



Appendix Y

Freshwater Ecology Impact Assessment

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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.

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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.

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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.

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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.

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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

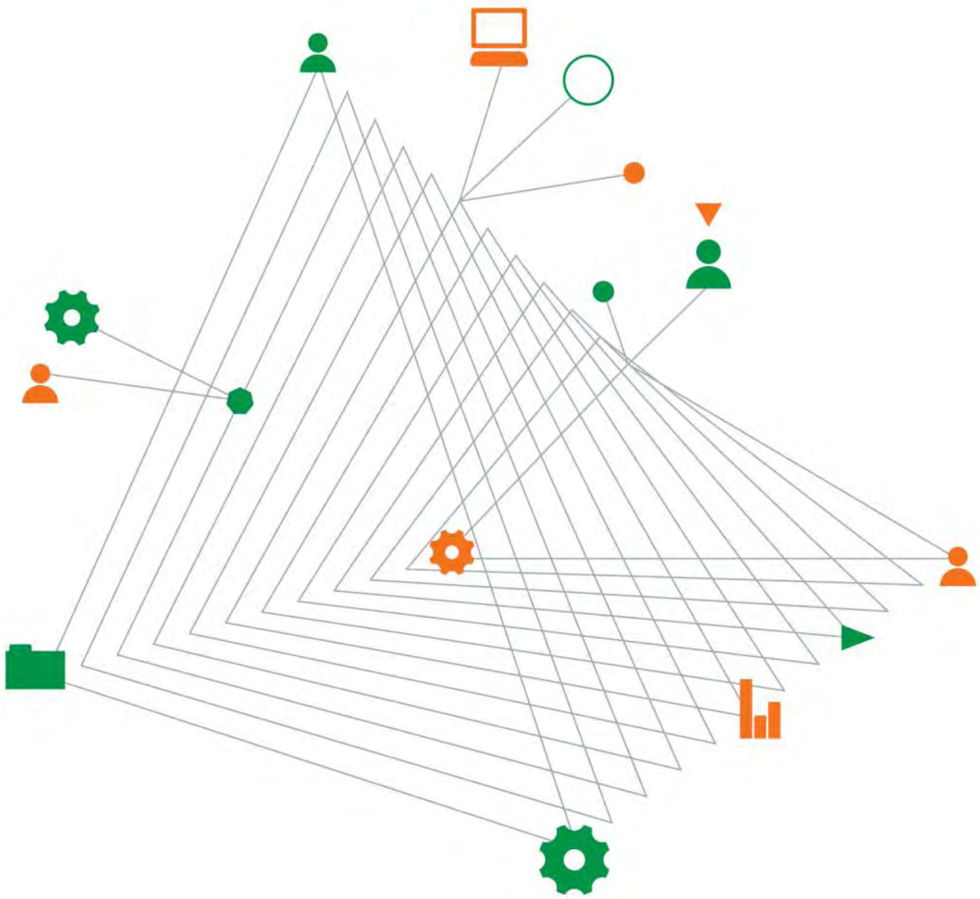
The Wafi-Golpu Joint Venture is an unincorporated joint venture between a wholly-owned subsidiary of Harmony Gold Mining Company Limited and a wholly-owned subsidiary of Newcrest Mining Limited.

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 Joint Venture

Freshwater ecology impact assessment

25 June 2018



Experience comes to life when it is powered by expertise

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Wafi-Golpu Project

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Glossary

Abbreviations

IUCN	International Union for Conservation of Nature
FEFLOW	Water modelling tool for water balance assessments
PHREEQC	Water modelling tool for water quality assessments
TSS	Total suspended solids

Terms

autotrophic	Getting nourishment independently; plants that form carbohydrates and proteins from carbon dioxide and inorganic compounds
decapod	Crustacean of the order *Decapoda*, such as a shrimp, crab, or lobster
diatom	Unicellular form of alga with walls impregnated with silica or carbonate
diadromous fish	Fish that spend parts of their life cycle partially in fresh water and partially in salt water
ephemeral watercourse	Watercourse that does not receive continuous flows and is dry for a portion of the year
heterotrophic	Obtaining nourishment from organic substances
hyporheic zone	The hyporheic zone is a region beneath and alongside a river or stream bed, where there is mixing of shallow groundwater and surface water
lotic	Running water; living in streams or rivers
lentic	Standing water; living in swamps, ponds or lakes
mixing zone	A term defined by the PNG Environment (Water Quality Criteria) Regulation 2002 as a discrete body of water into which waste is discharged and where the prescribed water quality criteria are not required to be met and the protection of aquatic life may not be guaranteed
palustrine wetland areas	Vegetated, non-riverine or non-channel systems
periphyton	All aquatic plant organisms, excluding plankton and rooted macrophytes, found on submerged materials in rivers, creeks and lakes
watercourse substratum	Structure of a watercourse bed

1. Introduction

This appendix of the environment impact statement (EIS), which assesses the potential effects of the Wafi-Golpu Project (the Project) on freshwater ecology, was prepared by Coffey and EnviroGulf Consulting.

This freshwater ecology impact assessment is based upon the following:

- Description of proposed Project activities (Chapter 6 of the EIS).
- Description of the existing freshwater environment (Chapter 9 of the EIS).
- Baseline Surface Water and Aquatic Ecology - Mine Area to Markham River report by BMT WBM (2018a) (Appendix G of the EIS).
- Freshwater Ecology Characterisation - Yalu to Wagang report (Coffey and Waterbug, 2018) (Appendix H of the EIS).
- Hydrology, sediment transport and water quality modelling completed by BMT WBM, which is reported in Catchment and Receiving Water Quality Modelling Report (BMT WBM, 2018b) (Appendix I of the EIS).
- Site-wide Water and Mass Balance Modelling report undertaken by Piteau Associates (Piteau) (2018a) (Appendix V of the EIS).
- Post-closure numerical modelling work completed by Piteau reported in the Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone (2018b) (Appendix X of the EIS).

Chapter 15 of the EIS, Freshwater Environment Impact Assessment provides a summary of the predicted hydrological, sediment transport and water quality impacts on the freshwater environment, and upon which consequential effects on freshwater habitats and biological communities have been assessed.

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

This report describes the findings of the freshwater ecology impact assessment study.

Future development of the Project remains subject to ongoing 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.

2. Project description

Wafi Mining Limited and Newcrest PNG 2 Limited (WGJV Participants) are equal participants in the Wafi-Golpu Joint Venture (the 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 “Wafi-Golpu Project” or the Project) in the Morobe Province of Papua New Guinea (PNG). The Project is located approximately 300 kilometres (km) north-northwest of Port Moresby and 65km southwest of Lae.

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 coast 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:

- **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 study area for this report includes the Mine Area, Infrastructure Corridor and the Coastal Area.

3. Approach to impact assessment

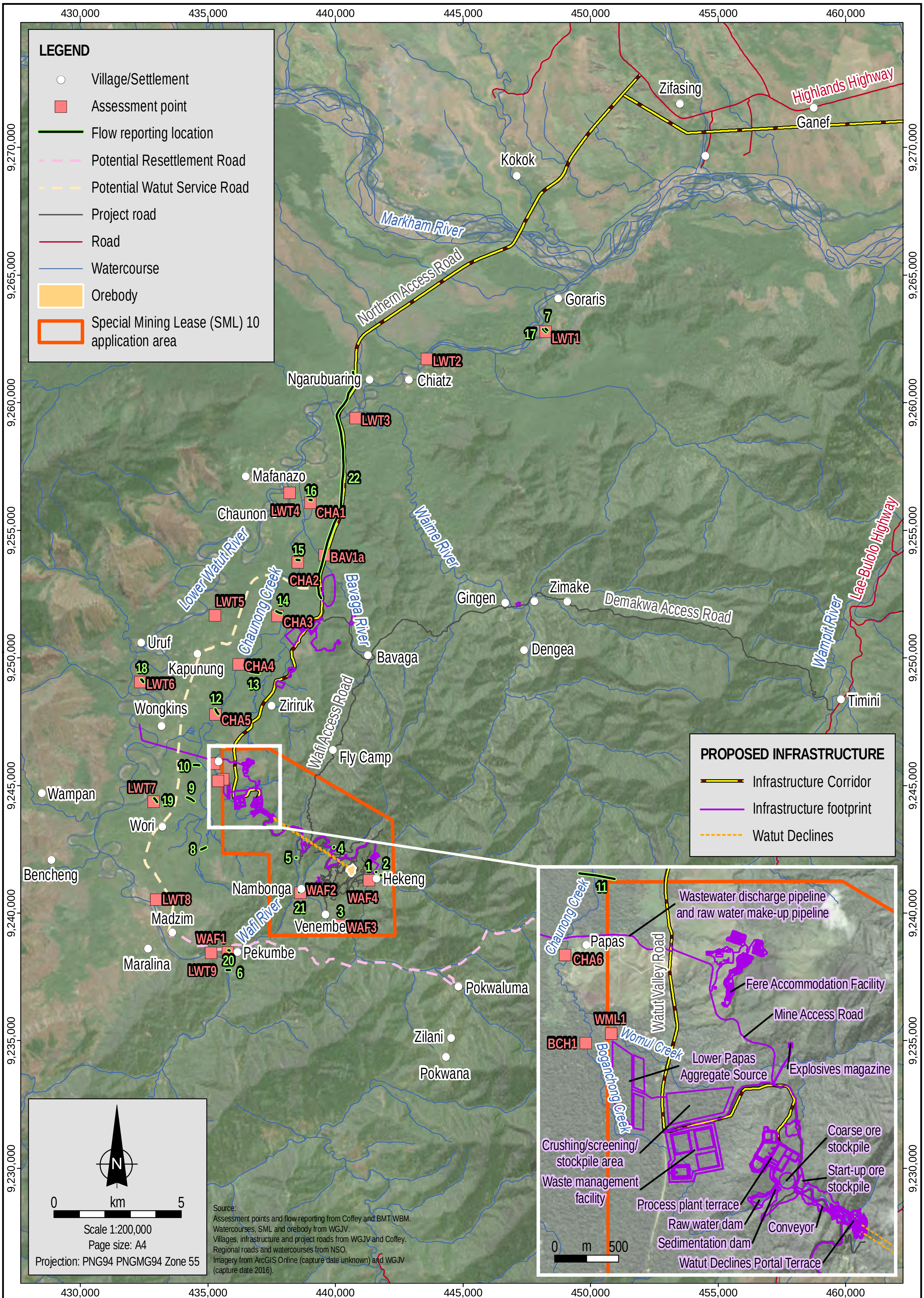
The potential impacts of the Project on the downstream receiving environment assessed in this report take into account relevant physical, chemical and biological considerations. This assessment has involved:

- Determination of the spatial and temporal scope of the assessment, based on the location of the Project facilities and timing of Project phases.
- Identification of appropriate assessment end-points, i.e., the beneficial values of the downstream receiving environment, which are to be protected.
- Determination of assessment criteria.
- Consideration of potential stressors on receiving waters. Stressors are defined as the physical, chemical or biological strain on the environment as a result of Project activities, with consideration given to the stressor’s nature, concentration/load (where relevant) and mode of action.
- Assessment of the potential impacts that these stressors will have on the beneficial values of the downstream receiving environment.
- Development of proposed management measures to mitigate or limit the impacts on the downstream receiving environment.
- Assessment of the residual impacts that these stressors are predicted to have on the downstream receiving environment assuming the adoption of proposed management measures.

3.1. Spatial and temporal scope

Mine-related changes to hydrology, sediment transport, water quality and aquatic ecology were predicted at selected reporting locations (or assessment points) downstream of Project activities and near selected villages as shown in Figure 3.1. In the case of freshwater ecology, specific river and creek reaches or floodplain waterbodies affected by the Project were assessed. Figure 3.2 shows watercourses in the southern portion of the Mine Area. Figure 3.3 shows watercourses in the Lower Markham River Floodplain and Coastal Area. The spatial extent of the assessment has been determined on the basis of the physical transport pathways that link possible sources of stressors to the downstream receiving environment (i.e., the Project Area and surrounds). This assessment therefore focuses on the following areas:

- Mine Area, which includes (Figure 3.1 and Figure 3.2):
  - Lower Watut River (main channel) to its confluence with the Markham River and tributaries of the Lower Watut River floodplain, including the Bavaga River and Pentag and Chaunong creeks.
  - Watercourses that drain to the Wafi River, including the Zamen, Tovu, Dumbeyo, Kwepkwep, Hekeng (upper Wafi) rivers and Yor, Buvu and Nambonga creeks.
  - Eastern floodplain catchments and floodplain rivers and creeks, including the Bavaga River and Bobul, Mari, Boganchong, Womul and Chaunong creeks.
- Lower Markham River floodplain watercourses, as shown in Figure 3.3, which includes:
  - Various watercourses traversed by the Infrastructure Corridor including the Rumu, Erap and Yalu rivers, Markham and Ngafir creeks and numerous small unnamed creeks.
- Coastal Area watercourses, as shown in Figure 3.3, which includes:
  - Bumbu River and Gaison, Bugalang and Bupeli creeks.



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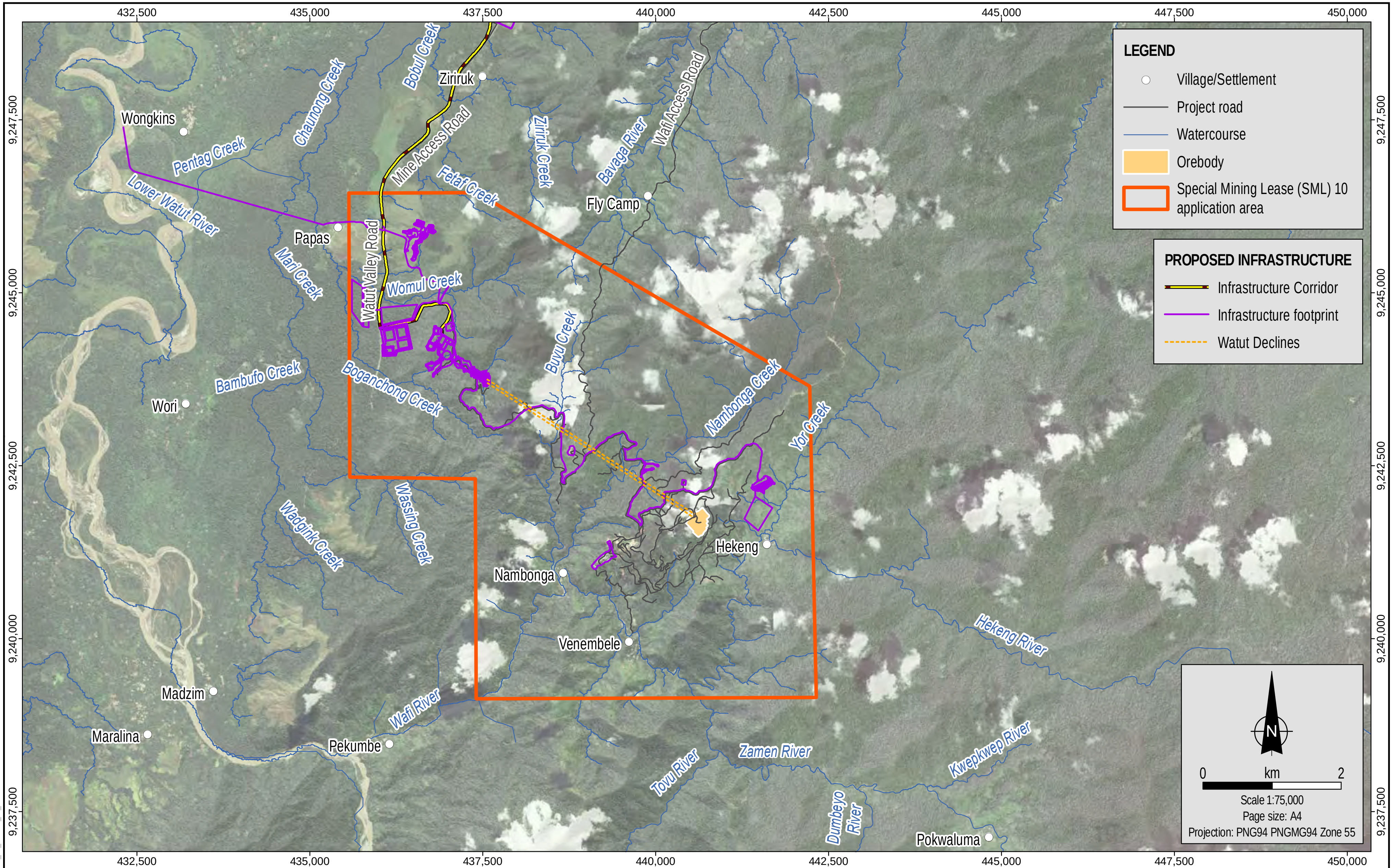
Date: 24.04.2018 Project: 754-ENAUABTF100520DD File Name: 0520DD_24_F03.01_GIS	WAFI-GOLPU JOINT VENTURE Wafi-Golpu Project	Assessment points	Figure No: 3.1



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

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Date: 17.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_24_F03.02_GIS

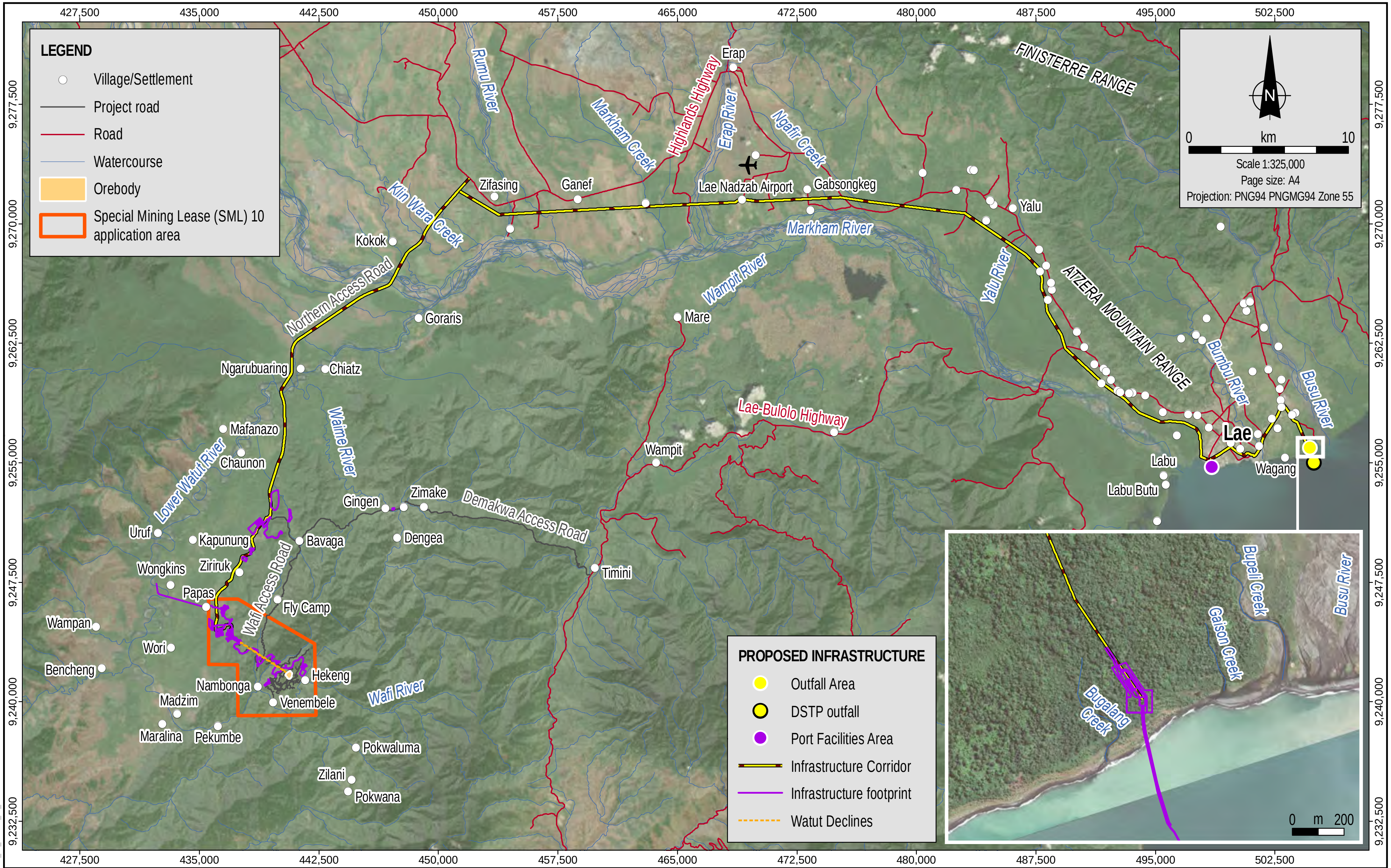
WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Watercourses in the Mine Area

Figure No: **3.2**

MXD Reference: 0520DD_24_GIS002_v0_1



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

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Date: 30.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_24_F03.03_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Watercourses in the Markham River Floodplain and Coastal Area

Figure No: **3.3**

MXD Reference: 0520DD_24_GIS004_v0_2

Freshwater ecology impacts for the construction phase (five years) and the operational phase (27 years[1]) are presented, as well as for the post-closure phase with respect to the subsidence zone lake.

3.2. Assessment approach

The environmental impact assessment approach generally adopts one of two methods to assess the level of residual environmental impacts of the Project on the identified environmental values.

The compliance standard assessment method has been adopted where a quantitative assessment is required. The method relies on international, national or best practice limits or guidelines to assess an impact. The compliance standard method was used for assessing water quality impacts, which is presented in Chapter 15 of the EIS, Freshwater Environment Impact Assessment.

The significance assessment method has been adopted where a qualitative (or semi-quantitative) assessment is required. This method allows for the development of the most suitable and practical management measures as it only considers credible impacts with a likelihood of occurring. Impacts to freshwater ecology values were assessed using the significance assessment method.

Impacts on species of listed conservation significance, such as IUCN-listed species, species of national conservation priority (listed as protected or restricted under the *Papua New Guinea (PNG) Fauna (Protection and Control) Act 1966*) or species endemic to the Lower Watut River catchment have been assessed separately in Section 7.10. Impacts on species of conservation significance are predicted to be the same as impacts on non-listed species and would also have sensitivities similar to other native (non-listed) species. Therefore, an aquatic species having conservation significance does not confer additional sensitivity compared to other introduced or native aquatic species within an area.

To support these assessments, numerical modelling was completed of the predicted physico-chemical changes due to Project activities including:

- Hydrology
- Sediment transport
- Water quality

A summary of these results is provided in Chapter 15 in the EIS, Freshwater Environment Impact Assessment. An overview of proposed management measures to address these potential impacts Section 5 and the Wafi-Golpu Project (the Project) Environmental Management Plan (EMP) (Attachment 3 of the EIS). The assessment of residual impacts also includes assumed implementation of the proposed management measures. Socioeconomic impacts with the potential to manifest as a result of the environmental impacts described in this report are addressed in Chapter 18 of the EIS, Socioeconomic Impact Assessment.

The potential for accidental events (e.g., hydrocarbon or chemical spillage from a road transport vehicle accident) or natural hazards during construction and operations are addressed separately in Chapter 21 of the EIS, Unplanned Events (Natural Hazards and Accident Events) and have not been considered here.

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

3.2.1. Compliance standard assessment method

The compliance standard assessment method was used to compare the results of modelling or other predictive techniques with statutory limits or guidelines. Where PNG has no such statutory limits or thresholds then surrogate limits or thresholds from other jurisdictions or guidelines have been adopted.

This approach enables development of compliance based water quality targets and identifies proposed management measures that may need to be applied.

Water quality criteria to protect aquatic ecosystems include the following, which are applicable to dissolved metals:

- State of Papua New Guinea Environment (Water Quality Criteria) Regulation 2002 (PNG ER). These criteria are legally enforceable.
- State of Papua New Guinea Environmental Code of Practice for the Mining Industry (PNG ECoP) (Office of Environment and Conservation, 2000). Compliance with these guidelines is voluntary.
- The Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ, 2000) water quality guidelines (ANZECC/ARMCANZ guidelines). While not legally enforceable, the ANZECC/ARMCANZ guidelines are widely regarded as one of the more robust ecosystem protection guideline currently available internationally and have therefore been considered for the assessment of impacts to freshwater aquatic ecosystems.

Predicted dissolved metal concentrations have been used for comparison to freshwater aquatic ecosystem protection guidelines. The PNG ER, ECoP and the ANZECC/ARMCANZ guidelines (for 95% ecosystem protection) have been used to inform comparisons with predicted concentrations of contaminants.

Where maximum background dissolved concentrations of parameters measured in the Mine Area rivers in the Lower Watut River catchment exceed the ANZECC/ARMCANZ (2000) guidelines, the background concentrations have been adopted as the site-specific criteria for comparison with predicted concentrations.

3.2.2. Significance assessment method

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

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

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

- Severity of the residual impact: in terms of the proportion, degree and/or rate of change of disturbance experienced by the environmental value.
- Spatial extent of the residual impact: the size of the area which may be directly or indirectly affected by Project-related activities.

- Temporal extent of the residual impact: whether the impact will be immediate or delayed, is seasonal, or is short or long term.

This section presents the specific definitions for sensitivity and magnitude used to derive residual impact ratings. In Table 3.1, the sensitivity of an aquatic environmental value, resource or receptor is determined if it meets one or more of the definitions in each row.

