table 27 Estimation of Emissions from IFO Power Generators

Parameter	Operation	Basis/Source
Size	9.8 MW	WGJV
Number of generators	12	WGJV
Exhaust temperature	300°C	WGJV
Stack height	54 m	WGJV
Stack diameter	1.1 m	WGJV
Exit velocity	33 m/s	WGJV
Sulphur content of IFO	2%	WGJV
NO_x emission rate	124.3 kg/hr	WGJV
PM emission rate	3.9 kg/hr	WGJV
SO_2 emission rate	82.2 kg/hr	WGJV (based on 2% sulphur fuel)
CO emission rate	5.3 kg/hr	WGJV

7.4 Dispersion Modelling Results

Predicted concentrations of relevant pollutants at the nearest sensitive receptors and pollutant contour plots for the Mine Area construction and operation are presented and discussed below. As outlined in **Section 7.1**, the following scenarios have been investigated in this study in relation to fugitive dust emissions:

- Scenario 1 – Construction; and
- Scenario 2 – Ore extraction at 16.84 Mtpa (maximum throughput).

The modelling of particulate emissions included the fugitive emissions estimates described in **Section 7.2.3** as well as the emissions of particulate matter estimated for the diesel generators and IFO power generation facilities as outlined in **Section 7.3**.

7.4.1 $PM_{2.5}$ Concentrations

The incremental (Project only) and cumulative (including background) $PM_{2.5}$ concentrations predicted at the surrounding sensitive receptors for each scenario are presented in **Table 28**. The estimated background $PM_{2.5}$ concentrations of 14.8 µg/m³ (24-hour average) and 5.9 µg/m³ (annual average) (refer to **Section 6.1.3**) were used to calculate the cumulative impacts at each sensitive receptor.

Contour plots presenting the cumulative $PM_{2.5}$ concentrations predicted across the modelling domain are included in **Appendix C**.

As shown in **Table 28**, the maximum 24-hour and annual average cumulative $PM_{2.5}$ concentrations predicted for both the construction and operational scenarios at surrounding sensitive receptors are below the relevant ambient air quality criteria. Papas is predicted to experience the highest concentrations during the construction phase, with cumulative 24-hour and annual average $PM_{2.5}$ concentrations of 16.7 µg/m³ (66% of the criterion) and 6.6 µg/m³ (83% of the criterion) predicted respectively. Ziriruk is predicted to experience the highest concentrations during the operational phase, with cumulative 24-hour and annual average $PM_{2.5}$ concentrations of 21.3 µg/m³ (85% of the criterion) and 8.8 µg/m³ (88% of the criterion) predicted respectively.

Considering that the estimated $PM_{2.5}$ background concentrations used in the cumulative impact assessment (refer to **Section 6.1.3**) are likely to be a conservative over-estimate of actual background $PM_{2.5}$ levels due to the adopted $PM_{2.5}/PM_{10}$ ratio of 0.5 (typical for urban areas with a significant amount of fine particle emissions from motor vehicles), it can be concluded from the modelling results that no adverse air quality impacts would be expected for the identified sensitive receptors as a result of $PM_{2.5}$ emissions from the Project.

Table 28 PM2.5 Concentrations Predicted at Surrounding Receptors

ID	Description	Incremental PM2.5 Predictions (µg/m³)				Cumulative PM2.5 Predictions (µg/m³) [1]			
		24-Hour Averages		Annual Averages		24-Hour Averages		Annual Averages	
		Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation
1	Bavaga	0.6	1.2	0.3	0.4	15.4	16.0	6.2	6.3
2	Kapunung	0.3	0.7	0.1	0.2	15.1	15.5	6.0	6.1
3	Gingen	0.2	0.7	<0.1	0.2	15.0	15.5	<6.0	6.1
4	Wori	0.4	1.1	0.1	0.4	15.2	15.9	6.0	6.3
5	Wongkins	0.3	1.0	<0.1	0.3	15.1	15.8	<6.0	6.2
6	Uruf	0.2	0.4	<0.1	0.1	15.0	15.2	<6.0	6.0
7	Madzim	0.4	1.0	0.1	0.3	15.2	15.8	6.0	6.2
8	Wampar	0.1	0.4	<0.1	0.1	14.9	15.2	<6.0	6.0
10	Bencheng	0.1	0.5	<0.1	0.2	14.9	15.3	<6.0	6.1
11	Maralina	0.3	0.7	<0.1	0.2	15.1	15.5	<6.0	6.1
12	Ziriruk	0.8	6.5	0.5	2.9	15.6	21.3	6.4	8.8
13	Mafanazo	0.2	0.7	<0.1	0.1	15.0	15.5	<6.0	6.0
15	Papas	1.9	1.9	0.7	0.8	16.7	16.7	6.6	6.7
16	Pokwana	<0.1	0.3	<0.1	<0.1	<14.9	15.1	<6.0	<6.0
17	Zilani	0.1	0.3	<0.1	<0.1	14.9	15.1	<6.0	<6.0
18	Hekeng	0.6	1.3	0.3	0.2	15.4	16.1	6.2	6.1
20	Dengea	0.1	0.4	<0.1	0.1	14.9	15.2	<6.0	6.0
21	Zimake	<0.1	0.3	<0.1	0.1	<14.9	15.1	<6.0	6.0
22	Pokwaluma	0.1	0.6	<0.1	<0.1	14.9	15.4	<6.0	<6.0
23	Venembele	0.5	0.8	0.1	0.2	15.3	15.6	6.0	6.1
24	Pekumbe	0.2	0.6	<0.1	0.2	15.0	15.4	<6.0	6.1
25	Fly Camp	0.7	3.1	0.2	0.5	15.5	17.9	6.1	6.4
26	Nambonga	0.5	0.7	0.2	0.2	15.3	15.5	6.1	6.1
29	Chaunon	0.8	1.4	0.1	0.2	15.6	16.2	6.0	6.1
39	Zindanga	0.1	0.5	<0.1	0.1	14.9	15.3	<6.0	6.0
Criteria						**25**	**25**	**10**	**10**

[1] Based on estimated background PM2.5 concentrations of 14.8 µg/m³ (24-hour average) and 5.9 µg/m³ (annual average).

7.4.2 PM_{10} Concentrations

The incremental (Project only) and cumulative (including background) PM_{10} concentrations predicted at the surrounding sensitive receptors for the construction and operational scenarios are presented in **Table 29**. The estimated background PM_{10} concentrations of 29.5 µg/m³ (24-hour average) and 11.8 µg/m³ (annual average) (refer to **Section 6.1.3**) were used to calculate the cumulative impact at each sensitive receptor.

Contour plots presenting the cumulative 24-hour and annual average PM_{10} concentrations predicted across the modelling domain are included in **Appendix C**.

The results presented in **Table 29** show that the maximum 24-hour and annual average cumulative PM_{10} concentrations predicted at surrounding sensitive receptors are well below the relevant ambient air quality criteria for both scenarios. Chaunon is predicted to experience the highest 24-hour average PM_{10} concentrations during the construction phase, with a maximum cumulative 24-hour concentration of 36.2 µg/m³ (72% of the criterion) predicted. Papas is predicted to experience the highest annual average PM_{10} concentration during the construction phase, at 15.1 µg/m³ (75% of the criterion).

During the operational phase, Ziriruk is predicted to experience the highest PM_{10} concentrations with cumulative 24-hour and annual average PM_{10} concentrations of 36.1 µg/m³ and 14.2 µg/m³ predicted respectively (equivalent to 72% and 71% of the relevant criteria respectively).

7.4.3 TSP Concentrations

The incremental (Project only) and cumulative (including background) TSP concentrations predicted at the surrounding sensitive receptors for the construction and operational scenarios are presented in **Table 30**. The estimated background TSP concentrations of 41.3 µg/m³ (24-hour average) and 29.5 µg/m³ (annual average) (refer to **Section 6.1.3**) were used to calculate the cumulative impact at each sensitive receptor.

Contour plots presenting the cumulative 24-hour and annual average TSP concentrations predicted across the modelling domain are presented in **Appendix C**.

Results presented in **Table 30** show that the maximum predicted 24-hour and annual average TSP concentrations are well below the relevant ambient air quality criteria at all surrounding sensitive receptor locations. Papas is predicted to experience the highest concentrations during the construction phase, with cumulative 24-hour and annual average TSP concentrations of 55.1 µg/m³ and 38.3 µg/m³ predicted respectively (equivalent to 37% and 51% of the relevant criteria respectively). Ziriruk is predicted to experience the highest concentrations during the operational phase with cumulative 24-hour and annual average TSP concentrations of 48.0 µg/m³ and 32.7 µg/m³ predicted respectively (equivalent to 32% and 44% of the relevant criteria respectively).

Table 29 PM_{10} Concentrations Predicted at Surrounding Receptors

ID	Description	Incremental PM_{10} Predictions (µg/m³)				Cumulative PM_{10} Predictions (µg/m³) [1]			
		24-Hour Averages		Annual Averages		24-Hour Averages		Annual Averages	
		Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation
1	Bavaga	2.4	1.3	1.2	0.4	31.9	30.8	13.0	12.2
2	Kapunung	0.8	0.8	0.3	0.3	30.3	30.3	12.1	12.1
3	Gingen	0.5	0.7	0.3	0.2	30.0	30.2	12.1	12.0
4	Wori	0.9	1.3	0.3	0.4	30.4	30.8	12.1	12.2
5	Wongkins	0.6	1.1	0.2	0.3	30.1	30.6	12.0	12.1
6	Uruf	0.4	0.5	0.1	0.2	29.9	30.0	11.9	12.0
7	Madzim	0.6	1.1	0.2	0.3	30.1	30.6	12.0	12.1
8	Wampar	0.2	0.5	<0.1	0.1	29.7	30.0	<11.9	11.9
10	Bencheng	0.2	0.5	<0.1	0.2	29.7	30.0	<11.9	12.0
11	Maralina	0.4	0.7	0.1	0.3	29.9	30.2	11.9	12.1
12	Ziriruk	2.0	6.6	1.2	3.1	31.5	36.1	13.0	14.9
13	Mafanazo	1.1	0.7	0.2	0.1	30.6	30.2	12.0	11.9
15	Papas	5.4	3.2	3.3	1.4	34.9	32.7	15.1	13.2
16	Pokwana	0.1	0.3	<0.1	<0.1	29.6	29.8	<11.9	<11.9
17	Zilani	0.1	0.3	<0.1	<0.1	29.6	29.8	<11.9	<11.9
18	Hekeng	2.1	1.4	0.9	0.2	31.6	30.9	12.7	12.0
20	Dengea	0.2	0.4	0.1	0.1	29.7	29.9	11.9	11.9
21	Zimake	0.2	0.3	<0.1	0.1	29.7	29.8	<11.9	11.9
22	Pokwaluma	0.2	0.6	<0.1	<0.1	29.7	30.1	<11.9	<11.9
23	Venembele	0.9	0.8	0.3	0.2	30.4	30.3	12.1	12.0
24	Pekumbe	0.4	0.7	0.2	0.3	29.9	30.2	12.0	12.1
25	Fly Camp	0.9	3.1	0.4	0.5	30.4	32.6	12.2	12.3
26	Nambonga	1.0	0.8	0.5	0.3	30.5	30.3	12.3	12.1
29	Chaunon	6.7	1.4	0.6	0.3	36.2	30.9	12.4	12.1
39	Zindanga	0.4	0.5	0.2	0.2	29.9	30.0	12.0	12.0
Criteria						**50**	**50**	**20**	**20**

[1] Based on estimated background PM_{10} concentrations of 29.5 µg/m³ (24-hour average) and 11.8 µg/m³ (annual average).

Table 30 TSP Concentrations Predicted at Surrounding Sensitive Receptors

ID	Description	Incremental TSP Predictions (µg/m³)				Cumulative TSP Predictions (µg/m³) [1]			
		24-Hour Averages		Annual Averages		24-Hour Averages		Annual Averages	
		Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation
1	Bavaga	7.5	1.3	3.5	0.4	48.8	42.6	33.0	29.9
2	Kapunung	1.4	0.9	0.6	0.3	42.7	42.2	30.1	29.8
3	Gingen	1.3	0.7	0.7	0.2	42.6	42.0	30.2	29.7
4	Wori	2.0	1.3	0.5	0.4	43.3	42.6	30.0	29.9
5	Wongkins	1.2	1.2	0.4	0.3	42.5	42.5	29.9	29.8
6	Uruf	0.5	0.5	0.2	0.2	41.8	41.8	29.7	29.7
7	Madzim	0.8	1.1	0.3	0.3	42.1	42.4	29.8	29.8
8	Wampar	0.3	0.5	<0.1	0.1	41.6	41.8	<29.6	29.6
10	Bencheng	0.3	0.5	0.1	0.2	41.6	41.8	29.6	29.7
11	Maralina	0.6	0.8	0.2	0.3	41.9	42.1	29.7	29.8
12	Ziriruk	4.4	6.7	2.3	3.2	45.7	48.0	31.8	32.7
13	Mafanazo	1.7	0.8	0.3	0.2	43.0	42.1	29.8	29.7
15	Papas	13.8	4.7	8.8	2.1	55.1	46.0	38.3	31.6
16	Pokwana	0.1	0.3	<0.1	<0.1	41.4	41.6	<29.6	<29.6
17	Zilani	0.1	0.3	<0.1	<0.1	41.4	41.6	<29.6	<29.6
18	Hekeng	4.6	1.4	2.1	0.2	45.9	42.7	31.6	29.7
20	Dengea	0.3	0.4	0.2	0.1	41.6	41.7	29.7	29.6
21	Zimake	0.3	0.3	0.1	0.1	41.6	41.6	29.6	29.6
22	Pokwaluma	0.2	0.6	<0.1	<0.1	41.5	41.9	<29.6	<29.6
23	Venembele	1.2	0.8	0.6	0.2	42.5	42.1	30.1	29.7
24	Pekumbe	0.5	0.7	0.2	0.3	41.8	42.0	29.7	29.8
25	Fly Camp	1.2	3.1	0.6	0.6	42.5	44.4	30.1	30.1
26	Nambonga	1.9	0.8	0.8	0.3	43.2	42.1	30.3	29.8
29	Chaunon	9.2	1.5	1.0	0.3	50.5	42.8	30.	29.8
39	Zindanga	0.7	0.5	0.4	0.2	42.0	41.8	29.9	29.7
Criteria						**150**	**150**	**75**	**75**

[1] Based on estimated background TSP concentrations of 41.3 µg/m³ (24-hour average) and 29.5 µg/m³ (annual average).

7.4.4 Dust Deposition Rates

The incremental (Project only) annual average dust deposition rates predicted at the surrounding sensitive receptors for the construction and operational scenarios are presented in **Table 31** and compared against the incremental guideline of 2 g/m^2/month.

Contour plots presenting the annual average incremental dust deposition rates predicted across the modelling domain for each scenario are presented in **Appendix C**. The contour plots do not include background and show the incremental impacts from the Project only.

Table 31 shows that the annual average dust deposition rates predicted at surrounding sensitive receptors for both scenarios are insignificant and are well below the amenity-based ambient air quality criterion. The predicted incremental impacts are unlikely to give rise to a measurable increase above annual average background levels which, based on the monitoring data available, range from around 1.5 – 2.9 g/m^2/month. Cumulative impacts (project plus background) would therefore also remain below the cumulative guideline of 4 g/m^2/month.

Table 31 Dust Deposition Rates Predicted at Surrounding Sensitive Receptors

ID	Description	Incremental Annual Average Dust Deposition Rate (g/m^2/month)	
		Construction	Operation
1	Bavaga	<0.1	<0.1
2	Kapunung	<0.1	<0.1
3	Gingen	<0.1	<0.1
4	Wori	<0.1	<0.1
5	Wongkins	<0.1	<0.1
6	Uruf	<0.1	<0.1
7	Madzim	<0.1	<0.1
8	Wampar	<0.1	<0.1
10	Bencheng	<0.1	<0.1
11	Maralina	<0.1	<0.1
12	Ziriruk	<0.1	<0.1
13	Mafanazo	<0.1	<0.1
15	Papas	0.2	<0.1
16	Pokwana	<0.1	<0.1
17	Zilani	<0.1	<0.1
18	Hekeng	<0.1	<0.1
20	Dengea	<0.1	<0.1
21	Zimake	<0.1	<0.1
22	Pokwaluma	<0.1	<0.1
23	Venembele	<0.1	<0.1
24	Pekumbe	<0.1	<0.1
25	Fly Camp	<0.1	<0.1
26	Nambonga	<0.1	<0.1
29	Chaunon	<0.1	<0.1
39	Zindanga	<0.1	<0.1
40	Wafi	<0.1	<0.1
Criterion (incremental impacts)		**2.0**	**2.0**

7.4.5 NO_2, SO_2 and CO Concentrations

Air quality impacts at surrounding sensitive receptors associated with emissions of products of combustion (NO_2, SO_2 and CO) from on-site vehicles and other mobile plant and equipment will be negligible as they will be emitted over a large area and therefore well dispersed before they reach sensitive receptor locations (refer **Section 3**). Operation of the diesel-fired generators at the Mine Area during construction, and the IFO power generation facilities during operation, however, have the potential to contribute to elevated pollutant (NO_2, SO_2 and CO) levels in the surrounding area as they will be emitted from fixed point sources and these concentrated plumes may impinge on the surrounding terrain.

Construction Scenario:

The predicted incremental (Project only) downwind concentrations of NO_2, SO_2 and CO emitted from the diesel-fired power generators are presented in **Table 32** and compared against the relevant assessment criteria for each averaging period. Contour plots are presented in **Appendix C** for each pollutant modelled.

Table 32 shows that the ground level NO_2, SO_2 and CO concentrations predicted at the surrounding sensitive receptors during the construction phase are well below the relevant ambient air quality criteria. As background levels of these pollutants would be expected to be negligible, no exceedances of the criteria are therefore anticipated to occur as a result of the construction generator stack emissions.

Operational Scenario:

The maximum incremental (Project only) NO_2, SO_2 and CO concentrations predicted by the modelling as a result of emissions from the IFO-fired power generation facilities are presented in **Table 33** and compared against the relevant assessment criteria for each averaging period. Contour plots are presented in **Appendix C** for each pollutant modelled.

Table 33 shows that:

- The ground level CO concentrations predicted at surrounding sensitive receptors for the operational phase are below the relevant ambient air quality criteria.
- The predicted 1-hour and annual average NO_2 concentrations comply with the relevant ambient air quality guideline at all receptors. It is noted that the 1-hour average NO_2 concentration predicted at Ziriruk (199.8 µg/m^3) is fractionally below the WHO criterion of 200 µg/m^3, while the predicted annual average NO_2 concentration of 39 µg/m^3 is also approaching the WHO criterion of 40 µg/m^3.
- The predicted 1-hour average SO_2 concentrations (based on the 99^{th} percentile of the daily maximum 1-hour SO_2 predictions) comply with the relevant ambient air quality guideline at all receptors with the exception of Ziriruk and Fly Camp. The predicted 1-hour average SO_2 concentration at Ziriruk is 849 µg/m^3, which is approximately 2.4 times the Project criterion of 350 µg/m^3. The concentration predicted at Fly Camp of 605 µg/m^3 is approximately 1.7 times the criterion. Implications of these exceedances for human health are considered in the Health Risk Assessment (Coffey, 2018) which is included in this EIS as Appendix W.
- It is noted that the SO_2 modelling results are based on predictions using only one year of site-representative meteorological conditions while the Project criterion is based on a three year average. A three year average of the annual 99^{th} percentile 1-hour average predictions would tend to flatten out peaks from unusual weather patterns or climate variations from year to year. The meteorological year used was 2016, which was the most recent year of data available at the time of performing the modelling. As there is limited historical meteorological data available for the region, it is not possible to assess whether 2016 would be considered a ‘worst case’ year in terms of dispersion characteristics.

- The sensitive receptor predicted to be exposed to the third highest 1-hour average SO_2 concentration is Hekeng, with a concentration of 226 µg/m³, while Papas is next at 218 µg/m³. These results are well below the criterion of 350 µg/m³ therefore any inter-annual variation in meteorological conditions would not be expected to result in exceedances at these receptors for other years, or over a three year averaging period.

The above results indicate that there is potential for adverse air quality impacts at Ziriruk and Fly Camp as a result of SO_2 emissions from the IFO power generation facilities during the operational phase, once it is operating at full load. During the detailed design phase, additional management measures will be reviewed to identify the best approach to mitigate these impacts, which may include the use of scrubbers to remove SO_2 from the exhaust gas flow. The WGJV is committed to achieving compliance with the adopted criterion.

The anticipated energy utilisation for the Project is shown in **Figure 18**. This plot shows that the power generation facilities will not operate above 50% of the proposed maximum load (as used in the modelling) for the first three years of the Project. Ambient monitoring at Ziriruk and Fly Camp could therefore also be performed during the early stages of the operational phase (i.e. when the power demand is lower and prior to all 12 IFO generators coming on-line) to verify the results of the modelling. Additional management measures (such as scrubbers etc.) may then be implemented if the monitoring confirms that concentrations above the Project criteria could be expected at these locations once the power generation facilities are operating at full load.

Figure 18 Projected Energy Utilisation

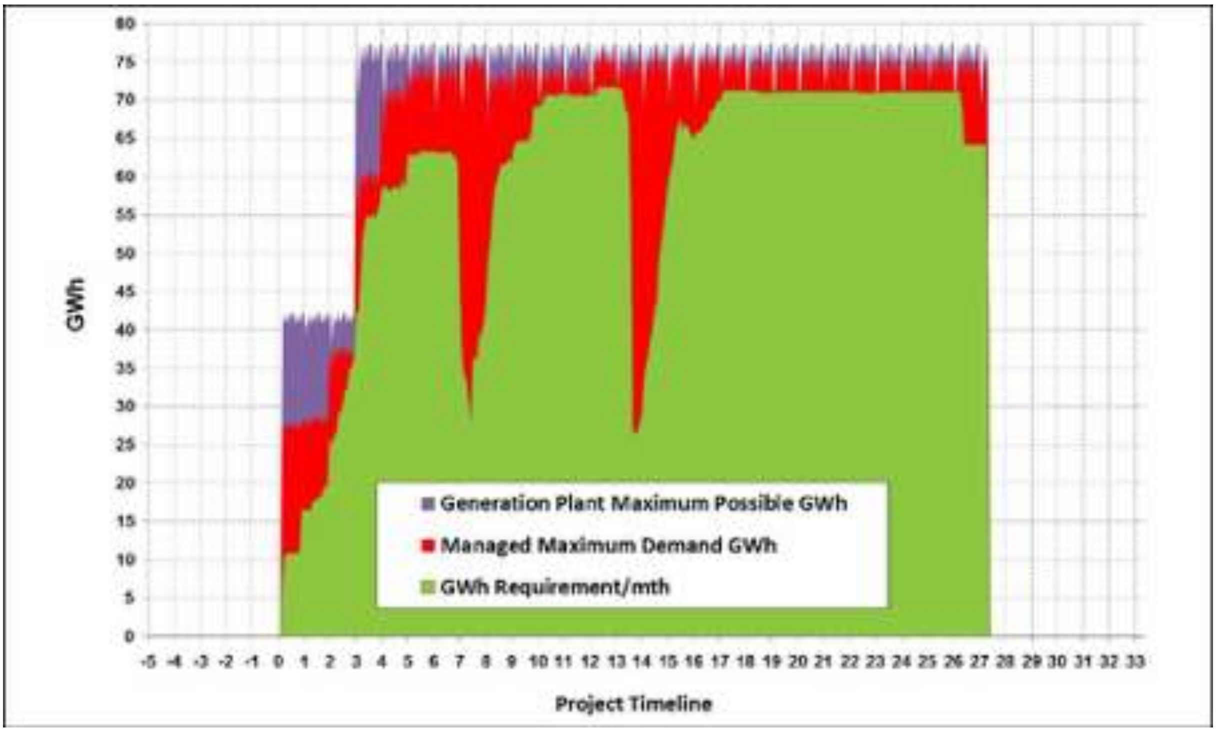


Table 32 Incremental NO_2, SO_2 and CO Concentrations Predicted at Sensitive Receptors – Construction

ID	Description	NO_2 Concentrations (µg/m²)		SO_2 Concentrations (µg/m²)	CO Concentrations (µg/m²)	
		1-Hour Average [1]	Annual Average	1-Hour Average [2]	1-Hour Average [1]	24-Hour Average
1	Bavaga	46.8	5.9	1.4	10.3	2.6
2	Kapunung	34.9	3.7	1.0	7.7	1.9
3	Gingen	17.7	2.2	0.6	3.9	1.1
4	Wori	50.8	3.2	1.5	11.2	2.3
5	Wongkins	35.3	2.7	1.0	7.8	1.9
6	Uruf	18.1	1.6	0.5	4.0	1.1
7	Madzim	39.7	3.1	1.1	8.8	2.5
8	Wampar	11.1	1.0	0.3	2.5	0.8
10	Bencheng	11.9	1.1	0.3	2.6	0.8
11	Maralina	24.1	2.2	0.7	5.3	1.8
12	Ziriruk	92.9	15.5	3.1	23.2	5.9
13	Mafanazo	14.5	1.7	0.4	3.2	0.8
15	Papas	98.6	12.4	4.6	35.8	10.8
16	Pokwana	9.6	0.5	0.3	2.1	0.7
17	Zilani	10.5	0.6	0.3	2.3	0.7
18	Hekeng	88.3	3.8	3.0	19.5	2.9
20	Dengea	12.5	1.6	0.4	2.8	0.8
21	Zimake	8.7	1.2	0.2	1.9	0.6
22	Pokwaluma	21.6	0.9	0.7	4.8	0.9
23	Venembele	82.2	3.7	3.1	18.1	3.1
24	Pekumbe	29.1	2.8	0.8	6.4	1.5
25	Fly Camp	83.9	7.7	2.4	18.5	5.1
26	Nambonga	78.6	4.6	2.3	17.4	2.7
29	Chaunon	27.5	3.0	0.8	6.1	1.5
39	Zindanga	13.3	1.6	0.4	2.9	0.8
Criteria		**200**	**40**	**350**	**30,000**	**10,000**

[1] The maximum 1-hour average NO_2 and CO concentrations presented are based on the 99.9^{th} percentile model predictions in accordance with standard modelling practice in Australia to remove outlier results from the modelling.

[2] The maximum 1-hour average SO_2 concentrations presented are based on the 99^{th} percentile of the daily maximum 1-hour average model predictions in accordance with the Project criterion derived by the HRA (Coffey, 2018).

Table 33 Incremental NO_2, SO_2 and CO Concentrations Predicted at Sensitive Receptors - Operation

ID	Description	NO_2 Concentrations (µg/m²)		SO_2 Concentrations (µg/m²)	CO Concentrations (µg/m²)	
		1-Hour Average [1]	Annual Average	1-Hour Average [2]	1-Hour Average [1]	24-Hour Average
1	Bavaga	106	11.6	188	10.4	1.7
2	Kapunung	93	6.7	73	4.4	1.0
3	Gingen	77	5.6	56	3.3	1.0
4	Wori	93	11.1	88	4.5	1.5
5	Wongkins	96	8.0	99	5.8	1.3
6	Uruf	58	4.1	45	2.5	0.6
7	Madzim	99	8.4	120	7.0	1.4
8	Wampar	34	3.8	25	1.5	0.6
10	Bencheng	48	4.7	33	2.1	0.7
11	Maralina	93	7.2	75	4.6	1.0
12	Ziriruk	200	39.2	**849**	51.0	8.9
13	Mafanazo	77	4.0	58	3.3	0.9
15	Papas	111	19.1	218	12.4	2.5
16	Pokwana	38	1.8	28	1.6	0.4
17	Zilani	48	2.0	37	2.1	0.4
18	Hekeng	113	6.1	226	13.1	1.8
20	Dengea	53	4.2	43	2.3	0.6
21	Zimake	44	3.8	35	1.9	0.4
22	Pokwaluma	91	2.6	62	4.0	0.8
23	Venembele	100	5.6	148	7.7	1.0
24	Pekumbe	95	6.9	95	5.6	0.8
25	Fly Camp	157	14.0	**605**	32.3	4.2
26	Nambonga	95	6.0	100	5.5	1.0
29	Chaunon	97	7.1	97	6.2	1.8
39	Zindanga	63	4.6	49	2.7	0.7
Criteria		**200**	**40**	**350**	**30,000**	**10,000**

[1] The maximum 1-hour average NO_2 and CO concentrations presented are based on the 99.9th percentile model predictions in accordance with standard modelling practice in Australia to remove outlier results from the modelling.

[2] The maximum 1-hour average SO_2 concentrations presented are based on the 99th percentile of the daily maximum 1-hour average model predictions in accordance with the Project criterion derived by the HRA (Coffey, 2018).

7.5 Other Emissions

Other sources of air emissions associated with the construction and operational phases of the Project that were not included in the modelling studies discussed in **Section 7.4** include:

- Emissions of VOCs from the storage and transfer of diesel and other fuels;
- Products of combustion from the waste incinerator at the Watut industrial area;
- Emissions of odour from sewage treatment facilities and from the storage, handling and disposal of municipal waste from the Fere Accommodation Facility;
- Emissions of odour from processing ore at the Watut Process Plant; and
- Emissions of dust and fumes from workshops (e.g. from sanding, welding and the use of solvents for cleaning equipment parts).

The potential for local air quality impacts due to the first four activities listed above is discussed below. Emissions of dust and fumes from workshops will be minor in nature and would not impact on air quality at sensitive receptor locations, and have therefore not been discussed further.

7.5.1 Fuel Storage

Emissions of VOCs from the storage and handling of diesel would occur as result of breathing losses (due to expansion and contraction of the gases in the head space of the storage tanks due to changes in ambient temperature) and working losses (due to displacement of vapour-laden gases from the head space of the storage tank as it is filled). There is also the potential for VOC emissions to occur as result of evaporation of minor spills during tank/vehicle filling activities.

These emissions would be minor in nature, will disperse rapidly, and would not be expected to have any measureable impacts on ambient concentrations beyond a few hundred metres of the fuel storage areas. Published recommended buffer distances for the separation of sensitive land uses from fuel storage areas are as follows (EPAV, 1990):

Storage of petroleum products and crude oil in tanks exceeding 2,000 t capacity:

a. *with fixed roofs 300 m*
b. *with floating roofs 100 m*

The identified sensitive receptors would be located well beyond 300 m of the fuel storage areas (i.e., 1,000 m+) and therefore it may be reasonably concluded that no adverse air quality impacts would be expected as a result of these activities.

7.5.2 Solid Waste Management

Recommended buffer distances to prevent air quality and odour nuisance impacts at sensitive locations due to emissions from the solid waste management activities are as follows (EPAV, 1990):

Composting – 500 m

Sanitary and garbage disposal services:

(a) *Recycling and composting centres – 200 m*
(b) *Transfer stations – 300 m*
(c) *Deport for refuse collection vehicles – 100 m*

Waste incineration:

(a) *For wood waste – 300 m*

(b) *For plastic or rubber waste – 500 m*

The identified sensitive receptors would be located beyond 500 m of the incinerator and other waste management areas and therefore it may be reasonably concluded that no adverse air quality impacts would be expected as a result of these activities.

7.5.3 Sewage Treatment

Recommended buffer distances to prevent odour nuisance impacts at sensitive locations due to emissions from sewage treatment plants (EPAV, 1990) are as follows:

Sewage Works (mechanical/biological wastewater plants):

(a) *Less than 5,000 people – 200 m*

(b) *Less than 20,000 people – 300 m*

No sewage treatment plants for the Project will be located within 300 m of any of the identified sensitive receptors, hence it may be reasonably concluded that no off-site odour nuisance impacts would occur.

7.5.4 Processing Plant

In the absence of specific guidelines for a copper flotation circuit, recommended buffer distances to prevent odour nuisance impacts at sensitive locations due to emissions from non-ferrous metal (i.e., a metal that does not contain iron in appreciable amounts) production were reviewed. The distances are as follows (EPAV, 1990):

Non-ferrous metal production (processing, smelting or melting non-ferrous metals or ores using furnaces, ovens or electrolysis):

(a) *100 to 2,000 tonnes per year – 250 m*

(b) *Greater than 2,000 tonnes per year – 500 m*

The Watut Process Plant will be located further than 500 m from any of the identified sensitive receptors, hence it may be reasonably concluded that no off-site odour nuisance impacts would occur.

7.6 Mine Area Closure Impacts

Potential sources of air emissions associated with the closure phase include fugitive particulate matter from earthworks, demolition activities and products of combustion (NOx, CO, CO_2, SO_2, VOCs and particulate) from on-site diesel-powered equipment such as trucks, excavators, bulldozers etc. Details of the scale and nature of these works are unknown at this stage. Given the five year construction and 27 year operation lifespan of the Project, there is also potential for new settlements to have been established in the vicinity of the Mine Area at the time of closure. Closure impacts have therefore not been assessed as part of this assessment, however they would be of similar scale to impacts predicted during construction.

8 AIR QUALITY IMPACT ASSESSMENT – INFRASTRUCTURE CORRIDOR

8.1 Road and Pipeline Construction Impacts

Construction of the access roads and the concentrate, tailings and fuel pipelines will involve:

- Vegetation clearing;
- Bulk earthworks (excavation and backfilling of pipeline trench);
- Welding and other pipeline construction activities; and
- Construction of access roads capable of accommodating both heavy and light vehicles.

In addition, there will be emissions of NO_X, CO, minor quantities of SO_2 and VOCs from internal combustion engines (i.e. diesel powered earthmoving equipment). Only dust emissions have been identified as requiring assessment of potential off-site impacts.

The potential risks associated with dust emissions from construction of the access roads and pipelines have been assessed qualitatively using the IAQM method, as outlined in **Section 6.2.1**. The findings of this assessment are presented below.

Step 1 – Screening Based on Separation Distance

The closest villages to the Infrastructure Corridor (located within 0.5 km) and their approximate separation distances are:

- Papas – 70 m
- Ziriruk – 300 m
- Markham Farm – 200 m
- Durung Farm – <20 m
- Atzera – 400 m

In addition to the above, at the eastern end of the pipeline corridors there are residences in Lae that are potentially as close as 20 m from the Infrastructure Corridor.

Atzera is located greater than 350 m from the Infrastructure Corridor, which is the distance from the site boundary recommended for screening out projects requiring assessment in the IAQM methods (IAQM, 2014). A qualitative assessment of potential risks has been performed for the remote villages listed above that are located within 350 m of the pipeline, as well as the residences in the northern areas of Lae.

Step 2a – Assessment of Scale and Nature of the Works

The magnitude of dust emissions from earthworks activities associated with the access road and pipelines' construction have been classified as outlined below:

- For the section of the roads and pipelines that will be constructed in more mountainous areas, the magnitude of dust emissions from earthworks activities has been classified as 'medium' due to the:
  - Total active work site area expected to range between 2,500 m^2 to 10,000 m^2;
  - Five to ten heavy earth moving vehicles expected to be active at any one time;
  - Any bunds/stockpiles expected to be less than 4 m in height; and
  - Soil type (sand, silt and clay) likely to range along the pipeline corridor.

- Once the works move onto the floodplain, and in the urban areas of Lae, the amount of earthworks required is expected to decrease and the magnitude of dust emissions from earthworks activities in these areas has been classified as 'small', indicative of:
  - Total site area less than 2,500 m^2;
  - Less than five heavy earth moving vehicles active at any one time;
  - Formation of bunds less than 4 m in height;
  - Total material moved less than 20,000 t.

Step 2b – Assessment of Sensitivity of the Area

Based on the criteria listed in **Table 15**, the sensitivity of identified receptors in the vicinity of the Infrastructure Corridor (i.e. villages) is concluded to be of 'high' sensitivity for health impacts and 'high' sensitivity for dust soiling, based upon the following assumptions:

- The identified sensitive receptor locations are dwellings where people would reasonably be expected to be present continuously, or at least regularly for extended periods (> 8 hours/day) as part of the normal pattern of use of the land; and
- In general, the local population could reasonably expect a high level of amenity (i.e. low annual average TSP concentrations and dust deposition rates) given the highly vegetated nature of the area and high rainfall which would result in little natural wind-blown dust and low background dust levels.

Based on this, the sensitivity of the areas surrounding the Infrastructure Corridor to dust soiling effects and human health impacts has been determined based on **Table 16** and **Table 17** as shown in **Table 34**. In relation to potential human health impacts, the background annual mean PM_{10} concentration at these villages has been assumed to be 11.8 µg/m^3 which is the annual average background PM_{10} concentration estimated for the Mine Area based on available monitoring data at nearby villages (see **Table 14**). The annual average background PM_{10} concentration estimated for residences in the northern areas of Lae has been assumed to be slightly higher (a nominal increase of around 5 µg/m^3) to account for local traffic, shipping emissions, local industry etc.

Table 34 Assessment of Sensitivity of Areas Surrounding the Infrastructure Corridor Construction Works

Value	Area	Sensitivity of receptors	Number of Receptors	Distance from Source	Annual Mean PM_{10} Concentration	Sensitivity of the Area
Dust soiling	Papas	High	10 - 100	70 m	-	Low
	Ziriruk	High	10 - 100	300 m	-	Low
	Markham Farm	High	10 - 100	200 m	-	Low
	Durung Farms	High	10 - 100	< 20 m	-	High
	Northern areas of Lae	High	>100	< 20 m	-	High
Human Health	Papas	High	10 - 100	70 m	11.8 µg/m^3 #	Low
	Ziriruk	High	10 - 100	300 m	11.8 µg/m^3 #	Low
	Markham Farm	High	10 - 100	200 m	11.8 µg/m^3 #	Low
	Durung Farms	High	10 - 100	< 20 m	11.8 µg/m^3 #	Low
	Northern areas of Lae	High	>100	< 20 m	17 µg/m^3 ^	Medium

As per **Table 14**

^ Increased by a nominal 5 µg/m^3 to account for local traffic, shipping emissions, local industry etc.

It is also noted that while the Infrastructure Corridor construction would be expected to occur prior to mining, there may be other construction activities occurring in the vicinity of some sections of the Infrastructure Corridor (e.g. construction of the Port Facilities Area, construction activities at the Mine Area) at the same time. However any cumulative impacts are expected to be localised and therefore relatively short-term as construction progresses. This has therefore not been considered in estimating the background annual mean PM_{10} concentrations.

Based on the local area sensitivity classifications shown in **Table 34** and the estimated magnitudes of dust emissions from the proposed earthworks activities, the resulting risk of air quality impacts associated with construction of the access roads and pipelines have been assessed using the impact matrices in **Table 18** and **Table 19**, and are presented in **Table 35**.

Table 35 Risk of Air Quality Impacts from Earthworks During Infrastructure Corridor Construction

Location	Sensitivity of Area	Dust Emission Magnitude	Preliminary Risk
Dust Soiling			
Papas	Low	Medium	Low
Ziriruk	Low	Medium	Low
Markham Farm	Low	Small	Negligible
Durung Farm	High	Small	Low
Northern areas of Lae	High	Small	Low
Human Health			
Papas	Low	Medium	Low
Ziriruk	Low	Medium	Low
Markham Farm	Low	Small	Negligible
Durung Farm	Low	Small	Negligible
Northern areas of Lae	Medium	Small	Low

The results indicate there is a 'low' risk of dust soiling impacts occurring at Papas, Ziriruk, Durung Farm and in Lae, even if no management measures were to be applied, and a negligible risk of dust soiling impacts at other identified sensitive locations. The risk of human health impacts is also classified as low or negligible at all locations, prior to application of management measures.

Step 3 – Site-Specific Mitigation

The IAQM method lists a number of management measures covering communication, site management, monitoring, site preparation, vehicle management and waste management (IAQM, 2014). The most relevant and appropriate of these measures are included in the management measures discussed in **Section 12.1**. These measures will be applied during the Infrastructure Corridor construction works to ensure that impacts associated with fugitive dust emissions are minimised wherever practicable.

Step 4 – Residual Impacts

Provided the management measures discussed in **Section 12.1** are applied during the Infrastructure Corridor construction works, the potential risks of dust deposition and human health impacts at sensitive receptors close to the corridor due to dust emissions from construction activities would be reduced from 'low' risk to 'negligible' risk.

In addition, the impacts in any given location will be short-term in nature as the works proceed along the Infrastructure Corridor. Provided the proposed management measures discussed in **Section 12.1** are applied during the construction works, it is anticipated that the potential risks of dust deposition and human health impacts for these receptors can be managed.

8.2 Pipeline Operational Impacts

As discussed in **Section 3.3**, air emissions from the operation of the concentrate, tailings and fuel pipelines will be minimal. These emissions would be limited to products of fuel combustion from vehicles and equipment operating in these areas which will have very low activity levels (vehicle and equipment movements) compared to urban transport corridors. For example, vehicles and trucks transporting staff and equipment during inspections and maintenance of the pipelines, chainsaws/brush cutters used to cut back vegetation within the Infrastructure Corridor. These emissions do not have any potential to adversely impact on off-site sensitive receptors and have not been considered further.

8.3 Access Road Operational Impacts

There is potential for wheel-generated dust and vehicle exhaust emissions to occur along the Project access roads during the operational phase. No significant adverse air quality impacts would occur as a result of the vehicle exhaust emissions given the remote location of the site (i.e. good background air quality) and the low numbers of vehicles using the roads (e.g. approximately 30 vehicles per direction, per day, for the Northern Access Road).

Proposed management measures to minimise any potential for nuisance dust impacts from wheel generated dust on the Project access roads are given in **Section 12.1**.

9 AIR QUALITY IMPACT ASSESSMENT – COASTAL AREA

9.1 Port Facilities Area

9.1.1 Port Facilities Area Construction Impacts

The proposed Port Facilities Area construction works will involve construction of the filtration and storage buildings and the ship loading facilities.

The potential risks associated with dust emissions from construction of the Port Facilities Area have been assessed qualitatively using the IAQM method, as outlined in **Section 6.2.1**. The findings of this assessment are presented below.

Step 1 – Screening Based on Separation Distance

The closest sensitive receptors to the Port Facilities Area site will be the houses located approximately 650 m from the site at the northwestern corner of the site boundary.

As these sensitive receptors are located beyond the largest separation distance (500 m from the site entrance) recommended for screening out projects requiring assessment in the IAQM methods (IAQM, 2014), further assessment has not been performed and the risk of potential impacts is concluded to be negligible.

9.1.2 Port Facilities Area Operational Impacts

The closest sensitive receptors to the Port Facilities Area site are located approximately 650 m away. During operation, the only potential source of dust emissions would be the concentrate filter cake. The concentrate filter cake will be stockpiled in a covered area or semi-enclosed building before being loaded into ships via a covered conveyor for export. On this basis, fugitive dust emissions from concentrate storage and handling are expected to be minimal and the potential for adverse air quality impacts at sensitive receptors will be negligible.

Exhaust emissions from mobile plant and machinery operating at the site (such as forklifts, light vehicles, etc.) will also be minimal and would not have the potential to impact on air quality at the nearest sensitive receptors.

9.2 Outfall Area

9.2.1 Outfall Area Construction Impacts

The proposed Outfall Area construction works would involve:

- Bulk earthworks (excavation for foundations)
- Building construction activities

As such, constructing the Outfall Area will have the potential to generate dust from earthworks and building construction activities.

The potential risks associated with dust emissions from construction of the Outfall Area have been assessed qualitatively using the IAQM method, as outlined in **Section 6.2.1**. The findings of this assessment are presented below.

Step 1 – Screening Based on Separation Distance

The closest sensitive receptors to the Outfall Area will be the village of Wagang located approximately 1.6 km to the west.

As these sensitive receptors are located beyond the largest separation distance (500 m from the site entrance) recommended for screening out projects requiring assessment in the IAQM methods (IAQM, 2014), further assessment has not been performed and the risk of potential impacts is concluded to be negligible.

9.2.2 Outfall Area Operational Impacts

The closest sensitive receptors to the Outfall Area site are located approximately 1.6 km away. Fugitive dust emissions from the mix/de-aeration tank are expected to be negligible and the potential for adverse air quality impacts at sensitive receptors will be negligible and has not been considered further.

10 POTENTIAL IMPACTS ON VEGETATION

In addition to human health and nuisance impacts addressed in the previous sections, there is also potential for other environmental impacts as a result of air emissions from the Project. The most significant of these is the potential for damage to vegetation due to dust deposition and SO_2 emissions.

High levels of dust deposition may cause physical damage to vegetation by blocking leaf stomata or inhibiting photosynthesis due to smothered leaf surfaces. The very high rainfall in the Project Area, however, will minimise such impacts by washing away dust deposited on leaves, and the low wind speeds characteristic of the area will minimise the area potentially affected as the majority of the particulate will not travel far before settling out of the air. As a result, any damage to vegetation due to dust deposition from the Project is expected to be very localised and limited to less than a few hundred metres from the active work areas.

Different plant species and varieties and even individuals of the same species may vary considerably in their sensitivity to SO_2. 'Critical levels' have been developed for a number of air pollutants by the United Nations Economic Commission for Europe (UN/ECE) for the protection of vegetation, with those for SO_2 listed in Error! Reference source not found. (ICP, August 2017). There are likely to be limitations in the relevance of these European-based guidelines to the types of vegetation and the growing conditions that exist in the Mine Area (warm temperatures and high rainfall), particularly given the fact that SO_2 impacts on vegetation are exacerbated by cold temperatures (Ashmore, Emberson, & Murray, 2003). However in the absence of local guidelines or data they have been used to provide guidance on the potential for adverse impacts on vegetation due to SO_2 emissions from the Project.

Table 36 Critical Levels for SO_2 by Vegetation Category

Vegetation Type	Critical SO_2 Level (µg/m^3)	Averaging Period
Cyanobacterial lichens	10	Annual mean
Forest ecosystems	20	Annual mean and half-year mean (Oct-Mar)
(Semi-)natural	20	Annual mean and half-year mean (Oct-Mar)
Agricultural crops	30	Annual mean and half-year mean (Oct-Mar)

The results of the modelling performed as part of this assessment indicates that:

- During the construction phase, annual average SO_2 concentrations are predicted to be far below the UN/ECE guideline for vegetation impacts on forest ecosystems across the modelling domain (see **Figure 19**).
- During the operational phase there is an area surrounding the IFO power generation facilities (approximately 1,500 ha) that is predicted to be exposed to annual average SO_2 concentrations above the UN/ECE guideline for vegetation impacts on forest ecosystems of 20 µg/m^3 (see **Figure 20**). Therefore, as recommended for the predicted exceedances of the 1-hour average Project-specific SO_2 criterion, it is suggested that ambient monitoring and vegetation surveys be performed within this area during the early stages of the operational phase (i.e. when the power demand is lower and prior to all 12 IFO generators coming on-line) to verify the results of the modelling and to assess the sensitivity of local vegetation to SO_2. If the monitoring confirms that there is potential for vegetation impacts to occur (such as impacts on gardens utilised by villagers) once the power generation facilities are operating at full load, then ongoing monitoring programs and management measures should be developed and implemented to offset identified impacts.

Figure 19 Predicted Annual Average SO_2 Concentrations – Construction

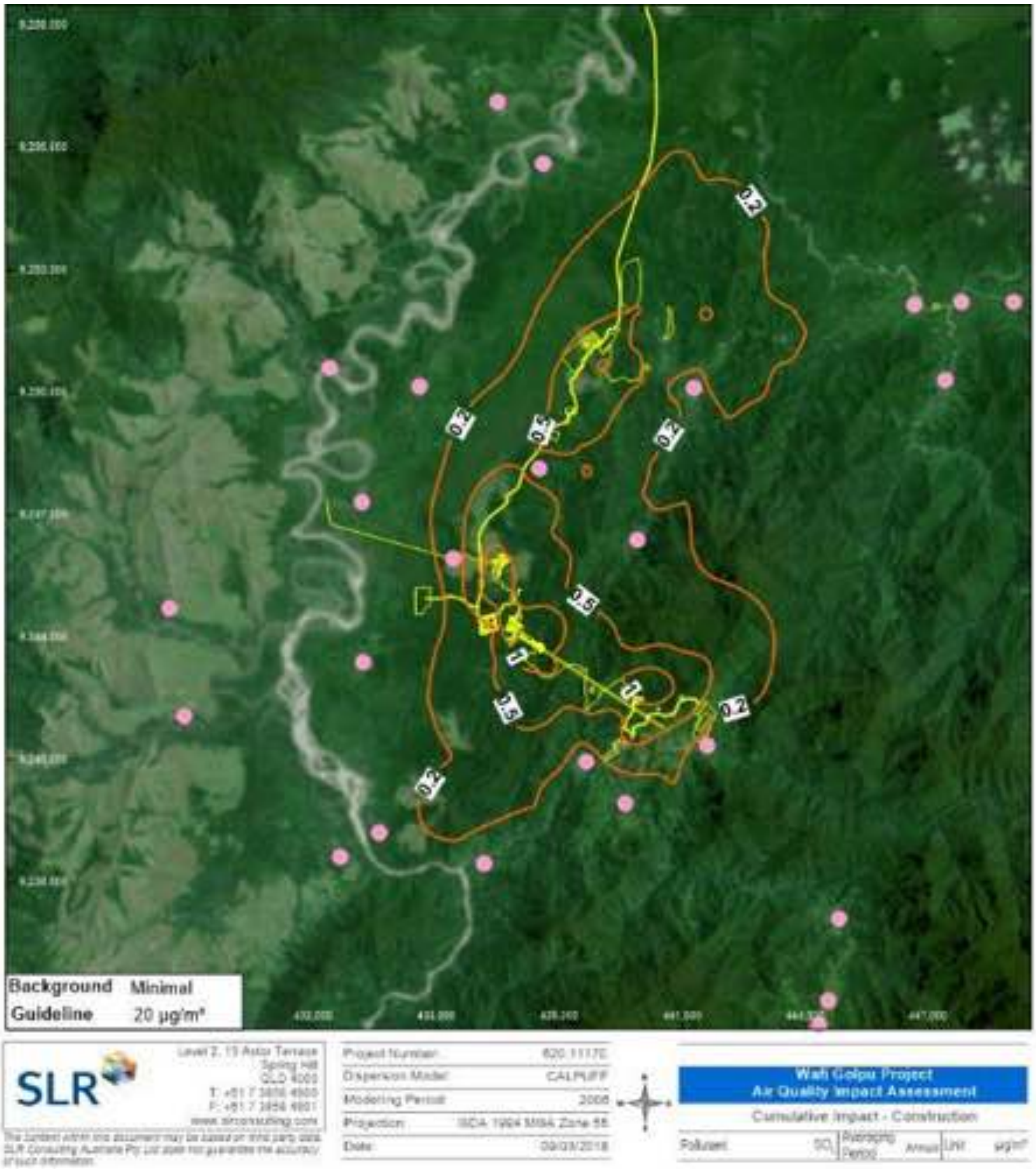
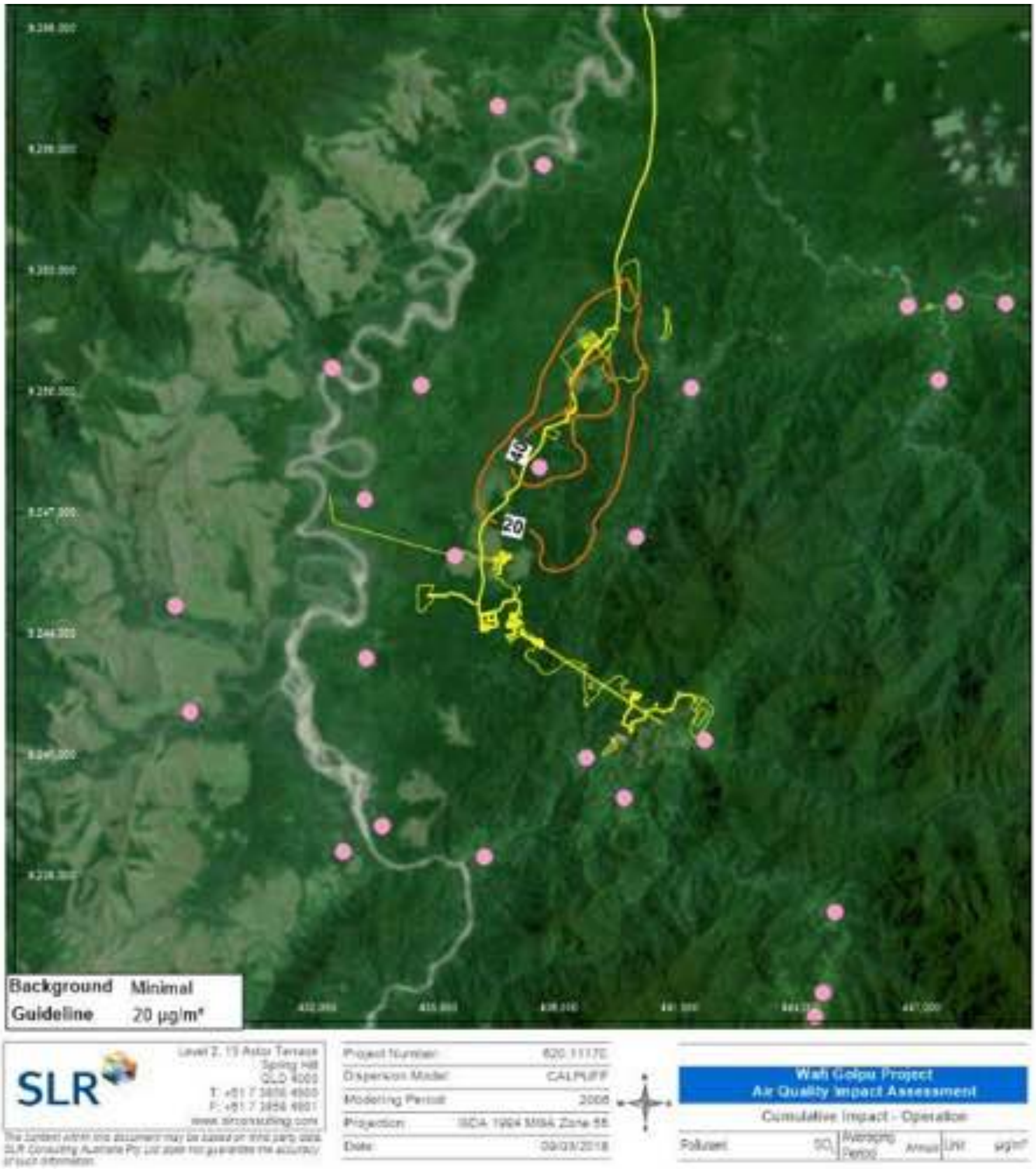


Figure 20 Predicted Annual Average SO_2 Concentrations – Operation



11 GREENHOUSE GAS ASSESSMENT

Air emissions from the Project will include a range of greenhouse gases (GHGs). While these emissions do not have the potential to adversely impact local or regional air quality, they will contribute to PNG's national GHG emission inventory and to the concentrations of GHGs in Earth's atmosphere. A GHG assessment has therefore been performed to:

- Identify the main potential sources of GHG emissions associated with the Project,
- Estimate the annual emissions of GHGs over the life of the Project for comparison against recent national inventories published for PNG; and
- Identify potential GHG management measures and monitoring requirements.