Table 3.1: Sensitivity of an aquatic environmental value or receptor

Sensitivity	Definition
Very high	• An environmental value that has a very restricted distribution. • An environmental value that has very low resilience to adapt to changed environmental conditions. • A site or environmental value that is fully intact and retains its intrinsic value prior to Project development. • An environmental value of essential (local) subsistence or commercial requirement or importance in maintaining ecological integrity (even if not otherwise listed). • A very rare natural resource.
High	• An environmental value that has a restricted distribution. • An environmental value that has low resilience or ability to adapt to changed environmental conditions. • A site or environmental value that is intact and retains its intrinsic value prior to Project development. • An environmental value of essential (local) subsistence or commercial requirement or importance in maintaining ecological integrity (even if not otherwise listed). • Rare natural resource.
Medium	• An environmental value that is limited in abundance and distribution. • An environmental value that has some resilience or ability to adapt to changed environmental conditions. • A site or environmental value that is in moderate to good condition prior to Project development. • An environmental value of common or frequent subsistence or commercial importance locally. • Restricted natural resource.
Low	• An environmental value that is abundant, widespread and numerous for which representative examples occur. • An environmental value that is resilient having a high ability to adapt to changed environmental conditions.
Very low	• An environmental value that is of widespread distribution and of no local subsistence or commercial importance. • An environmental value that is very resilient with a high ability to adapt to changed environmental conditions.

Table 3.2 presents the definitions for impact magnitudes.

Table 3.2: Magnitude of aquatic ecological impacts

Magnitude	Contributing Factor	Definition
Very high	Severity	• Total loss of, or severe alteration to an aquatic ecological value, and/or loss of a high proportion of the known population or range of the value with a strong likelihood that the viability of the value will be severely reduced.
	Geographical extent	• Widespread impacts occurring at the regional or national scale, extending beyond the catchment of a single river (e.g., large rivers such as the Watut and Markham river main channels). • The impact may extend as far downstream as the receiving marine environment with consequential impacts on marine habitats and biological communities.
	Duration	• Long-term (permanent or >30 years) persistent adverse changes to an aquatic biological community in terms of diversity and species richness, or growth, biomass and productivity.
High	Severity	• Major loss or alteration to an aquatic ecological value and/or loss of a significant proportion of the known population or range of the value with the viability of the value reduced.
	Geographical extent	• Widespread impacts occurring at the regional scale (i.e., extends beyond the catchment of a single river).
	Duration	• Long-term duration (e.g., beyond the life of mine; 15 to 30 years)
Moderate	Severity	• Loss or alteration to an aquatic ecological value that is readily detectible with respect to natural variability, and/or loss of a moderate proportion of the known population or range of the value with limited overall reduction in the viability of the value.
	Geographical extent	• Localised impacts occurring at the local spatial scale (i.e., contained within the catchment of single river).
	Duration	• Medium-term duration (within the life of mine; 5 to 15 years).
Low	Severity	• Minor effect compared to existing baseline conditions. Effects unlikely to reduce the overall viability of the aquatic ecological value.
	Geographical extent	• Highly localised impacts occurring at the sub-local spatial scale (i.e., contained within the catchment of a single creek or stream, or a reach of larger river).
	Duration	• Temporary or short-term duration (only during construction or less than five years during operations).
Very low	Severity	• Effects likely to be very low or barely detectable and reduction in the viability of the ecological value is not expected.
	Geographical extent	• Impacts are very low and barely detectable with respect to natural variability, regardless of the geographic extent or duration of the impact.
	Duration	• Impacts are temporary and recover within a short timeframe (less than 1 year).

The significance of an impact on an environmental value is determined by the product (i.e., the ‘residual impact significance rating’) of the sensitivity of the value/receptor and the magnitude of the impact. Table 3.3 shows the resulting matrix of significance.

Table 3.3: Matrix of significance

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

3.3. Summary of freshwater environmental values

Identification of the beneficial values of the downstream receiving environment that require protection is a key step in assessing the potential Project impacts. The *Environment Act 2000* provides the following definition of a beneficial value:

> *"beneficial value" means a quality or characteristic of the environment or any element or segment of the environment, which –*
>
> *(a) is conducive to ecological health, public benefit, welfare, safety, health or aesthetic enjoyment and which requires protection from environmental harm; or*
>
> *(b) is declared in an Environment Policy or permit to be a beneficial value;*

The beneficial values of the downstream receiving environment reflect the interaction of the physical and biological environment, local communities and other relevant stakeholders. Beneficial values in the Project Area relevant to aquatic ecosystem health is the main focus of this report. The ambient receiving water quality criteria that provide for protection of aquatic ecosystem health also generally protects human health. Social values of the downstream receiving environment are addressed in Chapter 18 of the EIS, Socioeconomic Impact Assessment and have not been considered here.

3.3.1. Aquatic ecosystem protection

Ecological values of the downstream receiving environment were defined through surveys of the Project Area as discussed in Chapter 9 of the EIS, Freshwater Environment Characterisation. The baseline assessment identified aquatic habitats, aquatic biological communities (flora, macroinvertebrates, fish and semi-aquatic fauna) and aquatic species of conservation significance as the freshwater ecological values that may potentially affected by the Project. These are described below.

3.3.2. Aquatic habitats

Four broad aquatic ecosystem types in the Project Area were identified by BMT WBM (2016), which were analogous to those described by Polhemus and Allen (2006) and IUCN (2017). Table 3.4 presents the main aquatic ecosystem types and habitat ecological values and their assessed sensitivity.

Table 3.4: Aquatic habitat ecological values and their sensitivity

Value	Description		Sensitivity
	Polhemus and Allen (2006)	Wetland type (IUCN/Ramsar)*	
High to moderate gradient tributary streams	• Lotic: Perennial stream (headwater and mid reaches)	5.1 Permanent Rivers, Streams, Creeks (includes waterfalls)	Low
Low gradient floodplain tributary streams and wetlands	• Lotic: perennial streams, intermittent streams • Lotic flowing springs • Palustrine: Lowland march (non-forested) • Palustrine: Lowland swamp (forested)	5.1 Permanent Rivers, Streams, Creeks (includes waterfalls) 5.2 Seasonal/Intermittent/Irregular Rivers, Streams, Creeks 5.3 Shrub Dominated Wetlands 5.4 Bogs, Marshes, Swamps, Fens, Peatlands (> 8 ha) 5.7 Permanent Freshwater Marshes/Pools (< 8 ha) 5.8 Seasonal/Intermittent Freshwater Marshes/Pools (< 8 ha) 5.9 Freshwater Springs and Oases	Low
Unconfined, turbid major rivers systems (e.g., Watut and Markham rivers)	• Lotic: Perennial stream (terminal reach)	5.1 Permanent Rivers, Streams, Creeks (includes waterfalls)	Low
Oxbow lakes and off-river waterbodies (ORWB)	• Lentic: Oxbow lake • Palustrine: Lowland marsh (non- forested)	5.6 Seasonal/Intermittent Freshwater Lakes (> 8 ha) 5.7 Permanent Freshwater Marshes/Pools (< 8 ha)	High

Source: Polhemus and Allen (2006); *BMT WBM (2018a).

The key aquatic habitats of the Project Area are predominantly riverine. Away from rivers, the predominant waterbodies present are oxbow lakes. Within the major rivers, the principal aquatic habitats include pools, runs, riffles and backwater areas of the main channels, as well as side tributaries. Within the Lower Watut River main channel there is a general transition along its length from a gravel bed downstream of the Wafi River confluence, to a coarse gravel and sand bed, and finally to a clay and silt bed within its meander reach until its confluence with the Markham River. These aquatic habitat types are well represented in the Project Area and have therefore been classified as having **low** sensitivity.

In steeper terrain, headwater and small streams of the escarpment adjoining the eastern floodplain of the Lower Watut River, or within the Wafi River catchment, tend to be fast-flowing, have coarse channel bed material comprised of either bedrock, boulders, stones cobble and gravels, and have good water quality (e.g., low turbidity and high dissolved oxygen concentrations). The substrata of the lower reaches of the escarpment streams become progressively finer with silts and clays as the streams enter their low gradient reaches within the floodplain. These aquatic habitat types are well represented in the Mine Area have therefore been classified as having **low** sensitivity.

There are few off-river waterbodies and oxbow lakes in the Lower Watut River floodplain compared to other PNG river floodplains (e.g., Fly and Sepik rivers); therefore, these lentic aquatic habitat types have been assessed as having high sensitivity.

3.3.3. Aquatic flora

Aquatic macrophytes and microphytes play a major role in the ecology of rivers and streams providing food resources to secondary consumers such as invertebrates and fish. Many of the rivers and streams in the Project Area and surrounds do not have aquatic macrophytes owing to their classification as either fast-flowing or turbid rivers and streams. However, aquatic macrophytes are present in the oxbow lakes of the Lower Watut River floodplain and non-forested marsh areas of this floodplain.

In the higher-gradient rivers and streams, aquatic microphytes are present such as periphyton (e.g., diatoms and encrusting algae) but at low densities; however, filamentous green algae (Chlorophyta) are generally absent due to periodic high flow regimes and floods. The presence of aquatic macrophytes and microalgae in the rivers and streams is indicative of water of long-term good quality including high water clarity (i.e., low total suspended solids (TSS) concentrations and low turbidity) with nutrients at concentrations sufficient to support plant growth.

Section 9.6, Aquatic Ecology, in Chapter 9 of the EIS, Freshwater Environment Characterisation assessed that diatom assemblages of the Lower Watut River area and along the Infrastructure Corridor had species composition, richness and abundance that were representative of those occurring elsewhere in the study area.

Periphyton and macrophytes in the study area have been assessed to have a **low** sensitivity given their wide distribution and multiple sources of recruitment.

3.3.4. Aquatic macroinvertebrate fauna

Aquatic macroinvertebrates play a major role in the ecology of rivers and streams providing food resources to secondary consumers such as fish. Aquatic macroinvertebrate diversity is critical to the maintenance of a healthy aquatic ecosystem. Section 9.6 (Freshwater ecology) of the EIS describes the aquatic macroinvertebrate fauna of the Project Area and surrounds in more detail.

While aquatic macroinvertebrate communities varied between sites, particularly between those of the mine site creeks (Wafi River system) and creeks of the escarpment and Lower Watut River floodplain, many aquatic macroinvertebrates were habitat generalists and found widely across the Project Area and surrounds.

Overall, benthic macroinvertebrates and the more mobile decapod crustaceans (e.g., river prawns) are widespread and common in the rivers and streams of the Mine Area and along the Infrastructure Corridor and have therefore been assessed to have a **low** sensitivity.

Aquatic macroinvertebrate species of conservation significance are summarised in Section 3.3.7 below.

3.3.5. Fish fauna

The fish fauna of rivers, streams and floodplain waterbodies of the Project Area are described in BMT WBM, 2018a. A total of 75 fish species are known to occur within the broader Watut River system (Powell and Powell, 2000).

During sampling undertaken in March 2015 a total of 1,156 individual fish from 28 species were captured. The catch was comprised of 22 native and six introduced (non-native) fish species (BMT WBM, 2018a).

Typically, fast-flowing and steep-gradient freshwater stream reaches of a river contain fish assemblages with low species richness, comprised mainly of small to medium bodied fish species, including those preferring swift-flowing waters.

The large numbers and biomass of introduced fish species in the Lower Watut River main channel and floodplain tributaries indicate that these fish are spreading across the Markham River system. EMPS (1993) recorded only one introduced fish species (tilapia), and then only in the Watut River. Independent of any potential impacts of the Project, the spread of introduced fish species in the Watut River system is likely to continue unabated given the absence of PNG freshwater fisheries management or intervention.

While the native fish species recorded in, or expected to be present in, the Lower Watut River system including the Wafi River system are common and widespread in the rivers and streams of the Mine Area and along the Infrastructure Corridor and, therefore, have been assessed to have a **medium** sensitivity. This sensitivity assessment is based on native fish being under pressure from competition with invasive species for food resources, shelter and foraging areas.

Fish species of conservation significance are summarised in Section 3.3.7 below.

3.3.6. Semi-aquatic fauna

The principal semi-aquatic fauna of the Project Area includes the aquatic life stages (e.g., eggs and tadpoles) of certain amphibian frog species (e.g., *Litoria* spp.), as well as the semi-aquatic juvenile and adult reptiles such as freshwater turtles and saltwater crocodiles.

Overall, semi-aquatic or water-associated fauna of the Project Area are widespread and common within the rivers, streams, and off-river waterbodies and oxbow lakes and have therefore been assessed to have a **low** sensitivity.

Semi-aquatic species of conservation significance are summarised in Section 3.3.7.

3.3.7. Aquatic species of conservation significance

This section describes aquatic fauna species of conservation significance that are known to be present or expected to occur within the Project Area and surrounds.

No aquatic macrophyte or microphyte (e.g., stream diatoms and benthic algae) species of conservation significance were found or expected to occur in the Project Area and surrounds (i.e., Mine Area, Infrastructure Corridor, Port Facilities Area or Outfall Area).

Three aquatic invertebrate species in PNG have been classified as either threatened or near threatened in PNG on the IUCN Red List (IUCN, 2017):

- The freshwater crayfish (*Cherax papuanus*) (VU, Vulnerable) – known only from Lake Kutubu in the Southern Highlands (Austin, 2010) and, on this basis, is unlikely to occur in the study area.
- The dragonfly (*Diplacina arsinoe*) (VU, Vulnerable) - reportedly confined to ranges around Port Moresby (Kalkman, 2009) and, on this basis, is unlikely to occur in the study area.
- The dragonfly *(Idiocnemis adelbertensis*) (NT, Near Threatened) - reportedly confined to ranges around Madang (Kalkman, 2009) and, on this basis, is unlikely to occur in the study area.

No threatened or near-threatened aquatic macroinvertebrates are listed under PNG legislation or international conservation schemes.

Three fish species in PNG have been classified as either critically endangered or near threatened in PNG on the IUCN Red List (IUCN, 2017):

- The largetooth sawfish (*Pristis pristis*) (CR, Critically Endangered) of the Indo-West Pacific subpopulation (formerly *Pristis microdon*) – juveniles and sub-adults occur in main channels of rivers and estuaries, and the adults are typically found in coastal waters of PNG. This sawfish is known to have been present in Lower Watut River downstream of the Wafi River from a 1988 sighting (Gwyther, 1998 reported in Powell and Powell, 2000) and, on this basis, may occur occasionally in the lower reaches of the Markham and Watut rivers. This species has not been recorded in subsequent surveys between 2007 and 2015.
- The Lake Wanam rainbowfish (*Glossolepis wanamensis*) (CR, Critically Endangered) - reportedly confined to the high-altitude Lake Wanam and, on this basis, is unlikely to occur in the Project Area and surrounds.

- The freshwater gudgeon (*Eleotris aquadulcis*) (NR, Near Threatened) - reportedly of restricted distribution within the Sepik and Ramu river systems preferring shallow lakes with abundant shoreline. The freshwater gudgeon has not been recorded to date in the Markham River system and, on this basis, is unlikely to occur in the Project Area and surrounds.

Two freshwater turtle species are present or expected to occur in the Project Area; namely, Schultze's snapping turtle (*Elseya schultzei*) that is classified as Least Concern on the IUCN's Red List of Threatened Species, while the northern New Guinea giant softshell turtle (*Pelochelys signifera*) has a Vulnerable (VU) classification (IUCN, 2017).

4. Potential impacts

A range of activities associated with the Project are likely to generate physico-chemical stressors to downstream watercourses, which in turn lead to potential consequential impacts on the beneficial values of the freshwater ecology. The Project may impact the beneficial values of the freshwater ecology in the following ways:

- Direct impairment of habitat through removal, modification, sedimentation (in suspension or deposited on river bed), or effects of toxicants on biota.
- Indirect effects that are at least one step removed from Project activities in terms of cause-and-effect links, e.g., changes to food availability, life cycle requirements or additive to existing stresses, resulting in selective survival favouring introduced species.

Potential effects of the Project on surface water and freshwater ecology are summarised in Table 4.1. Stressors and potential impacts on the freshwater aquatic ecological values due to Project activities are discussed in the following sections.

4.1. Potential impacts from physical disturbance

Direct disturbance of watercourses located within Project infrastructure footprints and along linear infrastructure (e.g., Infrastructure Corridor) will occur, ranging from major activities such as diversion of creeks (e.g., underdrains or contour diversion drains) to minor activities such as construction of watercourse crossings. Activities that could result in the physical disturbance include:

- Construction of Project infrastructure (e.g., Watut Declines Portal Terrace and raw water dam) causing:
  - Loss of aquatic habitat.
  - A barrier to migration or other longitudinal movements of aquatic fauna within a watercourse due to the physical presence of the raw water dam.
- Removal of watercourse substrata (e.g., gravel extraction in the Bavaga River) and consequential degradation of aquatic benthic habitat.
- Sedimentation and/or aggradation of watercourse beds and consequential loss or degradation of aquatic benthic habitat by reducing structural diversity.
- In-stream works, diversion of watercourses and bridge construction i.e., piling in rivers.

Sedimentation and bed aggradation may occur in watercourses downstream of Project disturbances. Sedimentation causes an infilling of the interstitial spaces within watercourse stony substrata, reducing void (pore) spaces and microhabitats important to stones-in-current aquatic macroinvertebrates, as well as fish in terms of food resources and reproduction (e.g., egg laying or attachment to stone surfaces).

The physical presence of infrastructure (i.e., the raw water dam and portal terrace) will create a barrier within Boganchong Creek to upstream or downstream movements or migration of fish and river prawns. However, in this case, two natural waterfalls, up to 4.5 m high, are located immediately downstream of the proposed raw water dam, which forms an existing natural barrier in this creek. On this basis, this was not considered further in this assessment.

Table 4.1: Project stage, activities, stressors and potential impacts on freshwater ecology

Activity	Project Stage	Potential Stressor	Potential Impact
Land clearing, vegetation removal and earthworks leading to increased erosion	Construction	• Increased coarse-grained sediment loading of the natural drainage, with localised sediment deposition and streambed aggradation. • Increased concentrations of dissolved/particulate-associated metals and metalloids in downstream drainage.	• Loss or reduction in structural diversity and quality of streambed habitats. • Loss or degradation of riparian habitat. • Potential TSS and turbidity effects on aquatic flora and fauna. • Potential toxic effects of dissolved and particulate-associated metals to aquatic flora and fauna. • Changes to aquatic flora and fauna diversity and abundance.
Diversion of watercourses, in-stream works and construction of bridges	Construction	• Altered hydrology and changed stream flow regimes • In-stream construction (diversion channels, raw water dam embankment, sedimentation ponds, gravel extraction and Infrastructure Corridor watercourse crossings) leading to increased coarse and fine-grained sediment loading. • Localised increased turbidity and TSS.	• Loss or reduction in structural diversity and quality of streambed habitats. • Loss or degradation of riparian habitat. • Potential TSS and turbidity effects on aquatic flora and fauna. • Changes to aquatic flora and fauna diversity and abundance.
Track and road construction to access major sites (Watut and Nambonga declines, plant and portal terraces, accommodation facility, Miapilli Waste Rock Dump and borrow pits), construction of the Northern Access Road, Watut Services Road and Resettlement Road	Construction and early operations	• Potential coarse and fine-sediment-laden runoff from construction of road upgrade sections or new road alignments entering the natural drainage resulting in increased sedimentation and stream aggradation. • Road surface runoff from road usage by construction traffic increasing fine sediment loads to natural drainage. • Exacerbate the spread of weeds and/or invasive fauna species to new catchments.	• Loss or reduction in structural diversity and quality of streambed habitats. • Potential TSS and turbidity effects on aquatic flora and fauna. • Changes to aquatic flora and fauna diversity and abundance.
Formation of engineered hard surfaces of Project facilities increasing runoff	Construction and operations	• Changes in catchment water yield and alteration of runoff to natural drainage, resulting in changed stream flow regimes. • Changes in water quality due to variable dilution conditions brought about by altered flow regimes. • Aggradation or scour of creek and river beds.	• Potential impacts on flow-sensitive aquatic species. • Potential effects on aquatic flora and fauna as a result of water quality changes. • Potential effects on aquatic flora and fauna as a result of river bed aggradation or scour.

Activity	Project Stage	Potential Stressor	Potential Impact
Road traffic on the access roads, Northern Access Road, Watut Services Road and Resettlement Road, during operations	Operations	• Potential for spillages or leaks of fuel, oils and mine processing chemicals, which may enter the natural drainage. • Changes in water quality caused by increased concentrations of petroleum hydrocarbons, solvents, flocculants and other processing chemicals transported on roads. • Road surface runoff from road usage by operations traffic increasing fine sediment loads to natural drainage. • Changes in water quality due to increased concentrations of TSS and turbidity. • Exacerbate the spread of weeds and/or invasive fauna species to new catchments.	• Potential impacts of increased concentrations of TSS and turbidity on aquatic flora and fauna. • Potential toxicity effects of spilled hydrocarbons to aquatic flora and fauna. • Potential toxicity effects of mine chemicals to aquatic flora and fauna. • Potential changes to the aquatic flora and fauna diversity and abundance.
Construction and operation of the Northern Access Road Borrow Pit and Mt Beamena quarry operation	Construction and operations	• Erosion-derived increased coarse- and fine-grained sediments in runoff entering waterways. • Localised sediment deposition and streambed aggradation. • Changes in water quality due to increased concentrations of TSS and turbidity.	• Loss or reduction in structural diversity and quality of streambed habitats. • Loss or degradation of riparian habitat. • Changes to benthic biota diversity and abundance. • Potential impacts of increased concentrations of TSS and turbidity on aquatic flora and fauna.
Discharge of mine wastewater; extraction of make-up water from the Watut River; discharge of mine wastewater to Nambonga Creek	Construction and operations	• Altered hydrology and changed stream flow regimes • Increased concentrations of TSS, sulphides, dissolved/particulate-associated metals and metalloids, and altered pH regimes in downstream drainage.	• Potential impacts on flow-sensitive aquatic species. • Potential effects on aquatic flora and fauna as a result of water quality changes. • Potential aggradation or scouring of the receiving river bed resulting in change of aquatic habitats.
Vehicle maintenance, workshops and fuel and oil storage	Construction and operations	• Contaminated surface runoff containing oil and grease, solvents or detergents resulting in changes to water quality. • Fuel, lubricant and/or hydraulic fluid spillages or leaks resulting in changes to water quality.	• Potential toxicity effects of petroleum hydrocarbons and detergents to aquatic flora and fauna.
Ore processing	Operations	• Runoff/spills/seepage	• Potential toxic effects of dissolved and particulate-associated metals to aquatic flora and fauna. • Potential TSS and turbidity effects on aquatic flora and fauna.

Activity	Project Stage	Potential Stressor	Potential Impact
Physical presence of infrastructure (e.g., raw water dam and sedimentation pond within Boganchong Creek drainage line)	Construction, operations and post-closure	• Physical impediment to fish and decapod crustacean movement and migration. • Watut Declines Portal Terrace, raw water dam and sedimentation pond replaces natural creek drainage of Boganchong Creek catchment. • Altered flow regimes.	• Fragmentation and isolation of upper catchment due to raw water and sedimentation pond dam walls acting as a physical barrier to fish and prawn migrations. • Loss of running water (lotic) habitats of Boganchong Creek catchment. • Changes to natural flow regimes affecting flora and fauna in Boganchong Creek.
Decline construction and block cave mining	Construction and operations	• Groundwater discharges and potential acid and metalliferous drainage (AMD) to Mine Area watercourses. • Increased concentrations of TSS, sulphides, dissolved/particulate-associated metals and metalloids, and altered pH regimes in downstream drainage.	• Potential impacts of increased concentrations of TSS and turbidity on aquatic flora and fauna. • Potential acute or chronic toxic effects of dissolved and particulate-associated metals to aquatic flora and fauna.
Construction of waste rock dumps	Construction and operations	• Potential seepage and runoff from waste rock dumps to Boganchong Creek and Yor Creek, resulting in increased concentrations of TSS, metals and metalloids.	• Potential toxic effects of dissolved and particulate-associated metals to aquatic flora and fauna.
Construction of accommodation camp/offices	Construction and operations	• Erosion-derived increased coarse- and fine-grained sediments in runoff entering waterways. • Treated water discharges (e.g., sewage effluent), and non-treated greywater, chemical spills and landfill leachate.	• Potential impacts of in-stream sedimentation and increased TSS concentrations and turbidity on aquatic flora and fauna. • Potential impacts of increased nutrient loading from sewage treatment plant effluent on aquatic flora and fauna. • Potential toxicity of chemicals and landfill leachate to aquatic flora and fauna.
Construction and operation of waste management facility	Construction and operations	• Potential for landfill leachate to infiltrate to surface water. • Potential for increased TSS and turbidity.	• Potential impacts of in-stream sedimentation and increased TSS concentrations and turbidity on aquatic flora and fauna. • Potential toxicity of chemicals and landfill leachate to aquatic flora and fauna.
Mine closure and formation of subsidence zone lake	Closure	• Cessation of mining results in flooding of the block caves and underground workings. • Exposure of potentially acid forming material to water and oxygen leading to AMD and poor water quality. • Formation of a permanent subsidence zone lake with poor water quality (low pH and elevated metals and sulphate).	• Potential acute or chronic toxic effects of dissolved and particulate-associated metals to aquatic flora and fauna. • Impacts on aquatic flora and fauna as a result of changes to baseflow affecting stream recharge.