11.1 Introduction

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

The amount of heat energy added to the atmosphere by the greenhouse effect is controlled by the concentration of GHGs in the Earth's atmosphere. Emissions of GHGs can result from natural or man-made (anthropogenic) sources. Examples of natural sources include the decomposition or burning of plant material and emissions of methane from animal digestion processes. Emissions also occur as a result of human activities and such sources include the burning of fossil fuels, the use and leakage of refrigerants, the clearing of forest and other vegetation, and the use of fertilisers, amongst other sources. This separation of natural versus anthropogenic sources is complicated by the fact that natural processes may be manipulated by humans, resulting in increased emissions of GHGs.

A number of gases are involved in the human-caused enhancement of the greenhouse effect. These include:

- **Carbon dioxide** (CO_2): A minor but very important component of the atmosphere, CO_2 is released through natural processes such as respiration and volcanic eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels.
- **Methane** (CH_4): A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock. On a molecule-for-molecule basis, CH_4 is a far more active GHG than CO_2, but also one which is much less abundant in the atmosphere.
- **Nitrous oxide** (N_2O): A powerful GHG produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.
- **Chlorofluorocarbons** (CFCs): Synthetic compounds entirely of industrial origin used in a number of applications, but now largely regulated in production and release to the atmosphere by international agreement for their ability to contribute to destruction of the ozone layer. They are also GHGs.

Over the last century, the burning of fossil fuels such as coal and oil has increased the concentration of atmospheric CO_2. This happens because the coal or oil burning process combines carbon with oxygen in the air to make CO_2. To a lesser extent, the clearing of land for agriculture, industry, and other human activities (such as housing/infrastructure) has also increased concentrations of GHGs. Vegetation and soils typically act as a carbon sink, storing carbon dioxide that is absorbed through photosynthesis. When the land is disturbed, part of the stored carbon dioxide is emitted, through mechanisms such as burning or decomposition of vegetation etc., and re-enters the atmosphere.

11.2 Relevant Legislation, Guidelines and Policies

11.2.1 The International Response to Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is the international body tasked with assessing scientific knowledge on climate change. It was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988, and endorsed by the UN General Assembly, to provide policy makers with regular scientific assessments of climate change, its impacts and future risks, and the mitigation and adaptation options.

The first meeting of the IPCC was held in Geneva in 1988. Since it was established, the IPCC has prepared five assessment reports, which have provided key inputs into the international negotiations to tackle climate change. Recent key dates and milestones relating to international activity on climate change, which are either relevant to PNG or are relevant to the development of the method of assessment adopted for this report include:

- March 2014: IPCC release the Fifth Assessment Report which considers new evidence of climate change based on independent analyses from observations of the climate system. This report includes refined estimates of impact probability.
- December 2015: The 2015 United Nations Climate Change Conference (COP 21) was held in Paris, which encompassed the 21st Conference of Parties (COP) to the UNFCCC and the 11th session of the Meeting of Parties to the 1997 Kyoto Protocol. The conference negotiated the Paris Agreement aimed at holding the increase in global temperature to below 2ºC above pre-industrial levels.
- March 2016 Papua New Guinea submits its first Climate Plan under the Paris Climate Change agreement (refer **Section 11.2.2**)
- August 2016 Papua New Guinea ratifies the Paris Climate Change Agreement (refer **Section 11.2.2**)
- November 2016 Paris Climate Change Agreement entered into force.

11.2.2 The Papua New Guinean Response to Climate Change

PNG ratified the United Nations Framework Convention on Climate Change in 1993, the Kyoto Protocol in 2002 and the Paris Climate Change Agreement in 2016.

In March 2008, PNG entered into a cooperative agreement with Australia to reduce GHG emissions from deforestation and forest degradation: the *'Papua New Guinea-Australia Forest Carbon Partnership*'. Nearly two-thirds of PNG's land area is forested (more than 29 million hectares in area). Additionally, PNG's tropical forests are being targeted for carbon emission reduction schemes under the REDD+ mechanism (OCCD, 2014). The REDD+ mechanism is aimed at offsetting carbon emissions by protection of forest that would otherwise have been degraded by logging or other means.

PNG 2050 is a framework for a long-term strategy for the future direction of PNG and has been compiled by the National Planning Committee (NSPT, 2009). It includes seven strategic focus areas (referred to as pillars) with one of these pillars related to environmental sustainability and climate change. The focus of strategic objectives (and priority activities) in this area relate to sustainable development, conservation and use of natural resources, improvement in the understanding of environmental issues, conservation of language and cultural diversity and effective partnerships and cooperation with the international community.

The PNG Office of Climate Change & Development (OCCD) also published the *National Climate Compatible Development Management Policy* (NCDMP) in August 2014 (OCCD, 2014). The policy aims to build a climate-resilient and carbon neutral pathway through sustainable economic development for PNG. The NCDMP is supported by the *Climate Change (Management) Act 2015* which provides a regulatory framework to:

- Promote and manage climate compatible development through climate change mitigation and adaptation activities;
- Implement relevant obligations of the State under applicable rules of international law and international agreements related to climate change; and,
- Establish PNG's Designated National Authority or equivalent for the purposes of the Kyoto Protocol and any other or subsequent arrangements or agreements made under the Kyoto Protocol (PNG Parliament, 2015).

In March 2016, PNG submitted its first Intended Nationally Determined Contribution (INDC) under the United Nations Framework Convention on Climate Change (PNG Parliament, 2016). This document notes:

> *PNG's current economic development is seeing a growth in fuel use therefore a big effort will be made to reduce fossil fuel emissions in the electricity generation sector by transitioning as far as possible to using renewable energy. The target in this respect will be 100% renewable energy by 2030, contingent on funding being made available. In addition PNG will improve energy efficiency sector wide and reduce emissions where possible in the transport and forestry sectors. The main forestry effort will be coordinated though the existing REDD+ initiative.*

In relation to the country's existing national GHG emissions, the document states:

> *The APEC energy supply and demand outlook 2009 gave the total primary energy supply in 2005 as a little under 2 MTOE which would give a CO_2 emission level of around 6 Mt CO_2 as of that year. 2010 CO_2 eq emissions were estimated from earlier reports including the draft SNC to be around 5 Mt tonnes (from a primary energy supply of 1.8 MTOE) which would give a per capita emission level of around 0.7 tonnes compared to the world average of just under 6 tonnes.*
>
> *It is likely, however, that the previous PNG figures do not include emissions from the indigenous oil and gas production sector. The growth of this sector in recent years has produced additional emissions which are likely to be around 5 Mt per annum (0.8 Mt Oil Search, 3.2 Mt Exxon Mobil, and 1 Mt other, including mining) as of 2014. The total would give around 10 Mt CO_2 eq. This would give per capita emissions (2014) of around 1.4 tonnes per person per year which is still low by world standards.*

In relation to the country's Business As Usual (BAU) projections of GHG emissions in the future, the document states:

> *Longer term national economic projections suggest emission increases at around the 3-4% level per annum, meaning that the 2014 emission level of 5 Mt per year could increase to around 8 Mt per year by 2030. A doubling of oil and gas sector emissions would produce some 10 Mt of additional CO_2 eq. emissions by the same date but the actual figure would depend on the extent of economically extractable oil and gas reserves, which are not well documented.*

11.2.3 Relevant GHG Performance Standards

11.2.4 The Equator Principles

The Equator Principles (Equator Principles Association, 2006) are applied by financial institutions globally across all industry sectors to all new project financings with project capital costs of US$10 million or more. For a project to be eligible for a loan through an Equator Principle Financial Institution (EPFI) it must conform to a set of nine principles of which *Principle 3: Applicable Social and Environmental Standards* is of specific importance with regard to this Project.

Principle 3 requires that Social and Environmental Assessments refer to International Finance Corporation (IFC) Performance Standards and Industry Specific EHS Guidelines. All assessments are to be carried out to the EPFI's satisfaction of overall compliance, or with justified deviation from the respective Performance Standards and EHS Guidelines.

In relation to GHG emissions, Performance Standard 3 requires that:

> *"The client will promote the reduction of project-related greenhouse gas emissions in a manner appropriate to the nature and scale of project operations and impacts.*
>
> *During the development or operation of projects that are expected to or currently produce significant quantities of GHG's, the client will quantify direct emissions from the facilities owned or controlled within the physical project boundary and indirect emissions associated with the off-site production of power used by the project."*

This GHG assessment has been prepared to meet the requirements of Performance Standard 3.

11.2.5 IFC Environmental Health and Safety Guidelines – Thermal Power Plants

The IFC EHS Guidelines for Thermal Power Plants (IFC, 2008), which as noted in **Section 4.3.2.3** are applicable to the power generation facilities, list a number of recommendations to avoid, minimise, and offset emissions of CO_2 from new and existing thermal power plants including:

> *'Use of less carbon intensive fossil fuels (i.e., less carbon containing fuel per unit of calorific value -- gas is less than oil and oil is less than coal) or co-firing with carbon neutral fuels (i.e., biomass)'*

The IFC EHS Guidelines for Thermal Power Plants (IFC, 2008) also requires that the Environmental Assessment for a new facility include estimation of GHG emissions associated with the Project. This GHG assessment has been prepared to meet the requirements of the IFC EHS Guidelines.

11.2.6 The Greenhouse Gas Protocol Initiative

Greenhouse gas accounting and reporting principles are intended to underpin all aspects of GHG accounting and reporting. The five principles outlined below are consistent with the World Resources Institute/World Business Council for Sustainable Development (WRI/WBCSD) GHG Protocol Initiative (a globally adopted and leading GHG accounting strategy), and ISO 14064-1, 2, and 3 (GHG) guidelines (internationally accepted best practice). These principles are based on financial accounting and reporting standards and are taken from the GHG Protocol documentation (WRI, 2004).

The following outlines the basic requirements of any GHG assessment, as defined by WRI/WBCSD.

Relevance: The relevance of a company's GHG report relates to the information which it contains. The information should allow stakeholders, both internal and external to the organisation, to make informed decisions about GHG management. An important aspect of relevance is the selection of appropriate boundary conditions which reflect the reality of the company's operations. The operation of the company, the purpose of the information and the needs of users will all inform the choice of the inventory boundary.

Completeness: All relevant emission sources within the chosen inventory boundary need to be accounted for so that a comprehensive and meaningful inventory is compiled. WRI (2004) states that no materiality threshold (or minimum emissions accounting threshold) should be defined as this is not in line with the principle of completeness. However, if emissions are not able to be estimated or estimated at a sufficient level of quality, then these should be transparently documented and justified.

Consistency: Consistency in an emissions inventory allows stakeholders to compare GHG emissions performance from year to year. This consistency also allows trends to be identified and performance against objectives and targets to be tracked. Any changes in the inventory (accounting approaches, boundaries, calculation methods) need to be transparently documented and justified.

Transparency: All processes, procedures, assumptions and limitations of an inventory should be presented clearly and accurately. Information needs to be recorded, compiled and analysed in a way that enables internal reviewers and external auditors to verify the credibility of the inventory. Specific exclusions and inclusions are to be documented and justified, assumptions disclosed and appropriate references provided for the calculation methods applied and the data sources used. Transparency is essential in the production of a credible GHG inventory.

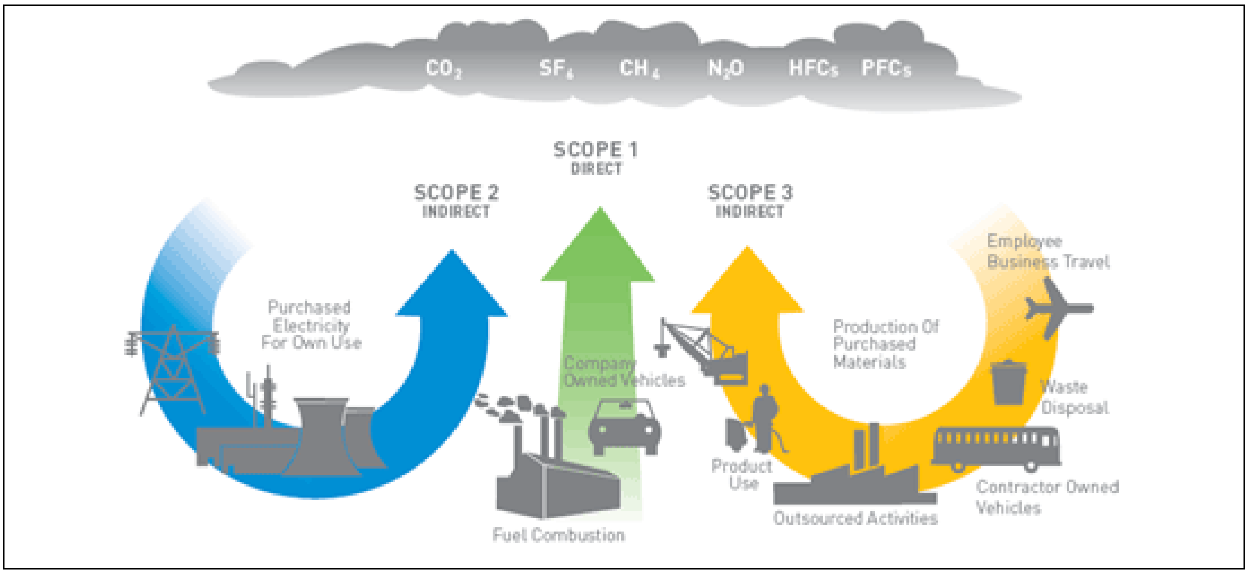
Accuracy: Accuracy describes how close the estimates of GHG emissions are to the 'true' value. The accuracy of a GHG inventory should be sufficient for stakeholders to make decisions with reasonable assurance of the integrity of the reported information. Quality management measures should be implemented to maximise inventory accuracy.

11.3 Scope Definition

Emissions of GHG can be termed as being *Scope 1, Scope 2* or *Scope 3*, and '*direct*' or '*indirect*' emissions (**Figure 21**). A discussion of what each Scope refers to, and how it relates to the Project is presented below.

The definitions below have been taken from the WRI and WBCSD GHG Protocol (WRI, 2004). These documents provide detailed information on the activities which should be included in each of the Scope 1, 2 and 3 boundaries. The definition of these boundaries allows the determination of those sources of GHG emissions which can be directly controlled by WGJV (Scope 1 and Scope 2), or those which WGJV would have some, but limited control over (Scope 3).

Figure 21 Scope 1, 2 and 3 GHG Emissions as Defined in the GHG Protocol Initiative



Source: WRI (2004)

11.3.1 Direct Emissions (Scope 1)

Direct emissions of GHG are termed Scope 1 emissions and are produced from sources within the boundary of an organisation and as a result of the organisation's activities. These direct emissions mainly arise from the following sources associated with proposed project activities.

- Transportation of materials, products, waste or people e.g. the combustion of diesel in mobile equipment, including on-road and off-road vehicles and stationary equipment
- Generation of electricity, heat and/or steam, e.g. the combustion of diesel in generators
- Fugitive emissions, both intentional and unintentional, e.g. through the use of switchgear, and land clearing
- On-site waste management, e.g. solid and liquid waste management through landfill, although this is not the main waste disposal option for the Project

11.3.2 Indirect Emissions (Scope 2 and Scope 3)

Indirect emissions are generated in the wider economy as a consequence of an organisation's activities but are physically produced by the activities of another organisation.

Scope 2 Emissions

The most important category of indirect emissions is from the consumption of purchased electricity (Scope 2 emissions). Scope 2 emissions relate to the GHG emissions from the generation of purchased electricity consumed in owned or controlled equipment or operations. For the Project, Scope 2 emissions are relevant to electricity purchased for the Port Facilities Area at the Port of Lae.

Scope 3 Emissions

Scope 3 indirect emissions are related to the upstream emissions generated in the extraction and production of fossil fuels and in the emissions from contracted/outsourced activities. Scope 3 emissions may be, but are not required to be, reported as part of a Project's GHG emissions assessment IPCC GHG emission calculation methodologies are not available for Scope 3 emissions and they have not been included in the GHG inventory compiled for the Project.

11.4 Global Warming Potential

Within this report, the term GHG relates to five of the six gases addressed in the Kyoto Protocol:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFC)
- Sulphur hexafluoride (SF_6)

Perfluorocarbons (PFCs) are not emitted by any equipment associated with the Project and are therefore not considered further.

For comparative purposes, non-CO_2 GHGs are awarded a "CO_2-equivalence" (CO_2-e) based on their contribution to the enhancement of the greenhouse effect. The CO_2-e of a gas is calculated using an index called the Global Warming Potential (GWP). The GWPs of relevance to this assessment, as taken from the IPCC's Fourth (AR4) and Fifth (AR5) Assessment Reports are presented in **Table 37**. The AR5 values (IPCC, 2013) are the most recent, but the AR4 values (IPCC, 2007) are also listed because they are currently used in Australia for inventory and reporting purposes.

Short-lived gases such as CO, NO_2, and non-methane volatile organic compounds (NMVOCs) vary spatially and it is consequently difficult to quantify their contribution to project GHG emissions. For this reason, GWP values are generally not attributed to these gases nor have they been considered further as part of this assessment.

Table 37 Global Warming Potentials

Gas	Chemical Formula	IPCC GWP (100 year horizon)	
		Fourth Assessment Report [1]	Fifth Assessment Report [2]
Carbon dioxide	CO_2	1	1
Methane	CH_4	25	28
Nitrous oxide	N_2O	298	265
Hydrofluorocarbons[1]	CH_2FCF_3	1,430	1,300
Sulphur hexafluoride	SF_6	22,800	23,500

1: (IPCC, 2007)
2: (IPCC, 2013)
3: HFCs assumed to be HFC-134a

11.5 Calculation of GHG emissions from the Project

A quantitative GHG assessment has been performed to determine the potential GHG emissions of the Project. In accordance with standard practice, this assessment has been guided with reference to the requirements of the GHG Protocol and IPCC and Australian Government emission calculation methodologies.

Calculation of GHG emissions from the Project has been performed in a five stage process:

- Definition of the Project boundary (**Section 11.5.1**)
- Identification of emission sources within the Project boundary (**Section 11.5.2**)
- Identification of activity data for each emission source (**Section 11.5.3**)
- Identification of emission calculation methodologies for each source (**Section 11.5.4)**
- Calculation of GHG emissions (**Section 11.5.5**)

11.5.1 Definition of the Project Boundary

Geographical Boundary

The geographical boundary set for the GHG assessment covers the Project Area comprising the footprint of proposed project infrastructure (including the Mine Area, Infrastructure Corridor, Port Facilities Area and Outfall Area). Specifically, emissions associated with Project construction and closure and all associated mobile plant and equipment are included in this assessment, in addition to the operational phase emissions.

Emissions associated with the transportation of materials and workforce to the Project Area from Lae have been considered, as well as their movement within the Project Area. Emissions associated with international transport of staff and materials have not been included.

Boundaries of a GHG assessment can be chosen to include/exclude sources as long as the process of definition is transparent and the inventory for the selected boundary is as complete as possible (refer **Section 11.2.6**).

Emission Scope Boundary

Operational boundaries for GHG emissions have been set with the aim of providing as complete an emissions inventory as possible. All Scope 1 and Scope 2 emissions have been identified and reported as far as possible.

11.5.2 Identification of Emission Sources

Emission sources have been based on the Project activities. Sources included in the emissions inventory are detailed in **Table 38**, **Table 39** and **Table 40**.

Table 38 GHG Emission Sources Associated with the Mine Area

Mine	Scope 1 GHG Emissions	Scope 2 GHG Emissions
Land clearance / disturbance for mine infrastructure and roads during mine construction	Loss of carbon stock and material decomposition	-
Consumption of diesel fuel in land clearance during mine construction	Emissions from combustion	-
Consumption of diesel fuel in transportation of materials to and from the Mine Area (from the Project boundary to elements within the Project Area) during mine construction and closure	Emissions from combustion	-
Consumption of diesel fuel in mobile plant and equipment during mine construction, operation and closure	Emissions from combustion	-
Consumption of diesel fuel to generate electricity during mine construction	Emissions from combustion (diesel fired generators)	-
Consumption of IFO to generate electricity during mine operation	Emissions from combustion (IFO fired generators)	-
Use of explosives during mine construction and operation	Emissions from explosive use	-
Consumption of diesel fuel in transportation of workforce from the mine to the Project Area boundary during construction, operation and closure	Emissions from combustion	-
Use of HFC in refrigeration during mine construction and operation	Emissions from HFC leakage	
Management of solid waste and wastewater during mine construction, operation and closure	Emissions from organic material decomposition	
Use of SF_6 in switchgear during mine operation	Emissions from SF_6 leakage	-

Table 39 GHG Emission Sources Associated with the Infrastructure Corridor

Concentrate Pipeline	Scope 1 GHG Emissions	Scope 2 GHG Emissions
Land clearance / disturbance for concentrate, tailings and fuel pipelines' infrastructure during construction	Loss of carbon stock and material decomposition	-
Consumption of diesel fuel in land clearance during concentrate, tailings and fuel pipelines' construction	Emissions from combustion	-
Consumption of diesel fuel in transportation of materials to and from the Mine Area (from the Project boundary to elements within the Project Area) during concentrate, tailings and fuel pipelines' construction and decommissioning	Emissions from combustion	-
Consumption of diesel fuel in mobile plant and equipment during concentrate, tailings and fuel pipelines' construction, operation and decommissioning	Emissions from combustion	-
Consumption of diesel fuel to generate electricity during concentrate, tailings and fuel pipelines' construction	Emissions from combustion (diesel fired generators)	-
Consumption of diesel fuel in transportation of workforce from the concentrate, tailings and fuel pipelines' to the Project Area boundary during construction, operation and decommissioning	Emissions from combustion	-
Management of solid waste and wastewater during concentrate, tailings and fuel pipelines' construction, operation and decommissioning	Emissions from organic material decomposition	
Use of SF_6 in switchgear during pipeline operation	Emissions from SF_6 leakage	-

Table 40 GHG Emission Sources Associated with the Coastal Area

Port Facilities and Outfall Areas	Scope 1 GHG Emissions	Scope 2 GHG Emissions
Consumption of diesel fuel in land clearance during Outfall Area construction	Emissions from combustion	-
Consumption of diesel fuel in transportation of materials to and from the Port Facilities Area and Outfall Area during construction and decommissioning	Emissions from combustion	-
Consumption of diesel fuel in mobile plant and equipment during Port Facilities Area and Outfall Area construction, operation and decommissioning	Emissions from combustion	-
Consumption of diesel fuel to generate electricity during Port Facilities Area and Outfall Area construction	Emissions from combustion (diesel fired generators)	-
Consumption of electricity during Port Facilities Area operation	-	Emissions associated with purchased electricity
Management of solid waste and wastewater during Port Facilities Area construction, operation and decommissioning	Emissions from organic material decomposition	
Use of SF_6 in switchgear during Port Facilities Area operation	Emissions from SF_6 leakage	-

11.5.3 Identification of Activity Data for Each Emission Source

The activity data and assumptions for each source of GHG emissions identified for the Project in **Table 38** to **Table 40**) are presented in **Appendix D**.

11.5.4 Emission Calculation Methodologies

Emission factors allow the quantity of GHG emitted by a source to be calculated from defined units of activity. Countries required to report their national GHG emissions under the UNFCCC are required to use the UNFCCC accepted IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) publication and the included emission factors. Broad, non-country specific emission factors are available from this publication, although IPCC identify that if a particular activity is a major GHG emissions source it is good practice to develop a country-specific emission factor for that activity.