4.2. Potential impacts from altered hydrology

Changes to the hydrological flow regime in watercourses beyond that of natural variability is a physical stressor to flow-sensitive aquatic flora and fauna. Altered hydrology also includes consideration of flow impedance, such as on the upstream side of linear infrastructure, and roads acting as a barrier to flood flows.

Project activities that could result in altered hydrology include:

- Construction of Project infrastructure resulting in:
  - Altered flow rates in lower Boganchong Creek due to the Watut Declines Portal Terrace, sedimentation pond and raw water dam.
  - Increased peak flows from higher water yields due to forest clearing and the presence of compacted surface areas of Project infrastructure footprints, terraces and roads.
- Siting of Project infrastructure altering natural drainage lines.
- Construction of linear infrastructure such as the Northern Access Road across the Lower Watut River floodplain.
- Water extraction and water discharge activities.
- Dewatering of the block caves and declines resulting in groundwater drawdown affecting baseflow. Impacts on groundwater are discussed in Chapter 14 of the EIS, Physical and Biological Environment Impact Assessment, and the implications of this for freshwater ecology are assessed in Section 7.12 of this report.

Linear infrastructure, such as roads constructed on floodplains, can have major impacts on local hydrology and aquatic ecosystems. Project roads are typically constructed using a cut-and-fill approach to help level local topography. Unless frequent culverts are installed, filled areas impede drainage, especially during heavy wet-season rainfall. This can lead to flooding on the upstream (upslope) side of the road, altering flood levels, water flow and velocities. This presents a physical stressor to flood-sensitive or flow-sensitive aquatic flora and fauna, as well as potential source of dieback of terrestrial flora and vegetation caused by ponding. Temporary ponding, which forms standing (lentic) water habitat, may be colonised by aquatic macrophytes and algae that prefer standing waters. Downslope of affected road segments, reduced flows or flow cessation may occur and cause the drying of creek beds, resulting in loss of aquatic habitat and the desiccation of aquatic flora and fauna that are not displaced downstream. These ponding effects are expected to be localised but temporary as floodwaters rise and fall, with associated expansion and contraction of the floodplain, and are conditions that aquatic flora and fauna are naturally exposed to.

The construction of access roads (e.g., Watut Services Road and Northern Access Road) across the Lower Watut River floodplain has the potential to detain floodwaters upstream of the roads, which creates temporary flood areas. BMT WBM (2018a and 2018b) identified that there were two major breakout locations from the Lower Watut River in the vicinity of the Project: immediately downstream of the confluence of Wafi River and at a section near Wongkins Village. These breakouts form a substantial overbank flow path on the inner (eastern) side of the Lower Watut River floodplain and are expected to inundate a large area of the floodplain characterised by a complex network of braided streams. An independent peer review of floodplain characteristics and modelling outputs (Hydrobiology, 2018) has provided further context for this behaviour, which is explained in further detail in EIS Chapter 15, Section 15.5.1.

The presence of the proposed nominally 2-m-high Watut Services Road has the potential to intercept Lower Watut River floodwaters on its eastern side causing flow diversions or flow impedance that may result in the temporary detention of floodwater until flood recession. However, proposed management measures including the appropriate number, sizing and siting of culverts are expected to reduce such potential impacts. Despite these measures, temporary detention of floodwater and alteration of floodwater velocities across the Lower Watut River's eastern floodplain is identified as a potential stressor to flow-sensitive aquatic flora and fauna.

For roads in steeper terrain (as opposed to floodplain or low-gradient (<2°) road locations), such as the Resettlement Road within the Wafi River catchment, runoff from impervious road surfaces and interception of subsurface flow at road cuts provide pathways for increased flows and storm runoff, which may accelerate erosion and deliver increased sediment loads to receiving watercourses. Roads constructed in steeper terrain (e.g., the Resettlement Road) will be designed and constructed to intercept and channel rainfall runoff within upslope road ditches to culverts beneath the road, such that flow impedance and ponding is not expected to occur.

4.3. Potential impacts from erosion and sedimentation

4.3.1. Erosion

The steepness of the terrain and the scale of the Project facilities within the Mine Area will necessitate localised excavation, filling or cut-and-fill of the ground surface during construction. Construction activities associated with the Project will involve the clearance and removal of vegetation, storing topsoil in stockpiles, stripping of topsoil exposing underlying subsoil, and other ground-disturbing works with widespread disturbance to soils. The soil-landform units in the Project Area and surrounds are susceptible to erosion, particularly those units situated on unstable and steep topography (i.e., colluvium, residual and slopewash soils). The high rainfall within the Project Area further increases the risk of soil erosion. In steep terrain disturbed soils will be most susceptible to rainfall-based erosion and scour because of the higher rates and velocity of surface runoff. This is further discussed in Chapter 14 of the EIS, Physical and Biological Environment Impact Assessment (Section 14.2).

Effects of erosion, such as increased scour, sedimentation, TSS and turbidity in downstream watercourses, can potentially lead to impacts on aquatic biota. These potential impacts could include: loss or reduction in structural diversity and quality of streambed habitats; loss or degradation of riparian habitat; TSS and turbidity effects on aquatic flora and fauna (see Section 4.4), and; changes to benthic biota diversity and abundance.

Potential physical stressors to freshwater ecology relating to downstream sedimentation as a result of soil erosion and increased sediment yields are characterised below.

4.3.2. Sedimentation of watercourses and floodplain

The high rainfall combined with steep, unstable slopes and associated high weathering rates generates significant natural background sediment loads entering the watercourses of the Project Area, resulting in frequent and rapid natural changes in the beds of the majority of rivers and creeks in the Project Area.

During the wet season, there is extensive natural sediment deposition throughout the Lower Watut River floodplain and across the eastern floodplain. This provides conditions favourable for the transport and re-suspension of sediments, allowing less time for mine-derived sediments to settle out of suspension, resulting in a relatively small proportion of mine-derived sediment deposition in the floodplain as a result of sediments being transported through the floodplain into the Lower Watut River and downstream into the Markham River. In the dry season, reduced flows through the floodplain and reduced sediment loads from catchment runoff, will reduce input of natural sediments to the floodplain. Conditions during this time will be more favourable for mine-derived sediments to settle out of slow-moving or standing water within the floodplain, albeit there will be less mine-derived sediment loads into the floodplain due to lower rainfall and reduced stream flow levels.

Coarse-grained sediments entering the natural drainage will generally be transported either as bed load or deposit on the stream beds causing localised bed aggradation. Subsequent rising and flood flows may be expected to resuspend settled sediments and transport them further downstream as suspended load. In the case of fine-grained sediments entering the natural drainage, these will be transported downstream as suspended load until they reach a lower energy hydrodynamic environment (e.g., pools, swampy areas and low-lying areas within the floodplain) where they will settle out of suspension. The very fine fraction of suspended sediment (e.g., <10µm particle diameter) will be transported without settling as wash load.

As indicated above, sedimentation and bed aggradation result in infilling of the interstitial spaces within watercourse stony substrata, reducing spaces for shelter and foraging habitat for aquatic macroinvertebrates. Nesting habitat for fish and their eggs can also be smothered by sediment, reducing reproductive success.

Independent of the Project, background sediment bed and suspended loads of the Lower Watut River are high, due mainly to the presence of alluvial and small-scale mining in the Middle Watut River, the Bulolo River sub-catchment and continuing erosion of the major Kumalu landslip in the catchment of the Kumalu River (a tributary of the Snake River), as well as legacy sediment loading from the construction phase of the Hidden Valley Mine in the Upper Watut River catchment. The Project has the potential to augment these background sediment loads in the Lower Watut River.

The main areas where Project construction-derived sedimentation of watercourses is anticipated are the creeks draining the escarpment along the Lower Watut River's eastern floodplain and sub-catchment rivers and creeks in the Wafi River catchment.

4.4. Potential impacts to water quality

A number of physico-chemical stressors have the potential to impact aquatic biological communities of watercourses and off-river waterbodies (e.g., oxbow lakes) as a result of Project development.

The primary water quality stressor during the construction phase will be the delivery of fine-grained sediments to downstream watercourses, which will report as suspended load (measured as TSS).

During the construction phase, erosion of disturbed or displaced natural soils can potentially deliver both particulate and dissolved metals and metalloids which, if their concentrations increase above background levels, have the potential to affect aquatic biological communities. However, most of the soils likely to be disturbed in the eastern sub-catchments of the Lower Watut River floodplain are not located within known mineralised areas. Some of the proposed Project infrastructure, such as the process plant and portal terraces, are located near the mineralised zone of the Golpu deposit. Disturbance of surface soils in these areas that may be enriched in trace metals (e.g., mineralised soils) has the potential to decrease the pH and increase the concentrations of metals and metalloids delivered to the natural drainage. Increased concentrations of metals and metalloids are potential stressors to the aquatic biological communities of affected watercourses, as well as to terrestrial vegetation, which is assessed in Section 14.4, Terrestrial Ecology of Chapter 14 of the EIS.

During the dry season or low flow regimes, the concentrations of dissolved physico-chemical stressors (e.g., metals and metalloids) tend to be higher than during the wet season or high flows, owing principally to lower dilution. However, total metals or particulate metal concentrations tend to be higher during the wet season or high flows, owing to rainfall runoff transporting higher loads of eroded sediments to the natural drainage.

In general, physico-chemical stressors can be assessed using well-established receiving water quality criteria or guidelines for the protection of aquatic life (e.g., those promulgated by ANZECC/ARMCANZ (2000)). However, there are few criteria or guidelines for TSS that, as a potential physical water quality stressor, requires a different approach. In the case of increased TSS concentrations, the effect on aquatic fauna is a time-concentration effect. Aquatic organisms vary in their level of tolerance to TSS. The effects of TSS may be considered both directly and indirectly at the individual, population and community level of organisation.

The direct effects of increased TSS concentrations and associated turbidity to aquatic organisms include:

- Lethal effects (mortality of adult, larval life stages).
- Sublethal effects (suppression of growth and productivity).
- Direct effects of high TSS concentrations including abrasion to body integuments, gills or other respiratory structures that causes tissue damage or clogging, as well as clogging of the filtering or feeding apparatuses of stream macroinvertebrates.

Indirect effects of high TSS concentrations and attendant turbidity include:

- Reduction of aquatic primary productivity, which immediately reduces the energy available to enter the food web, affecting macroinvertebrates and fish as secondary consumers.
- Displacement of macroinvertebrates by movement away from waters having continuously elevated TSS concentrations (e.g., river prawns and the larger, more mobile macroinvertebrates) to clear side tributaries.
- Downstream behavioural displacement through benthic macroinvertebrate drift (i.e., dispersal downstream passively or actively in the current to avoid areas of high TSS concentrations).
- Downstream behavioural displacement of fish exposed to continuously high TSS concentrations.
- Potential changes to aquatic flora and fauna species diversity and abundance as a result of the effects above.

4.5. Potential aquatic weeds and pest species

Only one species of aquatic weed, the water lettuce (*Pistia stratiotes*), was recorded in characterisation surveys at a single site on an oxbow on the Lower Watut River floodplain. The most widely distributed invasive aquatic weed in PNG, the water hyacinth (*Eichhornia crassipes*), was not observed in field surveys undertaken by BMT WBM (2013a and b). While both of these species are likely to be present in small oxbow lakes along the middle Watut River, no Project infrastructure is proposed in these areas.

Various field surveys conducted in the Project study area (e.g., BMT WBM, 2018a) indicated that non-native species represent an increasing proportion of the fish fauna of most aquatic ecosystem types, the exception being upland rivers and creeks. Many of the non-native species recorded in the Project study area are highly invasive species that are known elsewhere to adversely affect aquatic habitats and native fish species. The spread of invasive fish species in PNG including in the Markham and Watut river systems is likely to continue regardless of whether the Project proceeds or not. However, the Project has the potential to exacerbate the spread of invasive fish species and introduce pests to new catchments either accidentally by Project activities, or by intentional introductions by humans.

Introduced fish species have a competitive advantage over native fish species in river systems, which can reduce native fish diversity and abundance depending on the species targeted. Non-native introduced freshwater fish can impact upon endemic native species through predation and competition, introduction of disease, and ecosystem alterations. Introduced fish compete with native fish for food and habitat resources. The ability to modify habitats and ecosystems is a trait of many invasive species and, in particular, carp can destroy or reduce the value of habitat for native fish by increasing turbidity and destroying aquatic plant beds.

4.6. Existing stressors and adaptations

The freshwater aquatic biological communities of rivers, streams and floodplain waterbodies of the Project Area are naturally exposed to many of the same changes to those that may result from the Project; for example, through periodic sedimentation and high TSS concentrations during flood flows and from naturally occurring landslides in upper catchment areas. The presence of introduced species described above is an additional and more recent source of competition for native freshwater aquatic flora and fauna.

The existing freshwater aquatic flora and fauna species composition reflects the overall adaptations and tolerances to these changes, which may still be dynamic in the case of introduced species. For example, species that rely on food sources washed into the rivers will be more tolerant of periodic sedimentation than those dependent on in-stream sources whose habitats are smothered. There will therefore be existing tolerance to Project-related sedimentation effects that will favour the more sediment tolerant species to the extent that impacts are not prolonged beyond natural tolerances or further alter survivability of some species over others.

5. Proposed management measures

This section presents an overview of the proposed management measures to be implemented to reduce the impacts on the downstream receiving environment. Specific measures are detailed in the Project Environmental Management Plan (Attachment 3 of the EIS).

5.1. Hydrology and sediment transport

To limit impacts relating to hydrology and sediment transport, WGJV proposes to:

- Manage Project-related disturbance and apply procedures to control access to undisturbed areas.
- Design bridges and culverts to allow for high flow events following heavy rainfall, and to mimic natural flow characteristics where possible.
- Decommission and revegetate temporary access roads and restore disturbed primary drainage paths, where practicable.
- Install erosion and sediment control structures to reduce fugitive sediment reporting to watercourses and surface water features.
- Construct erosion and sediment control structures prior to construction at each location.

5.2. Water quality

To limit impacts relating to water quality, WGJV proposes to:

- Where necessary, capture and treat mine wastewater prior to discharge, to meet environment permit conditions.
- Treat sewage in accordance with environment permit conditions.
- Plan for progressive rehabilitation to limit exposed areas as sediment sources.
- Stabilise exposed areas susceptible to erosion by using methods such as covering with vegetation debris, jute netting, geogrid matting, mulching or similar.
- Reinstate and revegetate temporary work sites as soon as practicable after disturbance to stabilise soils and reduce runoff.
- Maintain water and wastewater treatment facilities.
- Actively manage potentially acid-forming (PAF) materials and control runoff and leachate from areas containing PAF material including:
  - Selective placement of PAF and non-acid forming (NAF) material in the waste rock dump in accordance with the waste rock dump design
  - In situ treatment or reprocessing stockpiled material through the process plant
  - Diversion of clean surface water around the site
  - Interception of leachate from the site and applying appropriate treatment methods if required prior to discharge
  - Treatment of contaminated runoff and leachate prior to discharge to meet environment permit conditions

5.3. Freshwater ecology

The proposed management measures described above are relevant to the management of freshwater ecology. Additional management measures the WGJV proposes to limit impacts to freshwater ecology include:

- Minimise the creation and extent of new access corridors in undisturbed catchments.
- Install diversion channels prior to clearing in-stream habitat and divert flows around in-stream work areas.
- Maintain hydraulic connectivity along linear infrastructure corridors for pipelines and roads (e.g. install culverts and drains where required).
- Implement risk-based control of weeds and plant pathogens that may include:
  - Weed and plant pathogen identification manual for contractors and personnel, and training in its use.
  - Visual inspection of vehicles, plant and equipment for soil, seeds and weed material.
  - Washdown of high-risk vehicles, plant and equipment before arrival at site.
  - Removal and/or destruction of weeds using appropriate methods.
- Prohibit the cultivation of invasive exotic species on Project sites and discourage the translocation of exotic fish species.

An aquatic biological monitoring program is proposed for development and implementation to verify predicted aquatic ecological impacts and to identify if further management measures are required. This is further described in Section 8.

6. Residual impacts to surface water

Changes to hydrology (stream flow), flooding, sediment transport and water quality in the Lower Watut River catchment (i.e., the Mine Area) as a result of Project development were assessed using outputs from numerical models developed by BMT WBM and presented in Wafi-Golpu Project EIS – Catchment and Receiving Water Quality Modelling Report (BMT WBM, 2018b (Appendix I of the EIS)). These models were based on the outputs of the Wafi-Golpu Site-wide Water and Mass Balance Model Life of Mine Projected Flow and Chemistry (Piteau 2018a, Appendix V of the EIS), which provided flow rates and water quality point sources for mine dewatering and other runoff sources. Piteau's water modelling outputs assumed water treatment performance as per the Clean TeQ (2017) report.

Two separate models were developed by BMT WBM to predict potential impacts to receiving water quality and hydrology:

- An integrated catchment and receiving water quality modelling framework (water quality and sediment transport modelling).
- A flood model.

Residual sediment and hydrological impacts along the Infrastructure Corridor segment that traverses the upper terrace of the Markham River floodplain between the proposed Markham Bridge and the Port Area in Lae, have been assessed qualitatively. Similarly, sediment transport impacts along the Resettlement Road, originating near Madzim Village that will traverse watercourses in the Wafi River catchment and terminate near Old Hengambu Village, have been assessed using a semi-quantitative method comparing baseline sediment concentrations in the Wafi River catchment with estimated road construction-related generation of sediment. The Watut Services Road that will traverse the Lower Watut River floodplain was assessed qualitatively.

A semi-quantitative assessment of the loads and concentrations of particulate-associated metals and metalloids for Boganchong Creek (which can be extrapolated to apply to other Mine Area catchments) was conducted using soils data reported by KCB (2013) (see Section 7.1.1).

Qualitative assessments based on literature, case studies of other mines in PNG and professional judgment were undertaken to support the quantitative data where required.

An additional consideration supporting the discussions below is the *Management of discharged metals via adsorption and complexation in the Watut River, Papua New Guinea*, as reported by CSIRO (Angel et al. 2016, Appendix G of Appendix G of the EIS). This report summarises the natural metals complexing capacity and adsorption capacity (of metals onto particulate matter) of the watercourses in the Mine Area.

During the post-closure period, the underground workings including block caves and declines will be allowed to flood with subsequent formation of a subsidence zone crater lake. Water and load balance modelling results for the post-closure period was undertaken by Piteau (2018b) (Appendix X of the EIS, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone).

A summary of the hydrology, flooding, sediment transport and water quality study methods and results are described in Chapter 15, Freshwater Environment Impact Assessment of the EIS and is not repeated here.

7. Residual impacts to freshwater ecology

This section assesses the residual impacts of the Project on the freshwater ecology of the creeks, rivers and floodplain watercourses in the Project Area and downriver environment. The residual impact assessment assumes that proposed management measures have been successfully implemented to avoid, reduce or ameliorate potential impacts.

As described in Section 3, the residual freshwater ecology assessment follows a significance approach. The significance approach draws extensively on the assessments of physico-chemical impacts to watercourses (presented in Chapter 15 of the EIS, Freshwater Environment Impact Assessment), which involved quantitative modelling and semi-quantitative and qualitative assessments to predict changes to hydrology, sediment transport and water quality arising from Project activities. Unlike the more predictable cause and effect relationships of the physico-chemical modelling, freshwater aquatic biological systems at the organism, population and community level respond variably to many environmental factors and consequently, changes can be more difficult to predict in time and space.

The residual impacts on aquatic habitats and aquatic biological communities (flora, macroinvertebrates and fish) are a synthesis and assessment of site-specific hydrological and water quality impacts (see Chapter 15 of the EIS, Freshwater Environment Impact Assessment) that have consequential impacts on freshwater ecology during Project construction and operations.

Via a thorough step-by-step process, the assessment of residual impacts on aquatic ecological values were evaluated in each of the sub-catchments listed in Table 7.1. At a high-level, this process revealed the following key points:

- Of all the catchments assessed in the Project Area, the only catchment with a residual **Moderate** impact significance rating was Boganchong Creek during construction.
- All of the other sub-catchments within and downstream of the Project Area were assessed as having a **Low** impact significance rating for all Project phases.

This appendix, however, assesses each of the sub-catchments in detail for completeness.

Table 7.1: High-level summary of residual impacts

Sub-catchment	Residual Impact Rating
Boganchong Creek	Moderate
Womul Creek	Low
Lower Bavaga River	Low
Wafi River	Low
Other Eastern Catchment Creeks	Low
Lower Watut River Eastern Floodplain	Low
Lower Watut River	Low
Markham River floodplain	Low
Coastal Area	Low

7.1. Boganchong Creek

Boganchong Creek drains a small catchment (approximately 2 km^2) that is located within the Mine Area. The Boganchong Creek catchment is one of numerous of small catchments distributed along the escarpment adjoining the eastern floodplain of the Lower Watut River, which will be affected by the Project during construction and operations. However, in the case of the Boganchong Creek upper catchment, there will be a major concentration in space and time of Project infrastructure within its catchment.

Project infrastructure within Boganchong Creek catchment includes:

- Upper catchment:
  - Watut Process Plant and terrace
  - Watut Declines Portal Terrace
  - Watut Waste Rock Dump
  - Sedimentation dam
  - Portal terrace twin sedimentation ponds
  - Raw water dam
  - Various access roads
- Floodplain catchment:
  - Waste management facility and stockpiles of topsoil, spoil and deforestation material (e.g., logs and mulch)

The residual impacts on freshwater ecology are assessed below for Project construction and operations.

7.1.1. Construction phase freshwater ecology impacts

The principal stressors on the freshwater ecology of Boganchong Creek during the construction phase include:

- Direct loss or degradation of aquatic habitats.
- Sedimentation resulting from the deposition of coarse-grained sediments.
- Increased suspended sediment concentrations and associated turbidity.
- Alteration of hydrology such as streamflow and water abstraction.
- Potential for mobilisation of metals and metalloids in eroded soils.

Loss of aquatic habitat

The main channel aquatic habitats of a 1.4-km-long section of the upper Boganchong Creek will be permanently lost due to the combined footprints resulting from installation of the raw water dam, sedimentation pond, Watut Declines Portal Terrace and Watut Waste Rock Dump. The upper Boganchong Creek is an ephemeral creek that ceases to flow during the dry season (the 90% exceedance flow is zero). Surface water flows from the upstream upper catchment above the Watut Declines Portal Terrace will be maintained by underdrains, which will convey flood flows to Boganchong Creek below the raw water dam.

The habitats of aquatic biological communities in upper Boganchong Creek relate principally to drought-tolerant macroinvertebrates (larval stages of egg-laying insects and beetles) and microalgae (diatoms and periphyton). There are no fish habitats in the upper Boganchong Creek due to the presence of two natural waterfalls up to 4.5 m-high located approximately 60 m downstream of the toe of the proposed raw water dam, and which act as a natural barrier to fish migration or other fish longitudinal movements.

The 1.4 km-long loss of microalgal and macroinvertebrate habitats represents about 58% of the upper Boganchong Creek main channel using the longest length of upper Boganchong Creek. The residual impacts of this habitat loss in the wet season are assessed as **Moderate** significance based on a **high** magnitude of impact and **low** sensitivity. When flowing, the underdrains will still represent aquatic habitat of poor quality; there is typically a lack of primary production due to absence of photosynthetically active light, reduced microalgal biomass and consequential reduced food resource to surviving or colonising macroinvertebrates. These depauperate aquatic biological communities also perish when ephemeral flows cease during the dry season. In the context of the broader region, the impact represents a small proportion of affected aquatic habitats.

During the dry season, there is a natural total loss of aquatic habitats and biological communities when upper Boganchong Creek ceases to flow; therefore, residual impacts of Project construction on aquatic habitats in the dry season are assessed as **Low** significance based on a **very low** magnitude of impact and a **low** sensitivity.

Sedimentation impacts

During the wet season, the floodplain aquatic habitats in the lower Boganchong Creek main channel and distributary channels comprise creek bed substrata comprised mainly of fine sands and larger sediments (i.e., particle sizes >125μm diameter), which have existing aquatic fauna of low diversity and biomass. The construction-derived increased bed sediment loading is expected to increase sedimentation rates within impacted creek reaches and produce a continually shifting bed substratum (i.e., bed sediment transport), which presents a creek bottom habitat of low structural diversity that is not conducive to many soft-bottom macroinvertebrate species, which are a food resource for fish.

Once the raw water dam is constructed, it will trap coarse sediments from construction-disturbed areas and downstream sedimentation impacts and floodplain sediment deposition will progressively reduce to pre-disturbance levels. Implementation of the Erosion and Sediment Control Plan is also expected to facilitate reduction of sedimentation rates. Overall, the residual impacts of sedimentation on the aquatic habitats of Boganchong Creek and its distributaries in its floodplain reach during the wet season are assessed as **Moderate** significance based on a **high** magnitude of impact and a **low** sensitivity.

During the dry season, flows in Boganchong Creek dry up, resulting in a temporary but natural total loss of in-creek aquatic habitat available to aquatic flora and fauna. During this period, mobile fauna (fish and river prawns and macroinvertebrate drift) are displaced downstream as creek flows recede, whereas non-mobile fauna desiccate and perish. Therefore, there are predicted to be no residual impacts on aquatic habitats during parts of the dry season, given their temporary absence in this ephemeral creek.