Emission factors relevant to each activity presented in **Table 38**, **Table 39** and **Table 40** have been sourced from the IPCC or the Australian Government Department of Climate Change and Energy Efficiency National Greenhouse Account (NGA) Factors publications (as the most comprehensive and up-to-date source of regionally representative emission factors).

The IPCC publication (IPCC, 2006) consists of five volumes:

1. General Guidance and Reporting
2. Energy
3. Industrial Processes and Product Use
4. Agriculture, Forestry and Other Land Use
5. Waste

Other IPCC publications have also been referenced in this document, including "*Good Practice Guidance for Land Use, Land-Use Change and Forestry*" (IPCC, 2003).

Details of the emission estimation methodologies used are provided in **Appendix E**.

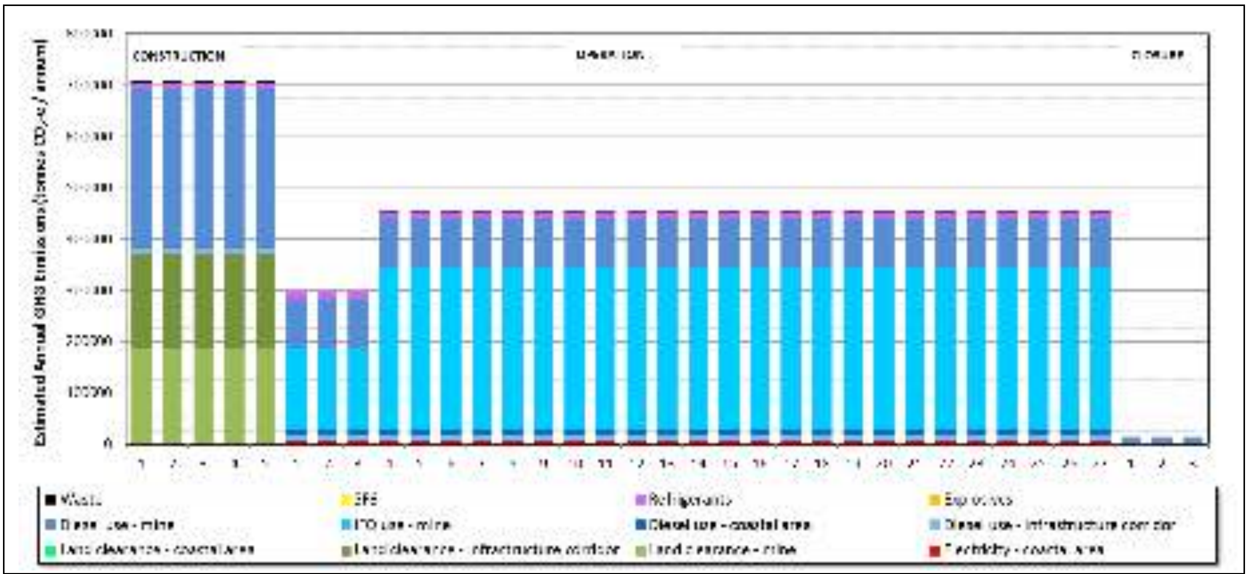
11.5.5 Calculated GHG Emissions

Based on the activity data outlined in **Appendix D** and emission estimation methods described in **Appendix E** for each source, GHG emissions for the Project have been calculated and are presented in **Table 41**. Additional details of the estimated emissions are provided in **Appendix F**. The contribution of each Project element to the total estimated total Project emissions for each year is illustrated in **Figure 22**. This plot includes the reduced power requirement of the Project for the first three years of the operational phase, when the maximum generation capacity of the IFO power generation facilities is approximately half the proposed total capacity (refer **Figure 18**).

Table 41 Estimated Scope 1 and 2 GHG Emissions

Source	t CO_2-e / annum		
	Scope 1	Scope 2	TOTAL
Mine Area			
Construction	507,265	0	**507,265**
Operation	423,477	0	**423,477**
Closure	10,611	0	**10,611**
Infrastructure Corridor			
Construction	196,423	0	**196,423**
Operation	11,963	0	**11,963**
Closure	1,382	0	**1,382**
Coastal Area			
Construction	3,160	0	**3,160**
Operation	11,961	6,364	**18,325**
Closure	1,327	0	**1,327**
TOTAL PROJECT			
Construction	706,848	0	**706,848**
Operation	447,401	6,364	**453,765**
Closure	13,319	0	**13,319**

Figure 22 Estimated Annual GHG Emission Totals Over Life of Project



The total scope 1 GHG emissions for the Project are estimated at 15,182 kt CO_2-e assuming a five year construction period, 27 year operation and a three year closure period (including the reduced fuel demand for the power generation facilities in the first three years). Averaged over the 35 year life span of the Project, this is equivalent to 433.8 kt CO_2-e/annum.

Taking into account both Scope 1 and Scope 2 emissions, total estimated GHG emissions for the Project are estimated at 15,354 kt CO_2-e. Averaged over the 35 year life span of the Project, this is equivalent to 438.7 kt CO_2-e/annum.

The main sources of GHG emissions are diesel combustion and land clearance during mine construction, and IFO and diesel combustion during mine operation.

11.6 Comparison of Emissions with National Totals

In order to assess the Project's potential impact on PNG's national GHG emissions inventory, the estimated annual average Project emissions have been compared to available historic data on PNG's national emissions.

Data collated by the Food and Agriculture Organization of the United Nations (FAO) is the most recent source of emissions information that includes emissions associated with land use change and forestry (LUCF). The total GHG emissions for Papua New Guinea reported for 2013 were (FAO, 2014):

- 70,855 kt CO_2-e including LUCF
- 16,434 kt CO_2-e excluding LUCF

The high total associated with the inclusion of LUCF provides an indication of the levels of emissions that are associated with forestry and agricultural activities, and are caused by factors such as deforestation of primary or native forest, deforestation of secondary forest which regenerates where native forest has been cleared, and forest degradation through selective logging.

It is noted that the total emissions of 16,434 kt CO_2-e excluding LUCF reported by FAO for 2013 is higher than the estimated emission projections noted in **Section 11.2.2** as being reported in PNG's 2016 Intended Nationally Determined Contribution (INDC) under the United Nations Framework Convention on Climate Change (PNG Parliament, 2016). This document estimated the following:

- 2010 emissions of around 5,000 kt CO_2-e, based on a primary energy supply of 1.8 MTOE; and
- 2014 emissions of around 10,000 kt CO_2-e including emissions from the indigenous oil and gas production sector.

A comparison of the estimated annual average Scope 1 and 2 GHG emissions over the life of the Project with the total national emissions (including LUCF) reported by the FAO is provided in **Table 42**. This comparison indicates that over the life of the Project, it would result in a relatively minor (0.6%) increase in the national emissions.

Table 42 Comparison Project-Related GHG Emissions with National Totals

	National GHG Emissions 2013 # (kt CO_2-e)	Annual Average Project Scope 1 & 2 Emissions Over Life of Project (kt CO_2-e/annum)	Percentage of National Emissions
Including LUCF*	70,855	438.7	0.6%

* LUCF: land use change and forestry
# (FAO, 2014)

The environmental value potentially impacted due to GHG emissions from the Project is defined as '*the maintenance of climatic systems to maintain the health, development and well-being of humans and the protection of ecosystems and biodiversity'* (**Section 4.1**). The sensitivity of climatic systems is somewhat unknown as there are remaining scientific uncertainties about the magnitude of the positive and negative feedbacks in the climatic system. For the purposes of this study, the sensitivity of this value has been characterised as moderate. The magnitude of change related to GHG emissions from the Project is considered to be low due to the minimal contribution these emissions will have to the overall greenhouse gas emissions of PNG (<1% based on the most recent national inventory data available (FAO, 2014).

12 MANAGEMENT AND MONITORING

12.1 Air Emissions Management Measures

The following section provides a summary of management measures that may be implemented to minimise the potential for adverse impacts on off-site air quality.

12.1.1 Nuisance Dust Control Measures

Ambient dust emissions from wheel-generated dust, excavation and rehabilitation, clearing and grading, truck loading and unloading, and wind erosion areas will be the primary focus of dust control. Typically, emissions from these processes can be minimised through the implementation of water spraying during dry, windy periods, particularly during periods of heavy on-site activity.

Other dust management measures that may be implemented during the construction and operational phases include:

- Maintain erosion and sediment control structures by:
  - Cleaning accumulated material from behind sediment fences and barriers, cut-off drains and diversion drains associated with temporary erosion control berms. Dispose of sediment appropriately.
  - Cleaning accumulated material from, and where required, dewatering sediment ponds. Dispose of sediment to an appropriate location. Treat water if required prior to discharge to meet PNG environment permit conditions.
  - Maintaining sediment fences or barriers as required.
- Maintain site access roads.
- Apply dust suppression in the vicinity of sensitive receptors (e.g., villages, schools, churches), as required during extended dry periods.
- 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).

12.1.2 Plant and Machinery

Control measures relating to plant and machinery that may be implemented during the construction and operational phases include:

- Procure fit-for-purpose vehicles, plant and machinery, and regularly inspect and maintain in accordance with manufacturer recommendations.
- 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.
- Clean the mobile conveyors of concentrate residue after each ship loading event.
- Install and maintain oil-water separation facilities where required (e.g., at vehicle maintenance workshops). Recover and appropriately dispose of trapped hydrocarbons and hazardous materials to approved facilities.
- Load the ship hatch through enclosed structures such as cement hatch hoppers.

12.1.3 Site Management

Air emissions should also be managed through compliance with the Environmental Management Plan so that:

- The Project is conducted in a manner that minimises to the greatest extent practicable the generation of air emissions
- The effectiveness of the implemented controls is monitored
- Appropriate additional measures are implemented where deemed required (i.e. in the event of complaints, staff identification of excessive emission, or if air monitoring identifies exceedances of criteria).

12.1.4 Complaints Handling

An effective complaints logging system should be maintained to monitor complaints, to effectively manage any requests for information or respond to any third party concerns in relation to the Project activities throughout the construction and operational phases, and to ensure identified incidents are dealt with through investigation and implementation of corrective treatments. Therefore, the WGJV should implement its community complaints and grievance mechanism which includes:

- Complaints and grievance register;
- Person/position responsible for investigating and addressing complaints;
- Person/position responsible for investigating and resolving grievances;
- Training and induction of Project personnel and contractors in managing grievances;
- Method for communicating grievance mechanism to communities; and
- Process for recording, acknowledging and addressing complaints.

12.2 Greenhouse Gas Management Measures

Energy efficiency options relating to the selection and operation of fixed and mobile plant and equipment will minimise GHG emissions attributable to the Project. This includes the diesel generators to be used during construction and the power generation facilities proposed for the operational phase. Appropriate sizing of this equipment and good load management once operating will assist in minimising fuel use and thus GHG emissions.

The use of diesel fuel in mobile plant can also be minimised through optimising on-site driving and maintenance practices as listed above for local air quality (e.g. vehicle speed reduction; reducing idling times of trucks; maintaining roads in good condition, maintaining vehicles according to the manufacturer's guidance etc.).

GHG emissions can also be reduced by limiting the vegetation cleared for the Project, which minimises Scope 1 emissions.

In addition, the following management measures are proposed:

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

12.3 Air Quality Monitoring Programs

12.3.1 Stack Emission Testing

Monitoring of emissions from the diesel generators, power generation facilities and waste incinerators should be performed on commissioning and then annually to confirm that the emission rates and other stack parameters are within the estimates used in this assessment.

For the power generators, this monitoring program should include consideration of:

- Oxides of nitrogen (NO, NO_2 and NO_X);
- Sulphur dioxide;
- Carbon monoxide;
- Particulate matter; and
- Exhaust gas conditions (temperature, exit velocity, oxygen and moisture contents).

For the waste incinerators, the monitoring program should include the above parameters, as well as:

- Metals; and
- Volatile organic compounds.

12.3.2 Ambient Air Quality and Meteorological Monitoring

Continuation of the existing dust deposition monitoring program will provide useful data on impacts on local amenity values as the Project proceeds.

Operation of the existing meteorological monitoring stations should continue in order to collect data for the area to verify the information used in this assessment, and to provide information for future use.

The dispersion modelling results indicate that there is potential for adverse air quality impacts at Ziriruk and Fly Camp as a result of SO_2 emissions from the power generation facilities during the operational phase, once it is operating at full load. It is therefore recommended that ambient monitoring of SO_2 be performed at these locations during the early stages of the operational phase (i.e. when the power demand is lower and prior to all 12 IFO generators coming on-line) to verify the results of the modelling.

12.4 Greenhouse Gas Monitoring Programs

A major requirement for any GHG management system is that emissions are accurately quantified on a regular basis. This allows the major sources of emissions and the effectiveness of any adopted measures to be continually identified, measured and indexed. Using nationally and internationally recognised and approved calculation methodologies, WGJV should maintain records of all activity within the Project Area to enable the estimation of GHG emissions from the Project on a minimum of an annual basis.

Where possible, this data should be collated for each Project element (e.g. kWh/annum for mills and booster pump, etc.). This level of disaggregation allows for examination of the reasons in any changes in calculated GHG emissions totals over time and also allows the targeted implementation of cost-effective energy reduction measures.

13 CONCLUSIONS

13.1 Air Quality Assessment

The potential air quality impacts associated with air emissions from the Project have been assessed using a mixture of quantitative and qualitative assessment techniques. Design data available for the Project were reviewed to identify the key Project activities that have the greatest potential for impacts on local air quality, which were then assessed quantitatively. The emissions to air from these activities were estimated and atmospheric dispersion modelling was performed to simulate the dispersion of these emissions downwind (taking into account the local topography and meteorology) in order to estimate maximum ground level concentrations at nearby sensitive receptors. Assessment of the results of the modelling was based on international air quality guidelines and standards. Activities with a much lower potential for impacts on local air quality were assessed qualitatively, using a risk based approach.

Based on the information provided, the key air pollutants requiring assessment for the Project were identified as:

- Particulate emissions, which have the potential to impact on:
  - human health due to elevated suspended particulate concentrations
  - local amenity, visibility and aesthetic enjoyment due to elevated suspended particulate concentrations and dust deposition levels
  - health of other forms of life, including the protection of ecosystems and biodiversity, due to elevated dust deposition levels
- Products of fossil fuel combustion (in particular NO_x and SO_2) which have the potential to impact on the health and well-being of humans

PNG does not currently have specific statutory air quality standards. A review of relevant international guidelines and standards was therefore performed to identify appropriate criteria to use in the assessment, including:

- IFC
- WHO Air Quality Guidelines
- US EPA standards
- Australian guidelines

In addition to the review of relevant international guidelines and standards, as preliminary SO_2 dispersion modelling results predicted exceedances of the 2005 WHO criteria due to emissions from the IFO power generation facilities, WGJV commissioned a health-risk assessment (HRA). The HRA included a targeted evaluation of relevant literature, international and national guidelines for the protection of human health from SO_2 emissions, and derived a Project-specific SO_2 criterion based on US EPA methodology and the European Union Member States' air quality directive criteria. This Project-specific SO_2 criterion of 350 µg/m^3 (as the 3-year average of the 99th percentile of the annual distribution of daily maximum 1-hour concentrations) is equivalent to the 1-hour average ambient air quality limit for SO_2 set by European Union Directive 2008/50/EC (EU, 2008), and was used to assess the predicted SO_2 impacts from the Project.

The key findings of the air quality impact assessment are summarised below.

Mine Area

- Fugitive dust emission calculations indicate that during construction, hauling is estimated to be the major source of TSP and PM_{10} emissions in the Mine Area. The estimated $PM_{2.5}$ emissions are almost equally weighted between hauling, material handling, wind erosion and power generation operations, with a minor contribution from ventilation emissions. During the operational phase of the Project, the IFO power generation facilities was the major source of the estimated TSP, PM_{10} and $PM_{2.5}$ emissions.
- Maximum ground level suspended particulate concentrations (including the TSP, PM_{10} and $PM_{2.5}$ size fractions) and dust deposition rates were predicted by the modelling to comply with the adopted assessment criteria at all identified sensitive receptor locations in the vicinity of the Mine Area (i.e. surrounding villages) for both the construction and operational scenarios. Based on the results of the modelling, no health-related or nuisance (amenity) based impacts are therefore anticipated as a result of particulate emissions from the Mine Area.
- Modelling of emissions from the on-site diesel generators during the construction phase showed that predicted NO_2, SO_2 and CO concentrations would be below the adopted assessment criteria at the surrounding sensitive receptors. Provided the generators are installed, operated and maintained in accordance with the manufacturer's instructions and good engineering practice, no adverse air quality impacts are therefore anticipated as a result of these emissions.
- Modelling of emissions from the proposed IFO power generation facilities during the operational phase showed that:
  - The predicted CO concentrations were well below the relevant assessment criteria at all surrounding sensitive receptors.
  - The predicted NO_2 concentrations comply with the relevant ambient assessment criteria at all receptors, acknowledging that Ziriruk is fractionally below the 1-hour average WHO criterion of 200 $\mu g/m^3$, with a predicted maximum concentration of 199.8 $\mu g/m^3$.
  - The predicted 1-hour average SO_2 concentrations comply with the Project-specific criterion of 350 $\mu g/m^3$ derived from the HRA (Coffey, 2018) at all receptors with the exception of Ziriruk and Fly Camp. The predicted 1-hour average SO_2 concentration predicted at Ziriruk is 849 $\mu g/m^3$, which is approximately 2.4 times the Project-specific criterion, and the concentration predicted at Fly Camp of 605 $\mu g/m^3$ is approximately 1.7 times the criterion. The sensitive receptor predicted to be exposed to the third highest 1-hour average SO_2 concentration is Hekeng, with a concentration of 226 $\mu g/m^3$, which is well below the Project-specific criterion of 350 $\mu g/m^3$.
- The above results indicate that there is potential for adverse air quality impacts at Ziriruk and Fly Camp as a result of SO_2 emissions from the IFO power generation facilities during the operational phase, once it is operating at full load. Ambient monitoring at these locations could be performed during the early stages of the operational phase (i.e. when the power demand is lower and prior to all 12 IFO generators coming on-line) to verify the results of the modelling. If the monitoring confirms that concentrations above the Project criteria could be expected at these locations once the power generation facilities are operating at full load, then further management measures could be implemented. Management measures to be investigated include scrubbers on the power generation facilities' stacks or increasing the exhaust gas exit velocity, with the WGJV committed to achieving compliance with adopted air quality criteria.
- Emissions of combustion products from mobile plant and machinery will be emitted over a large area and will be well-diluted before they can travel off-site. The potential for elevated off-site concentrations as a result of these emissions is therefore considered to be negligible.

Infrastructure Corridor

- Construction activities associated with the pipelines have the potential to generate dust from demolition, earthworks and construction activities. The potential risks associated with dust emissions from construction of the pipelines have been assessed qualitatively using the risk assessment procedure published by the Institute of Air Quality Management, UK.
- The assessment of potential impacts due to dust emissions for pipeline construction works concluded that there is a 'low' risk of dust soiling impacts occurring at the nearest sensitive receptors even if no management measures were to be applied during the earthworks, and a 'negligible' risk of dust soiling impacts at other sensitive locations located further away. The risk of human health impacts is classified as 'low' or 'negligible' at all locations, even if no management measures were to be applied.
- Provided appropriate management measures are applied during pipeline construction works, it is anticipated that the potential risks of dust deposition and human health impacts at sensitive receptors close to the pipelines' corridor due to dust emissions from construction activities can be reduced from 'low' or 'medium' risk to 'negligible' risk. In addition, the impacts in any given location will be short-term in nature as the works proceed along the corridor. A detailed environmental management plan should be prepared and implemented prior to construction works, and should include contingency plans and response procedures (e.g. proactive response procedures and complaints handling procedures) and suitable reporting and performance monitoring procedures.
- Air emissions from the operation of the concentrate, tailings and fuel pipelines will be minimal and do not have potential for any adverse air quality impacts at the nearest sensitive receptors.

Coastal Area

- Construction activities associated with the Port Facilities Area and the Outfall Area have the potential to generate dust from construction activities. The potential risks associated with dust emissions from construction activities at these sites have been assessed qualitatively using the IAQM risk assessment methodology. This assessment concluded that the closest sensitive receptors to these sites are located well beyond the largest separation distance recommended for screening out projects requiring assessment. No further assessment has therefore been performed and the risk of potential impacts can be expected to be negligible.
- Air emissions from the operation of the Port Facilities Area and the Outfall Area will be minimal and do not have potential for any adverse air quality impacts at the nearest sensitive receptors.

Other Impacts

- High levels of dust deposition may cause damage to vegetation by blocking leaf stomata or inhibiting photosynthesis due to smothered leaf surfaces. The very high rainfall in the Project Area, however, would minimise such impacts by washing away dust deposited on leaves, and the low wind speeds characteristic of the area would minimise the area potentially affected as the majority of the particulate would not travel far before settling out of the air. As a result, any damage to vegetation due to dust emissions is expected to be very localised and limited to less than a few hundred metres from the active work areas.
- Different plant species and varieties and even individuals of the same species may vary considerably in their sensitivity to SO_2. 'Critical levels' have been developed for a number of air pollutants by the United Nations Economic Commission for Europe (UN/ECE) for the protection of vegetation (ICP, August 2017). While there are likely to be limitations in the relevance of these European-based guidelines to the types of vegetation and the growing conditions that exist in the Mine Area (warm temperatures and high rainfall), in the absence of local guidelines or data they have been used to provide guidance on the potential for adverse impacts on vegetation due to SO_2 emissions from the Project.
- The results of the modelling performed as part of this assessment indicates that:

- During the construction phase, annual average SO_2 concentrations are predicted to be far below the UN/ECE guideline for vegetation impacts on forest ecosystems across the modelling domain.
- During the operational phase there is an area surrounding the IFO power generation facilities that is predicted to be exposed to annual average SO_2 concentrations above the UN/ECE guideline for vegetation impacts on forest ecosystems of 20 µg/m^3. Therefore, as recommended for the predicted exceedances of the 1-hour average Project-specific SO_2 criterion, it is recommended that ambient monitoring and vegetation surveys be performed within this area during the early stages of the operational phase (i.e. during the first three years when the power demand is lower and prior to all 12 IFO generators coming on-line) to verify the results of the modelling and to assess the sensitivity of local vegetation to SO_2. If the monitoring confirms that there is potential for vegetation impacts to occur (such as impacts on gardens utilised by villagers) once the power generation facilities are operating at full load, then additional management measures should be developed and implemented to offset identified impacts.

13.2 Greenhouse Gas Assessment

A quantitative GHG assessment has been performed for the Project. The assessment was performed in a six stage process:

- definition of the Project boundary
- identification of emission sources within the Project boundary
- identification of activity data for each emission source
- identification of emission calculation methodologies for each source
- calculation of GHG emissions
- identification of potential GHG mitigation strategies to reduce the GHG impact of the Project

GHG sources have been identified through the examination of process descriptions and activity data for each source provided by WGJV. Internationally accepted GHG emission calculation methods were used (Intergovernmental Panel on Climate Change [IPCC] and Australian Government Department of Climate Change and Energy Efficiency [DCCEE]) to calculate direct (Scope 1) emissions attributable to Project construction and operation activities.

The total scope 1 GHG emissions for the Project are estimated at 15,182 kt CO_2-e assuming a five year construction period, 27 year operation and a three year closure period. Averaged over the 35 year life span of the Project, this is equivalent to 433.8 kt CO_2-e/annum.

Taking into account both Scope 1 and Scope 2 emissions, total estimated GHG emissions for the Project are estimated at 15,354 kt CO_2-e. Averaged over the 35 year life span of the Project, this is equivalent to 438.7 kt CO_2-e/annum.

The main sources of GHG emissions are diesel combustion and land clearance during mine construction, and IFO and diesel combustion during mine operation.

The most recent total GHG emissions reported for Papua New Guinea were for 2013, with emissions of 70,855 kt CO_2-e including land use change and forestry (LUCF) and 16,434 kt CO_2-e excluding LUCF (FAO, 2014). Comparison of the estimated annual average Scope 1 and Scope 2 GHG emissions over the life of the Project of 438.7 kt CO_2-e/annum with the total national emissions (including LUCF) reported by the FAO indicates that over the life of the Project, it would result in a relatively minor (0.6%) increase in the national emissions.

The environmental value potentially impacted due to GHG emissions from the Project is defined as the maintenance of climatic systems to maintain the health, development and well-being of humans and the protection of ecosystems and biodiversity. The sensitivity of climatic systems is somewhat uncertain as there are remaining scientific uncertainties about the magnitude of the positive and negative feedbacks in the climatic system. For the purposes of this study, the sensitivity of this value has been characterised as moderate. The magnitude of change related to GHG emissions from the Project is considered to be low due to the minimal contribution these emissions will have to the overall greenhouse gas emissions of PNG.