Suspended sediment and turbidity impacts

During the early construction phase (i.e., Construction Year 1) and prior to the installation of the sedimentation dam in Boganchong Creek downstream of the proposed Watut Declines Portal Terrace and other upstream infrastructure, fine-grained sediments comprising very fine sands, silts and clays (<125μm diameter) will enter the natural drainage via overland flow during and following rainfall. The sources of fine sediment loading include direct in-creek construction activities (e.g., disturbance of creek bed and adjacent banks at creek road crossings), rainfall-based erosion of construction-disturbed soils and subsoils exposed during land clearing (e.g., tree felling, grubbing, topsoil stockpiling), access road construction to the sedimentation dam, as well as from other early construction sites, such as the Watut Process Plant Terrace, waste management facility, water treatment plant and their various access roads.

Background TSS concentrations in Boganchong Creek during low to average flows are low (<5 mg/L), which is typical for relatively intact forested catchments in PNG (DBA, 2005). The significant increase in construction-derived TSS concentrations in Boganchong Creek when it is flowing is predicted to have adverse effects on aquatic flora, macroinvertebrates and fish downstream of the sedimentation dam and/or raw water dam. The primary response of the more mobile macroinvertebrates and fish is likely to be displacement downstream or laterally to clean water tributaries (e.g., the southern tributary of Boganchong Creek that drains a similar-sized sub-catchment).

While many of the nine species of native fish and two introduced fish species captured in the Lower Watut River floodplain (moderate and low gradient floodplain ecosystem types surveyed in 2015, see Chapter 9 of the EIS, Freshwater Environment Characterisation and BMT WBM, 2018a) are sediment-tolerant species, it is the continuous nature of construction-derived TSS concentrations (duration-concentration effect (NSR, 1986; Newcombe et al., 1991; Newcombe, 1994; DBA, 2005)) that causes the displacement impact on macroinvertebrates and fish. The same macroinvertebrate and fish species are naturally displaced downstream when Boganchong Creek aquatic habitats recede as flows decrease to zero (i.e., it is an ephemeral creek).

In addition, most macroinvertebrates and fish in the Lower Watut River's eastern floodplain tributaries naturally experience very high TSS concentrations during breakout flows causing inundation of the floodplain when TSS concentrations often exceed 1,000 mg/L and up to a maximum of 10,300 mg/L (Wiles and Bollaert, 2015). Fish are also known to tolerate extremely high TSS concentrations in the short term. For example, a total 15 species of northern hemisphere freshwater fish tolerated and survived clay suspensions containing TSS concentrations of 100,000 mg/L for one week (Wallen, 1951; Alabaster and Lloyd, 1982). For southern hemisphere (PNG) fish, the red-striped rainbowfish (*Melanotaenia splendida*) survived five days in mine tailings having respective mean and peak concentrations of 13,030 mg/L and 44,645 mg/L, prior to the test being halted due to excess sedimentation (DBA and MFG, 2005).

Overall, the residual impacts of construction-derived increases in TSS concentrations in Boganchong Creek are assessed as **Moderate** significance at the sub-local scale, based on a **very high** magnitude of impact and a **low** sensitivity.

Impacts arising from altered hydrology

The progressive clearing of land and construction of mine infrastructure including the sedimentation pond, Watut Declines Portal Terrace, twin sedimentation ponds, Watut Waste Rock Dump, raw water dam, and erosion control and water treatment plant infrastructure is expected to alter the flow regime of downstream receiving environments, as follows:

- Alteration of peak flows:
  - Land clearing involves tree feeling and construction of gravel wearing access roads (hard impermeable surfaces), which may lead to an increase in catchment water yield that may affect peak flows.
  - Retention structures (e.g., sedimentation dam basins), may result in delayed storage of overland flows, with a likely net result of reducing the magnitude of peak flows events downstream of the basins, changes to the timing of flow events (measured in hours to possibly tens of hours), and modifications to the frequency and duration of low flow periods.
- The Watut Declines Portal Terrace is located entirely within Boganchong Creek catchment, and subterranean drains (or underdrains) will therefore be constructed under the terrace to allow flows from the northern and southern arms of Boganchong Creek in its upper catchment (i.e., upstream of the terrace). The underdrains will likely experience high flow velocities, depending on sizing and materials.
- Minor spillway flows from the sedimentation pond in Boganchong Creek will be diverted around the proposed raw water dam to allow its construction within a dry creek bed. The raw water dam will be built two years after the sedimentation dam is in place.

These features are expected to result in highly localised changes to flow regimes in Boganchong Creek immediately downstream of the Mine Area infrastructure in this creek's catchment.

Increased water yield from hard surfaces (impermeable and compacted soil areas) compared to the water yield from pre-disturbance forested land is expected to be small and unlikely to affect peak flows. For example, the total area of the mine infrastructure footprint in Boganchong Creek catchment upstream of the toe of the raw water storage dam is approximately 30 ha (the major part being the combined Watut Process Plant terrace and portal terrace at 20.2 ha), which represents about 27% of the catchment total area of 112 ha.

Similarly, as construction progresses (Construction Years 1 to 5), retention structures (e.g., the sedimentation basin and the raw water dam) may result in delayed storage of overland flows, with a likely net result of reducing the magnitude of peak flows events. However, the residual impact on peak flow events and the overall flow regime of Boganchong Creek downstream of the Mine Area is not predicted to be significant. For example, a southern unnamed tributary of the Boganchong Creek enters the creek's main channel about 280 m downstream of the waterfall, which drains a comparable sub-catchment area of 1.14 km^2 that is 87% of the sub-catchment with mine infrastructure (1.33 km^2) and augments the flow in Boganchong Creek in its floodplain reach.

Overall, during the wet season, minor alterations of peak flows and general flow regimes in Boganchong Creek downstream of Mine Area infrastructure are assessed to have negligible to minor effects on the aquatic habitats and biological communities and residual impacts on both aquatic habitats and resident aquatic flora and fauna are assessed as **Low** significance based on a **low** magnitude of impact and a **low** sensitivity. No impacts are predicted for the dry season when Boganchong Creek does not flow.

Increased particulate and dissolved contaminant impacts

Construction disturbance and displacement of soils within the Mine Area of Boganchong Creek catchment has the potential to increase the loads and concentrations of particulate-associated metals and metalloids and expose sediment-ingesting freshwater biota to this stressor.

In order to assess the potential for enrichment of metals, KCB (2013) sampled soils of the eastern catchments draining to Chaunong Creek, including one alluvial site (Site 62) in the floodplain of Boganchong Creek. The geochemical quality of alluvial soils is reflective of the geochemistry of soils in the catchment (i.e., the source) that will be disturbed by construction activities.

KCB (2013) determined that some metals and metalloids concentrations in the Boganchong Creek alluvial soil sample were elevated compared to natural crustal abundance levels. Table 7.2 shows the geochemical abundance index (GAI) for six metals or metalloids. A GAI of zero indicates an element is present at a concentration similar to, or less than, the median abundance and a GAI of 6 indicates approximately a 100-fold, or greater, concentration above median abundance. A GAI equal to three or above indicates a sample that is significantly enriched with a specified element. However, identified element enrichment does not necessarily mean that an element would be a concern for revegetation, water quality, or freshwater ecology, as the GAI is a guidance value used to identify any significant element enrichments that warrant further examination.

Table 7.2: GAI of elements in Boganchong Creek alluvium

Site	Concentration of metal or metalloid (mg/kg)					
	Arsenic	Copper	Nickel	Lead	Selenium	Zinc
SS 62	-2	0	-2	-1	3	6

Source: KCB (2013). Table cells highlighted in grey shading denote elements having significant enrichment.

Based on Table 7.2, selenium and zinc are enriched in the alluvial sediment (soil) sample from Boganchong Creek in its floodplain reach, which indicates that catchment soils are also enriched compared to their average crustal abundances of these two elements. However, selenium was also enriched in 75% of the soil samples collected from 20 other sites sampled across the Mine Area and along the escarpment (Infrastructure Corridor) and zinc was also enriched in 95% of the soil samples tested. Therefore, both selenium and zinc appear to be naturally enriched in the soils on a catchment-wide basis that includes upper Boganchong Creek sub-catchment, and despite the absence of mineralised zones that could contribute to such enrichment.

In order to assess the significance of potential enrichment of Boganchong Creek, which will receive construction-derived sediments, the total metal or metalloid concentrations in Boganchong Creek or nearby creek bed sediments were examined. Analyses of the <63 μm and <2,000 μm size fractions of creek bed sediments in the Mine Area were undertaken by BMT WBM (2018a). Data for the <63μm size fraction were examined as soil particles in this size fraction have a large surface area to volume ratio and the highest adsorption capacity. It is the size fraction most likely to be ingested by benthic macroinvertebrates and infauna, or inadvertently ingested by benthophagic (bottom feeding) fish.

No sediment metal or metalloid data were available for bed sediments from Boganchong Creek (BMT WBM, 2018a); however, sediment metal data were available for Womul Creek (site E20, see Figure 9.1, Chapter 9 in the EIS), which lies to the north and adjacent to Boganchong Creek, and drains a catchment of similar geology (Babuaf Conglomerates) and soils (Eutropepts), and the soils are assumed to have similar metal and metalloid concentrations.

Table 7.3 gives the metal and metalloid concentrations in the <63 μm size fraction of Womul Creek bed sediments.

Table 7.3: Metal/metalloid concentrations in fine-grained bed sediment

Site E20 Womul Creek	Concentration of metals/metalloids (mg/kg) in <63 μm size fraction					
	Arsenic	Copper	Nickel	Lead	Selenium	Zinc
Maximum	8	130	55	24	5	1,140
75-percentile	7	90	52	11	5	113
Median	5	62	43	8	5	96
25-percentile	5	52	42	7	5	79
Minimum	5	18	0	5	5	41
Average	6	69	43	10	5	171

Source: BMT WBM (2018a)

A noticeable feature of Table 7.3 is the low concentrations of selenium and zinc found in the bed sediments of Womul Creek, despite the elevated concentrations of these two elements in catchment soils as indicated by GAIs of 3 and 6, respectively in Table 7.2.

BMT WBM (2018a) particle size analyses of Womul Creek bed sediments on the floodplain indicated that they were comprised of 9% silts and clays (<63 μm), 73% sands (0.063 mm to 2 mm), 18% gravels (<2 mm and <6 mm) and less than 1% cobbles (>6 mm). Similar size distributions were observed for the bed sediments sampled in Chaunong Creek, which commences immediately downstream of the confluence of Womul and Boganchong creeks.

The median and average metal and metalloid concentrations in Table 7.3 were compared with ANZECC/ARMCANZ (2000) sediment quality guidelines and only the median total nickel concentration (43 mg/kg) was above the Sediment Quality Guideline (SQG) trigger value of 21 mg/kg. None of the median sediment metal or metalloid concentrations exceeded the higher sediment quality guideline (SQG-High) values, above which effects on filter-feeding or sediment-ingesting macroinvertebrates and inadvertent sediment-ingestion by bottom-feeding fish may be expected. The generally low concentrations of metals and metalloids in the <63μm size fraction (silts and clays) of creek bed sediments lends evidence to support the contention by BMT WBM (2018a), Pickup (2013a, 2013b) and Hydrobiology (2018) that fine sediments are deposited on the floodplain due to reduced flow velocities and the trapping efficiency of vegetation.

During the wet season, the residual impacts of metal and metalloid concentrations in construction-derived fine sediments delivered to the floodplain reaches of Boganchong Creek main channel and distributaries are assessed to be **Low** significance based on a **low** magnitude of impact and **low** sensitivity of the benthic aquatic fauna.

No impacts are expected during the dry season due to absence of aquatic habitats and biological communities.

7.1.2. Operations phase freshwater ecology impacts

During early operations, residual surface erosion of construction-disturbed soils and slopes not fully stabilised or revegetated is expected to continue contributing fine sediment loading of Boganchong Creek above pre-disturbance levels. However, as above for the construction phase, such fine sediments are likely to deposit of the floodplain of the eastern backplain of the Lower Watut River's eastern floodplain. Sediment loading of Chaunong Creek is not anticipated (BMT WBM, 2018a; Appendix G of the EIS), Pickup (2015a, 2015b) and Hydrobiology (2018).

Drainage from the Watut Process Plant and terrace, the Watut Declines Portal Terrace, and seepage from the Watut Waste Rock Dump are proposed to be intercepted and treated, such that contaminants such as metals and metalloids in the wastewater discharge to the Lower Watut River near Wongkins Village will comply with PNG ER and/or ANZECC/ARMCANZ (2000) ambient water quality guidelines the end of a mixing zone (see Chapter 15 of the EIS, Freshwater Environment Impact Assessment), such that aquatic flora and fauna are protected. Due to the interception and treatment of contaminated waters within Boganchong Creek upstream of the raw water dam and the discharge of treated wastewaters to the Lower Watut River main channel near Wongkins, significant levels (i.e., concentrations above water quality criteria) of dissolved or particulate-associated metals or metalloids are not anticipated in Boganchong Creek.

Overall, residual impacts during operations on the aquatic flora and fauna of Boganchong Creek downstream of the raw water dam are assessed as **Low** significance based on a **moderate** magnitude of impact and their **low** sensitivities. Aquatic flora and faunal communities remaining after the construction phase would have had an opportunity to adapt to the changed conditions in Boganchong Creek and would therefore be exposed to reduced TSS and sedimentation impacts during operations compared to the construction phase. Residual impacts on downstream aquatic flora and fauna in Boganchong Creek will be a component in the Project's monitoring program to assess the performance of the Project's interception and treatment of potentially contaminated waters in the water treatment system.

7.2. Womul Creek

Womul Creek drains a small catchment (approximately 2.2 km^2) that is located within the Mine Area. This creek flows westwards to the eastern backplain of the Lower Watut River's eastern floodplain. Womul Creek and Boganchong Creek join to form the start of Chaunong Creek.

The Womul Creek sub-catchment is also one of numerous small catchments along the escarpment adjoining the eastern floodplain of the Lower Watut River that will be affected by the Project during construction and operations.

Project infrastructure within Womul Creek upper catchment includes:

- Northern part (2 ha) of the Watut Process Plant and terrace.
- A 2.9 km-long section of the Northern Access Road and Infrastructure Corridor.
- Waste management facility (10.5 ha) and stockpiles.
- Water treatment plant (1 ha).
- Explosives magazine (0.1 ha) and its access road.
- A major part (9 ha) of the Fere Accommodation Facility.
- A 1.4 km-long section of the Mine Access Road that passes to the west of the Fere Accommodation Facility.

The residual impacts on freshwater ecology are assessed below for Project construction and operations.

7.2.1. Construction phase freshwater ecology impacts

During the construction phase, Womul Creek will receive mine-derived sediment loads resulting from rainfall-based erosion and scour of disturbed or displaced soils associated with infrastructure sites and the Infrastructure Corridor.

The principal stressors on freshwater ecology include:

- Direct loss or degradation of aquatic habitats by in-creek Project infrastructure.
- Sedimentation resulting from the deposition of coarse-grained sediments.
- Increased suspended sediment concentrations and associated turbidity.

Unlike Boganchong Creek, potential stressors related to alteration of hydrology (e.g., streamflow or flooding) of Womul Creek are not anticipated, owing to the absence of sedimentation dams within the creek, water detention or abstraction as process plant make-up water.

Loss of aquatic habitat impacts

Within upper Womul Creek, where the valley is incised, both the Northern Access Road and explosives magazine access road will require an embankment across the creek, with culverts to handle the 20-year ARI flood. Both the upstream and downstream sides of the creek crossings will have flow and scour protection in the form of gabions, as well as flow dissipation by rock fill or rock mattresses on the downstream side. These access road creek crossings represent a very small loss of creek bed habitat.

Overall, the loss or alteration of creek bed habitat at these two road crossings is assessed to be **Low** significance based on a magnitude of impact of **low** and a sensitivity of **low**.

Sedimentation impacts on freshwater aquatic habitats

During the construction phase, Womul Creek will receive construction-derived sediment loads resulting from rainfall-based erosion and scour of disturbed or displaced soils. Most of the construction work for mine access roads and the waste management facility and stockpiles site will be undertaken in the first year of construction. The Watut Process Plant (northern area within Womul Creek catchment), the water treatment plant and southern part of the Fere Accommodation Facility and will be constructed in Construction Years 2 to 3.

Implementation of the Project Erosion and Sediment Control Plan includes management strategies to reduce sediment loading of Womul Creek from construction areas.

The aquatic biological communities of the natural depositing substratum reach of the lower Womul Creek are already exposed to a sandy creek bed substratum and, as such, are adapted to this environment when this ephemeral creek is flowing. The bed load increment from construction-derived sediments is expected to increase sediment rates and increase sediment transport in the short term, with the consequent potential for short-term bed aggradation. As sediment production from construction-disturbed areas reduces through natural or assisted revegetation, sediment loads to the natural drainage and Womul Creek are predicted to progressively diminish over an 18-month to two-year period. In the interim, rising and flood flows in Womul Creek are expected to resuspend and transport construction-derived bed sediments downstream and across the floodplain.

The aquatic biological communities in Womul Creek have developed and are adapted to the extreme range of flow regimes between the wet and dry seasons. Overall, residual impacts of sedimentation on the aquatic habitats and biological communities (principally benthic macroinvertebrates and fish) are assessed to be **Low** significance based on a **moderate** magnitude of impact and a **low** sensitivity. These residual impacts apply during the wet season when Womul Creek is flowing. During the dry season, Womul Creek is dry (i.e. it is an ephemeral creek) and there are no aquatic habitats in the creek channel.

Water quality impacts on freshwater aquatic biota

The soils of Womul Creek catchment are assumed to have the same levels of metals and metalloids as Boganchong Creek catchment soils given their similar geology (i.e., Babuaf Conglomerates) and soil type (i.e., Eutropepts). Therefore, potential dissolved and particulate metal or metalloid contaminants in sediment entering the natural drainage and Womul Creek main channel are not expected to affect aquatic biological communities, which are already exposed to similar metal and metalloid concentrations.

The principal water quality contaminant will be the delivery of fine-grained sediments from soil erosion, which will increase TSS concentrations and associated turbidities in the main channel of Womul Creek downstream of Project infrastructure.

The residual impact assessment for Boganchong Creek above is also applicable to Womul Creek and is not repeated here. However, the duration of residual impacts of construction-derived increases in TSS concentrations in Womul Creek are predicted to be shorter, given the fewer construction sites and short section (approximately 3 km) of the access road to be built within its catchment. Most infrastructure components will be built in Construction Years 1 and 2, such that after about 18 months to two years following construction, disturbed or displaced soils will have been stabilised and revegetated through implementation of the Project Erosion and Sediment Control Plan, and erosion reduced. Therefore, the recovery period is anticipated to be much shorter. Notwithstanding, the residual impacts of construction-derived increased TSS concentrations on downstream aquatic macroinvertebrates and fish fauna of Womul Creek are assessed as **Low** significance, based on a **high** magnitude of impact and a **low** sensitivity.

7.2.2. Operations phase impacts on freshwater ecology

There are few, if any, operations phase impacts on freshwater ecology in Womul Creek, since the soils of most construction-disturbed areas will have been stabilised against erosion through natural and assisted revegetation. The primary source of fine sediment that may enter the natural drainage to Womul Creek is from road traffic and road surface maintenance (e.g., grading of road gravel surfaces and maintenance upslope and downslope drainage lines). However, typical sediment generation from this sort of road usage is relatively minor compared to road construction-derived sources.

Overall, residual impacts of the Project during operations on Womul Creek and its aquatic biological habitats and biological communities are assessed to be **Low** significance based on a **very low** magnitude of impacts and **low** sensitivity.

7.3. Other Eastern Floodplain Catchment creeks

Within the Lower Watut River catchment, there is a further series of six eastern sub-catchments along the escarpment and adjacent floodplain that are crossed by the Infrastructure Corridor and/or include Project infrastructure sites. The affected creeks including Project infrastructure are (see Figure 3.1):

- Fetaf Creek:
  - Infrastructure Corridor
- Ziriruk Creek:
  - Infrastructure Corridor
- Finchif Creek:

  - Infrastructure Corridor
  - Power generation facility
  - Finchif 1 Construction Accommodation Facility
  - Finchif 2 Construction Accommodation Facility (part only)
- Kufikasap Creek:
  - Infrastructure Corridor
  - Finchif 2 Construction Accommodation Facility (part only)
- Bobul Creek:
  - Infrastructure Corridor
  - Mt Beamena Borrow Pit Access Road (part only)
  - Mt Beamena spoil and laydown area in floodplain
  - Humphries Borrow Pit
- Lower Chaunong Creek
  - Infrastructure Corridor
  - Western drainage of Northern Access Borrow Pit

In the majority of cases, the Infrastructure Corridor traverses low gradient (<2°) floodplain areas, which will result in minimal offsite delivery of sediments to the natural drainage and the floodplain at higher flow regimes. Given that the residual impacts on the freshwater ecology of Womul Creek were assessed as **Low** significance despite the higher concentrations of construction activity and steeper terrain, then the residual impacts on the freshwater ecology of these additional creeks are also assessed to be **Low** significance given that there are fewer infrastructure sites present and that most of the Infrastructure Corridor traverses flat terrain. Therefore, individual residual impact assessments of Project construction and operations on each of the above six creeks is not warranted, as the residual impacts will be less than that assessed for Womul Creek.

7.4. Lower Bavaga River

The Bavaga River drains a medium-sized catchment (27.5 km^2). Proposed Project and existing infrastructure within the lower Bavaga River catchment includes:

- Lower Bavaga River gravel extraction area (14 ha).
- A 1.5 km-long access road to gravel extraction sites along the river.
- A 1 km-long segment of the Infrastructure Corridor.
- The Mt Beamena Quarry (0.4 ha) and 2.4 km-long access road.
- Part of Northern Access Borrow Pit (approximately 50% in Bavaga River catchment).
- A 3.3 km-long section of the existing Link Road.
- A 9.3 km-long section of the existing Wafi Access Road.
- A 2.5 km-long section of the existing Demakwa Access Road.

A major Project activity in the lower Bavaga River catchment is the proposed gravel extraction and processing site, which will operate throughout the five-year construction phase and continue into the operations phase. The estimated footprint of the lower Bavaga River extraction site is about 14 ha and covers a 1.5 km-long reach of river having sufficient gravel resources. It is expected that active sites of gravel extraction will move gradually along the river.

The removal of river gravels will have implications on freshwater ecology in terms of the loss or degradation of benthic habitat quality, as well as increasing TSS concentrations downstream of the construction areas.

Two other major activities within the lower Bavaga River are the development of the Northern Access Road Borrow Pit of which about 50% lies within its catchment, and the Mt Beamena Quarry (0.4 ha) and a 2.4 km-long section of the quarry access road that will be built in steep terrain but includes many road segments on lower gradients, such as those that follow hillside contours and ridge tops.

The residual impacts of the above activities on freshwater ecology are assessed below for Project construction and operations within the Lower Bavaga River catchment.

7.4.1. Construction phase freshwater ecology impacts

During the construction phase, the Lower Bavaga River will receive mine-derived sediment loads resulting from rainfall-based erosion and scour of disturbed or displaced soils associated with infrastructure sites and the Infrastructure Corridor. Additional mine-derived sediment loads will arise directly from in-river gravel extraction and washwater and discharges from sedimentation ponds on the eastern side of the Northern Access Borrow Pit.

The principal stressors on freshwater ecology include:

- Direct loss of freshwater aquatic habitats.
- Altered hydrology.
- Sedimentation resulting from the deposition of coarse-grained sediments.
- Altered water quality from suspended fine-grained sediments.

Loss of freshwater aquatic habitat

The principal construction phase activity impacting directly upon freshwater aquatic habitats will be the gravel extraction at successive sites along a 1.5 km reach of the lower Bavaga River, located 2 km downstream of Bavaga Village.

The extraction of river gravel from bars has a direct impact on the existing gravel bed freshwater aquatic habitat. In general, gravel bars as a freshwater aquatic habitat are exposed to air during low flow regimes, such that habitat is only available to macroinvertebrates and fish during higher flow regimes. However, some freshwater aquatic invertebrates inhabit the hyporheic[2] zone of exposed gravel bars. Natural hydrological variability in river ecosystems can include prolonged periods of flow recession (low flow regimes) and a reduction in discharge is accompanied by abiotic changes in benthic and hyporheic habitats, often including reductions in habitat availability (Stubbington et al., 2010).

Overall, there will be a loss of hyporheic invertebrate habitat within the gravel extraction trenches or other sites (e.g., pits); however, the total area or volume of this freshwater aquatic habitat type is small in comparison to the remaining large area and volume of similar habitat along the Lower Bavaga River. The loss of invertebrate hyporheic habitat is assessed to be **Low** significance, based on a **low** magnitude of impact and **low** sensitivity.

The removal of river gravels in the Lower Bavaga River will cause a lowering of the existing gravel bars; however, areas of the river bed where gravel has been removed will still have a gravel bed base, which will continue to be available as freshwater aquatic habitat when inundated during rising

[2] The hyporheic zone is a region beneath and alongside a river or stream bed, where there is mixing of shallow groundwater and surface water.

and flood flows. The gravel extraction-impacted river reach will be replenished in the longer term with fresh materials (i.e., gravels, cobbles and boulders) delivered by the high bed sediment transport capacity of the Upper Bavaga River.

Altered hydrology impacts

Surface management of the Northern Access Borrow Pit includes directing approximately 70% water outflows to the Lower Watut River's eastern floodplain and 30% of flows to the Lower Bavaga River, which reduces the proportion of sub-catchment flows that would normally report to the Lower Bavaga River. However, the total flow volumes during the wet or dry season from the original 35 ha (0.35 km^2) of pre-disturbed sub-catchments located within the quarry area to the Lower Bavaga River are not expected to affect flows in the Lower Bavaga River, which has a much larger catchment area of 27.5 km^2. Therefore, the minor reduction in total flows from the Northern Access Borrow Pit are unlikely to alter the flow regimes of the Lower Bavaga River downstream of it.

Water abstracted from the Lower Bavaga River for use in the gravel extraction washing plant will be returned to the river. The abstraction volumes will also be reduced by the recycling of a proportion of sump water from the washing plant.

Overall, residual impacts of altered hydrology on the freshwater aquatic habitats and biological communities of the Lower Bavaga River are assessed as **Low** significance, based on a **very low** magnitude of impact and a **low** sensitivity (due to the common aquatic habitat type and widespread aquatic biological species in the lower Bavaga River and other Project Area rivers).

Sedimentation impacts

Potential sedimentation impacts on aquatic habitats are expected to arise from the three major construction activities described above: the gravel extraction in the Lower Bavaga River and development of the Northern Access Borrow Pit and the Mt Beamena Quarry and access road, which are assessed separately below as they affect different sub-catchments. BMT WBM (2018b) (Appendix I of the EIS) estimated that during construction, unmitigated sediment loads increased by a factor of approximately 30 during the dry season and by 7 times in the wet season. Further discussion specific to the facilities within each catchment is given below.

Lower Bavaga River gravel extraction

The Lower Bavaga River gravel extraction process will recover a wide size range of materials for Project construction and includes medium sands to boulders. When larger size fractions are required (e.g., coarse gravels and boulders as road base material), the washwater outflow will contain coarse-grained sediments (e.g., sands) that will, if not required, be discharged indirectly to the river via a sedimentation pond. During rising and flood flows in the Lower Bavaga River, deposited coarse-grained sediment will be transported downstream as either bed load or suspended load depending on flow velocities. While temporary areas of localised in-river sedimentation may occur, river bed aggradation due to coarse-grained sediments from the gravel extraction washing plant site is not predicted. The discharge of water back to the river as a part of the gravel extraction operation does not add any settleable sediments that were not already a part of the natural bed or suspended sediment load in the river.

Overall, residual impacts of sedimentation on the aquatic habitats of the Lower Bavaga River from the gravel extraction operations are assessed to be **Low** significance, based on a **low** magnitude of impacts and **low** sensitivity.

Northern Access Road Borrow Pit

During early construction activity, land clearing, grubbing and the installation of diversion drains and sedimentation ponds, coarse-grained sediment delivery to creeks draining to the Lower Bavaga River is expected to result in highly localised sediment deposits in the creek beds in proximity to the construction areas. However, following high rainfall events and during rising and flood flows in the upper catchment creeks, temporarily deposited material will be resuspended and transported downstream mainly as suspended load towards the Lower Bavaga River. The upper catchment creeks draining the eastern slopes of Northern Access Borrow Pit area are incised, have steep gradients (between 15° and 27°) and their beds are comprised of a rock and boulder substratum, which are indicative of their flashy nature (rapid response to rainfall runoff and rapidly rising flood flows) and very high sediment transport capacity. During the later development phase of the borrow pit (e.g., late construction phase and early operations), there will a greater emphasis on in-pit surface water and stormwater management, resulting in a major reduction of coarse-grained sediment delivery to the natural drainage.

In the lower reaches of creeks and upstream of their confluences with the Lower Bavaga River, the reduced gradients (<2 to 5°) will allow temporary settling of construction-derived coarse-grained sediments. These deposits will be either moved by bed sediment transport or resuspended and transported downstream as suspended load to the receiving lower Bavaga River, where they will form part of the river's bed load and subsequently be transported downstream to the Lower Watut River.

Overall, residual impacts of sedimentation on the freshwater aquatic habitats of the Lower Bavaga River from the construction and development of the Northern Access Borrow Pit are assessed to be **Low** significance, based on a **moderate** magnitude of impact and **low** sensitivity.

Mt Beamena Quarry and access road

The construction of the Mt Beamena Quarry is predicted to have little or no delivery of coarse-grained sediment to the Lower Bavaga River, as in-quarry erosion and sediment control will be implemented under the Project Erosion and Sediment Control Plan. However, construction of the 2.4 km-long section of the Mt Beamena Quarry access road in steep terrain has the potential to deliver coarse-grained sediments from rainfall-based erosion of road cuts and fills and surface soil erosion to the natural drainage. During access road construction and the early post-construction period (6 to 18 months), coarse-grained sediments entering the upper catchment creeks is expected to cause short-term, highly localised but temporary sediment deposits downstream of construction sites, which will be resuspended and transported downstream during high flows. In the lower gradient reaches of sediment-impacted creeks, bed sediment transport is expected to carry temporarily deposited coarse sediments to the Lower Bavaga River, especially by accelerated bed sediment transport during creek flood flows.

As the quarry access road's cut slopes and fill slopes stabilise through surface sediment control measures, including natural or assisted revegetation, coarse-grained sediment delivery to the creeks is expected to reduce over a period of 18 months to 2 years post construction towards background levels, provided access road maintenance and erosion and sediment control measures are implemented.

Overall, the residual impacts of sedimentation on the aquatic habitats of the Lower Bavaga River derived from coarse-grained sediment delivery from the Mt Beamena Quarry and access road are assessed as **Low** significance, based on a **moderate** magnitude of impact and a **low** sensitivity.

Water quality impacts

During construction, potential changes in water quality that may directly affect freshwater aquatic biological communities arise principally from construction-derived increases in suspended sediment concentrations and turbidity.

Lower Bavaga River gravel extraction

The construction of the access road to the gravel extraction sites along the 1.5 km-long river segment with gravel resources is not expected to be a significant source of fine-grained sediments (<125 μm size fraction) given that it is located on a flat gradient (<2°) that follows the river's west bank floodplain. Proposed access road management measures include installing culverts across drainage lines and directing roadside drains to vegetation areas. Therefore, construction-derived increments to the TSS load and concentrations of the Lower Bavaga River are predicted to be low. However, it is difficult to estimate the delivery of fine-grained sediment loads from the gravel extraction operation.

The river gravel extraction operations will have a number of safeguards to reduce off-site impacts on water quality including the Erosion and Sediment Control Plan. Mobilisation of sediment within and to the river will be variable depending on the flow, the location of extraction and methods in place. Monitoring of water quality upstream and downstream of the extraction sites will be undertaken and, if required, additional methods used to further reduce impacts on water quality (e.g., larger sedimentation ponds or silt curtains).

Among the ten species of fish caught in the Lower Bavaga River (BMT WBM, 2018a), all of the species are sediment-tolerant species such as the long-finned and short-finned eels, grunters, gudgeons, mouth almighties, whitewater gobies and the introduced walking catfish (*Clarias batrachus*). These fish assemblages are not anticipated to be adversely impacted by occasional pulses or protracted periods of elevated TSS concentrations and turbidity, which they experience regularly in the Lower Bavaga River during rising and flood flows.

Overall, the residual impacts of deteriorated water quality (i.e., increased TSS concentrations and turbidity) from river gravel extraction operations on the freshwater aquatic biological communities of the Lower Bavaga River are assessed to be **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity.

Northern Access Road Borrow Pit

During initial construction, land clearing, tree feeling, vegetation removal, grubbing and access road construction is required to initially develop the quarry. During this period sediment loading of the upper catchment creeks that flow to the Lower Bavaga River are expected to carry high coarse-grained and fine-grained sediments in the short term. As the quarry development proceeds and in the longer term (including during operations), sediments mobilised during extraction of rock will remain within the pit where it is lower than the surrounding natural topography. The use of sedimentation ponds with spillways to headwater creeks in sub-catchments of the Lower Bavaga River or use of exhausted pit areas as additional settling ponds (if required), is expected to reduce the fine-grained sediment loads to the Bavaga River.

Given the in-quarry management of surface and stormwater, as well as implementation of the proposed management measures for the quarry in the Project Erosion and Sediment Control Plan, fine-grained sediment loading of creeks draining to the Lower Bavaga River are predicted to be low.

Overall, the residual impacts of deteriorated water quality (i.e., increased TSS concentrations and turbidity) on the aquatic biological communities of the Lower Bavaga River from the Northern Access Borrow Pit are assessed to **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity.

Mt Beamena Quarry and access road

The Mt Beamena Quarry has a small perimeter and area (0.4 ha) within which direct rainfall and runoff takes pace. Within-quarry surface water management and storm runoff will likely include a settling pond having an outflow to an upper sub-catchment drainage line. The quality of outflow is expected to have low TSS concentrations, nominally between <50 to 100 mg/L, assuming a sediment pond trap efficiency of 85%. The outflow volumes are also small compared to flows in the receiving Bavaga River; therefore, no significant TSS loading of the Bavaga River is anticipated from this source.

Given the short length of the Mt Beamena access road, which largely follows ridge top locations and the contours of the upper sub-catchment hills, with few steep gradient segments, TSS loads in rainfall runoff is predicted to be a small component of existing TSS loads in the receiving Bavaga River downstream of the affected sub-catchment creeks. Notwithstanding, short-term increases in the TSS concentrations of the Lower Bavaga River are expected to occur during the first six months to a year following road construction. Dilution within the Lower Bavaga River will reduce these road construction-derived TSS loads to low levels. It is difficult to predict TSS concentrations in the Bavaga River as flow duration data and information on cut to fill along the access road are not available.

Overall, the residual impacts of deteriorated water quality (i.e., increased TSS concentrations and turbidity) on the aquatic biological communities of the Lower Bavaga River from the Mt Beamena Quarry and access road are assessed to **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity. Continued road maintenance as a part of the Project Erosion and Sediment Control Plan for road construction will further reduce TSS loading of the natural drainage.

7.4.2. Operations phase impacts on freshwater ecology

During operations, there will be a continuing development and expansion of the Northern Access Borrow Pit, as well as continuing gravel extraction from the Lower Bavaga River to supply aggregates for Project infrastructure and road maintenance.

The principal stressor to freshwater ecology will be the continuing water quality impacts (mainly TSS and turbidity).

The residual impacts of fine-sediment loading and increased TSS concentrations to the freshwater ecology of the Lower Bavaga River are essentially the same as assessed for the construction phase. Therefore, the residual impacts of deteriorated water quality (i.e., increased TSS concentrations and turbidity) on the freshwater aquatic biological communities of the Lower Bavaga River from the Northern Access Borrow Pit and access road are also assessed to be **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity.

7.5. Lower Watut River Eastern Floodplain

This section assesses residual impacts of Project construction on the freshwater ecology of the eastern floodplain of the Lower Watut River. The residual impacts on freshwater ecology that were assessed for Boganchong, Womul and other inner backplain creeks are addressed above and are not considered further in this section, as these creeks are located to the east of Mari and Chaunong creeks and the escarpment and do not affect the western part of the Lower Watut River's eastern floodplain.

The Project infrastructure within the Lower Watut River's eastern floodplain includes:

- Construction of the entire length (18.5 km) of the Watut Services Road across the floodplain from north to south.
- Construction and installation of a 4.4 km-long section of the buried wastewater discharge and raw water extraction pipelines, and service track across the floodplain from east to west.
- Floodplain gravel extraction area (Lower Papas Aggregate Source) located on the floodplain between the lower reaches of Womul and Boganchong creeks, and 1 km southeast of Papas Village. This area comprises:
    - Lower Papas Aggregate Source gravel pit (7.9 ha).
    - A 0.2 km-long access spur road from the Northern Access Road.
    - Overburden storage area (4 ha).
    - Crushing/screening and stockpile area (10.5 ha).

A short 0.6 km-long section of the proposed Resettlement Road lies within the Lower Watut River's eastern floodplain between Madzim Village and the Wafi River, however, is excluded from the current residual impact assessment on freshwater ecology due to its relatively short length. However, the residual impacts on floodplain freshwater ecology of this section of the Resettlement Road will be same as those assessed for the Watut Services Road, which is located on the same floodplain.

The residual impacts of linear infrastructure and gravel extraction site on floodplain freshwater ecology are assessed below for Project construction and operations.

7.5.1. Construction phase freshwater ecology impacts

The principal stressors on freshwater ecology during the construction phase include:

- Altered floodplain hydrology
- Sedimentation impacts on aquatic habitats
- Water quality impacts on aquatic biological communities.

Altered hydrology impacts

The potential for altered hydrology relates to the construction of access roads and the trenching, installation and burial of the wastewater and raw water pipelines. During the construction phase, the physical presence of completed sections of the Watut Services Road, which is typically around 2 m above ground level and therefore elevated above the floodplain, has the potential to impede surface water and flood flows. The impacts on floodplain hydrology due to the Watut Services Road and wastewater discharge pipeline have been assessed below. In addition, the impacts of the floodplain gravel extraction in the Lower Papas Aggregate Source area are also assessed.

Watut Services Road

The Watut Services Road (see Figure 3.1), a community access road, is a proposed 18.5-km-long road that will be constructed between the Northern Access Road adjacent to the Northern Access Road Borrow Pit (Chainage Point 11.6 km) and terminate at a point 0.2 km southwest of Madzim Village.

For most of its length, the road route follows high ground across the floodplain that is known from the tracks and paths used by floodplain villagers during the wet season when the Lower Watut River overtops its banks during flood flows. However, the middle section about 2 km wide either side of Pentag Creek (see Figure 3.2) is a low-lying part of the floodplain that is subject to more regular flooding from the Lower Watut River at the breakout location of the river. The Watut Services Road will cross Pentag Creek over a bridge; hence, breakout flood flows from the Lower Watut River across the floodplain are not predicted to be impeded in this section of the road.

During high flood flows (e.g., >2 year ARI) in the Lower Watut River main channel, other low-lying road segments have the potential to impede flows and create temporary flooded areas, or to direct flows along the alignment of the western face of the road embankment. However, mitigation against flow impedance will be achieved by installation of a greater number and density of culverts in those road sections where flood flow paths are observed or anticipated. Since the floodplain regularly floods from Lower Watut River breakouts, the aquatic biological communities are also naturally exposed to floodplain flooding and flood recessions. During floodplain inundation, fish species and other mobile aquatic fauna (e.g., freshwater turtles and river prawns) can readily move across the floodplain, as well as between floodplain creeks.

Overall, the residual impacts of flow impedance and temporary areas of detained flood waters is a very short-term impact that has been assessed as **Low** significance based on a **low** magnitude of impact and **low** sensitivity for aquatic habitats and biological communities.

Wastewater discharge and raw water pipelines and service track

The wastewater discharge and raw water make-up pipelines will be co-located in a trench and will cross three watercourses including Chaunong, Mari and Pentag creeks. Trenching, installation and burial of the pipelines will be undertaken to coincide with the dry season, where practicable, which will minimise temporary impacts on creek channel flows. The proposed watercourse crossing methods will include trenching and the direct pipe trenchless method. During the wet season, minor temporary diversion of flows (likely to be the dam and pump 'dry' crossing method) during installation of the pipeline is expected. Given that the direct pipe method (to be used for the Pentag Creek crossing) is similar to microtunnelling (whereby the pipeline is pushed forward by a pipe thruster as the tunnel-boring machine simultaneously excavates the earth), impacts on flows are not expected at these watercourse crossings. An adjacent supporting service track will be required for access to the pump stations along the pipeline route. The pipeline alignment will originate at the wastewater treatment plant on the Watut Process Plant terrace and will terminate at the wastewater discharge pipe outfall and water intake screen (a few metres further upstream) in the Lower Watut River main channel upstream of Wongkins Village. The trenching, installation and burial of the wastewater and raw water pipelines is anticipated to result in short term and highly localised impacts on hydrology.

For the first 3 km, the pipelines will lay alongside the Infrastructure Corridor (i.e., Northern Access Road alignment), and the alignment will then deviate from the Infrastructure Corridor and traverse across the Lower Watut River's eastern floodplain to the discharge outfall on the Lower Watut River main channel (4.4 km-long).

The service track will also be designed and constructed with the appropriate number and density of culverts to avoid flooding on the upstream side of the road. In general, no significant impacts on floodplain surface flows or the Lower Watut River flood flows across the floodplain are anticipated.

Overall, the residual impacts of altered hydrology associated with service track construction and installing the pipelines on floodplain aquatic habitats and biological communities are assessed to be **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity.

Lower Papas Aggregate Source

The site of the proposed Lower Papas Aggregate Source is located on very flat terrain within the Lower Watut River's eastern floodplain and near the lower floodplain reaches of Womul and Boganchong creeks (Figure 3.1).

The gravel extraction pit, overburden storage areas, crushing/screening and gravel stockpiles will have contour drains around their perimeters or berms to prevent the inflow of surface water. If required, a sedimentation pond (or ponds) may be constructed to allow the settling of suspended fine sediments and subsequent discharge offsite to the natural drainage. Rock and gravels will be wet mined (i.e., extracted) by a backhoe excavator through the existing high water table. The gravel extraction pit will also fill with groundwater inflows given the shallow water table (1 to 2 m below ground level). Significant alteration of the hydrology of surface flows in natural drainage channels in the vicinity of or downstream of the gravel extraction site is not anticipated, given the very flat terrain and the implementation of management measures in the Project Erosion and Sediment Control Plan, including a surface water management system and the recycling of washwater.

Overall, the residual impacts of the floodplain gravel extraction area on surface hydrology and creek flows and downslope or downstream (assuming the presence of minor drainage lines) aquatic habitats and biological communities are assessed as **Low** significance, based on a **very low** magnitude of impact and **low** sensitivity.

Sedimentation impacts on freshwater ecology

The residual impacts of sedimentation on aquatic habitats are assessed below for the Watut Services Road, wastewater discharge and return make-up water pipelines, service track, and the floodplain gravel extraction area adjacent to the Boganchong and Womul creek confluence are assessed below.

Watut Services Road

Soil erosion along the Watut Services Road and the delivery of coarse-grained sediment to the natural drainage is assessed to be minor given the results of previous studies of sedimentation impacts from roads constructed across floodplains, which show that coarse-grained sediment loading of the natural drainage is low and highly localised to areas immediately downslope of the road alignments, principally due to the flat terrain, or downstream of watercourse crossings due to very low flow velocities (DBA, 2005; Balloch et al., 2005). Where sedimentation impacts are noted immediately downstream of watercourses crossings, they tend to be highly localised and temporary, and subsequent watercourse flood flows resuspend or move deposited road construction-derived coarse-grained sediments downstream as bed sediment transport. For the Watut Services Road, very short-term sedimentation impacts are anticipated to occur immediately downstream of the creeks crossed by the road. Well-established environmental management measures will be implemented to reduce potential impacts and to achieve post-construction, long-term stability of the watercourse crossings.

Overall, the residual impacts of predicted short-term and minor sedimentation associated with the construction of the Watut Services Road are assessed as **Low** significance, based on a **very low** magnitude of impact and **low** sensitivity. During natural flood breakouts of the Lower Watut River across its eastern floodplain, the floodwaters have very high TSS concentrations (median 628 mg/L, range 115 to 10,300 mg/L (Wiles and Bollaert, 2015)) and much of this fine sediment load settles out on the floodplain and creek channels (i.e., sedimentation), and to which the floodplain aquatic habitats and biological communities are frequently exposed.

Wastewater discharge and raw water pipelines and service track

Given the flat terrain along the wastewater discharge and raw water pipelines route, no significant generation of the coarse-grained sediments in surface runoff are expected to reach the floodplain downslope of the pipeline installation activities. Any generation of sediment will deposit in close proximity to the surface runoff outflows to the floodplain.

At the three creek crossings (Chaunong, Mari and Pentag creeks), the wastewater discharge and raw water make-up pipelines will be undertaken using trenching or the direct pipe trenchless method. Trenching during the wet season will result in coarse-grained sediments in the creek bed to deposit downstream in close proximity to the water crossing as evidenced elsewhere in PNG (e.g., DBA, 2005; Balloch et al, 2005). At watercourse crossings, the creek bed will be reinstated to the pre-disturbance creek bed level, such that water flow erosion of the creek bed is unlikely to erode the in-filled trench surface. Therefore, temporary and highly localised generation of coarse and fine-grained sediments at trenched creek crossings is expected due to in-stream and river bank disturbance. For watercourse crossings where the direct trenchless method, which is similar to microtunelling, is used, such as at Pentag Creek, generation of sediment is not expected.

The supporting service track adjacent to the pipelines will be constructed in flat terrain and with the implementation of management measures, no significant generation of the coarse-grained sediments in surface runoff are expected to reach the floodplain downslope as the sediment will deposit in close proximity to the surface runoff outflows to the floodplain. The surface of the service track will become compacted by vehicular traffic, which reduces the amount of coarse-grained sediment in surface runoff.

Overall, the residual impacts of sedimentation of floodplain aquatic habitats associated with the installation of the wastewater discharge and raw water pipelines, and service track are assessed to be **Low** significance, based on a **very low** magnitude of impact and a **low** sensitivity.

Lower Papas Aggregate Source

Sedimentation impacts on floodplain creek aquatic habitats are not anticipated from the site of the Lower Papas Aggregate Source extraction and stockpiling operation, owing to the retention of coarse-grained sediment on site. As the gravel extraction operation proceeds, there will be spent gravel extraction pits (i.e., exhausted of gravels), which can be used as settling ponds for trapping coarse-grained sediments in washwater from the crushing and washing plant. In addition, the gravel extraction area is located on very flat terrain and flood flows in either Womul or Boganchong creeks are known to spread out as shallow sheetflow across the floodplain (BMT WBM, 2018a; Pickup, 2015a,b; Hydrobiology, 2018); hence, floodwater flushing out settled coarse-grained sediments in the setting ponds is unlikely to occur due to reduced flow velocities (retardation by floodplain vegetation), as well as the presence of perimeter berms diverting surface water flows away from the settling ponds.

Overall, the residual pacts of sedimentation of floodplain aquatic habitats from the gravel extraction operation are assessed to be **Low** significance, based on a **very low** magnitude of impact and **low** sensitivity.

Water quality impacts to aquatic biota

Potential water quality impacts on the aquatic biota of the Lower Watut River's eastern floodplain relates primarily to rainfall-based erosion and scour of construction-disturbed or displaced soils and increased fine-grained (<125 µm particle size diameter) sediment loading downstream of creek crossings. The residual impacts of increased TSS concentrations and associated turbidity on floodplain aquatic biological communities are assessed below.

Watut Services Road

During the wet season, when floodplain creeks are flowing, construction within the creek bed crossings is expected to increase TSS concentrations downstream of the crossings. In addition, surface runoff from the creek banks and approaches to the creeks is also expected to deliver fine-grained sediments to the creeks and downstream reaches during construction, as well as during the post-construction period (six months to one year) until surface soils are stabilised and naturally (or assisted by intervention) revegetated in a sustainable manner.

Pentag Creek is a large floodplain creek that the Watut Services Road will cross using a bridge, whereas smaller creeks will be crossed by a typical dam and pump crossing method, which is a 'dry' crossing method. Predicted increased TSS concentrations downstream of creek crossings are expected to be of short duration, basically for the period of active in-creek construction works. Post-construction, the TSS concentrations will reduce but continue to be above the median background level 5 mg/L (interquartile[3] range 3 to 12 mg/L and a maximum of 69 mg/L) based on limited water quality sampling of Chaunong Creek (a typical floodplain creek) sampled by BTM WBM (2018a) during low to average flows. However, during overbank inundation of the floodplain and floodplain creeks following breakouts from the Lower Watut River, very high TSS concentrations (median 628 mg/L, range 115 to 10,300 mg/L at Uruf (Wiles and Bollaert, 2015)) will occur in the floodplain creeks. Therefore, the aquatic biological communities of the floodplain creeks are already exposed to very wide range of TSS concentrations.

Along segments of the road corridor on the floodplain at distance from creek channels or natural drainage lines, sediment-laden surface runoff to vegetated areas is expected to reduce TSS concentrations and increase deposition of the settleable component of TSS, owing to low gradient on downslope concave areas, reduced runoff flow velocities and the trapping efficiency of the vegetation.

[3] Interquartile range quotes the 25% and 75% percentile TSS concentrations.

The residual impacts of the Watut Services Road construction on water quality (i.e., increased TSS concentrations and associated turbidity) are assessed to be short term and minor, arising mainly from in-channel construction works at creek crossings. Overall, the residual impacts of altered water quality on the aquatic biological communities of the affected floodplain creeks are assessed to be **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity. Water quality recovery is expected to be rapid once the sources of fine-grained sediments reduce in response to cessation of in-creek construction activities and as construction-disturbed soils are stabilised and are revegetated. No impacts on water quality of creeks are expected during the dry season if creek flows are absent, with no consequential impacts on aquatic biological communities.