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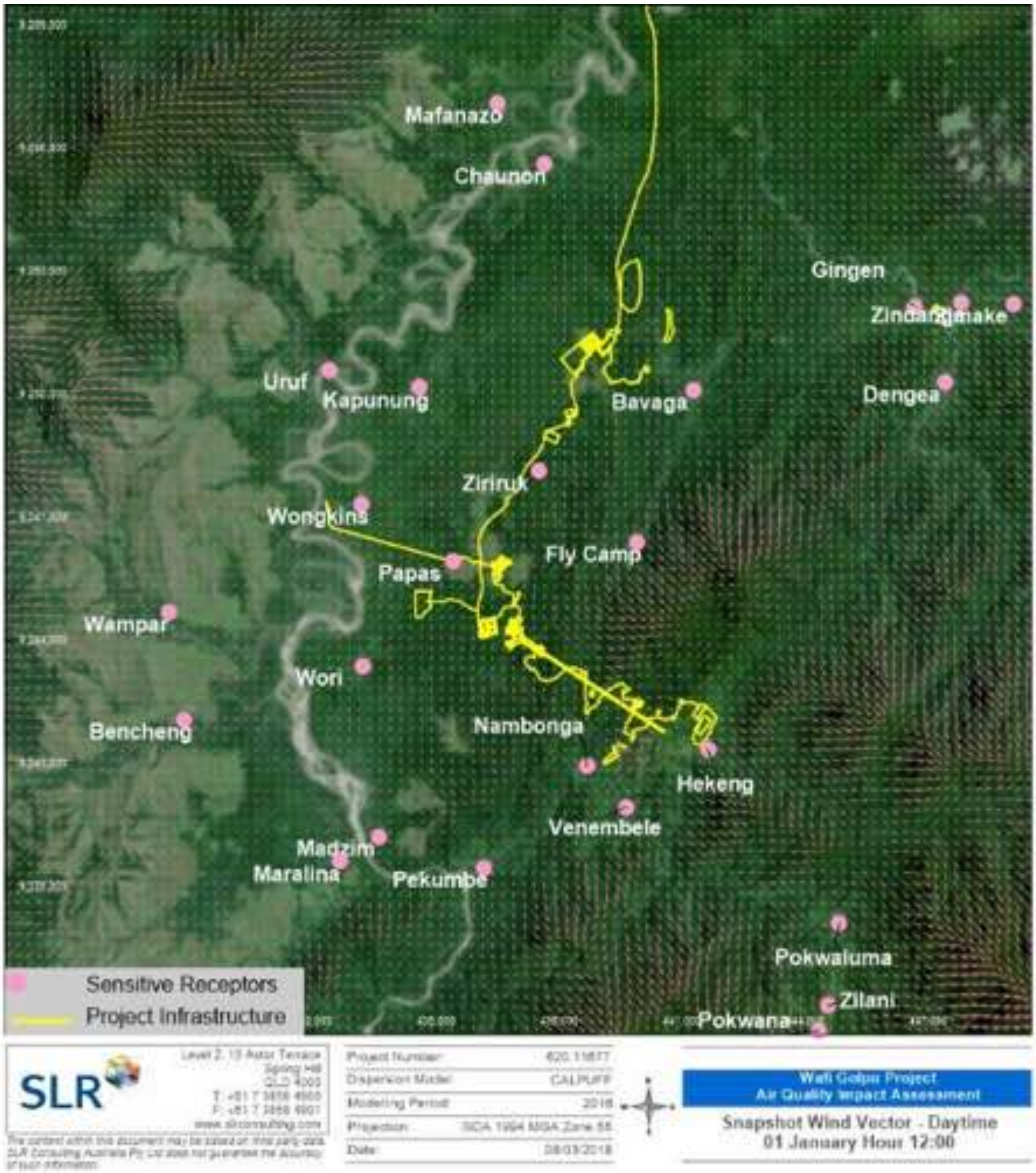
SPATIAL VARIATION OF WIND



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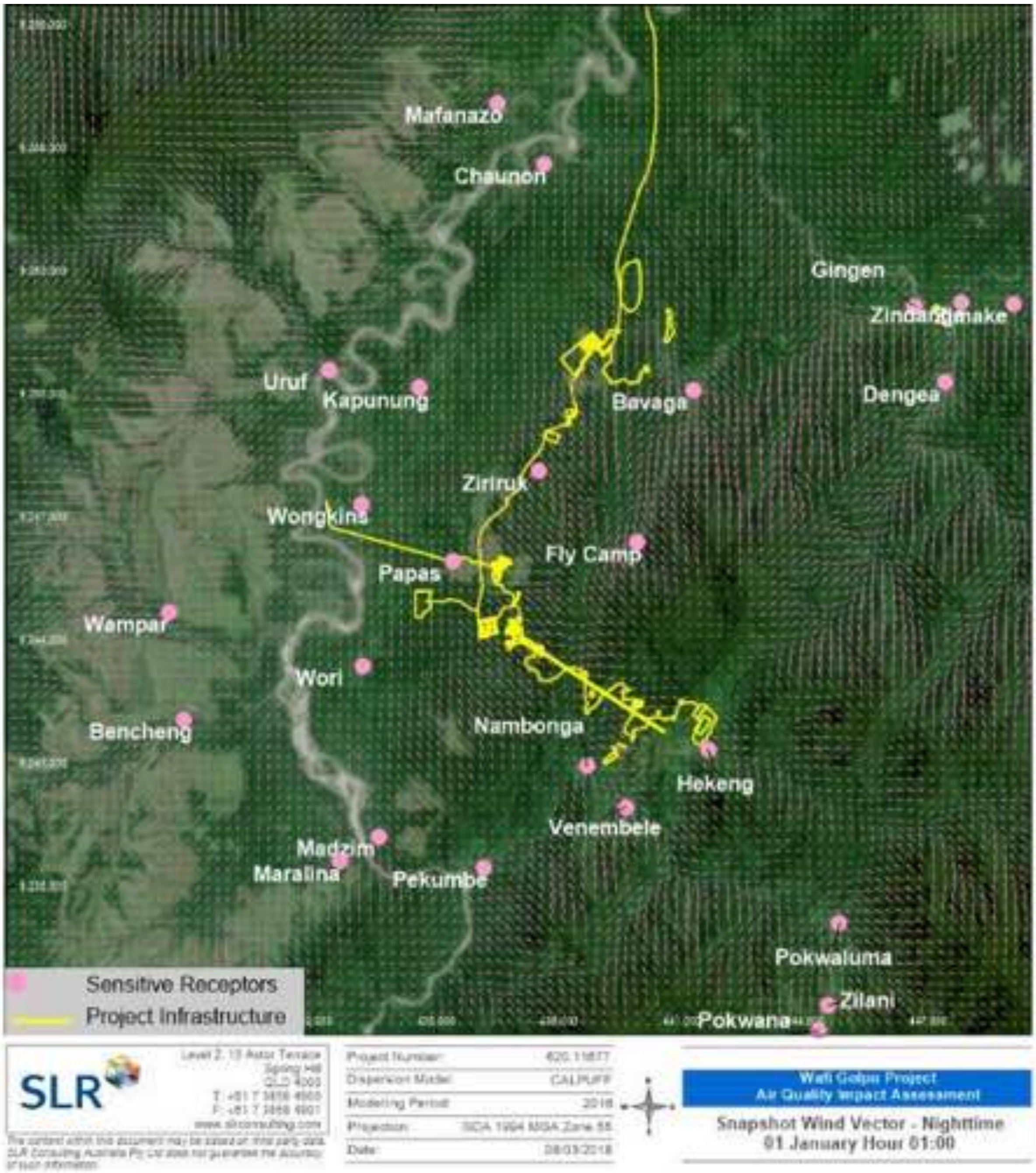


EMISSION FACTORS

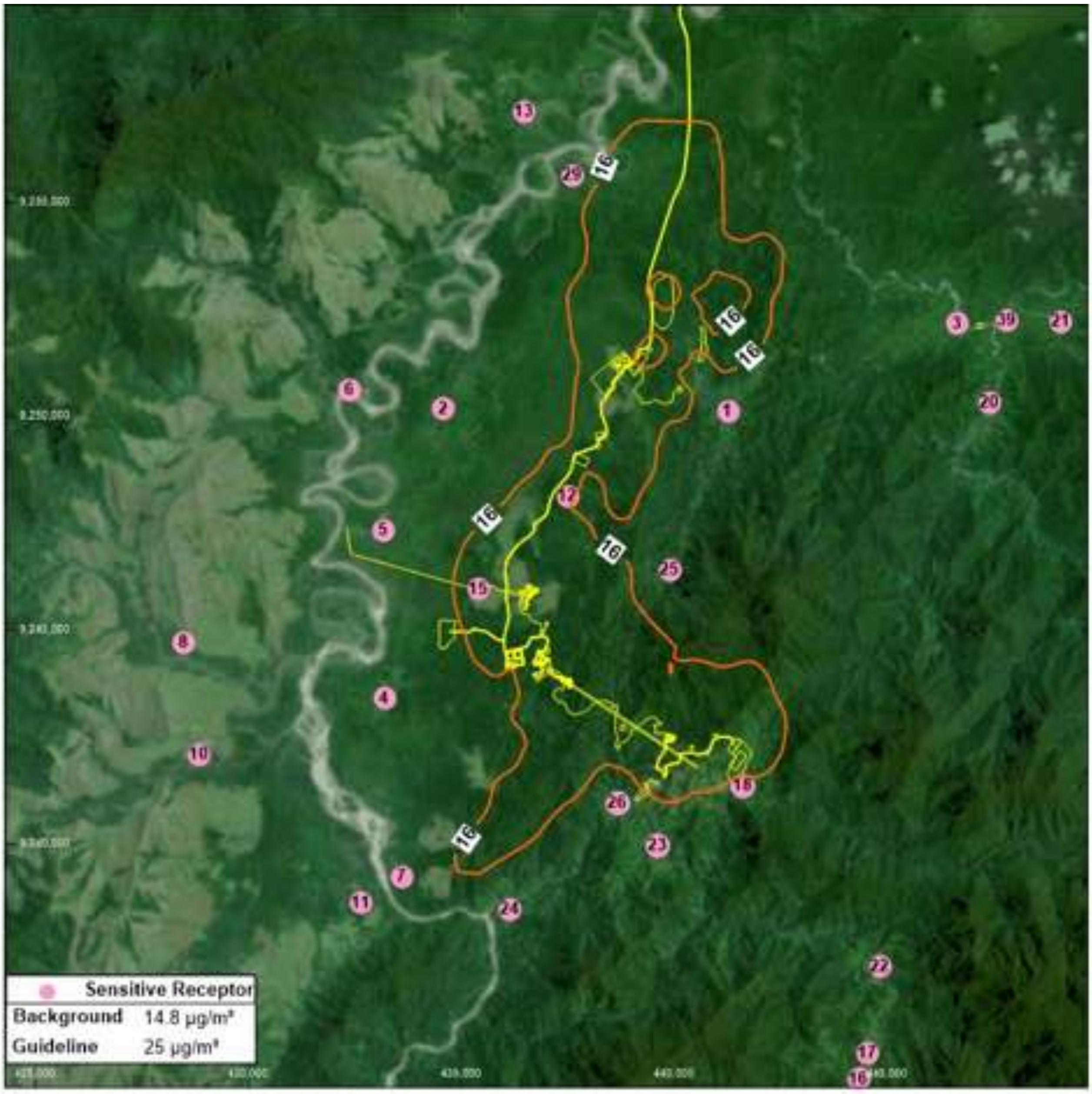
Table B1 Estimated Emission Factors - Construction

Activity	Emission Factors			Unit
	TSP	PM_{10}	$PM_{2.5}$	
Bulldozer	1.8	0.3	0.2	kg/h
Blasting	0.404	0.210	0.121	kg/blast
Drilling	0.59	0.3068	0.0276	kg/hole
Rock crushing	0.0027	0.0012	0.00012	kg/t
wind erosion	0.40	0.20	0.02	kg/ha/hour
Loading/unloading materials	0.0001	0.0001	0.00001	kg/t
Hauling materials from quarry	1.224	0.247	0.025	kg/VKT
Concrete Batching Plant	0.05	0.05	0.01	kg/t
Ventilation system exhaust (dust particulates)	0.42	0.42	0.04	mg/m³
Construction activities	2.69	1.35	0.13	kg/ha/month

Table B2 Estimated Emission Factors - Operation

Activity	Emission Factors			Unit
	TSP	PM_{10}	$PM_{2.5}$	
Loading/unloading ore materials	0.0050	0.0020	0.0002	kg/t
Bulldozer	1.8	0.3	0.2	kg/h
Milling	0.0050	0.0020	0.0002	kg/t
Wind erosion	0.40	0.20	0.02	kg/ha/hour
Concrete Batching Plant	0.05	0.05	0.01	kg/t
Ventilation system exhaust (dust particulates)	0.42	0.42	0.04	mg/m³

CONTOUR PLOTS



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Modelling Period:	2016
Projection:	GDA 1994 MGA Zone 55
Date:	13/03/2018

Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Construction

Pollutant	PM	Averaging Period	24-hour	Unit	µg/m³


13
29
3
39
21
6
2
1
20
12
5
25
15
8
4
10
18
26
23
7
11
24
22
17
16
Sensitive Receptor
Background 5.9 µg/m³
Guideline 10 µg/m³
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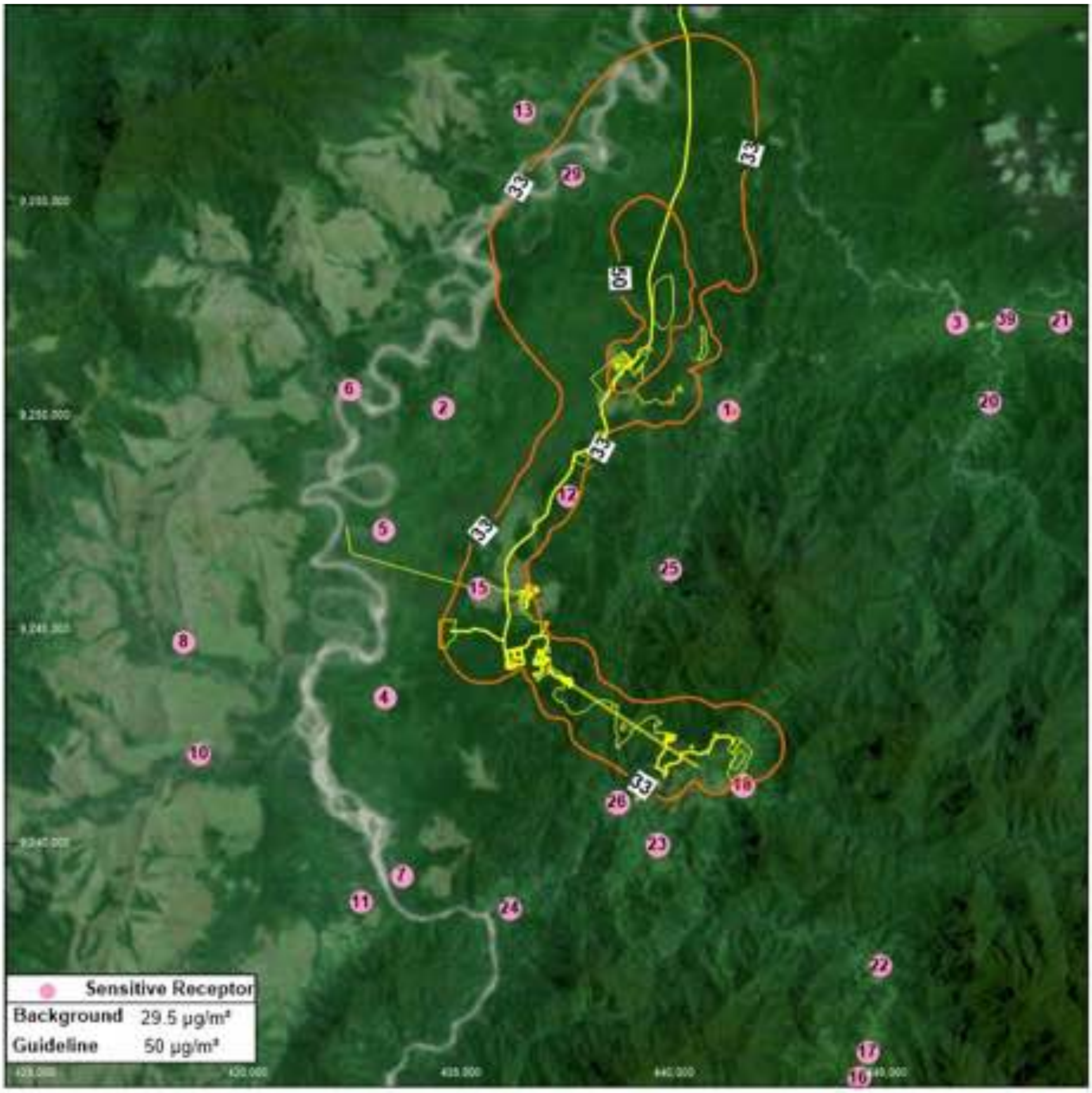
Cumulative Impact - Construction
Pollutant PM2.5
Averaging Period Annual
Unit µg/m³



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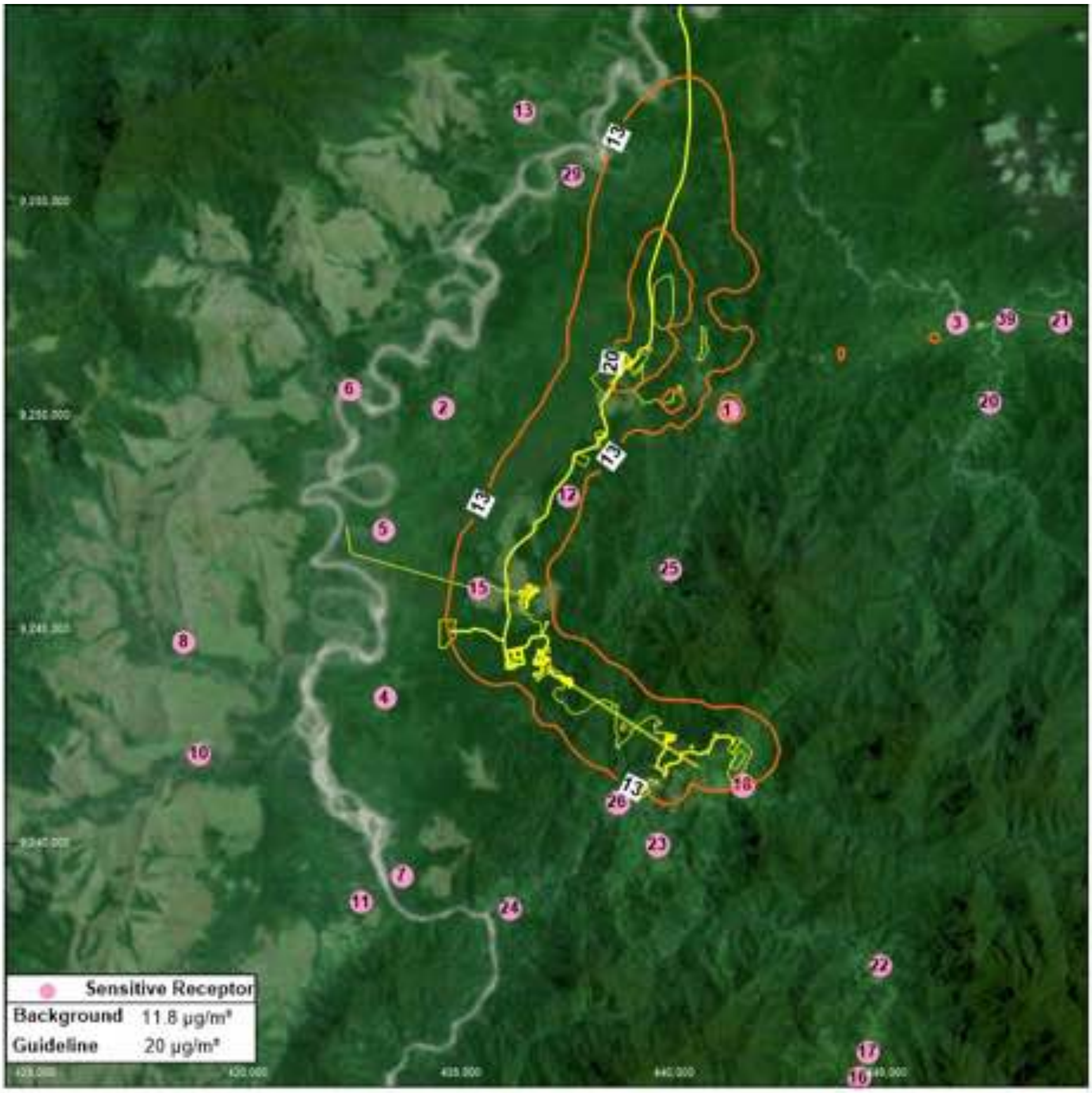
Air Quality Impact Assessment

Cumulative Impact - Construction

Pollutant	PM_{10}	Averaging Period	24-hour	Unit	µg/m³



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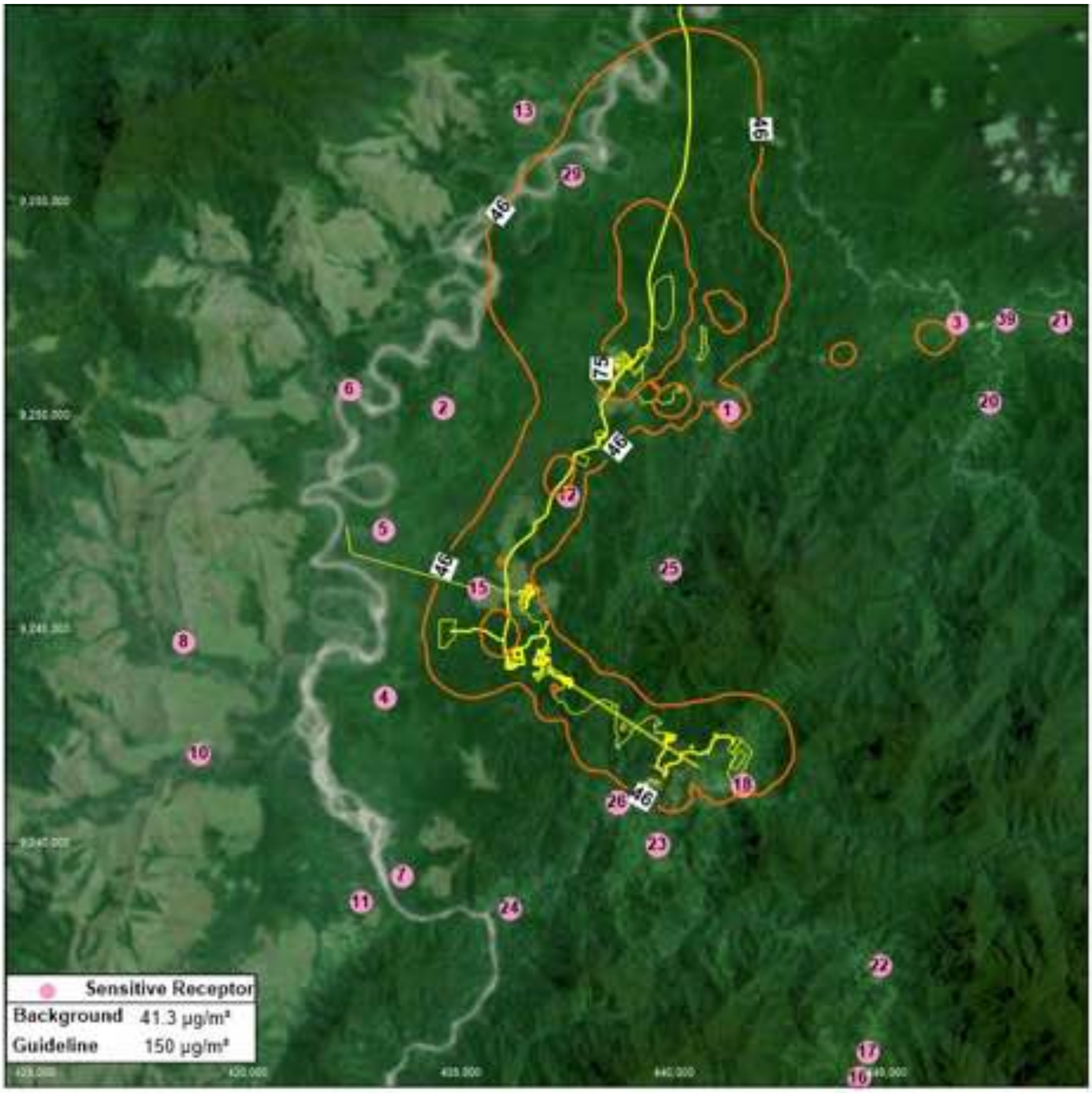
Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Construction

Pollutant	PM_{10}	Averaging Period	Annual	Unit	µg/m³



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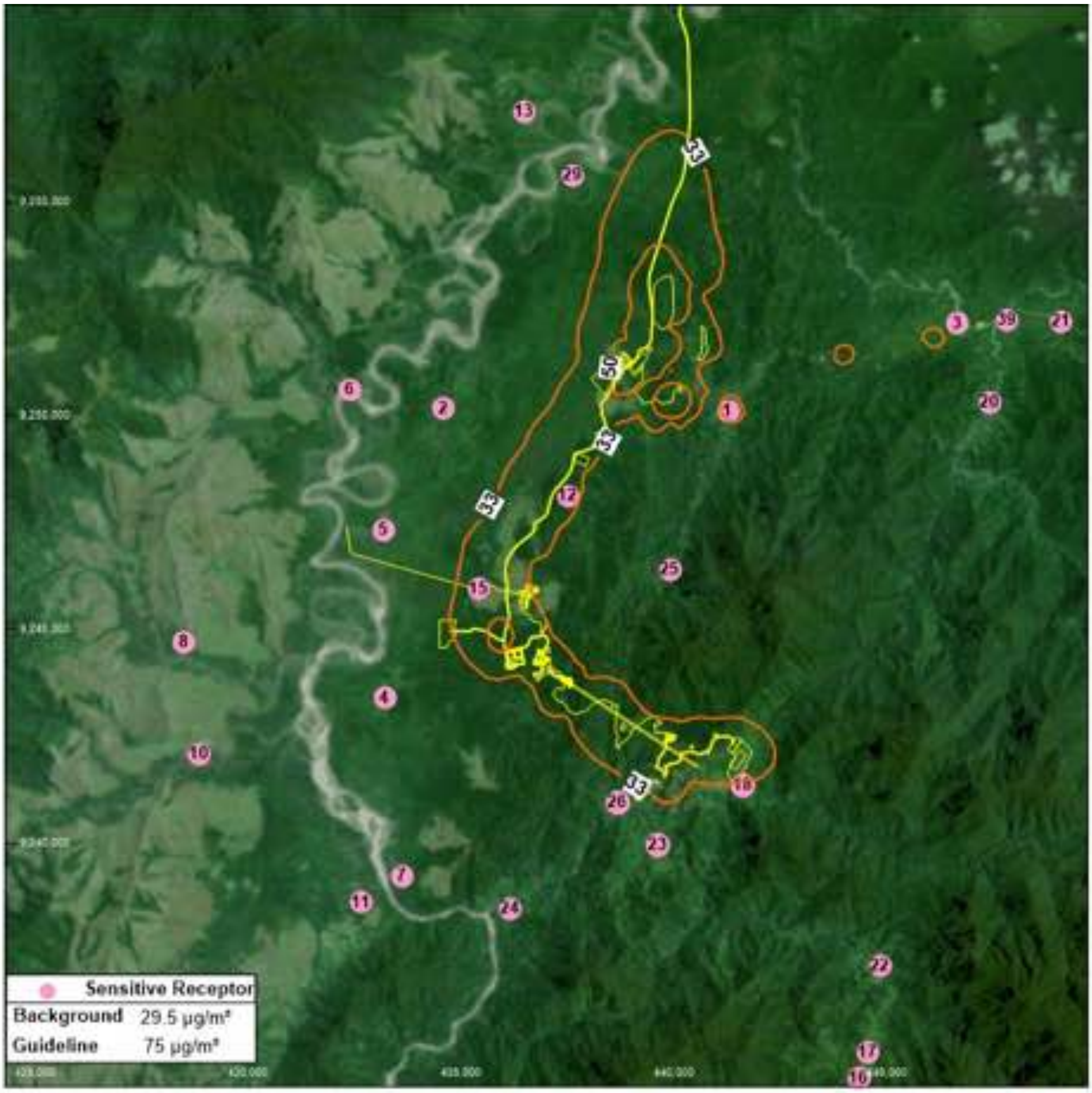
Air Quality Impact Assessment