Wastewater discharge and raw water pipelines and service track

Temporary and localised generation of TSS is expected during the trenching, installation and burial of the wastewater discharge and raw water discharge pipelines. At the three creek crossings (including Chaunong, Mari and Pentag creeks), the wastewater discharge and raw water make-up pipeline will be installed using trenching or direct pipe trenchless method. During the wet season, trenching of the wastewater discharge pipeline at creek bed crossings is expected to increase TSS concentrations downstream of the crossings and generate similar impact extents and durations as the road construction describe above. Generation of TSS as a result of pipeline construction using trenching will be reduced if undertaken during the dry season. For the larger Pentag Creek crossing, the direct pipe method will be used, which is expected to have little impact on TSS concentrations given that the pipeline is pushed forward under the creek bed without first digging a trench.

The supporting service track adjacent to the pipelines will be constructed in flat terrain and with the implementation of management measures, construction-derived TSS concentrations are not expected to be significant and will be highly localised.

Consequently, little or no impact on downstream aquatic biological communities is expected as a result of these Project activities.

Overall, the residual impacts of pipeline installation across the Lower Watut River’s eastern floodplain on downstream aquatic biological communities affected by deteriorated creek water quality (i.e., increased TSS concentrations and turbidity) are assessed as **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity.

Lower Papas Aggregate Source

The Lower Papas Aggregate Source extraction operation on the Lower Watut River’s eastern floodplain is predicted to have little or no impact on floodplain creek water quality (i.e., increased TSS concentrations and turbidity), owing to the wet extraction process by backhoe within the prevailing high water table (<1 to 2 m). Containment of disturbed and suspended sediments within the pit is also expected to limit off-site sediment laden water entering the lower reaches of Womul and Boganchong creeks.

A sedimentation pond (or ponds) may be constructed to allow the settling of fine-grained washwater sediments and the settled water (typically below 50 to 100 mg/L) discharged offsite to the natural drainage, if required. Given the management measures of the Erosion and Sediment Control Plan and the surface water management system, and the recycling of washwater and use of sedimentation pond(s) to reduce off-site fugitive fine-grained sediments, significant TSS loading of the floodplain creeks will be minor and within the natural range of TSS concentration variability of the Womul and Boganchong creeks when flowing during the wet season.

Overall, the residual impacts of deteriorated water quality associated with potential floodplain gravel extraction discharges from the Lower Papas Aggregate Source extraction and stockpiling operation on the aquatic biological communities of the Lower Watut River’s eastern floodplain are assessed as **Low**, based on a **low** magnitude of impact and a **low** sensitivity.

7.5.2. Operations phase freshwater ecology impacts

During the operations phase, there will be no physical impacts of the wastewater discharge pipeline and return raw water pipelines as the natural ground level will be reinstated over the buried pipelines. The surface of the pump service track will become compacted by traffic, thereby reducing sediment loading and TSS to local surface water drainage.

Surface runoff from the gravel wearing Watut Services Road will continue to be a minor source of fine sediment loading to the floodplain. The residual impacts of fine sediment loading are assessed to be **Low** significance, based on a **very low** magnitude of impact given the flat terrain and a **low** sensitivity (due to the common widespread floodplain aquatic habitats and biological communities).

7.6. Wafi River

The Wafi River catchment (121 km^2) is a sub-catchment of the Watut River and covers the southern and eastern portions of the Mine Area. The catchment is comprised of four sub-catchments that have Project infrastructure; namely the Hekeng River, and the Buvu, Nambonga and Yor creeks. Tributary rivers of the southern Wafi River catchment crossed by the Resettlement Road include the Zamen, Tovu, Dumbeyo and Kwepkwep rivers. Figure 3.2 and Figure 7.1 shows the Wafi River catchment and Project Infrastructure.

Proposed Project infrastructure and existing and existing infrastructure within the Wafi River catchment includes (see Figure 7.1):

- Buvu Creek sub-catchment:
  - Migiki Borrow Pit (1.1 ha) and its existing access road (0.2-km-long).
  - A 2.7-km-long section of the Portal Haul Road of which 0.6 km is new road alignment and 2.1 km is an upgrade of the existing mine access road.
- Nambonga Creek sub-catchment:
  - A 4.5 km-long section of Nambonga Haul Road to the Miapilli Waste Rock Dump.
  - Nambonga Decline Portal Terrace (0.45 ha) located on the pad of the old scrap steel yard.
  - Ventilation shaft and shaft waste rock terrace (5 ha).
- Yor Creek sub-catchment:
  - Miapilli Waste Rock Dump (5 ha).
  - Miapilli Clay Borrow Pit (7 ha).
  - A 0.5 km-long section of the Nambonga Haul Road.
- Resettlement Road sub-catchments:
  - A 16.5 km-long section of the Resettlement Road crosses the lower Wafi River upstream of Pekumbe Village, as well as the Tovu, Zamen, Dumbeyo, Kwepkwep and Hekeng rivers and their sub-catchments.

The residual impacts on freshwater ecology are assessed below for Project construction and operations.

7.6.1. Construction phase freshwater ecology impacts

Construction phase freshwater ecology impacts are assessed below for the main sub-catchments.

Buvu Creek impacts

The principal stressors on freshwater ecology during the construction phase include:

- Sedimentation resulting from the deposition of coarse-grained sediments.
- Increased suspended sediment concentrations and associated turbidity.

Sedimentation impacts on freshwater aquatic habitats

Buvu Creek has a small catchment (5.4 km^2) upstream of its confluence with Nambonga Creek. The creek has a steep gradient (65% slope, or approximately 33°), is deeply incised and has a bed substratum comprised of gravels, rocks and boulders, which is indicative of high sediment transport capacity.

The Migiki Borrow Pit is a small pit (1.1 ha) that will be developed on a hilltop, such that its perimeter will eventually be below ground surface level. In-pit surface water management and sediment controls will be developed under the Project Erosion and Sediment Control Plan, such that coarse-grained sediment delivery to the natural drainage will be minimal. The 0.2-km-long access road to the borrow pit is an existing section of road. Therefore, coarse-grained sediment delivery to the local drainage lines will also be minimal. Overall, sedimentation of first order creeks in the upper headwater catchment at the site of the Migiki Borrow Pit and access road, if it occurs, will be temporary and transported downstream as either bed load or resuspended and transported downstream as suspended load with rising and flood flows following high rainfall. No significant sedimentation of the aquatic habitats of Buvu Creek is predicted from construction and development of the Migiki Borrow Pit and its access road.

The construction of new sections of the Portal Haul Road (0.6 km) and upgrading 2.7 km of an existing access road is also not expected to produce significant quantities of coarse-grained sediment that may report to Buvu Creek. Not all coarse-grained sediment will reach watercourses as coarse sediments deposit downslope of road sections, especially on concave slopes and assisted by the trapping efficiency of vegetation. Coarse sediments that do reach the Buvu Creek main channel will be characterised by localised, temporary deposits in the vicinity of sites of sediment production and delivery points. Given the high sediment transport capacity of Buvu Creek, these temporary deposits will be transported downstream during successive rising and flood flows.

Overall, the residual impacts of sedimentation on the freshwater aquatic habitats of Buvu Creek main channel from Project construction are assessed as **Low**, based on a **low** magnitude of impact and **low** sensitivity. The existing freshwater aquatic habitats of Buvu Creek are naturally exposed to frequent sediment loading and temporary localised areas of sedimentation, which arise from flood flows undercutting outer bend creek banks as well as from numerous landslides in its catchment (KCB, 2013).

Water quality impacts on freshwater aquatic biota

The principal stressors affecting water quality of Buvu Creek are increased TSS concentrations and associated turbidity. Disturbance of the soils of the area is unlikely to lead to increased mobilisation of metals or metalloids, as the soils are not located in mineralised areas and are expected to have average crustal abundance values.

As noted above, the implementation of the Erosion and Sediment Control Plan for the Migiki Borrow Pit and section of the Portal Haul Road within Buvu Creek catchment is expected to reduce sediment delivery to the natural drainage. Nevertheless, fine-grained sediments (<125 µm fraction) in overland flow following rainfall-runoff events are expected to increase TSS concentrations in Buvu Creek. It is difficult to estimate TSS loads and concentrations due to a lack of information on existing flow duration data (i.e., flow exceedances) and access road cut and fill information, but most of the access road is an upgrade of the existing Mine Access Road, which is expected to generate lower fine sediment loads than clearing forest and land to construct a new road. Based on experience in other parts of PNG with similar high rainfall, during the first 18 months following road construction there is expected to be a general doubling of TSS concentrations at average flows and a quadrupling of TSS concentrations at high flows (Balloch et al., 2005) in Buvu Creek upstream of its confluence with Nambonga Creek.

Background TSS concentrations in lower Buvu Creek are a median of 5 mg/L, minimum of <5 mg/L and a maximum of 28 mg/L (Wiles and Bollaert, 2015). In terms of residual impacts on freshwater aquatic macroinvertebrate and fish fauna, the general doubling of TSS concentrations at average flows and quadrupling at high flows is not predicted to impact significantly on resident freshwater aquatic fauna of Buvu Creek and, in the medium to longer term, TSS concentrations are expected to reduce to natural levels as soils stabilise and revegetate with minimal erosion.

During freshwater ecology surveys of the Project Area by BMT WBM (2018a, Appendix G of the EIS) only one species of fish, the silver rainbowfish (*Chilatherina crassispinosa*) was caught in the adjoining Nambonga Creek and may also be expected to occur in lower Buvu Creek. This species is known to be a sediment-tolerant species as it is found in many of the frequently turbid creeks along the Highlands Highway from Lae to Madang (IUCN, 2017). In addition, short- and long-finned eels (Anguillidae) and river prawns (*Macrobrachium* spp.) may also be found in Buvu Creek, all of which are sediment-tolerant species.

Overall, the residual impacts of deteriorated water quality (increased TSS concentrations) associated with Project construction in Buvu Creek catchment on freshwater aquatic macroinvertebrate and fish fauna are assessed to be **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity.

Nambonga Creek impacts

Nambonga Creek is a tributary of the Wafi River and has a small catchment (9.3 km^2) upstream of its confluence with Buvu Creek.

The principal potential stressors on freshwater ecology during the construction phase include:

- Sedimentation resulting from the deposition of coarse-grained sediments.
- Increased suspended sediment concentrations and associated turbidity.
- Discharge of treated wastewater from underground dewatering flows and seepage from the Miapilli Waste Rock Dump to Nambonga Creek.

The residual impacts of these potential stressors on freshwater ecology are assessed below.

Sedimentation impacts on freshwater aquatic habitats

Nambonga Creek has a steep gradient (65% slope, or approximately 33°), is deeply incised and has a bed substratum comprised of gravels, rocks and boulders, which is indicative of high sediment transport capacity.

Offsite coarse-grained sediment runoff into freshwater habitats from the Nambonga Decline Portal Terrace is expected to be low given the small area of the portal terrace (0.45 ha), the fact that it will be built largely on an existing pad, having a generally flat terrain and a vegetated buffer strip between the terrace and Nambonga Creek main channel. Implementation of the Project Erosion and Sediment Control Plan, including silt fences, surface drainage and sedimentation pond (if required) is expected to minimise off-site delivery of coarse sediments to Nambonga Creek.

The 0.2 km-long section of the Nambonga Haul Road to the Nambonga Decline Portal is a small section of road and coarse sediment delivery to the natural drainage is expected to be minimal with most sediments settling on land immediately downslope of the road. However, minor quantities of coarse-grained sediment will be transported in overland flow to the creek during high rainfall runoff events. Erosion of road cut-slopes and fill-slopes will be reduced by proposed road construction-related management measures, which are provided in the Project Erosion and Sediment Control Plan. In addition, the 4.5 km-long Nambonga Haul Road within the Nambonga Creek catchment mainly follows a ridge line between the Nambonga and Yor creeks and, as such, is unlikely to result in significant off-site egress of sediment-laden surface runoff.

The ventilation shaft terrace located to the south of the Nambonga Portal Terrace has a projected area of 5 ha which, along with batters, will be exposed to rainfall runoff and erosion. Implementation of the Erosion and Sediment Control Plan is predicted to reduce off-site fugitive sediment delivery and sedimentation impacts in Nambonga Creek.

Based on the analyses of the above potential sources of coarse-grained sediments, only temporary and localised sediment deposits are expected in Nambonga Creek. Subsequent rising and flood flows are expected to resuspend the deposits and transport them downstream either as bed or suspended sediment loads.

Overall, the residual impacts of sedimentation on the freshwater aquatic habitats of Nambonga Creek main channel from Project construction are assessed as **Low** significance, based on a **low** magnitude of impact and **low** sensitivity. As for Buvu Creek, the existing freshwater aquatic habitats of Nambonga Creek are naturally exposed to frequent coarse sediment loading and temporary localised areas of sedimentation, which arise from flood flows undercutting outer bend creek banks as well as from numerous landslides in its catchment (KCB, 2013).

Water quality impacts on aquatic biota

The principal stressors affecting water quality of Nambonga Creek will be increased TSS concentrations and associated turbidity, as well as discharge of treated mine wastewater to Nambonga Creek. Disturbance of the soils of the area is unlikely to lead to increased mobilisation of metals or metalloids, as the soils are not located in mineralised areas and are expected to have average crustal abundance values.

Fine-grained sediments (<125μm) carried in overland flow from construction areas will report as suspended load to Nambonga Creek. As was the case for the Buvu Creek water quality impact assessment above, there is expected to be a general doubling of TSS concentrations at average flows and a quadrupling of TSS concentrations at high flows over the first 18 months following site construction and the access road upgrade, based on experience of other sites in PNG with similar rainfall (DBA, 2005). However, TSS concentrations for Nambonga Creek are expected to be lower given the smaller area of soils disturbance.

Background TSS concentrations in lower Nambonga Creek have a median of 14 mg/L (range of 5 to 866 mg/L) (Wiles and Bollaert, 2015). The high maximum TSS concentration probably reflects natural landslides within its catchment. In terms of residual impacts on freshwater aquatic macroinvertebrate and fish fauna, the general doubling of TSS concentrations at average flows and quadrupling at high flows are not predicted to impact significantly on resident freshwater aquatic fauna of Nambonga Creek and, in the medium term (18 months to two years), TSS concentrations are expected to reduce as soils stabilise and revegetate with minimal erosion.

The above assessment of water quality (TSS concentrations) impacts on macroinvertebrate and fish fauna for Buvu Creek applies equally to the case for Nambonga Creek, which has a similar species matrix. Most fine-grained sediments entering the Nambonga Creek and reporting as TSS concentrations will occur at high flows (e.g., 10% exceedance flow). In the case of high TSS concentrations at the 10% exceedance flow, this represents a total of 36.5 days per year, which is likely to be intermittent and spread out over several days throughout the year corresponding with storm events. Given that the effects of TSS concentrations on fish, for example, are time-concentration dependent (NSR, 1986; Newcombe and MacDonald, 1991; Newcombe, 1994; DBA, 2005), then intermittent exposure to such high concentrations is of short duration, readily tolerated and inconsequential.

As discussed in Chapter 15 of the EIS, Freshwater Environment Impact Assessment, underground dewatering flows from the Nambonga Decline Portal and seepage from the Miapilli Waste Rock Dump will be treated, if necessary, to meet environment permit conditions using a water treatment plant located at the Nambonga Decline Portal Terrace with treated water discharged to Nambonga Creek adjacent to the terrace. The proposed compliance point on Nambonga Creek is located approximately

1.6 km downstream of the discharge point and 0.7 km upstream of Nambonga Village. While no modelling of the treated discharge to Nambonga Creek has been undertaken, the quality is expected to be similar to the treated mine wastewater quality that will be discharged to the Lower Watut River.

A peak discharge range of 44 to 58L/s is estimated for the three year duration of the Nambonga Decline Portal development. Thereafter, discharge rates would be much smaller reflecting only the Miapilli Waste Rock Dump component (with further underground water handled through the mine's primary water treatment facility and discharged to the Lower Watut River). The peak discharge rate represents approximately 12 to 23% of the average stream flow in lower Nambonga Creek (250 to 500L/s, Highlands Hydrology, 2015) and therefore offers between a 4.3 and an 8.6-fold dilution of the discharge during average flows.

Compliance with PNG ER Criteria in Nambonga Creek and the Wafi River

Given that the assumed water treatment performance will be as per the Clean TeQ (2017) report (assuming 50% is treated using the DeSALx® treatment system), most PNG ER water quality criteria are expected to be met at the compliance point regardless of flow in Nambonga Creek. The exception to this is the sulphate criterion (400mg/L), which may not be met at low flows, with a discharge concentration of 695mg/L (requiring approximately 1.7 dilutions to meet the criterion). During average flows, which will provide between 4.3 and 8.6 dilutions, it is expected that the sulphate concentrations will be meet the PNG ER criterion at the compliance point based on dilution. During low flows in Nambonga Creek, the proportion of mine wastewater feed to the DeSALx® treatment facility of the water treatment plant will be increased to improve discharge water quality so that PNG ER criteria can be met at the compliance point at the end of the mixing zone.

Compliance with ANZECC/ARMCANZ (2000) in Nambonga Creek and the Wafi River

As described in Chapter 9 of the EIS, within the Nambonga Creek catchment, background concentrations of metals and metalloids, including dissolved aluminium, copper and zinc, are naturally elevated as a result of its proximity to the mineralised zone. Given that background maximum concentrations of aluminium, copper and zinc exceed the ANZECC/ARMCANZ guidelines, the background concentrations (at A100) then become the site-specific guidelines for Nambonga Creek.

Based on the predicted concentrations of dissolved parameters in the discharge (assuming 50% is treated using the DeSALx® treatment system, Clean TeQ, 2017), to meet the site-specific criteria in Nambonga Creek:

- Copper concentrations in the discharge (0.05mg/L) would require 5 dilutions, based on a site-specific copper criterion of 0.01mg/L.
- Zinc concentrations in the discharge (0.06mg/L) would require 2 dilutions, based on a site-specific zinc criterion of 0.03mg/L.

During the average flow range (250 to 500L/s), zinc concentrations will meet the site-specific criterion at the compliance point and the site-specific copper criterion will be met during the mid to upper end of the average flow range based on dilution. During low flows in Nambonga Creek, a larger proportion of mine wastewater will be fed to the DeSALx® treatment facility of the water treatment plant so that the site-specific copper and zinc criteria can be met at the compliance point at the end of the mixing zone.

Overall, the residual impacts of deteriorated water quality (increased TSS concentrations and dissolved contaminant concentrations) associated with Project construction and discharge of treated water (in a 2.4km stretch of Nambonga Creek) on aquatic macroinvertebrate and fish fauna are assessed to be **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity.

Yor Creek impacts

Yor Creek is a tributary within the Wafi River catchment and has a small catchment (4.3 km^2) upstream of its confluence with the Hekeng River.

The principal potential stressors on the freshwater ecology of Yor Creek during the construction phase include:

- Sedimentation resulting from the deposition of coarse-grained sediments.
- Increased suspended sediment concentrations and associated turbidity.
- Potential trace metal contamination from the Miapilli Waste Rock Dump.

The residual impacts of these potential stressors on freshwater ecology area assessed below.

Sedimentation impacts on aquatic habitats

Waste rock from the Nambonga Decline will be stored within the 5 ha and 10-m-high Miapilli Waste Rock Dump located in the Yor Creek catchment. The Miapilli Waste Rock Dump will store approximately 0.9Mt of waste rock from the Nambonga and Watut Declines Portals, comprising mostly potentially acid forming (PAF) waste rock (0.83Mt) plus a small amount of NAF waste rock (0.03Mt). Competent NAF material will be used during construction of the waste rock dump as lining and capping for the PAF waste rock cells within the waste rock dumps. In addition, clay and rocks will be extracted from the Miapilli Clay Borrow Pit to aid in isolating the cells of PAF waste rock cells within the waste rock dump. As mentioned above, seepage collection downstream of drainage lines from the waste rock dump will be designed to capture metal contaminated runoff and seepage waters. Captured runoff and seepage will be treated, if necessary, using a portable water treatment plant located at the Nambonga Decline Portal Terrace, and discharged to Nambonga Creek adjacent to the Nambonga Decline Portal Terrace.

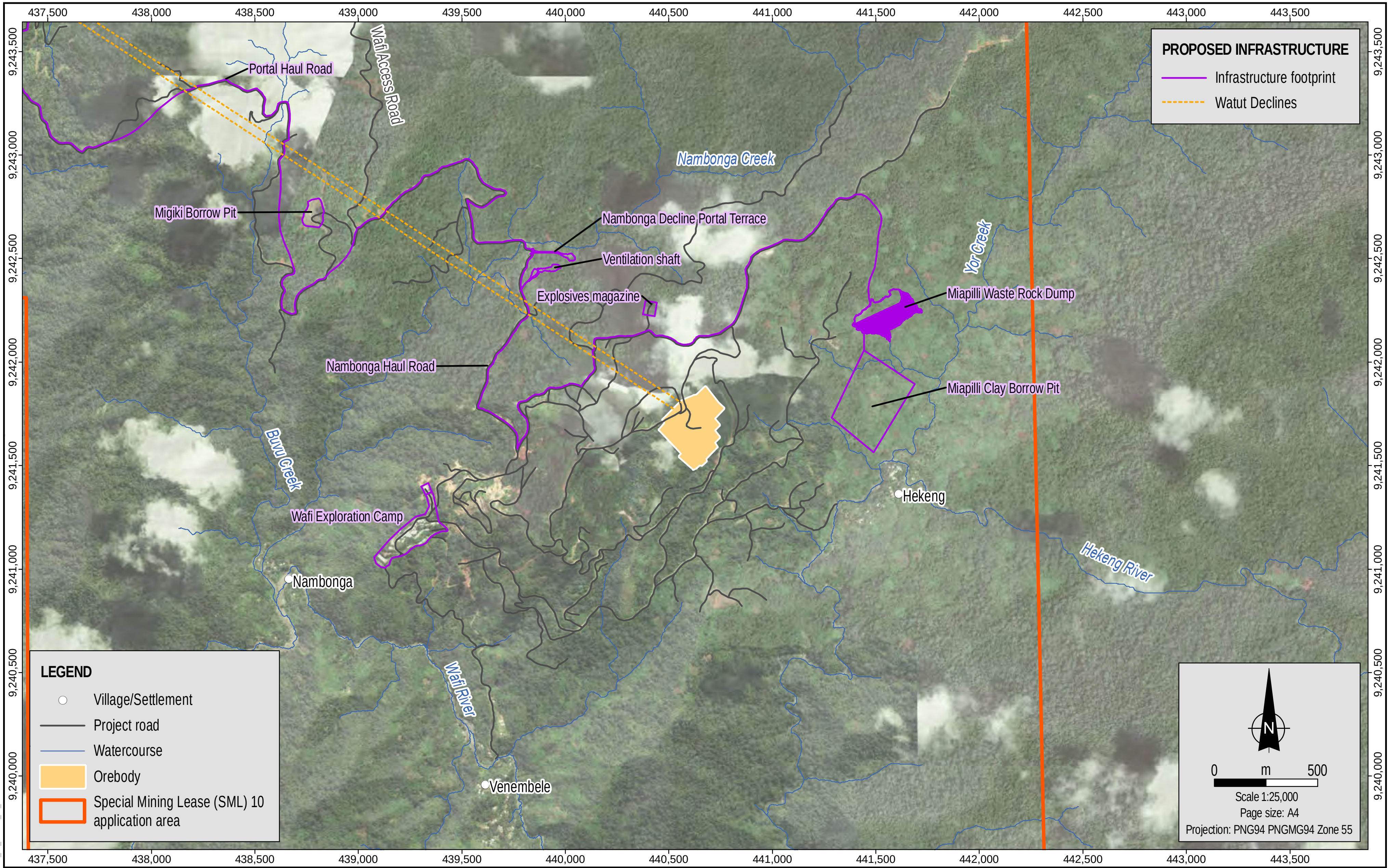
Figure 7.1 shows the conceptual arrangement of the Miapilli Waste Rock Dump and the Miapilli Clay Borrow Pit.

The total area of Project infrastructure in Yor Creek catchment is about 12 ha, which represents about 2.7% of the creek's total catchment area of 4.3 km^2.

During early works construction of the 0.5 km-long section of the Nambonga Haul Road and land vegetation clearing and grubbing of the Miapilli Waste Rock Dump and Miapilli Clay Borrow Pit, there is expected to be short-term delivery coarse-grained sediments in rainfall runoff to the natural drainage. Within Yor Creek, which is a steep fast-flowing creek, temporary deposits of settled construction-derived sediments will occur but will be resuspended and transported downstream with rising and flood creek flows. Perimeter drainage channels will be constructed upslope of the waste rock dump and borrow pit to intercept and divert uncontaminated drainage towards Yor Creek.

The aquatic habitats of Yor Creek, like those of Buvu and Nambonga creeks, are also likely to be exposed to frequent natural temporary sedimentation impacts and high bed sediment transport during flood flows and resulting from the numerous landslides observed in Wafi River sub-catchment creeks within steep terrain (KCB, 2013).

Overall, residual sedimentation impacts on the aquatic habitats of Yor Creek downstream of Project infrastructure are assessed to be **Low** significance, based on a **low** magnitude of impact and **low** sensitivity.



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

coffey
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File Name: 0520DD_24_F07.01_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Nambonga Decline Portal overview

Figure No: 7.1

Water quality impacts on aquatic biota

The principal stressors affecting water quality of Yor Creek will be increased TSS concentrations and associated turbidity in rainfall runoff to the natural drainage. Chemical water quality impacts from AMD seepage from the Miapilli Waste Rock Dump and underground dewatering flows are not expected on the assumption that this seepage will be collected and treated, if required, prior to discharge within the Nambonga Creek catchment.