Cumulative Impact - Construction

Pollutant	TSP	Averaging Period	24-hour	Unit	µg/m³



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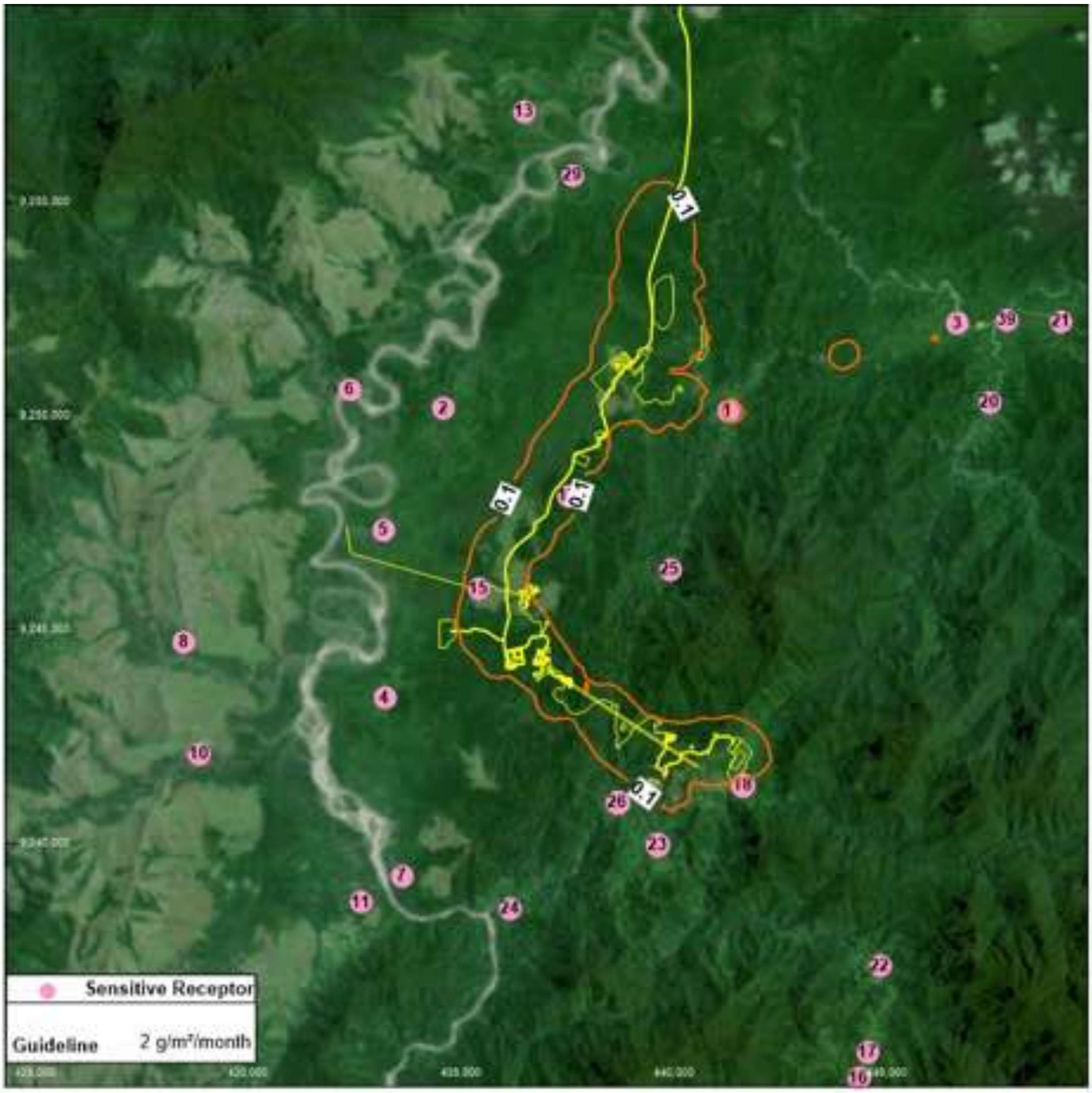
Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Construction

Pollutant	TSP	Averaging Period	Annual	Unit	µg/m³



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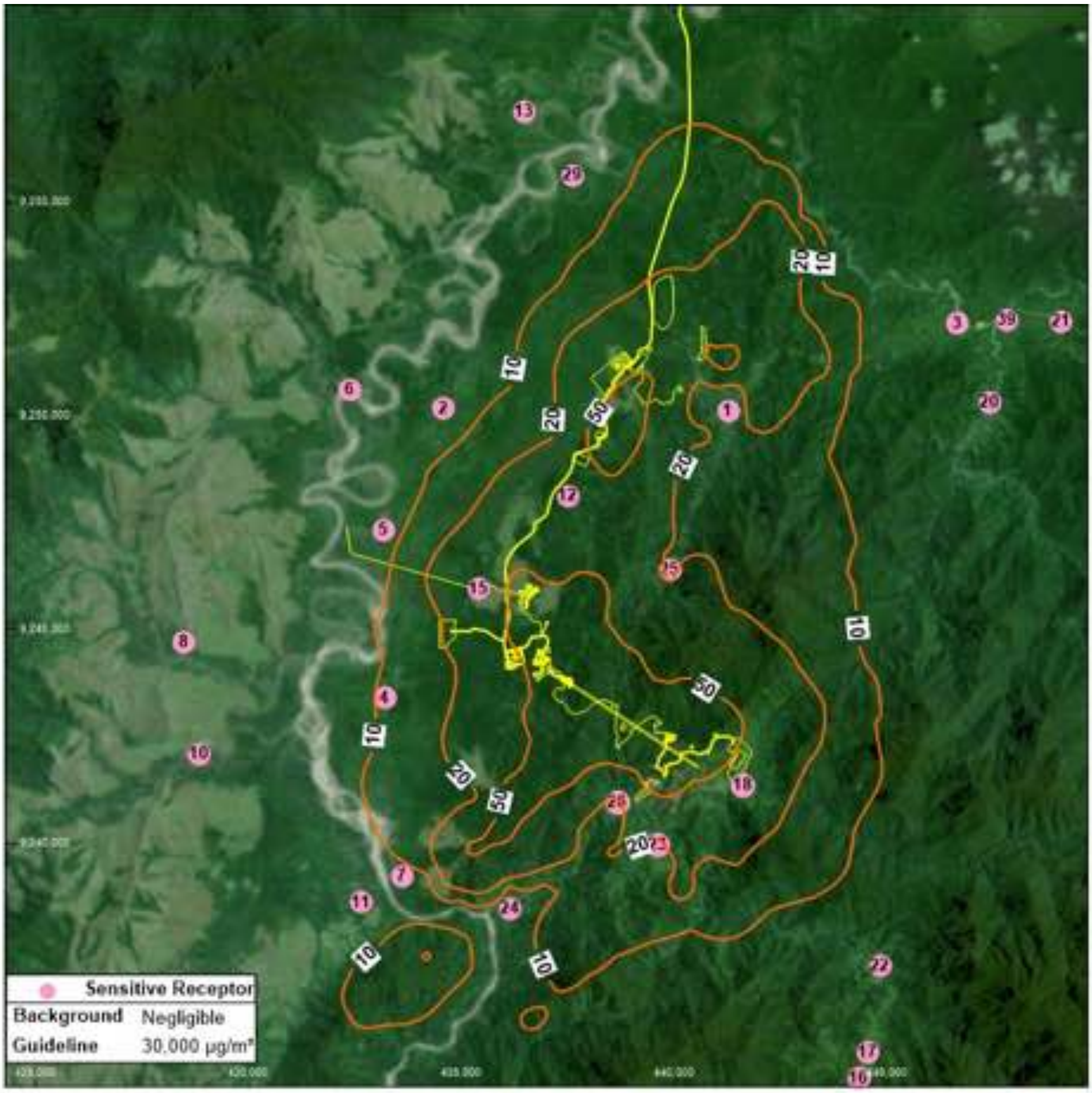
Air Quality Impact Assessment

Incremental Impact - Construction

Pollutant	Dust Deposition	Averaging Period	Annual	Unit	g/m²/month



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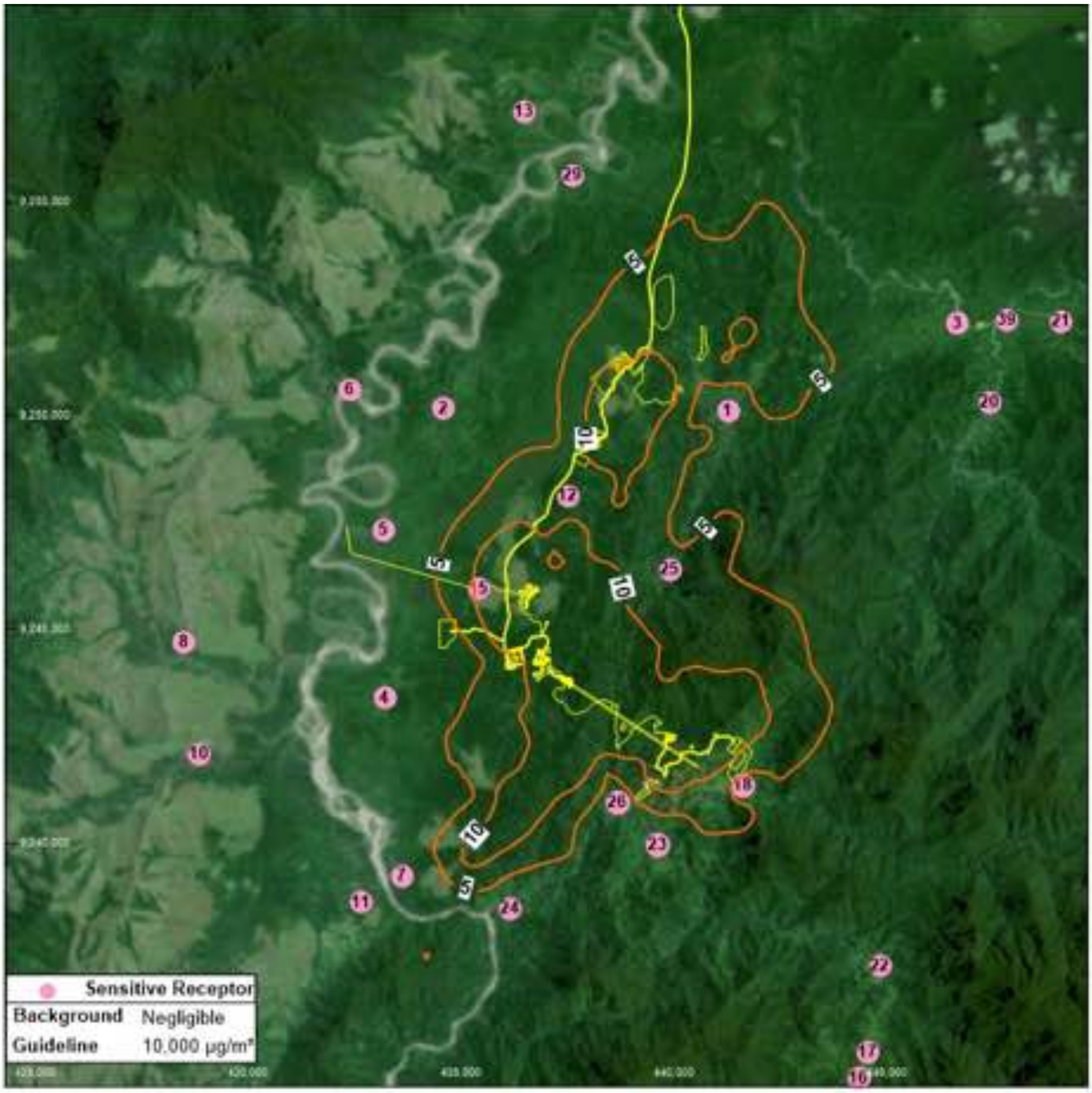
Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Construction

Pollutant	CO	Averaging Period	1-Hour	Unit	µg/m³



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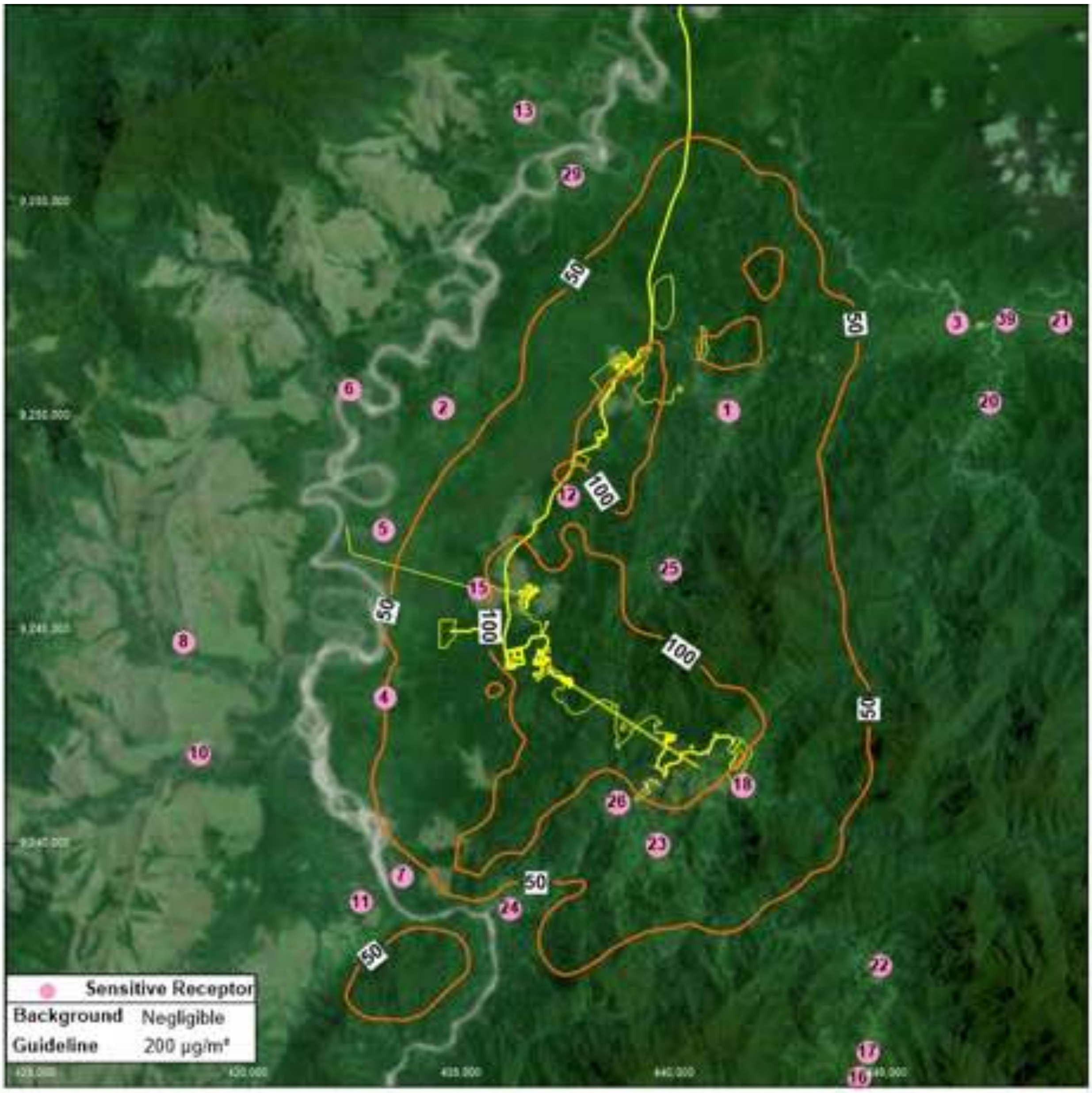
Cumulative Impact - Construction

Pollutant	CO	Averaging Period	24-hour	Unit	µg/m³



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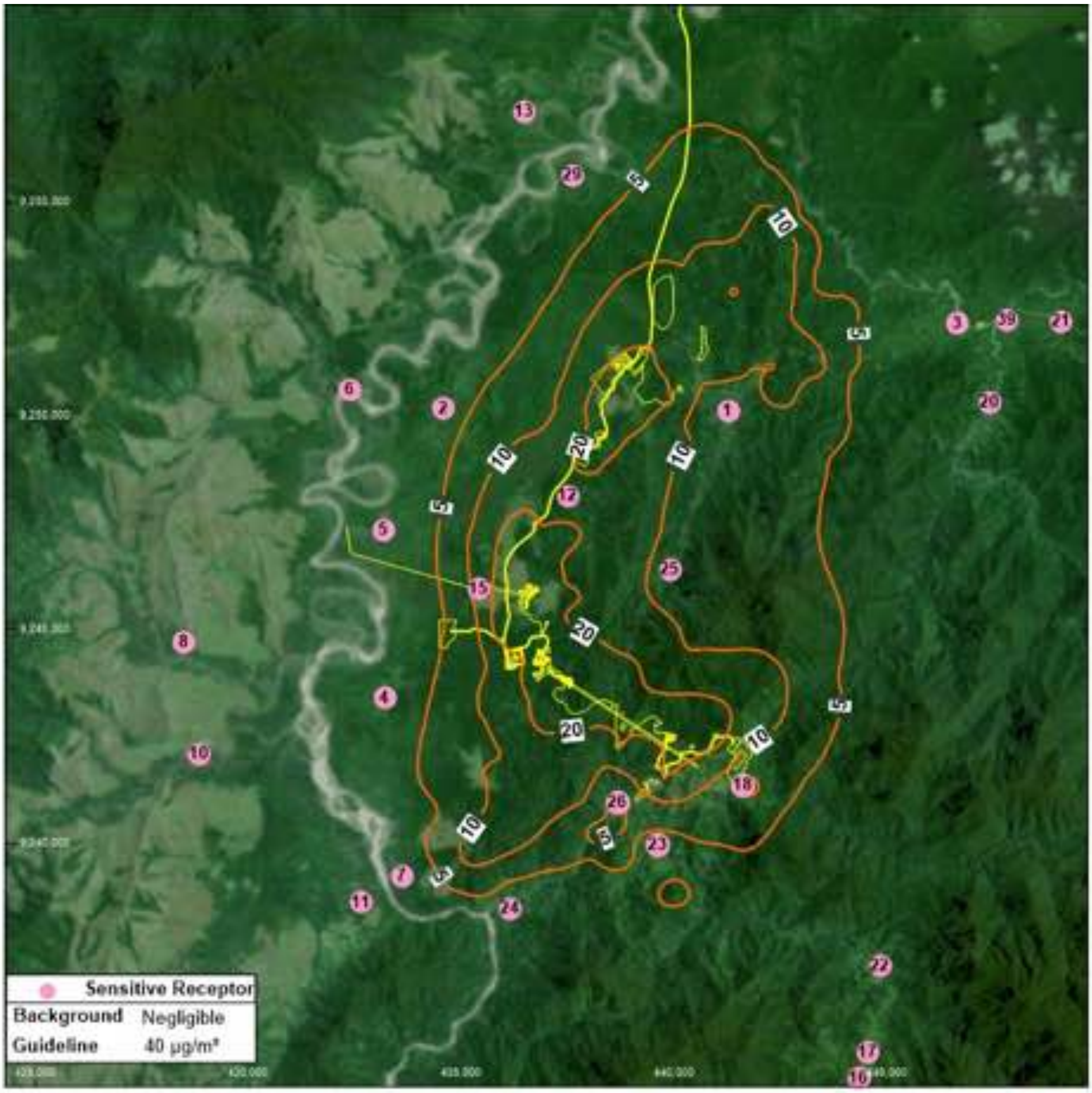
Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Construction

Pollutant	NO_2	Averaging Period	1-Hour	Unit	µg/m³



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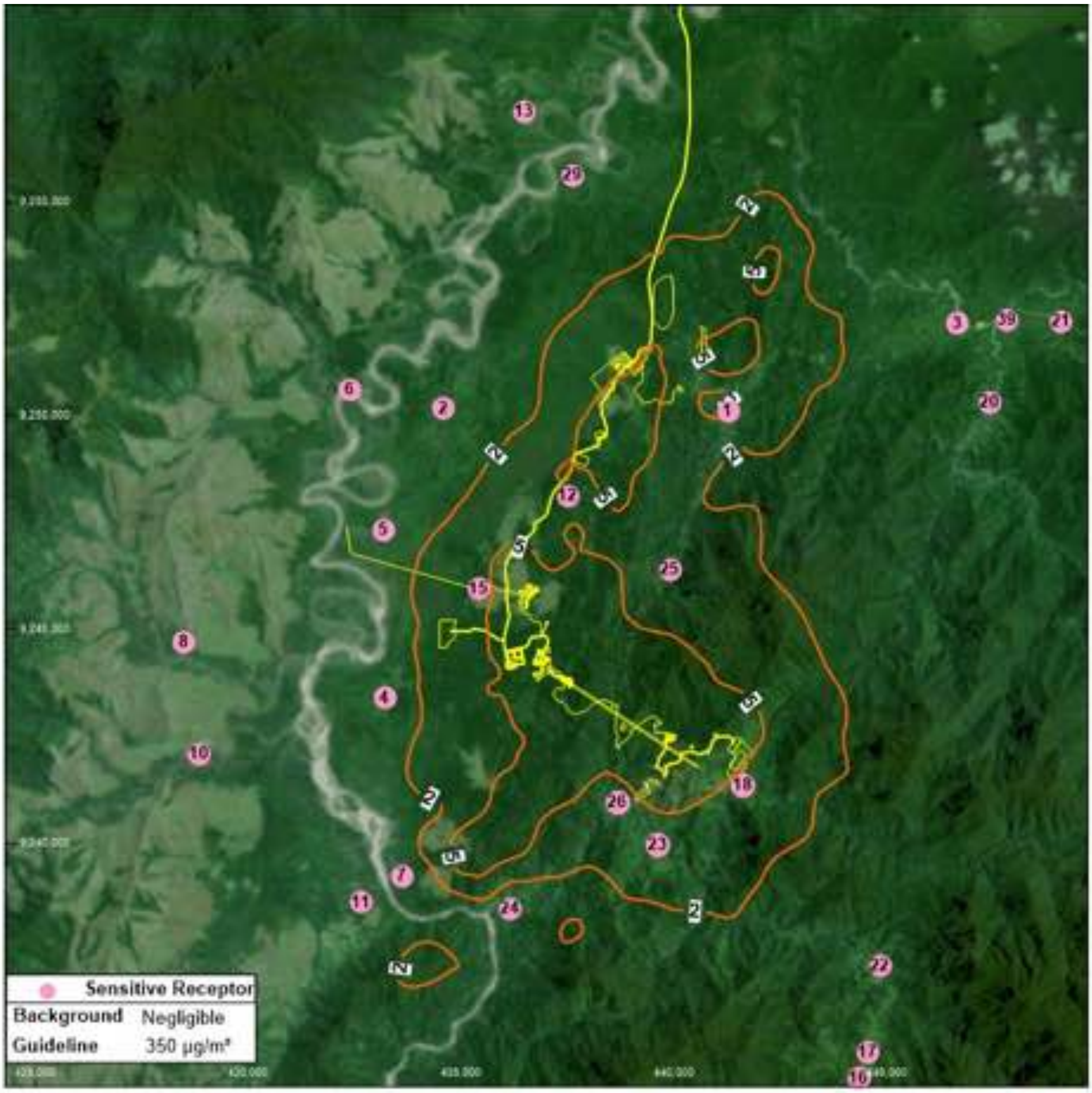
Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Construction

Pollutant	NO_2	Averaging Period	Annual	Unit	µg/m³



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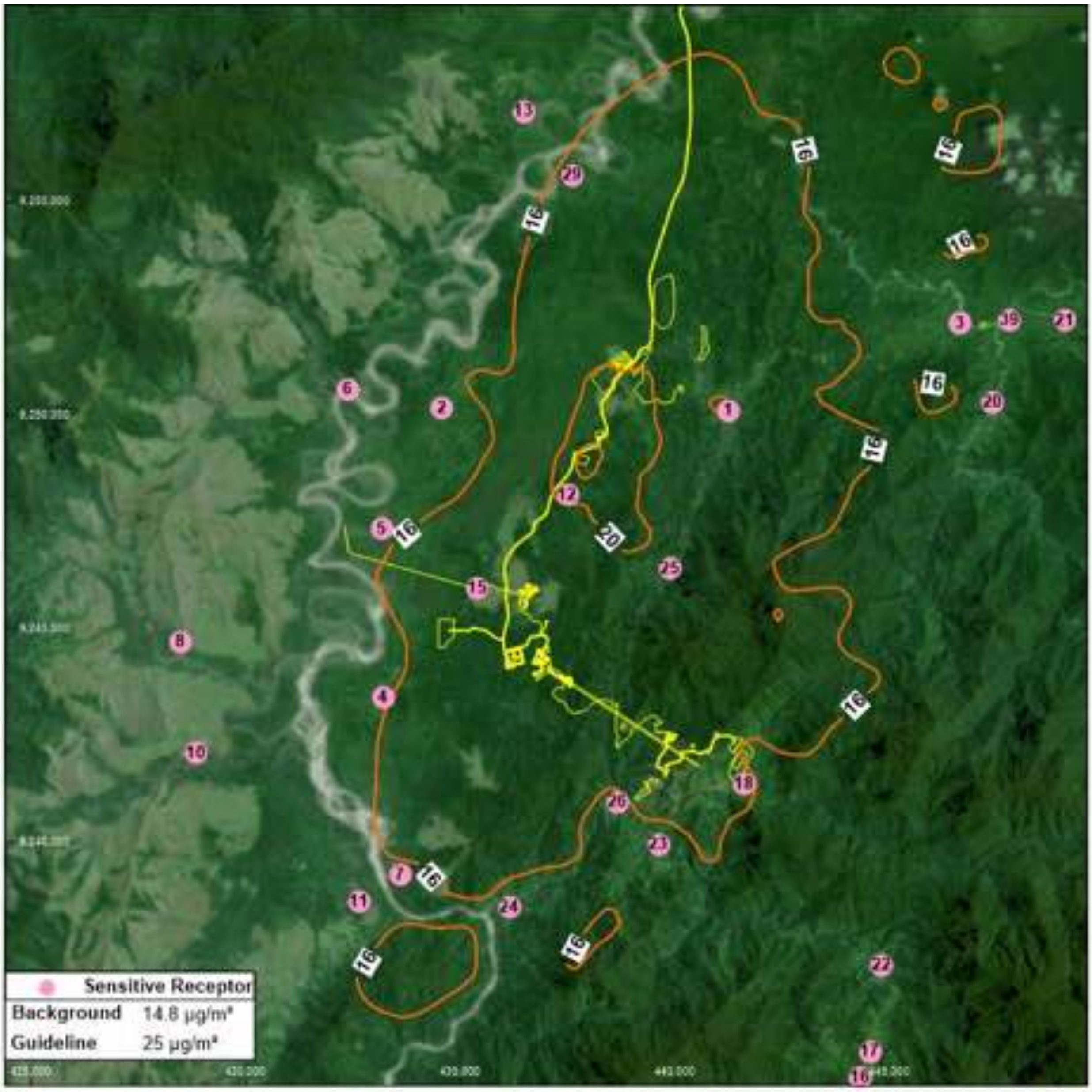
Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Construction

Pollutant	SO_2	Averaging Period	1-Hour	Unit	µg/m³



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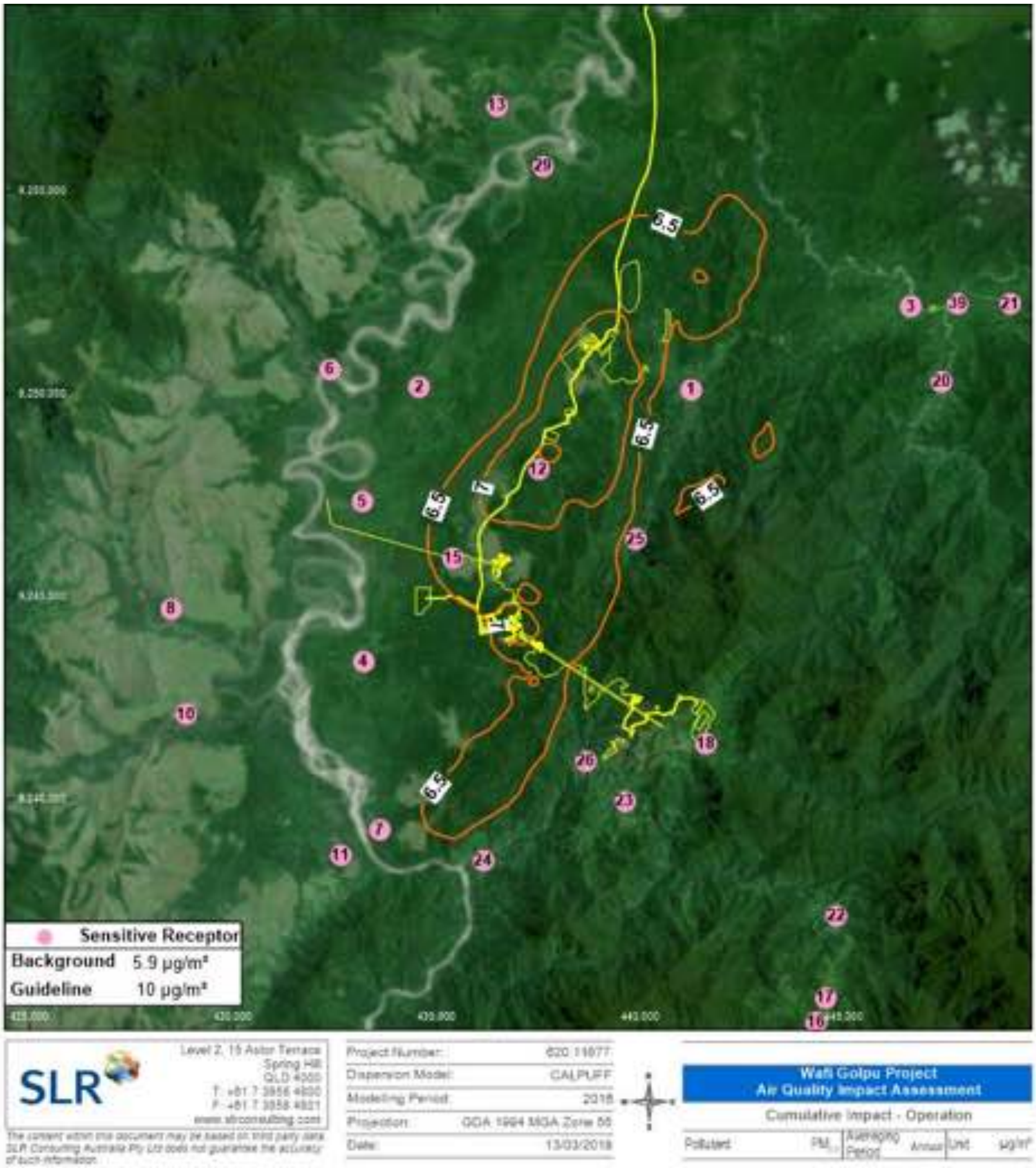
Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Operation

Pollutant	$PM_{2.5}$	Averaging Period	24-hour	Unit	µg/m³


Sensitive Receptor
Background 5.9 µg/m³
Guideline 10 µg/m³
6.5
7
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Pollutant
Averaging Period
Annual
Unit
µg/m³

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Air Quality Impact Assessment

Cumulative Impact - Operation

Pollutant	PM_{10}	Averaging Period	24-hour	Unit	µg/m³


12.5
12.5
12.5
12.5
12.5
12.5
Sensitive Receptor
Background 11.8 µg/m³
Guideline 20 µg/m³
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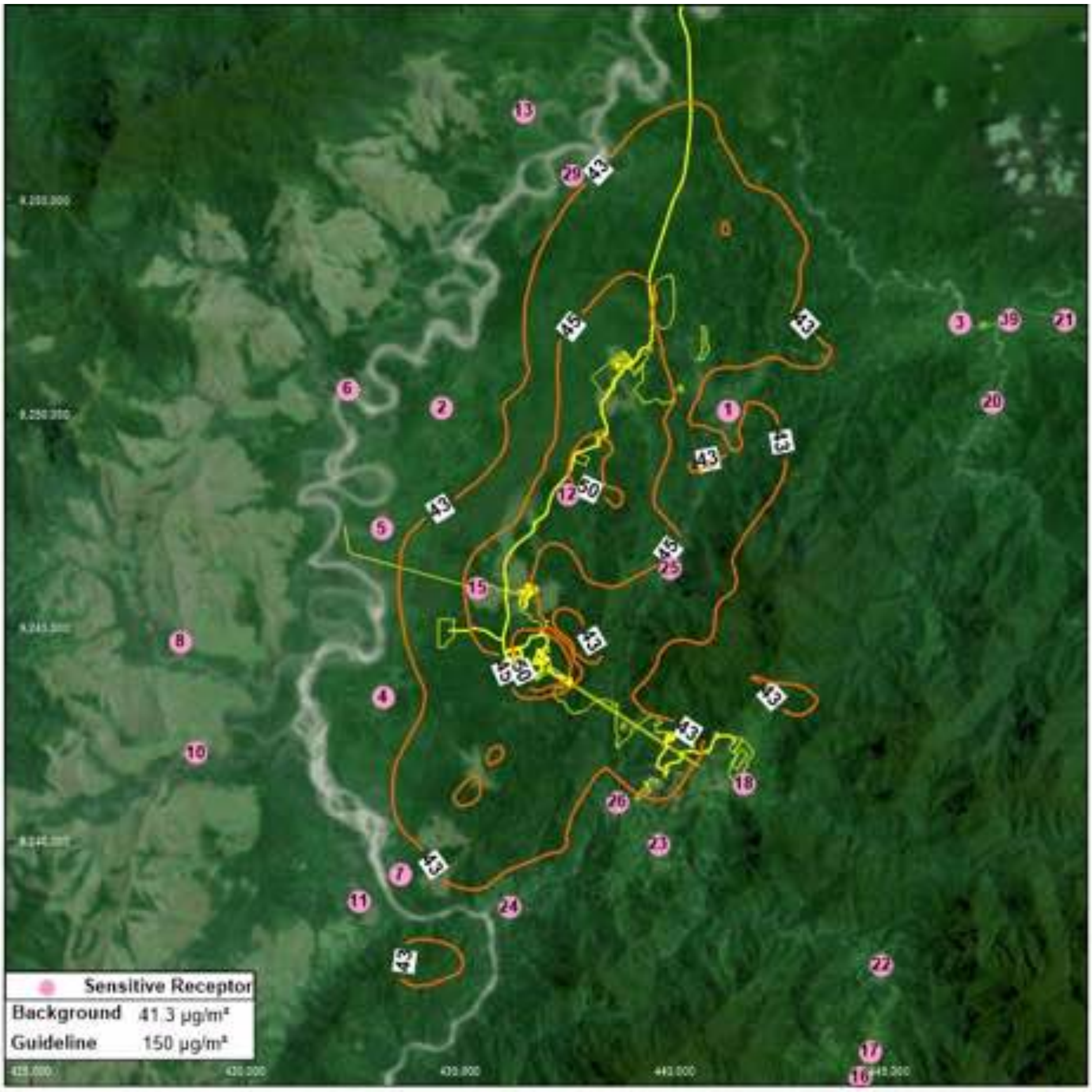
Project Number: 620.11677
Dispersion Model: CALPUFF
Modelling Period: 2016
Projection: GDA 1994 MGA Zone 55
Date: 13/03/2018
Wafi Golpu Project
Air Quality Impact Assessment
Cumulative Impact - Operation
Pollutant PM10
Averaging Period Annual
Unit µg/m³



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Wafi Golpu Project
Air Quality Impact Assessment
Cumulative Impact - Operation

Pollutant	TSP	Averaging Period	24-hour	Unit	µg/m³

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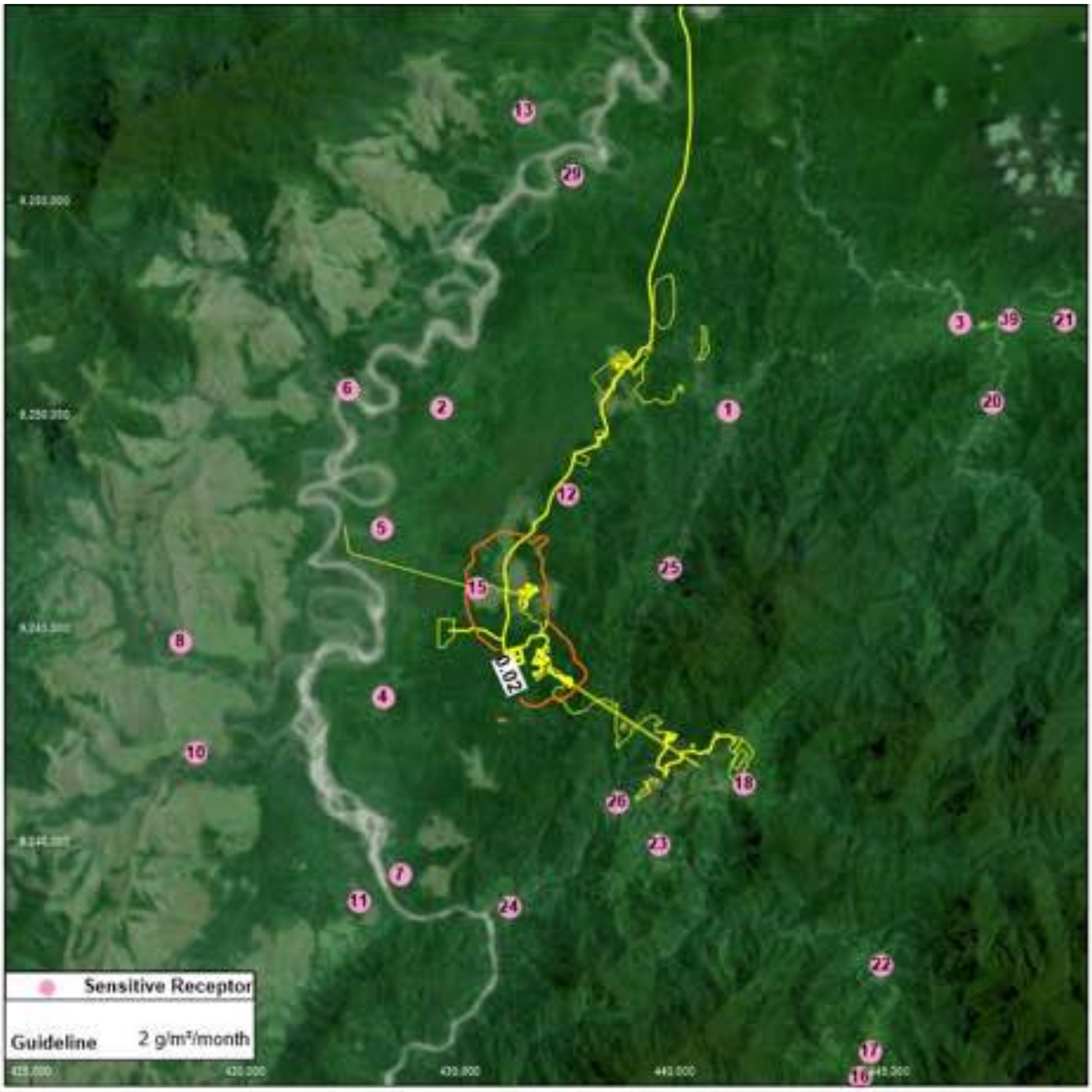
Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Operation

Pollutant	TSP	Averaging Period	Annual	Unit	µg/m³



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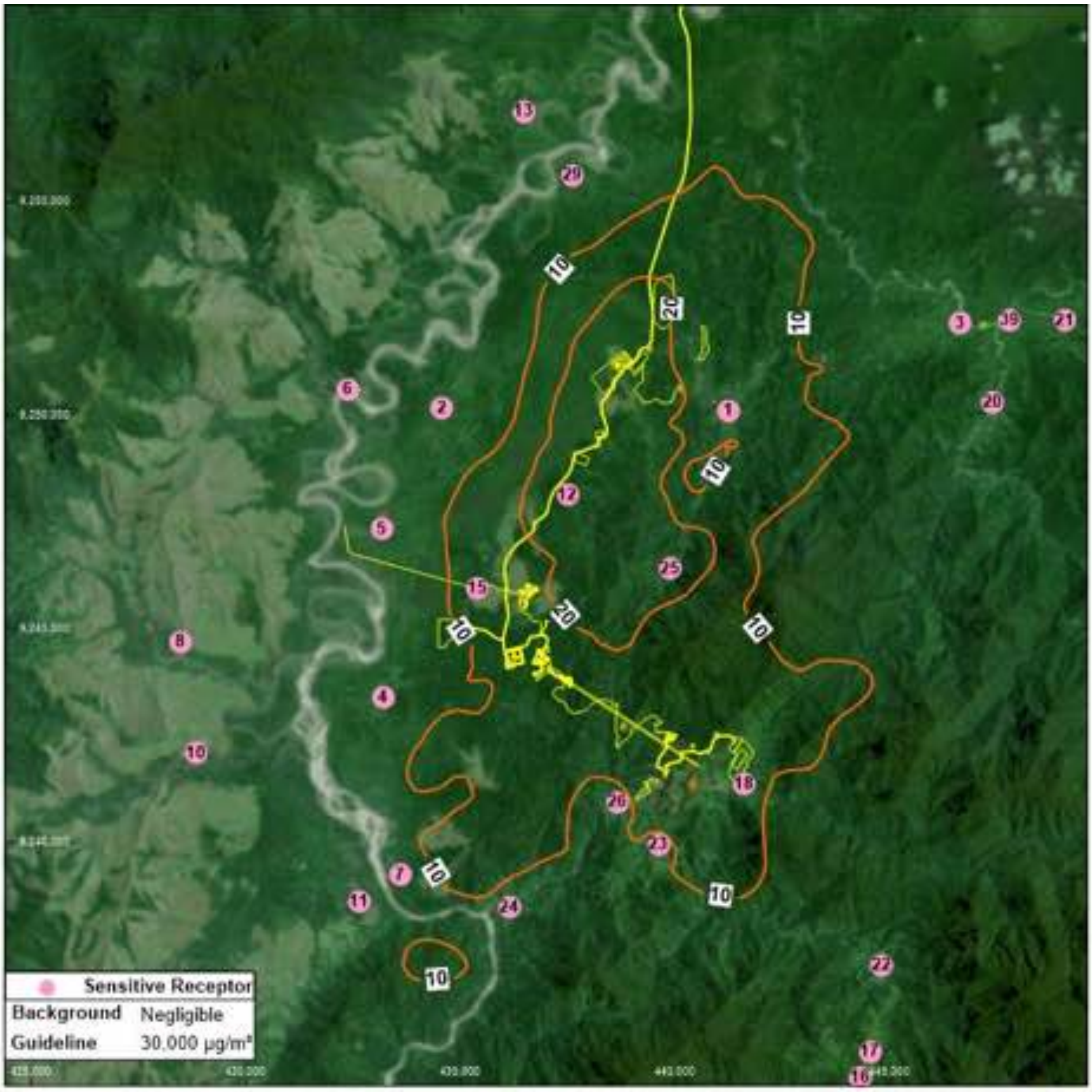
Wafi Golpu Project
Air Quality Impact Assessment

Incremental Impact - Operation

Pollutant	Dust Deposition	Averaging Period	Annual	Unit	g/m²/month



Project Number:	620.11677
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Modelling Period:	2016
Projection:	GDA 1994 MGA Zone 55
Date:	13/03/2018

Pollutant	CO	Averaging Period	1-Hour	Unit	µg/m³

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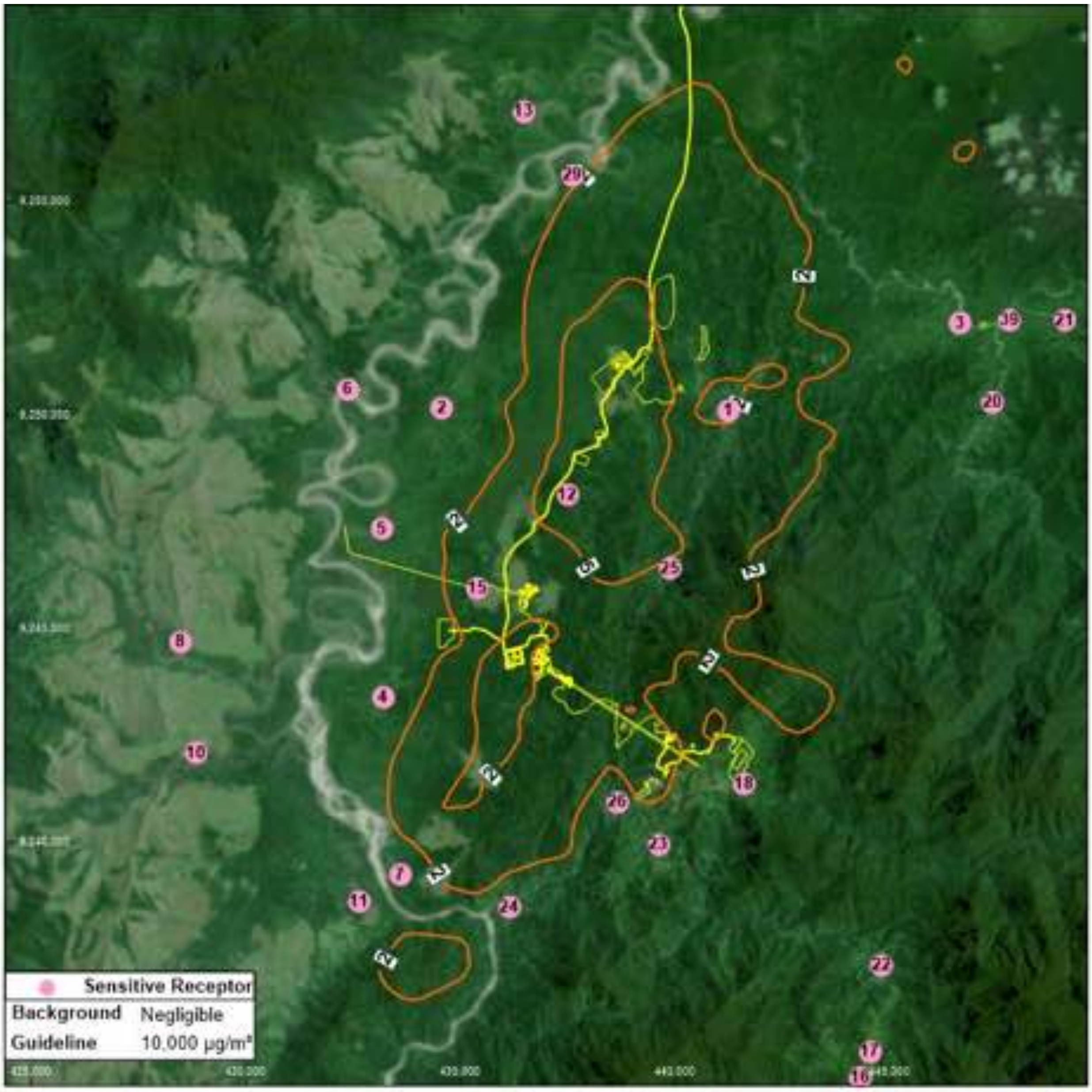

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Project Number:	620.11677
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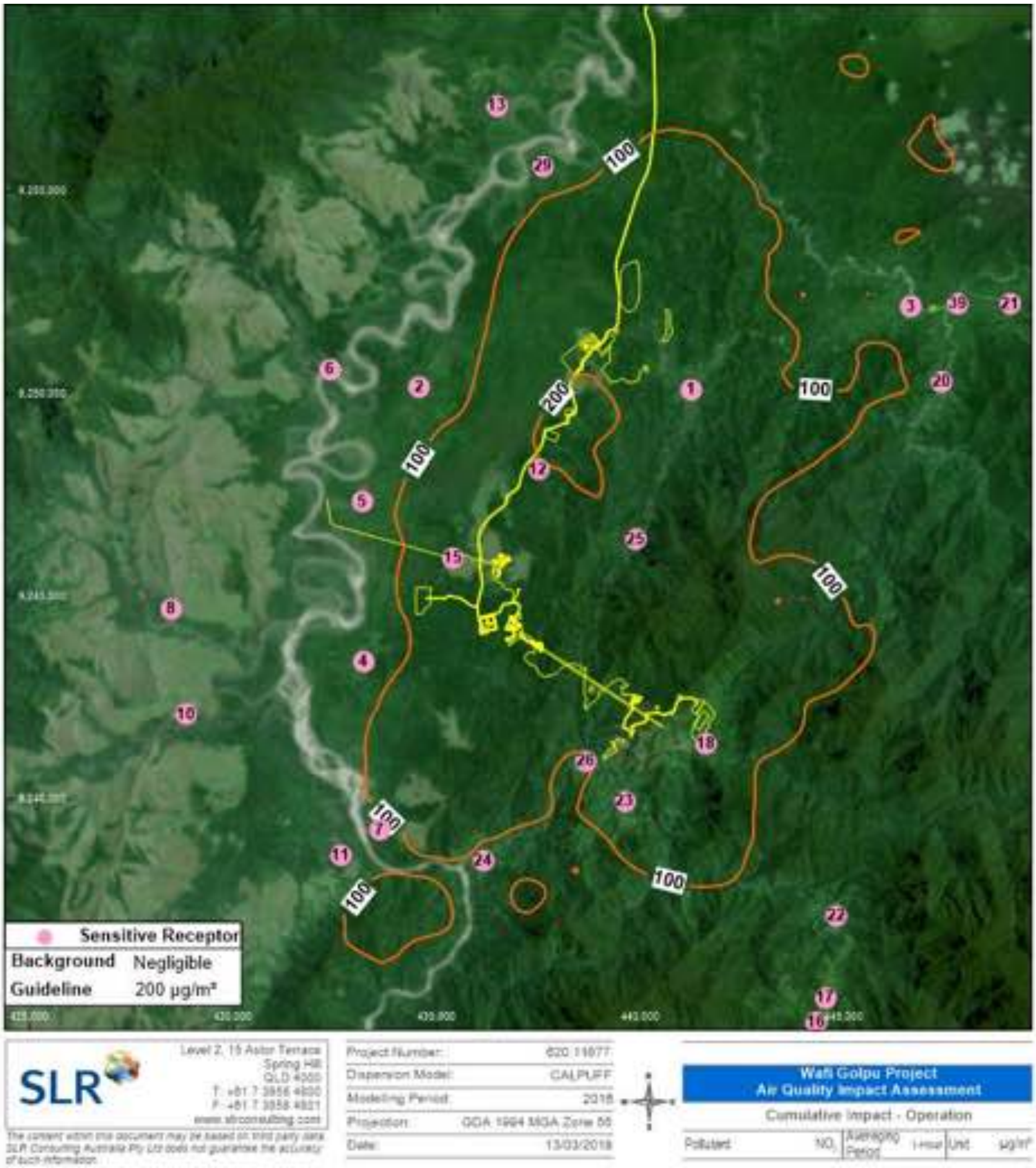
Date:	13/03/2018

Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Operation

Pollutant	CO	Averaging Period	24-hour	Unit	µg/m³


100
200
Sensitive Receptor
Background Negligible
Guideline 200 µg/m³
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Cumulative Impact - Operation
Pollutant NO2
Averaging Period 1-Hour
Unit µg/m³