Disturbance of the soils of the area is unlikely to lead increased mobilisation of metals or metalloids, as the soils are not located in mineralised areas and are expected to have average crustal abundance values based on geochemical soil sampling across the Mine Area and outside surface mineralised soils of the Mt Golpu area (KCB, 2013).

Background TSS concentrations in lower Yor Creek near Hekeng Village are a median of 5 mg/L, minimum of 5 mg/L and a maximum of 71 mg/L (Wiles and Bollaert, 2015), which is indicative of good quality water draining a forested catchment.

The implementation of the Erosion and Sediment Control Plan for both the Miapilli Waste Rock Dump and Miapilli Clay Borrow Pit and that section of the Nambonga Haul Road within Yor Creek catchment is expected to reduce fine sediment delivery to the natural drainage. If required, sedimentation ponds may be constructed immediately downstream of or within the Miapilli Clay Borrow Pit to reduce fine sediment egress to the natural drainage.

In terms of residual impacts on aquatic macroinvertebrate and fish fauna, short-term construction-derived increases in TSS concentrations in Yor Creek at average and high flows are not predicted to impact significantly on resident aquatic fauna. By the end of the five-year construction phase and active placement of waste rock within the waste rock dump, in Yor Creek, TSS concentrations are expected to return to reduce as soils stabilise and revegetate with minimal erosion.

Overall, the residual impacts of deteriorated water quality (increased TSS concentrations) associated with Project construction in Yor Creek catchment on aquatic macroinvertebrate and fish fauna are assessed to be **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity.

Resettlement Road impacts

The proposed Resettlement Road from Madzim to Old Hengambu villages is approximately 18.8 km, of which a 16.5 km-long segment is located in the Wafi River catchment. This segment of the road is mostly along mountainous terrain and crosses six rivers. The road will link Pekumbe, Pokwaluma, and old Hengambu villages with the two additional resettlement villages (i.e., Nongokwa and Kwepkwep). Figure 3.2 shows the Resettlement Road within the Wafi catchment.

The proposed road construction works include, but are not limited to:

- Clearing and grubbing.
- Cutting and backfilling.
- Drainage works.
- Culvert installation.
- Bridge construction.
- Retaining and benching
- Shaping and compacting.

The principal potential stressors on the freshwater ecology of creeks and rivers traversed by the Resettlement Road during the construction phase include:

- Sedimentation resulting from the deposition of coarse-grained sediments.

- Increased suspended sediment concentrations and associated turbidity.

The residual impacts of these potential stressors on freshwater ecology area assessed below.

Sedimentation impacts on aquatic habitats

During construction of the Resettlement Road, crossings of six rivers within the Wafi River catchment involves bridge construction. For smaller creek crossings, the installation of culverts to accommodate existing streamflow regimes will suffice.

In the case of bridge construction, the bridge piles would be on land with the bridge spanning the rivers from bank to bank. Residual impacts on aquatic habitats from bridge construction are assessed as **Low** significance, based on a **very low** magnitude of impact and **low** sensitivity.

Rainfall-based erosion and scour of construction disturbed or displaced soils at the approaches to and banks of the creeks at road crossings is predicted to cause temporary sedimentation of aquatic habitats immediately downstream of the crossing sites. The installation of culverts, including upstream and downstream stabilisation of creek banks with rock-filled gabions, results in only a small area of creek bed disturbance. However, successive rising and flood flows are expected to resuspend settled coarse-grained deposits and transport them downstream and thence to the receiving Wafi River. This pattern of sedimentation of coarse-grained sediments and subsequent resuspended and transport downstream is expected to continue until erodible soils have been stabilised and are revegetated either naturally or by intervention.

Overall, the degradation rather than loss of such small areas of creek bed aquatic habitat is assessed as negligible compared to the large areas aquatic habitats in undisturbed creek reaches. Residual impacts on aquatic habitats from road culvert installations are assessed as **Low** significance at the sub-local scale, based on a **low** magnitude of impact and **low** sensitivity.

Changes in water quality

The section of the proposed Resettlement Road within the catchment of Wafi River has been assessed on a whole of catchment basis, with impacts being assessed at the lower Wafi River at Pekumbe (see Figure 3.2). This approach is necessary as there has been no hydrological, water quality or freshwater ecology sampling of the southern tributaries of the Wafi River (i.e., Tovu and Dumbeyo rivers) and little sampling for others (e.g., Kwepkwep).

Table 7.4 gives six slope classes crossed by the 18.8 km-long Resettlement Road and cumulative length and percentage of road segments within each slope class. The calculations were for the total road length; however, the 12.5% (2.36 km) in the Lower Watut River catchment does not significantly affect the prediction of TSS loads in the Wafi River, as most of the Watut River floodplain section is on flat terrain with little sediment production.

Table 7.4: Adopted slope classes for Resettlement Road

Slope class	Gradient Description	Cumulative road length in slope class		
		(m)	(km)	(%)
0.0° to 0.9°	Very Low	4,874	4.87	25.9
2.0° to 9.9°	Low	7,887	7.89	41.8
10.0° to 14.9°	Moderate	3,999	4.00	21.2
15.0° to 19.9°	High	483	0.48	2.6
20.0° to 29.9°	Very High	1,611	1.61	8.5
>30.0°	Extreme	0.0	0.00	0.0
Totals		**18,854**	**18.85**	**100.0%**

Figure 7.2 shows a profile of the Resettlement Road across the Wafi River catchment.

Based on sediment production rates of 500 m^3/ha/year for road construction in high rainfall areas of PNG (Hydrobiology, 2008; DBA, 2005; NSR 1988), a maximum total fine-grained sediment load of 8,538 t of sediment is predicted to report as suspended load in the Wafi River. Based on the lower Wafi river downstream of Pekumbe Village, the predicted construction-derived TSS concentration increment at median flow is 38 mg/L, which compares with the existing background TSS concentration of 23 mg/L (catchment modelled background TSS concentration estimated by BMT WBM, 2018b). The construction-derived increment brings the total TSS concentration at Pekumbe to 61 mg/L, which represents a 2.6-fold increase in TSS concentration in the first year following construction of the Resettlement Road. Construction-derived TSS loads will progressively reduce as disturbed soils are stabilised and revegetated.

Implementation of the Project Erosion and Sediment Control Plan includes ongoing road maintenance and identification of erosion hot spots, which will be remedied and stabilised. After the first year of construction, road construction-derived TSS loads and concentrations in the Wafi River main channel are expected to progressively decline within 18 months to two years.

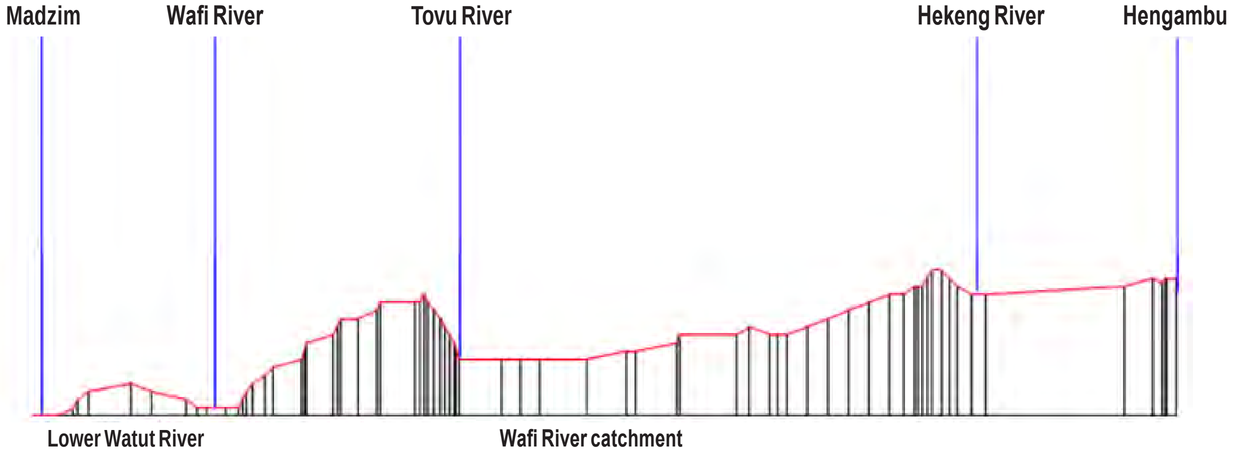
Most of the macroinvertebrate and fish assemblages of the Wafi River system (BMT WBM, 2018a) are sediment-tolerant species, some of which are also found in Buvu and Nambonga creeks highlighted above. Additional fish species include the introduced walking catfish (*C. batrachus*), marbled eel (*Anguilla reinhardtii*) and the greenback gauvina (*Oxyeleotris gyrinoides*), all of which are sediment-tolerant species.

Overall, residual impacts of constructing the Resettlement Road in the Wafi River catchment on aquatic biota are assessed to be **Low** significance, based on a **moderate** magnitude of impact and a **low** sensitivity.

7.6.2. Operations phase freshwater ecology impacts

During operations, impacts on freshwater ecology in the Wafi River catchment are predicted to be minor, since the soils of most construction-disturbed areas will have been stabilised against erosion through natural and assisted revegetation. The primary source of fine sediment that may enter the natural drainage to tributaries of the Wafi River is from road traffic and road surface maintenance (e.g., blading of road gravel surfaces and maintenance upslope and downslope drainage lines). However, typical sediment generation from this sort of road usage is relatively minor compared to road construction-derived sources.

Residual impacts of the Project during operations on Wafi River and its aquatic biological habitats and biological communities are assessed to be **Low** significance based on a **very low** magnitude of impacts and **low** sensitivity.



Source:
WGJV, 2017

coffey
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Date:
30.04.2018
Project:
754-ENAUABTF100520DD
File Name:
0520DD_24_F07.02_GRA

WAFI-GOLPU
JOINT VENTURE

Wafi-Golpu Project

Profile of the Resettlement Road in the Wafi River catchment

Figure No:
7.2

INDD Reference: 0520DD_24_GRA001.indd 1

7.7. Lower Watut River

Previous sections have assessed the residual impacts of Project construction and operations on the freshwater ecology of rivers and creeks that eventually flow into the Lower Watut River. This section addresses residual impacts within the Lower Watut River for Project construction and operations. Figure 3.1 shows the Lower Watut River catchment.

7.7.1. Construction phase freshwater ecology impacts

The principal potential stressors to the Lower Watut River freshwater ecology are:

- Sedimentation impacts on aquatic habitats.
- Changes in water quality.

During the construction phase, the Lower Watut River will receive construction-derived sediment bed and suspended loads principally via the Wafi and Bavaga rivers.

Sedimentation impacts to freshwater aquatic habitats

Coarse-scale catchment modelling of construction disturbance areas by BMT WBM (2018b; Appendix I of the EIS) assessed that, on a whole-of-catchment basis, the construction sediment loads would contribute a very small proportion (approximately 0.21% annually) to the high natural loads of the Lower Watut River main channel. Therefore, residual impacts on main channel habitats and aquatic biological communities of the Lower Watut River during the construction phase are assessed to be **Low** significance based on a **low** magnitude of impact and **low** sensitivity. Given this very small proportional contribution of sediment load, the residual impacts on the aquatic habitats of the main channel of the receiving Markham River to the Huon Gulf are assessed to be negligible and have not been considered further.

During the latter period of the construction phase (Construction Years 2 to 5) and continuing into the early operations phase, sediment loading from previous construction areas is expected to decrease progressively as disturbed or displaced soils in these areas area stabilised and revegetate naturally or by intervention (i.e., targeted stabilisation and revegetation of remaining areas prone to surface soil erosion). Long-term implementation of the Project Erosion and Sediment Control includes identifying continuing or fresh erosion problem areas and undertaking corrective remedial action.

Water quality impacts

During the construction phase, treated mine wastewater will be discharged via the wastewater discharge pipeline from the water treatment plant at the Watut Process Plant terrace to the main channel of the Lower Watut River. Receiving water quality criteria will be complied with at the boundary of a regulatory mixing zone to be established downstream of the pipeline outfall in consultation with the PNG Government. A proposed compliance point is located on the Lower Watut River approximately 0.5 km upstream of the Wongkins Village and approximately 3 km downstream from the outfall of the wastewater discharge pipeline. The WGJV proposes that this compliance point shall be the downstream boundary of the mixing zone and the waters between the wastewater discharge pipeline and the compliance point shall be a mixing zone where PNG ER water quality standards shall not be required to be met (see Chapter 15 of the EIS, Freshwater Environment Impact Assessment).

BMT WBM (Appendix I of the EIS, Catchment and Receiving Water Quality Modelling) used a tracer in its hydrological model to calculate a minimum dilution factor of 1 to 45. Chapter 15 of the EIS, Freshwater Environment Impact Assessment, assessed that there are no residual water quality impacts at the end of a short mixing zone downstream of the treated wastewater discharge point in the Lower Watut River near Wongkins Village, as all dissolved metal/metalloid predictions are below the PNG ER and (hardness corrected) ANZECC/ARMCANZ (2000) guidelines, as well as within natural background variability.

In addition, within the mixing zone the presence of highly turbid water in the Lower Watut River main channel (background median TSS concentration of 628 mg/L (range 115 to 10,300 mg/L at Uruf Village (Wiles and Bollaert, 2015))) will reduce the bioavailability of dissolved metals/metalloids via adsorption onto suspended sediments, as well as reduction due to the natural complexing capacity of the river water. Chapter 9 of the EIS, Freshwater Environment Characterisation provides further details.

Overall, residual contaminant impacts on the aquatic biological communities of the Lower Watut River during operations are assessed to be **Low** significance, based a **low** magnitude of impact and **low** sensitivity, and also based on the plan to treat (if required) all potentially contaminated water prior to discharge to the Lower Watut River main channel.

7.7.2. Operations phase aquatic ecological impacts

During the operations phase, potential stressors on freshwater ecology include continuing sediment loading and elevated concentrations of metal and metalloid contaminants in treated wastewater from the wastewater discharge pipeline outfall.

Sediment load impacts

During operations, sediment loads, albeit at very reduced levels compared to the construction phase, will continue to enter the Lower Watut River via the Wafi River and Bavaga River from surface erosion and sediment delivery from previous construction areas. In addition, there will be a continuation of sediment loads arising from the Northern Access Road Borrow Pit and other borrow pits and quarries, as well as in-river gravel extraction on the Bavaga River. On a whole of catchment basis (as per BMT WBM (Appendix I of the EIS, Catchment and Receiving Water Quality Modelling)), the operations phase sediment loads are predicted to contribute a very small proportion (approximately less than 1% annually) to the high natural loads of the Lower Watut River main channel.

Overall, residual impacts of mine-derived coarse- and fine-grained sediment loads on the main channel habitats and aquatic biological communities of the Lower Watut River during the operations phase are assessed to be **Low** significance based on a **low** magnitude of impacts and **low** sensitivity.

Water quality impacts

For the majority of the operations phase, discharge of treated wastewater from the wastewater discharge pipeline outfall in the Lower Watut River is not predicted except for two periods when there is a transition between the block cave operations, and possibly during scheduled plant shutdowns. The wastewater discharge quality is expected to be no worse than that discharged during construction and therefore the water quality impacts on freshwater ecology in the Lower Watut River are predicted to be the same, or less than, as for construction above.

7.8. Markham River Floodplain

This section assesses residual impacts of Project construction on the freshwater ecology of the eastern floodplain of the Markham River Floodplain. Figure 3.3 shows the main rivers and creeks crossed by the Infrastructure Corridor along the floodplain

Project infrastructure within Markham River northern floodplain includes:

- An 8.7 km-long section of the Northern Access Road.
- A 45 km-long section of the Infrastructure Corridor

The residual impacts of the above Project infrastructure on freshwater ecology are assessed below for Project construction and operations.

7.8.1. Construction phase freshwater ecology impacts

During the construction phase, the principal stressors on freshwater ecology in watercourses on the Markham River Floodplain include:

- Direct loss or degradation of aquatic habitats by:
  - Trenching and installation of pipelines along the Infrastructure Corridor.
  - Construction of the Northern Access Road across creeks.
- Sedimentation of watercourses resulting from the deposition of coarse-grained sediments.
- Deterioration of water quality by increased suspended sediment concentrations and associated turbidity.

Loss or degradation of aquatic habitats

Loss or degradation of aquatic habitats are assessed for the flowing Project infrastructure.

Northern Access Road

During construction of the Northern Access Road, crossings of small creeks will involve the installation of culverts to accommodate existing streamflow regimes, whereas for larger creeks (e.g., Klin Wara Creek) a bridge is proposed.

The installation of culverts, including upstream and downstream stabilisation of creek banks with rock-filled gabions, results in only a small area of creek bed disturbance. Overall, the degradation rather than loss of such small areas of creek bed aquatic habitat is assessed as negligible compared to the large areas aquatic habitats in undisturbed creek reaches. Residual impacts on aquatic habitats from road culvert installations are assessed as **Low** significance at the sub-local scale, based on a **low** magnitude of impact and **low** sensitivity.

Similarly, in the case of bridge construction, the bridge piles for a larger creek crossing would be on land with the bridge spanning the creek form bank to bank. Residual impacts on aquatic habitats from bridge construction are assessed as **Low** significance at the sub-local scale, based on a **very low** magnitude of impact and **low** sensitivity (i.e., common and widespread habitat type in the same river and other large rivers along the Markham River's northern floodplain terrace).

Rainfall-based erosion and scour of construction disturbed or displaced soils at the approaches to, and banks of, the creeks at road crossings is predicted to cause temporary sedimentation of aquatic habitats immediately downstream of the crossing sites. However, successive rising and flood flows are expected to resuspend settled coarse-grained deposits and transport then downstream and thence to the receiving Markham River. This pattern of sedimentation of coarse-grained sediments and subsequent re-suspended and transport downstream is expected to continue until erodible soils have been stabilised and revegetated either naturally or by intervention.

Overall, the residual impacts of temporary sedimentation on the aquatic habitats downstream of road crossings are assessed as **Low** significance, based on a **low** magnitude of impact and **low** sensitivity. Recovery of the aquatic habitats immediately downstream creek and bridge crossing is expected to be relatively rapid and reduce towards background levels within six months.

Infrastructure Corridor

The 45 km-long section of the Infrastructure Corridor in the Markham River's northern floodplain traverses low gradient terrain (<2°) and also crosses a number of major rivers, including the Rumu, Erap and Yalu rivers as well as a number of creeks. The smaller creeks are proposed to be crossed using wet crossing methods where upstream flows are temporarily diverted around the trench excavations to a point downstream. Residual impacts from such wet crossings on aquatic habitats are temporary and are assessed as **Low** significance at the sub-local scale, based on a **low** magnitude of impact and **low** sensitivity. Recovery is expected within 6 to 12 months as the post-trench creek bed level will be re-contoured to the original creek bed level.

At the larger river crossings, the Infrastructure Corridor traverses their wide alluvial fans with numerous distributaries, which have developed on the shallower gradients of Markham River's northern floodplain. The Rumu, Erap and Yalu rivers carry very high bed and suspended sediment loads resulting from very high erosion rates in their headwater reaches within the Saruwaged Range. The main rivers with wide alluvial fans that will be traversed are the Rumu and Erap rivers. However, the proposed method of crossing is micro-tunnelling, which does not disturb the main river channels or distributary channels of their alluvial fans. Therefore, construction of the Infrastructure Corridor across these major rivers is assessed to have no residual impacts on aquatic habitats of these rivers.

Along other sections of the Infrastructure Corridor within flat terrain (<2°), rainfall based erosion of disturbed and temporarily stored topsoil or subsoils along the Infrastructure Corridor pipelines trench is expected to deposit coarse-grained sediments (i.e., >125 μm diameter size fraction) downslope, where it typically deposits on concave slopes assisted by the trapping efficiency of vegetation and is unlikely to be eroded and transported further downslope to the natural drainage. Consequently, sedimentation impacts on aquatic habitats are assessed to be minimal and a residual impact assessment of **Low** significance, based on a **very low** magnitude of impact and a **low** sensitivity (common widespread aquatic habitat type along the Markham River terrace).

Water quality impacts to aquatic biota

Water quality impacts on rivers and creeks from the construction of the Northern Access Road and Infrastructure Corridor within the northern floodplain of the Markham River relate principally to increased concentrations of TSS and associated turbidity.

Rainfall-based erosion and scour of construction disturbed soils and subsoils along the alignment of the Infrastructure Corridor is expected to result in the delivery of fine-grained sediments (<125 μm diameter silts and clay size particles) in overland flow to the natural drainage downstream of construction areas. The main areas of fugitive fine sediments entering the natural drainage will be at river and creek crossings and their immediate approaches, especially at locations along the 8.7 km-long segment of the Northern Access Road within the Markham River's northern floodplain.

In general, there is expected to be a progressive reduction in the erosion of road construction-disturbed soils, cut-slopes and fill-slopes over a six to 18-month period, as exposed surfaces stabilise through natural or assisted revegetation. Consequently, there will be a concomitant reduction of fine-grained sediment delivery from the road alignment to the natural drainage. A number of proposed management measures within the Project Erosion and Sediment Control Plan will address both point and diffuse sources of soil erosion along the road alignment to limit sediment delivery to streams.

Along the Infrastructure Corridor on flat terrain (<2°), eroded and transported fine-grained sediments are expected to be deposit downslope having been trapped (filtered out) by vegetation (mostly grasslands) with little fine sediment reaching the natural drainage.

Most the rivers and creeks of the northern floodplain carry naturally very high concentrations of TSS due to significant erosion in their upper catchments in the Saruwaged Range. For example, Coffey (2018, Appendix H of the EIS, Freshwater Ecology Characterisation Report) measured background turbidities of between 649 and 690 NTU in the Yalu River in which several species of fish (e.g., rainbowfish and river gobies) and river prawns (*Macrobrachium* spp.) are known to be sediment-tolerant species. Therefore, the aquatic biological communities of these rivers and creeks are frequently exposed to naturally elevated TSS concentrations and turbidity, especially at average to high flows.

Overall, water quality impacts to aquatic flora and fauna arising from construction-derived fine-grained sediments causing temporary increases in TSS concentrations and turbidity are assessed as **Low** significance, based on a **low** magnitude of impact and **low** sensitivity (due to the common and widespread flora and fauna communities), as well as given the naturally turbid nature of many of the rivers and creeks in the northern floodplain of the Markham River.

7.8.2. Operations phase freshwater ecology impacts

No residual impacts of the Project on the freshwater ecology of rivers and creeks of the Markham River northern floodplain are predicted during operations, given that the various pipelines in the Infrastructure Corridor are buried and do not impede flows or affect water quality of surface waters.

7.9. Coastal Area

The Coastal Area includes rivers and creeks that flow directly to the Upper Huon Gulf near Lae, which will be traversed by the Infrastructure Corridor. Construction and operation of the Port Facilities Area and the Outfall Area (mixing and de-aeration tanks and shore crossing) are assessed separately in Chapter 16 of the EIS, Nearshore Marine Environment Impact Assessment, and are not covered here.

Figure 3.3 shows a map of the Coastal Area and key rivers and streams.

Project infrastructure within the Coastal Area comprises a:

- A 4.4 km-long section of the Infrastructure Corridor containing the co-buried concentrate, tailings and fuel pipelines and comprising the following segments:
  - A 2.4 km-long section in a rural setting.
  - A 1.8 km-long section within the urban drainage system of the City of Lae.
- A 10.3 km-long section of the Infrastructure Corridor containing only the tailings pipeline from near the Port Facility to the Outfall Area and comprising of the following segments:
  - An 8.4 km-long section within the urban drainage system of the City of Lae.
  - A 1.9 km-long section in a rural setting.
- Mixing/de-aeration tank at the Outfall Area (1.8 ha)

The residual impacts on freshwater ecology of Coastal Area rivers and creeks are assessed below for Project construction and operations.

7.9.1. Construction phase freshwater ecology impacts

The principal stressors on freshwater ecology include:

- Loss or degradation of aquatic habitats by excavation and installation of pipelines along the Infrastructure Corridor and sedimentation of watercourses.
- Deterioration of water quality by increased suspended sediment concentrations and associated turbidity.

Loss or degradation of aquatic habitats

Within the Coastal Area, the Infrastructure Corridor traverses low gradient terrain (<2°), as well as crossing one major river (i.e., Bumbu River) within the City of Lae and a number of mostly unnamed coastal creeks. Near the Outfall Area, the tailings pipeline traverses tributaries within the catchments of Gaison and Bugalang creeks (see Figure 3.3), and includes low-lying areas of both freshwater and brackish water swamps that are fished by local Wagang villagers.

Loss of habitat at watercourse crossings will be temporary, as the trench will be backfilled and the surface re-contoured to simulate the pre-disturbance watercourse bed level. Therefore, no lasting impacts on creek bed aquatic habitat at stream crossings are predicted.

Soil erosion along the Infrastructure Corridor along the eastern section of the Coastal Area and the delivery of coarse-grained sediment to the natural drainage is assessed to be negligible given experience of sedimentation impacts from roads constructed across floodplains elsewhere in PNG, which shows that coarse-grained sediment loading of the natural drainage is low and highly localised to areas immediately downslope of the road alignments, principally due to the flat terrain, or downstream of watercourse crossings due to very low flow velocities (DBA, 2005; Balloch et al., 2005).