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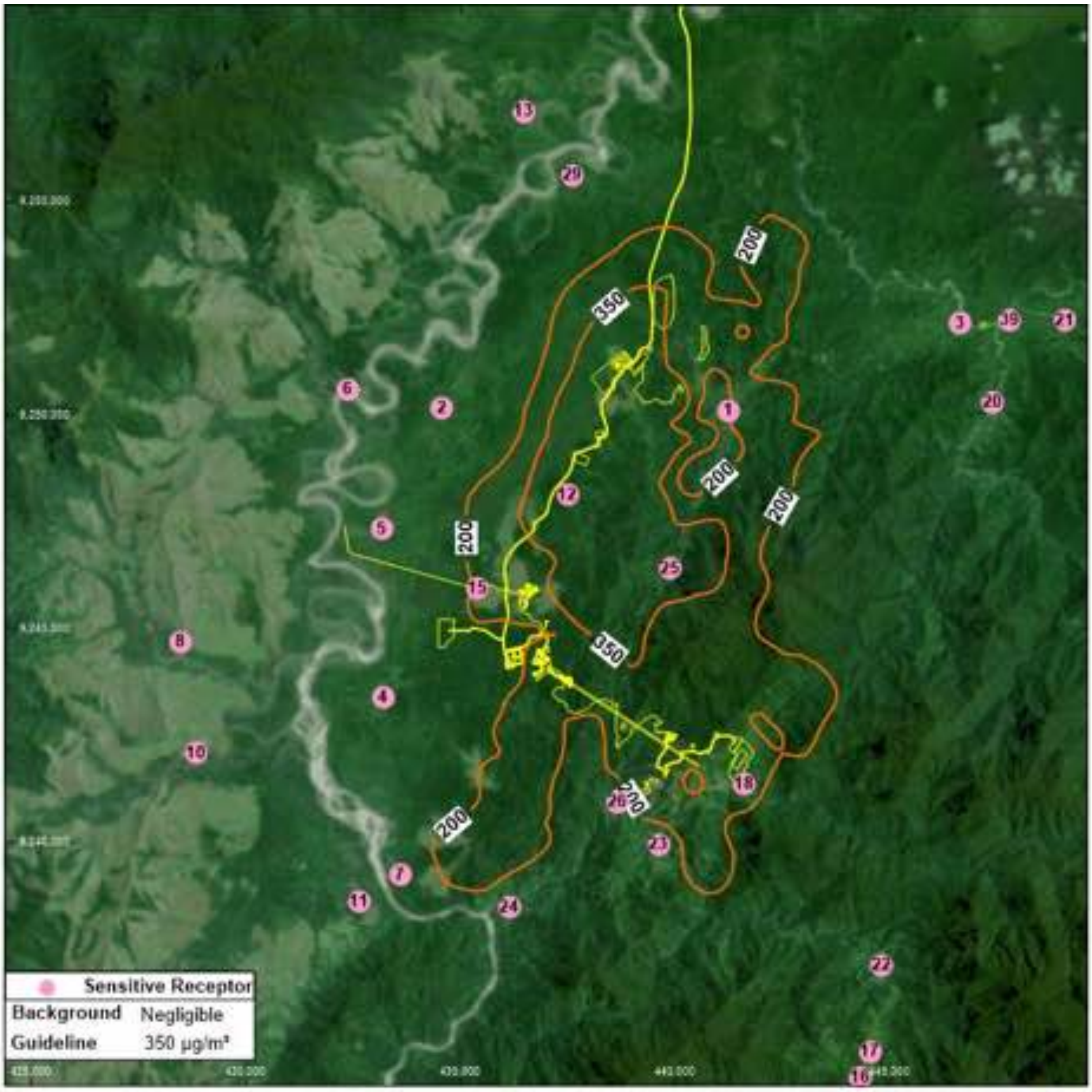
Wafi Golpu Project
Air Quality Impact Assessment

Cumulative Impact - Operation

Pollutant	NO_2	Averaging Period	Annual	Unit	µg/m³



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Air Quality Impact Assessment

Cumulative Impact - Operation

Pollutant	SO_2	Averaging Period	1-Hour	Unit	µg/m³

Table D1 Activity Data for the GHG Assessment

Activity	Activity Rate	Units	Key Assumptions	Source
Mine Construction				
Land clearance for mine infrastructure, roads and pipelines	224.4	ha/annum	Land cleared over a 3 year period	Provided by WGJV, July 2015
Diesel used in land clearance for mine infrastructure	3,366	kL/annum	Assumed 15 kL diesel used per ha cleared	Based on previous SLR assessment in PNG
Fuel Consumption in Trucks moving materials to Mine Area	55.2	kL/annum	252 L/day assumed to cover logistics fleet across entire Project Area (mine, pipeline and Port Facilities Area), split of 60%, 30%, 10% assumed - rate assumed for both construction and closure (bringing materials to and from site)	Table 6.10.35 PFOS
Fuel consumption in mine construction fleet	1,380	kL/annum	252 L/day (Logistics fleet) + 3,380 L/day (Decline development fleet) +150 L/day (Surface support fleet)	Table 6.10.35 PFOS
Diesel consumption in power generation for mine infrastructure during construction	109,500	kL/annum	20 MW demand, produced on-site in diesel generators, 625 L/hr/unit, 20 units	Cummins C1250 D2R PowerBox 20X Specifications
Explosive use during mine construction	1,516	tonnes/annum		Table 6.10.37 PFOS
Fly in Fly out and Bus in Bus out during mine construction	17.5	kL/annum	Assume all 2500 personnel taken to Lae 12 times per year (and back), 140 km per round trip, 50 pax per minibus = 84,000 km per annum @ 26 L/100 km = 21.84 kL/annum Assume 80% of workforce at Mine, 10% at Pipeline and 10% at Port Facilities Area	-
Refrigeration during mine construction	48,000	kg charge	-	Table 6.10.38 PFOS
Waste production during mine construction	513	tonnes/annum	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by WGJV, July 2015
Wastewater production during mine construction	2,000	persons	Based on 1,730 FTE for construction	Provided by Worley Parsons, July 2015

Activity	Activity Rate	Units	Key Assumptions	Source
Mine Operation				
Fuel consumption in mine operation fleet	35,110	kL/annum	43,800 L/day for SLC operating fleet + 240 L/day for surface support fleet, assumed to cover operation of Mine, Pipeline and Port Facilities Area, split of 80%, 10%, 10% assumed	Table 6.10.35 PFOS
IFO consumption for power generation during operation	107,722	kL/annum	98 MW, 40% efficiency, LHV for IFO of 40,400 kJ/kg, 0.9942 kg/L	SLR assumption
SF6 used in switchgear during mine operation	73.7	kg charge	-	Table 6.10.39 PFOS
Refrigeration during mine operation	48,000	kg charge	-	Table 6.10.38 PFOS
Explosive use during mine operation	2,502	tonnes/annum	-	Table 6.10.37 PFOS
Waste production during mine operation	644	tonnes/annum	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by WGJV, July 2015
Wastewater production during mine operation	600	persons	Assume 80% of workforce at Mine, 10% at Pipeline and 10% at Port Facilities Area	Provided by Worley Parsons, July 2015
Fly in Fly out and Bus in Bus out during mine operation	5.2	kL/annum	Assume all 750 personnel taken to Lae 12 times per year (and back), 140km per round trip, 50pax per minibus = 25,200 km per annum @26l/100km = 6.55kl/annum - Assume 80% of workforce at Mine, 10% at Pipeline and 10%	-
Mine Closure				
Fuel consumption in mine closure fleet	3,511	kL/annum	Assumed 10% of operation	-
Fly in Fly out and Bus in Bus out during mine closure	17.5	kL/annum	Assume all 2500 personnel taken to Lae 12 times per year (and back), 140km per round trip, 50pax per minibus = 84,000 km per annum @26l/100km = 21.84kl/annum - Assume 80% of workforce at Mine, 10% at Pipeline and 10% at Port Facilities Area	-
Waste production during mine closure	513	tonnes/annum	Assumed same as construction	-
Wastewater production during mine closure	2,000	persons	Assumed same as construction	-
Fuel Consumption in Trucks moving materials from Mine Area	55.2	kL/annum	Assumed same as construction	-

Activity	Activity Rate	Units	Key Assumptions	Source
Pipeline Construction				
Land clearance for pipeline infrastructure	223.7	ha/annum	Land cleared over a 3 year period	GIS analysis (includes buffer zones) dated 5 April 2018
Diesel used in land clearance for pipeline infrastructure	3,356	kL/annum	Assumed 15 kL diesel used per ha cleared	Based on previous SLR assessment in PNG)
Fuel Consumption in Trucks moving materials to pipeline site	27.6	kL/annum	252 L/day assumed to cover logistics fleet across entire Project Area (mine, pipeline and Port Facilities Area), split of 60%, 30%, 10% assumed - rate assumed for both construction and closure (bringing materials to and from site)	Table 6.10.35 PFOS
Fuel consumption in pipeline construction fleet	878	kL/annum	Assume 20% of operation	-
Fly in Fly out and Bus in Bus out during pipeline construction	2.2	kL/annum	Assume all 2500 personnel taken to Lae 12 times per year (and back), 140 km per round trip, 50 pax per minibus = 84,000 km per annum @ 26 L/100 km = 21.84 kL/annum Assume 80% of workforce at Mine, 10% at Pipeline and 10% at Port Facilities Area	-
Waste production during pipeline construction	64	tonnes/annum	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by WGJV, July 2015
Wastewater production during pipeline construction	250	persons	Assume 80% of workforce at Mine, 10% at Pipeline and 10% at Port Facilities Area	Provided by Worley Parsons, July 2015
Pipeline Operation				
Fuel consumption in pipeline operation fleet	4,389	kL/annum	43,800 L/day for SLC operating fleet + 240 L/day for surface support fleet, assumed to cover operation of Mine, Pipeline and Port Facilities Area, split of 80%, 10%, 10% assumed	Table 6.10.35 PFOS
SF6 used in switchgear during pipeline operation	11.4	kg charge	-	Table 6.10.39 PFOS
Waste production during pipeline operation	81	tonnes/annum	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by WGJV, July 2015
Wastewater production during pipeline operation	75	persons	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by Worley Parsons, July 2015

Activity	Activity Rate	Units	Key Assumptions	Source
Fly in Fly out and Bus in Bus out during pipeline operation	0.7	kL/annum	Assume all 750 personnel taken to Lae 12 times per year (and back), 140km per round trip, 50pax per minibus = 25,200 km per annum @26l/100km = 6.55kl/annum - Assume 80% of workforce at Mine, 10% at Pipeline and 10%	-
Pipeline Decommissioning				
Fuel consumption in pipeline decommissioning fleet	439	kL/annum	Assumed 10% of operation	-
Fly in Fly out and Bus in Bus out during pipeline decommissioning	2.2	kL/annum	Assume all 2500 personnel taken to Lae 12 times per year (and back), 140km per round trip, 50pax per minibus = 84,000 km per annum @26l/100km = 21.84kl/annum - Assume 80% of workforce at Mine, 10% at Pipeline and 10% at Port Facilities Area	-
Waste production during pipeline decommissioning	64	tonnes/annum	Assumed same as construction	-
Wastewater production during pipeline decommissioning	250	persons	Assumed same as construction	-
Fuel Consumption in Trucks moving materials from pipeline site	27.6	kL/annum	252 L/day assumed to cover logistics fleet across entire Project Area (mine, pipeline and Port Facilities Area), split of 60%, 30%, 10% assumed - rate assumed for both construction and closure (bringing materials to and from site)	Table 6.10.35 PFOS
Port Facilities Area and Outfall Area Construction				
Land clearance for Outfall Area	0.8	ha/annum	Land cleared over a 3 year period	GIS analysis (includes buffer zones) dated 5 April 2018
Diesel used in land clearance for Outfall Area	12.7	kL/annum	Assumed 15 kL diesel used per ha cleared	Based on previous SLR assessment in PNG)

Activity	Activity Rate	Units	Key Assumptions	Source
Fuel Consumption in trucks moving materials to Coastal Area sites	9.2	kL/annum	252 L/day assumed to cover logistics fleet across entire Project Area (mine, pipeline and Port Facilities Area), split of 60%, 30%, 10% assumed - rate assumed for both construction and closure (bringing materials to and from site)	Table 6.10.35 PFOS
Fuel consumption in Coastal Areas construction fleet	877.8	kL/annum	Assume 20% of operation	-
Waste production during Coastal Areas construction	64	tonnes/annum	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by WGJV, July 2015
Wastewater production during Coastal Areas construction	250.0	persons	Assume 80% of workforce at Mine, 10% at Pipeline and 10% at Coastal Area	Provided by Worley Parsons, July 2015
Port Facilities Area Operation				
Fuel consumption in Port Facilities Area operation fleet	4,389	kL/annum	43,800 L/day for SLC operating fleet + 240 L/day for surface support fleet, assumed to cover operation of Mine, Pipeline and Port Facilities Area, split of 80%, 10%, 10% assumed	Table 6.10.35 PFOS
Electricity consumption during Port Facilities Area operation (average)	8,223,934	kWh/annum	Average of all years' electricity demand	Electrical Load Profile.xlsx
SF6 used in switchgear during Port Facilities Area operation	12	kg/annum	-	Table 6.10.39 PFOS
Waste production during Port Facilities Area operation	81	tonnes/annum	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by WGJV, July 2015
Wastewater production during Port Facilities Area operation	75	persons	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by Worley Parsons, July 2015
Port Facilities and Outfall Area Decommissioning				
Fuel consumption in Coastal Areas decommissioning fleet	439	kL/annum	Assumed 10% of operation	-
Waste production during Coastal Areas decommissioning	64	tonnes/annum	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by WGJV, July 2015
Wastewater production during Coastal Areas decommissioning	250	persons	Assume 80% Mine, 10% Pipeline, 10% Port	Provided by Worley Parsons, July 2015

Activity	Activity Rate	Units	Key Assumptions	Source
Fuel Consumption in Trucks moving materials from Coastal Area sites	9.2	kL/annum	252 L/day assumed to cover logistics fleet across entire Project Area (mine, pipeline and Port Facilities Area), split of 60%, 30%, 10% assumed - rate assumed for both construction and closure (bringing materials to and from site)	Table 6.10.35 PFOS

Greenhouse Gas Assessment – Emission Factors

Emission factors are presented below for those emission sources for which emissions have been calculated based on raw activity data as presented in **Appendix D** (e.g. tonnes of waste deposited, kL of fuel combusted).

E.1 Land Disturbance

Although biomass is carbon neutral (e.g. no net release of CO_2 if the growth/reduction cycle is sustained), an area of biomass can act as a carbon sink as atmospheric CO_2 is used in photosynthesis to form organic compounds. As biomass increases, so does the quantity of carbon stored in the area. Disturbance of the area of biomass removes both the carbon stored in the biomass and removes the ability for the area to assimilate any further CO_2.

Burning of the cleared biomass would result in a 'pulse' of CO_2 being released to the atmosphere as opposed to the gradual release when exposed to decay over decadal timeframes. In either case, the same quantity of carbon is released back into the atmosphere. Estimation of the total carbon stock lost, and the incremental loss in carbon sink due to clearance have been performed using emission factors within UNFCCC (2009) "Estimation of GHG emissions due to clearing, burning and decay of existing vegetation attributable to a CDM A/R project activity" which is based on the method outlined in Chapter 2 and Chapter 4 of IPCC (2006), Volume 4, Chapter 2 and Chapter 4.

Key variables have been selected for the calculation of biomass losses as presented in **Table E1**.

Table E1 Key Variables in Calculation of Biomass Losses

Variable	Value	Source
Climate Region	TAr (Tropical Rain Forest)	Vol. 4 Chapter 4, IPCC (2006)
Carbon Fraction of Above Ground Biomass (CF)	0.47 tonnes C / tonne d m[1] (default)	Table 4.3 Vol. 4 Chapter 4, IPCC (2006)
Ratio of below ground biomass to above ground biomass (R)	0.37 tonnes root d m / tonne shoot d m (Tropical Rain Forest)	Table 4.4 Vol. 4 Chapter 4, IPCC (2006)
Above ground biomass in forests	350 (280 – 520) tonnes d m / ha / yr (Tropical Rain Forest (Asia [insular]))	Table 4.7 Vol. 4 Chapter 4, IPCC (2006)
Above ground net biomass in forests (≤ 20yrs)	13 tonnes d m / ha / yr (Tropical Rain Forest (Asia [insular]))	Table 4.9 Vol. 4 Chapter 4, IPCC (2006)

1: tonne d m = tonne dry mass

Annual losses of carbon due to disturbances have been calculated using Equations 1, 2 and 3 of UNFCCC (2009):

Equation 1 $$E_{BiomassLoss,t} = \left(L_{SP,tree,t} + L_{SP,shrub,t}\right)\frac{44}{12}$$

and:

Equation 2 $$L_{SP.tree,t} = A_{s,t}B_{AB,tree}(1 + R_{tree})CF_{tree}$$

Equation 3 $$L_{SP.shrub,t} = A_{s,t}B_{AB,shrub}(1 + R_{tree})CF_{shrub}$$

where:

$E_{BiomassLoss}$ = Increase in CO_2 emissions from loss of biomass in existing vegetation as a result of site preparation; t CO_2

L_{SP} = Carbon stock loss in existing tree or shrub vegetation as a result of site preparation in year *t*; t C

$A_{s,t}$ = Area of the stratum in year *t*; ha

B_{AB} = Average above ground biomass stock of tree or shrub vegetation; t d.m. ha^{-1}

R = ratio of below ground biomass to above ground biomass

CF = carbon fraction of dry matter (tonnes C / tonnes d m)

$\frac{44}{12}$ = Conversion factor: ratio of molecular weights of CO_2 and C; mol mol^{-1}

E.2 Combustion of Fuel

Scope 1 emission factors for the combustion of fuel have been sourced from Chapter 2 of (DEE, 2017) and are reproduced in **Table E2**. These factors include the GWP values outlined in **Table 37**. Activity data has been provided in kL as outlined in **Appendix D**.

Table E2 GHG Emissions Associated with Fuel Combustion

Fuel Type	Purpose	Emission Factor Units	Greenhouse Gas		
			CO_2	CH_4	N_2O
Diesel	Stationary energy	kg CO_2-e/GJ	69.9	0.1	0.2
Diesel	Mobile sources		69.9	0.1	0.5
Diesel	Heavy Vehicles (Euro i)		69.9	0.2	0.5
IFO	Stationary energy		73.6	0.04	0.2

Assumed energy content of diesel oil – 38.6 GJ/kL (DEE, 2017)
Assumed energy content of IFO – 39.7 GJ/kL (DEE, 2017)

E.4 Waste Management

E.4.1 Solid Waste

The calculated quantities of organic waste sent to landfill have been calculated based on details of total waste, waste to be recycled and waste sent for incineration. The Australian Government Clean Energy Regulator National Greenhouse and Energy Reporting (NGER) Solid Waste Calculator tool has been used to calculate GHG emissions associated with the landfill source. These calculations are consistent with those outlined in Chapter 5 of (IPCC, 2006).

E.4.2 Wastewater

GHG emissions resulting from treatment of domestic wastewater have been calculated using the Australian Government Clean Energy Regulator National Greenhouse and Energy Reporting (Domestic and Commercial) Wastewater Calculator tool. No capture of methane has been assumed to occur. These calculations are consistent with those outlined in Chapter 5 of (IPCC, 2006).

E.5 Use of Sulphur Hexafluoride in Switchgear

The NGA Factors Workbook (DEE, 2017) provides default annual leakage rates of SF_6 for gas insulated switchgear derived from Section 4.102 of the National Greenhouse and Energy Reporting (Measurement) Determination 2008 (DCCEE, 2008b). Default leakage rates are assumed to be 0.89%.

E.6 Use of Refrigerants

The NGA Factors Workbook (DEE, 2017) provides default annual leakage rates of HFCs for industrial refrigeration equipment derived from Section 4.102 of the National Greenhouse and Energy Reporting (Measurement) Determination 2008 (DCCEE, 2008b). Default leakage rates are assumed to be 16%.

E.7 Electricity Consumption

Scope 2 emission factors associated with electricity consumption are not provided in the IPCC publication (IPCC, 2006) and factors within the NGA Factors are Australia-specific. An electricity Scope 2 emission factor of 0.7738 kg CO_2-e/kWh for PNG has been sourced from the World Bank Group GHG Emissions Inventory Plan (WBG, 2009).

No electricity Scope 3 emission factors are available in either IPCC documents (IPCC, 2005) or (IPCC, 2006) for and therefore the latest Scope 3 emission factor for the Australian Northern Territory (NT) (0.09 kg CO_2/kWh) has been adopted from the NGA Factors (DEE, 2017).

E.8 Use of Explosives

The use of explosives can result in emissions of GHG, mainly through the combustion of fuel (usually diesel) used within the explosive mixture.

In pre-prepared fuel/explosive mixtures, it is difficult to assess the quantity of fuel used. IPCC (IPCC, 2006) do not provide default emission factors for explosive mixtures. The Australian DEE have previously published GHG emission factors for pre-prepared explosive mixtures, although the most recent version of the National Greenhouse Accounts (NGA) Factors Workbook (DEE, 2017) does not include these factors.

To quantify emissions of GHG from explosive use, the emission factor published in the NGA Factors Workbook, 2008 (DCCEE, 2008) has been adopted and is taken to be 0.17 tonnes of CO_2-e per tonne.

Table F1 Estimated GHG Emissions

Activity	Activity Data		Scope 1	Scope 2
	Value	Units	t CO_2-e / annum	t CO_2-e / annum
MINE				
CONSTRUCTION				
Land clearance for mine infrastructure, roads and TSF	224.4	ha/annum	185,436	
Diesel used in land clearance for mine infrastructure	3,366.1	kL/annum	9,102	
Fuel Consumption in Trucks moving materials to Mine Area	55.2	kL/annum	149	
Fuel consumption in mine construction fleet	1,380.4	kL/annum	3,733	
Diesel consumption in power generation for mine infrastructure during construction	109,500	kL/annum	295,709	
Explosive use during mine construction	1,516	tonnes/annum	258	
Fly in Fly out and Bus in Bus out during mine construction	17.5	kL/annum	47	
Refrigeration during mine construction	48,000	kg charge	12,595	
Waste production during mine construction	512.6	tonnes/annum	111	
Wastewater production during mine construction	2,000	persons	124	
OPERATION				
Fuel consumption in mine operation fleet	35,110	kL/annum	94,941	
IFO consumption in power generators during operation	107,722	kL/annum	314,757	
SF6 used in switchgear during mine operation	73.7	kg charge	15	
Refrigeration during mine operation	48,000	kg charge	12,595	
Explosive use during mine operation	2,502	tonnes/annum	425.34	
Waste production during mine operation	644.3	tonnes/annum	693	
Wastewater production during mine operation	600.0	persons	37	
Fly in Fly out and Bus in Bus out during mine operation	5.2	kL/annum	14	
DECOMMISSIONING				
Fuel consumption in mine decommissioning fleet	3,511.0	kL/annum	9,494	
Fly in Fly out and Bus in Bus out during mine decommissioning	17.5	kL/annum	47	

Waste production during mine decommissioning	512.6	tonnes/annum	796	
Wastewater production during mine decommissioning	2,000.0	persons	124	
Fuel Consumption in Trucks moving materials from Mine Area	55.2	kL/annum	149	
INFRASTRUCTURE CORRIDOR				
CONSTRUCTION				
Land clearance for Infrastructure Corridor	223.7	ha/annum	184,865	
Diesel used in land clearance for Infrastructure Corridor	3,355.7	kL/annum	9,074	
Fuel consumption in trucks moving materials to Infrastructure Corridor sites	27.6	kL/annum	75	
Fuel consumption in Infrastructure Corridor construction fleet	877.8	kL/annum	2,374	
Fly in fly out and bus in bus out during Infrastructure Corridor construction	2.2	kL/annum	6	
Waste production during Infrastructure Corridor construction	64.1	tonnes/annum	14	
Wastewater production during Infrastructure Corridor construction	250.0	persons	16	
OPERATION				
Fuel consumption in pipeline maintenance/operation fleet	4,388.8	kL/annum	11,868	
SF6 used in switchgear during pipeline operation	11.4	kg charge	2	
Waste production during pipeline operation	80.5	tonnes/annum	87	
Wastewater production during pipeline operation	75.0	persons	5	
Fly in fly out and bus in bus out during pipeline operation	0.7	kL/annum	2	
DECOMMISSIONING				
Fuel consumption in pipeline decommissioning fleet	438.9	kL/annum	1,187	
Fly in fly out and bus in bus out during pipeline decommissioning	2.2	kL/annum	6	
Waste production during pipeline decommissioning	64.1	tonnes/annum	100	
Wastewater production during pipeline decommissioning	250.0	persons	16	
Fuel consumption in trucks moving materials from pipeline site	27.6	kL/annum	75	
COASTAL AREA				
CONSTRUCTION				
Land clearance for Coastal Area infrastructure	0.8	ha/annum	698	
Diesel used in land clearance for Coastal Area infrastructure	12.7	kL/annum	34	
Fuel consumption in trucks moving materials to Coastal Area sites	9.2	kL/annum	25	

Fuel consumption in Coastal Areas construction fleet	877.8	kL/annum	2,374	
Waste production during Coastal Areas construction	64.1	tonnes/annum	14	
Wastewater production during Coastal Areas construction	250.0	persons	16	
OPERATION				
Fuel consumption in port operation fleet	4,388.8	kL/annum	11,868	
Electricity consumption during port operation (maximum)	8,971,564	kWh/annum		6,942
Electricity consumption during port operation (average)	8,223,934	kWh/annum		6,364
SF6 used in switchgear during port operation	12.0	kg/annum	2	
Waste production during port operation	80.5	tonnes/annum	86.6	
Wastewater production during port operation	75.0	persons	4.65	
DECOMMISSIONING				
Fuel consumption in Coastal Areas decommissioning fleet	438.9	kL/annum	1,186.8	
Waste production during Coastal Areas decommissioning	64.1	tonnes/annum	99.5	
Wastewater production during Coastal Areas decommissioning	250.0	persons	15.5	
Fuel consumption in trucks moving materials from Coastal Area sites	9.2	kL/annum	24.9	