Overall, the residual impacts of construction of the Infrastructure Corridor across flat gradient or swampland terrain of aquatic habitats are assessed to be **Low**, based on a **very low** magnitude of impact and a **low** sensitivity (due to the common aquatic habitat type within the Project Area and beyond).

Water quality impacts to aquatic biota

Potential water quality impacts on the aquatic biota of the sub-catchment creeks and swampland waterbodies of the eastern section of the Coastal Area relates primarily to rainfall-based erosion and scour of construction-disturbed or displaced soils, and the resultant fine-grained (<125μm particle size diameter) sediment loading downstream of watercourse crossings. The area of swampland has its own coastal sub-catchment that is separate from the Bumbu River system to the west and the Busu River system to the east. No impacts on the water quality of the Bumbu River are anticipated as the tailings pipeline will cross this river via a single span gantry or attached to the existing road bridge.

If construction of the access road and the trenching and burial of the tailings pipeline is undertaken during the drier parts of the year, fine sediment loading of watercourses will be minimal. However, if construction is during the wet season, the likelihood of soil surface erosion and fine sediment delivery to the natural drainage is more likely. Conservatively assuming the wet season scenario, the following section assesses the residual impact of deteriorated water quality to aquatic biota.

The watercourses of the flat swampland terrain in the eastern Coastal Area are generally low in TSS concentrations and turbidity. Downstream of watercourses, short periods of increased TSS concentrations are expected, though with low flows, particles in the size range 0.016 mm (medium silts) through to 0.125 mm (very fine sands) will deposit on the watercourse beds, leaving finer particles sizes <0.016 mm (fine silts to clays) to be transported further downstream. In general, elevated TSS concentrations in the receiving watercourses will be short term (a few weeks to a month), as surface erosion site stabilise.

Overall, the residual impacts of short-term increased TSS concentrations on the aquatic biota of the eastern Coastal Area swamplands are assessed to be **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity (swamplands are a common widespread habitat type along the small coastal catchments of the Huon Gulf and river systems).

7.9.2. Operations phase freshwater ecology impacts

No residual impacts of the Project on the freshwater ecology of rivers and creeks of the Coastal Area are predicted during operations, given that the various pipelines in the Infrastructure Corridor will be buried and do not impede flows or affect water quality of surface waters. The filled trench surfaces will have been stabilised and revegetated naturally or by intervention, such that fugitive sediments are most unlikely to enter the natural drainage. The surface of the filled-in trenches will be re-contoured to match the pre-disturbance ground level.

7.10. Species of conservation significance

Impacts on species of conservation significance, such as IUCN-listed, species of national conservation priority (listed as protected or restricted under the *Papua New Guinea (PNG) Fauna (Protection and Control) Act 1966*) are predicted to be the same as impacts on non-listed species and would also have sensitivities similar to other native species. Therefore, an aquatic species having conservation significance does not confer additional sensitivity compared to other introduced or native fish species within an area.

There were no IUCN-listed aquatic flora or macroinvertebrate species found or expected in the Mine Area and Infrastructure Corridor. However, there was a low likelihood of adult individuals of the Indo-Pacific subpopulation of the largetooth sawfish (*P. pristis*) occurring occasionally in the Markham and Lower Watut rivers as upstream migrating adults or downstream movement of juveniles to coastal waters. This species of sawfish is known to frequent the Fly and Strickland river systems (Roberts, 1978), which are large unconfined and turbid rivers and hence indicate that this species is sediment-tolerant.

The residual impacts of construction-derived increases in TSS concentrations of the Lower Watut River main channel water quality and fish assemblages were assessed above as low; therefore, residual impacts of the Project on largetooth sawfish, if present, are also assessed as **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity (due to it being a known sediment-tolerant fish species).

Residual impacts on freshwater turtle species of conservation significance, such as the northern New Guinea softshell turtle (*P.s signifera*) classified as Vulnerable (VU) on the IUCN's Red List of Threatened Species (IUCN, 2017) are not anticipated as their likely preferred habitats of oxbow lakes along the Lower Watut and Markham rivers are not predicted to be impacted by Project construction or operations.

7.11. Invasive aquatic flora and fauna

This section addresses residual impacts of the Project on the potential to exacerbate the spread of non-native aquatic plants (macrophytes), macroinvertebrates and fish within the Project Area.

7.11.1. Invasive aquatic macrophytes

Only one species of aquatic weed, the water lettuce (*P. stratiotes*), was recorded at Uruf Oxbow on the Lower Watut River floodplain. One of the most widely distributed invasive aquatic macrophytes in PNG is the water hyacinth (*E. crassipes*), which was not observed in field surveys undertaken by BMT WBM (2013a,b; 2018a, Appendix G of the EIS). While both of these species are likely to be present in small oxbow lakes along the middle Watut River, no Project infrastructure is proposed in these areas. However, additional invasive aquatic flora species have the potential to be introduced to the Project Area either through intended introductions into the environment by local communities (e.g., exotic species used as a food resource) or accidentally by Project activities.

Within the Lower Watut River's eastern and western floodplains, it is the oxbow lakes where invasive aquatic macrophytes have been found such as the water lettuce. There are no Project construction or operational activities that physically impinge directly on these oxbow lakes; therefore, the likelihood of accidental dispersal by the Project is very low.

Within the eastern floodplain of the Lower Watut River, the construction of the Watut Services Road will follow an alignment that keeps to elevated ground on the floodplain to avoid future flooding risks. Potential aquatic macrophytes could be encountered in floodplain tributaries at watercourse crossings; however, the risk of spreading invasive species can be reduced by the hosing-down of construction plant equipment as a management measure, following completion of watercourse crossings.

Overall, the residual impacts of the Project on invasive aquatic macrophytes are assessed to be **Low** significance, based on a **very low** magnitude of impact and a **high** sensitivity (i.e., based on a higher risk to the environment).

7.11.2. Invasive exotic fish species

Freshwater ecology surveys by BMT WBM (2013a,b; 2018a) found a total of six species of introduced fish species, most of which were introduced by the PNG Government in the 1960s through the 1970s to either control mosquito larvae for malaria control (e.g., mosquitofish, *G. holbrooki*) or to provide a food source of protein to local communities across the country.

Many species such as European carp (*C. carpio*), swordtails (*X. helleri*), mosquitofish and Mozambique tilapia (*O. mossambicus*) prefer lentic waters of the oxbow lakes or slow-flowing (i.e., low water velocities) in the floodplain tributaries. The oxbow lakes will not be directly affected by the Project and only short-term construction impacts are predicted in the floodplain watercourse crossings and swamps. During natural inundation of the floodplain occasioning overbank breakout flows from the Lower Watut River main channel, both native and introduced fish species may migrate across the floodplain and enter or leave different watercourses. The spread of such species across the floodplain tributaries has occurred, presently occurs and will continue to occur independently of any potential Project construction or operational impacts on the floodplain swamps and tributaries.

Some species of introduced fish such as the golden mahseer (*T. putitora*) prefers swift-flowing waters of rivers and streams. This species was the most abundant and widespread species of introduced fish captured during fish surveys of the Lower Watut River system (BMT WBM, 2018a, Appendix G of the EIS) and was generally not found in the floodplain oxbow lakes, swamps and tributaries, but was found in the Lower Watut River main channel and the upland Wafi River system. Its presence in the Wafi River main channel, Zamen River and Nambonga Creek suggest that this relatively abundant species may be out-competing native species for aquatic habitat and food resources.

Another introduced species that has a very high tolerance of turbid water conditions (i.e., increased TSS concentrations) is the walking catfish (*C. batrachus*), which was found in Boganchong and Womul creeks and floodplain swamps (BMT WBM, 2018a, Appendix G of the EIS).

Overall the residual impacts of the Project on introduced fish species are assessed to be **Low** significance based on a **low** magnitude of impact and a **medium** sensitivity. There is some potential for introduced fish species being more adaptable to colonising disturbed habitat conditions within watercourses affected by the Project, which could accelerate the spread of some species. However, this is considered a low probability given that all over PNG, the spread of introduced species has been gaining in the last few decades from initial low densities and distributions, as well as independently of natural resource mining and onshore oil and gas developments.

7.12. Post-closure freshwater ecology impacts

Residual impacts of potentially metal/metalloid contaminated waters on aquatic biological communities are assessed below for future seepages or overflow waters from the post-closure crater lake, and post-closure seepage waters from the Watut Declines Portal Terrace, the Nambonga Portal Terrace and the Watut and Miapilli Waste Rock Dumps.

7.12.1. Post-closure subsidence zone lake outflows

In Chapter 15 of the EIS, Freshwater Environment Impact Assessment, it was assessed that water quality modelling of the subsidence zone lake is subject to a large number of uncertainties; however, any discharges from the subsidence zone lake are predicted to be acidic with elevated concentrations of metals and metalloids, which are expected to exceed PNG ER Criteria and ANZECC/ARMCANZ (2000) receiving water guidelines for the protection of 95% of aquatic species. In the Project Environmental Monitoring Program, it is proposed to monitor the quality of seepage and spill from the crater lake and treat any contaminated water during the post-closure period until water quality closure objectives are met.

Post-closure, flooding of the block caves and declines will be accelerated using mine wastewater and pumped raw water from the Watut River to reduce the exposure period of sulphidic material in the decline and block cave walls to atmospheric conditions, thereby reducing AMD and subsequent leaching of contaminants. The resultant subsidence zone lake will be treated using lime to increase pH and reduce dissolved metals concentrations via solids precipitation.

With lime treatment, the predicted concentrations of manganese (3.2 mg/L) and iron (2.9 mg/L), however, are predicted to still exceed the PNG ER criteria (0.05 mg/L and 1 mg/L, respectively) 50 years post-closure. Concentrations of copper (0.2 mg/L) and aluminium (1.6 mg/L) also exceed the PNG ECoP guidelines (0.0065 mg/L and 0.005 mg/L, respectively), however these concentrations comply with the PNG ER criteria for these parameters.

Notwithstanding the uncertainty of the predicted water quality within the subsidence zone lake, while a degree of dilution is likely to be provided by watercourses in the Wafi River catchment, discharge of water from the subsidence zone lake may require treatment to meet regulatory water quality criteria at the agreed compliance point for an unknown period (at least 50 years).

At this juncture, the residual impacts of treated seepage and/or crater lake overtopping discharges to the Wafi River system are assessed to be **Low** significance, based on a **low** magnitude of impact and a **low** sensitivity and the assumption that such metal- and metalloid-contaminated waters will be treated.

Should the assumption that the capture and treatment of poor quality water during the post-closure period prove to be ineffective in practice, post-closure impacts may be higher than predicted. As such, modelling of final pit lake water quality and engineering solutions will be progressively improved as actual data is accumulated during operations.

7.12.2. Post-closure drawdown impacts on baseflows in creeks

Piteau (2018c, Appendix X of the EIS) modelled the effects of groundwater drawdown and mine dewatering on baseflows in creeks within the draining the Mt Golpu area. The main affected creeks are Buvu and Nambonga creeks, which have sub-catchments within the drawdown zone. In the very long term, say after 36 years of operation, the simulated baseflow in Buvu and Nambonga catchments are reduced by 34% and 26%, respectively (Piteau, 2018c, Appendix X of the EIS). The combined Hekeng River and Wafi River catchments are substantially larger and are predicted to have a much smaller reduction in baseflow (9%) across their catchments.

While reduced baseflows could add stress to the aquatic ecosystems and groundwater dependent, riparian vegetation associated with Buvu and Nambonga creeks, particularly during dry periods when baseflow accounts for most of the total stream flow, the residual effects on aquatic biological communities of these creeks are limited. For example, most of the macroinvertebrate fauna are opportunistic flying insects (e.g., mayflies and caddisflies) that lay eggs in creek waters when present. There is expected to be sufficient baseflow to accommodate insect eggs, nymphs and larvae but resident fish may be temporarily displaced downstream during dry weather flows (i.e., during baseflows).

Overall, the residual impacts of groundwater drawdown reductions in baseflows in Buvu and Nambonga creeks on aquatic biological communities during very low (i.e., baseflow) or dry weather flows are assessed as **Low** significance, based on a magnitude of impact of **low** and a sensitivity of **low**.

7.13. Residual impact summary

Table 7.5 presents a summary of the predicted residual impacts on freshwater ecology. Most of the Project residual impacts on freshwater ecology relate to the construction phase when fugitive coarse and fine sediments are mobilised following rainfall events and delivered in overland flows to watercourses, mainly as a consequence of rainfall-based erosion and scour of construction-disturbed or displaced soils. Through the process of natural or assisted revegetation and full implementation of the Project Erosion and Sediment Control Plan, construction-disturbed surfaces will be stabilised resulting in a progressive reduction in the delivery of fugitive sediments to the natural drainage. In many cases, short-term residual impacts on aquatic habitats and biological communities are predicted to persist during the first 18 months to 2 years following construction, when water quality is predicted to return to comparable to pre-disturbance levels. This pattern and duration of recovery has been observed at many other mines in PNG (e.g., NSR, 1988 and 1999).

Table 7.5: Residual impacts to the freshwater environment

Impact	Causes	Environmental Values Affected	Sensitivity of Environmental Value	Impact Magnitude	Residual Impact Significance
Boganchong Creek					
Loss or degradation of aquatic habitats during the wet season	Direct loss of habitat (e.g., Watut Declines Portal Terrace), sedimentation and raw water storage dams and impoundments.	Freshwater aquatic habitat	Low	High	Moderate
Loss or degradation of aquatic habitats during the wet season	Sedimentation impacts in lower reaches of Boganchong Creek	Freshwater aquatic habitat	Low	High	Moderate
Loss or degradation of aquatic habitats during the dry season	Loss of habitat occurs naturally as Boganchong Creek is ephemeral. Potential residual sedimentation impacts in lower reaches.	Freshwater aquatic habitat	Low	Very low	Low
Alteration of hydrology	Changes in streamflow and peak flows	Freshwater aquatic biological communities	Low	Low	Low
Changes in water quality during construction	Increased TSS concentrations and turbidity when the creek is flowing	Freshwater aquatic biological communities	Low	High	Moderate
Changes in water quality	Increased concentrations of dissolved and particulate-associated metals and metalloids with potential toxicity during construction phase	Freshwater aquatic biological communities	Low	Low	Low
Changes in water quality during operations	Increased concentrations of dissolved and particulate-associated metals and metalloids with potential toxicity during the operations phase	Freshwater aquatic biological communities	Low	Low	Low
Womul Creek					
Loss or degradation of aquatic habitats	Direct loss of habitat (e.g., tributary crossings (culverts and fill slopes) of Northern Access Road and Infrastructure Corridor (buried pipelines))	Freshwater aquatic habitat	Low	Low	Low
Degradation of aquatic habitats	Sedimentation of creek bottom habitats	Freshwater aquatic habitats and benthic macroinvertebrate fauna	Low	Moderate	Low

Impact	Causes	Environmental Values Affected	Sensitivity of Environmental Value	Impact Magnitude	Residual Impact Significance
Changes in water quality	Increased TSS concentrations and turbidity during construction phase	Aquatic biological communities (macroinvertebrates and fish)	Low	Moderate	Low
Changes in water quality during operations	Increased TSS concentrations and turbidity during operations phase	Aquatic biological communities	Low	Very low	Low
Other eastern floodplain creeks					
Loss or degradation of aquatic habitats	Direct loss of habitat (e.g., tributary crossings (culverts and fillslopes) of Northern Access Road and Infrastructure Corridor (buried pipelines, laydown areas and sedimentation))	Freshwater aquatic habitats	Low	Low	Low
Changes in water quality	Increased TSS concentrations and turbidity during construction phase	Aquatic biological communities (macroinvertebrates and fish)	Low	Low	Low
Lower Bavaga River					
Aquatic habitat loss or degradation	Direct loss of hyporheic habitat (e.g., removal of river bed gravels); Sedimentation of downstream benthic habitats	Freshwater aquatic habitat	Low	Low	Low
Aquatic habitat loss or degradation	Sedimentation effects of Northern Access Road Borrow Pit construction and development, and sediment-laden surface runoff from quarry and access roads	Freshwater aquatic habitats	Low	Moderate	Low
Aquatic habitat loss or degradation	Sedimentation effects of Mount Beamena quarry construction and development, and sediment-laden surface runoff from quarry and access road	Freshwater aquatic habitats	Low	Moderate	Low
Altered hydrology	Water abstraction for gravel washing at Lower Bavaga River gravel extraction site	Freshwater aquatic habitat	Low	Low	Low

Impact	Causes	Environmental Values Affected	Sensitivity of Environmental Value	Impact Magnitude	Residual Impact Significance
Water quality changes during construction	Increased TSS concentrations and turbidity downstream of gravel extraction	Aquatic flora and fauna of lower Bavaga River	Low	Low	Low
Water quality changes during construction	Increased TSS concentrations and turbidity downstream of Northern Access Road Borrow Pit and access roads	Aquatic flora and fauna of lower Bavaga River	Low	Low	Low
Water quality changes during construction	Increased TSS concentrations and turbidity downstream of Mount Beamena Quarry and access road	Aquatic flora and fauna of lower Bavaga River	Low	Low	Low
Water quality changes during operations	Increased TSS concentrations and turbidity downstream of continuing development of Northern Access Borrow Pit and river gravel extractions in the Lower Bavaga River	Aquatic flora and fauna of lower Bavaga River	Low	Low	Low
Lower Watut River eastern floodplain					
Altered hydrology	Flow impedance effects on floodplain creeks associated with the Watut Services Road construction	Aquatic habitats and biological communities	Low	Low	Low
Altered hydrology	Flow impedance effects on floodplain creeks associated with the wastewater discharge pipeline construction	Aquatic habitats and biological communities	Low	Low	Low
Altered hydrology	Flow impedance and water abstraction effects on floodplain creeks associated with the floodplain Lower Papas Aggregate Source extraction site	Aquatic habitats and biological communities	Low	Very low	Low
Loss or degradation of aquatic habitats	Sedimentation of floodplain aquatic habitats associated with the wastewater discharge pipeline	Aquatic habitats and biological communities	Low	Very low	Low
Lower Papas Aggregate Source altered hydrology	Changes in surface hydrology	Aquatic habitats and biological communities	Low	Low	Low
Watut Services Road during operations	Increased TSS loading of natural drainage from vehicular usage of the Watut Services Road	Aquatic habitats and biological communities	Low	Very low	Low

Impact	Causes	Environmental Values Affected	Sensitivity of Environmental Value	Impact Magnitude	Residual Impact Significance
Aquatic habitat loss or degradation	Sedimentation of benthic habitats of creeks downstream of Watut Services Road construction	Aquatic habitats	Low	Low	Low
Aquatic habitat loss or degradation	Sedimentation of benthic habitats of creeks downstream of wastewater discharge pipeline construction	Aquatic habitats	Low	Very low	Low
Aquatic habitat loss or degradation	Sedimentation of benthic habitats of creeks downstream of Lower Papas Aggregate Source extraction site	Aquatic habitats	Low	Very low	Low
Water quality changes	Increased TSS concentrations and turbidity downstream of Watut Services Road construction	Aquatic biological communities	Low	Low	Low
Water quality changes	Increased TSS concentrations and turbidity downstream of wastewater discharge pipeline construction	Aquatic biological communities	Low	Low	Low
Water quality changes	Increased TSS concentrations and turbidity downstream of Lower Papas Aggregate Source extraction site	Aquatic biological communities	Low	Low	Low
Water quality changes during operations	Increased TSS concentrations and turbidity in Watut Services Road runoff due to road maintenance and vehicular traffic on gravel road	Aquatic biological communities	Low	Very low	Low
Wafi River					
Changes to water quality in Buvu Creek during construction	Increased TSS concentrations and turbidity	Freshwater biological communities	Low	Low	Low
Aquatic habitat loss or degradation from Project construction in Nambonga Creek catchment	Increased sedimentation from delivery of coarse-grained construction sediments	Freshwater habitats	Low	Low	Low
Changes to water quality in Nambonga Creek during construction	Increased TSS concentrations and turbidity	Freshwater macroinvertebrates and fish	Low	Low	Low

Impact	Causes	Environmental Values Affected	Sensitivity of Environmental Value	Impact Magnitude	Residual Impact Significance
Changes to water quality in Nambonga Creek during construction	Treated wastewater discharges (underground dewatering flows and Miapilli Waste Rock Dump seepage) to Nambonga Creek	Freshwater macroinvertebrates and fish	Low	Low	Low
Aquatic habitat loss or degradation from Project construction in Yor Creek	Increased sedimentation from delivery of coarse-grained construction sediments	Freshwater habitats	Low	Moderate	Low
Changes to water quality in Yor Creek during construction	Increased TSS concentrations and turbidity	Freshwater macroinvertebrates and fish	Low	Moderate	Low
Post-closure treated seepage and/or crater lake overtopping discharges to the Wafi River system	Increased TSS concentrations and trace metal concentrations	Aquatic biological communities	Low	Low	Low
Post-closure groundwater drawdown reductions in baseflows in Buvu and Nambonga creeks	Reductions in baseflow in creeks	Aquatic biological communities	Low	Low	Low
Lower Watut River (regional scale)					
Loss or degradation of aquatic habitats	Sedimentation of aquatic habitats	Freshwater aquatic habitats	Low	Low	Low
Changes in water quality during construction phase	Treated wastewater discharges to Lower Watut River near Wongkins Village	Main channel aquatic biological communities	Low	Low	Low
Changes in water quality during operations	Increased TSS concentrations and turbidity	Main channel aquatic biological communities	Low	Low	Low
Markham River floodplain					
Aquatic habitat loss or degradation from Northern Access Road during construction	Sedimentation impacts; temporary loss of tributary benthic habitat at wet trenching sites (tributary bed level re-contoured to pre-disturbance levels)	Freshwater aquatic habitat	Low	Low	Low

Impact	Causes	Environmental Values Affected	Sensitivity of Environmental Value	Impact Magnitude	Residual Impact Significance
Aquatic habitat loss or degradation from pile installation during bridge construction	Sedimentation impacts	Freshwater aquatic habitats	Low	Very low	Low
Aquatic habitat loss or degradation downstream of road crossings during construction	Sedimentation impacts	Freshwater aquatic habitats	Low	Low	Low
Aquatic habitat loss or degradation downstream of Infrastructure Corridor (pipelines) crossings of Rumu, Erap and Yalu rivers during construction	Sedimentation impacts	Freshwater aquatic habitats	Low	Low	Low
Aquatic habitat loss or degradation downstream of Infrastructure Corridor (pipelines) crossings of low gradient (<2°) terrain of the Markham River floodplain reaches during construction	Sedimentation impacts	Freshwater aquatic habitats	Low	Very low	Low
Changes to water quality in Markham River floodplain rivers and creeks downstream of Infrastructure Corridor during construction	Increased TSS concentrations and turbidity	Freshwater aquatic biological communities	Low	Low	Low
Coastal Area					
Aquatic habitat loss or degradation from construction of Infrastructure Corridor across low gradient (<2°) terrain of the Coastal Area	Sedimentation of aquatic habitats by coarse-grained sediments	Freshwater habitats	Low	Very low	Low
Changes in water quality during Infrastructure Corridor construction in the Coastal Area	Increased TSS concentrations and turbidity	Freshwater flora and fauna	Low	Low	Low

Impact	Causes	Environmental Values Affected	Sensitivity of Environmental Value	Impact Magnitude	Residual Impact Significance
Project-wide species of conservation significance					
Water quality changes	Increased TSS concentrations and turbidity	Largetooth sawfish (*Pristis pristis*)	Low	Low	Low
Water quality changes	Increased TSS concentrations and turbidity	Northern New Guinea softshell turtle (*Pelochelys signifera*)	Low	Low	Low
Invasive aquatic plants and animals					
Invasive aquatic macrophytes	Potential spread of existing introduced or new aquatic macrophytes to Project rivers and creeks	Native macrophytes	Low	Very low	Low
Invasive fish species	Potential spread of existing invasive fish species or introduction of new invasive fish species	Diversity and abundance of native fish species (competition with invasive species)	Medium	Low	Low

8. Monitoring

The Project Environmental Management Plan (Attachment 3 of the EIS) details the standard, Project-wide inspection and monitoring requirements for assessing the Project's overall environmental performance.

Monitoring of the impacts of the Project on the freshwater aquatic environment is proposed to include the following:

- Monitoring the quality of water discharged from the sedimentation dams and comparison against agreed regulatory permit criteria for discharges to confirm the performance of sediment control structures.
- Monitoring water extracted from underground workings and other potentially contaminated sites to determine if it is of suitable quality for direct discharge to the downstream environment or whether pre-discharge water treatment is required to meet environment permit criteria.
- Continued monitoring of appropriate baseline sites already established (see Figure 9.1, Chapter 9 in the EIS) that will not be impacted by Project construction and operation.
- Continued use of gauging stations to monitor water level and flow.
- Monitoring of freshwater ecology (flora and fauna) in watercourses downstream of the Project Area, as well as at already-established baseline sites (see Figure 9.1, Chapter 9 in the EIS), including the collection of fish tissue and macroinvertebrate samples to determine the presence (or not) of elevated metal concentrations above baseline levels.
- Monitoring for weeds and/or invasive species of flora and fauna.

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