# Chapter 15

## Freshwater Environment Impact Assessment

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### 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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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.

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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.

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

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

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

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**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**

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**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.

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# 15. FRESHWATER ENVIRONMENT IMPACT ASSESSMENT

This chapter presents the assessment and findings of potential impacts from Project activities on the three main physico-chemical aspects of the surface water environment described in Chapter 9, Freshwater Environment Characterisation, namely impacts on hydrology (Section 15.5.1), sediment transport (Section 15.5.2) and water quality (Section 15.5.3). Combined, these aspects are referred to as the downstream receiving environment.

This chapter is based upon the results of the:

- Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River report by BMT WBM (Appendix G)
- Surface Water and Freshwater Aquatic Ecology Characterisation – Yalu to Wagang (Appendix H)
- Hydrology, sediment transport and water quality modelling completed by BMT WBM, which is reported in Catchment and Receiving Water Quality Modelling (Appendix I)
- Site-wide Water and Mass Balance Modelling undertaken by Piteau Associates (Piteau) (Appendix V)
- Post-closure numerical modelling completed by Piteau reported in Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone (Appendix X)

A separate technical appendix for the freshwater ecology impact assessment is presented in Appendix Y, Freshwater Ecology Impact Assessment and the findings of this report are summarised in Section 15.6. The focus of the freshwater environment impact assessment presented in this chapter is placed on the sub-catchments most likely to be impacted by the Project, including those catchments in the Mine Area containing the greatest concentration of Project infrastructure and anticipated construction intensity. In some cases, however, sub-catchments that were assessed as having low residual impacts are discussed for contextual purposes or because they are of particular interest to stakeholders (e.g., the Lower Watut River).

## 15.1. Approach to Impact Assessment

The potential impacts of the Project on the downstream receiving environment assessed in this chapter 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.

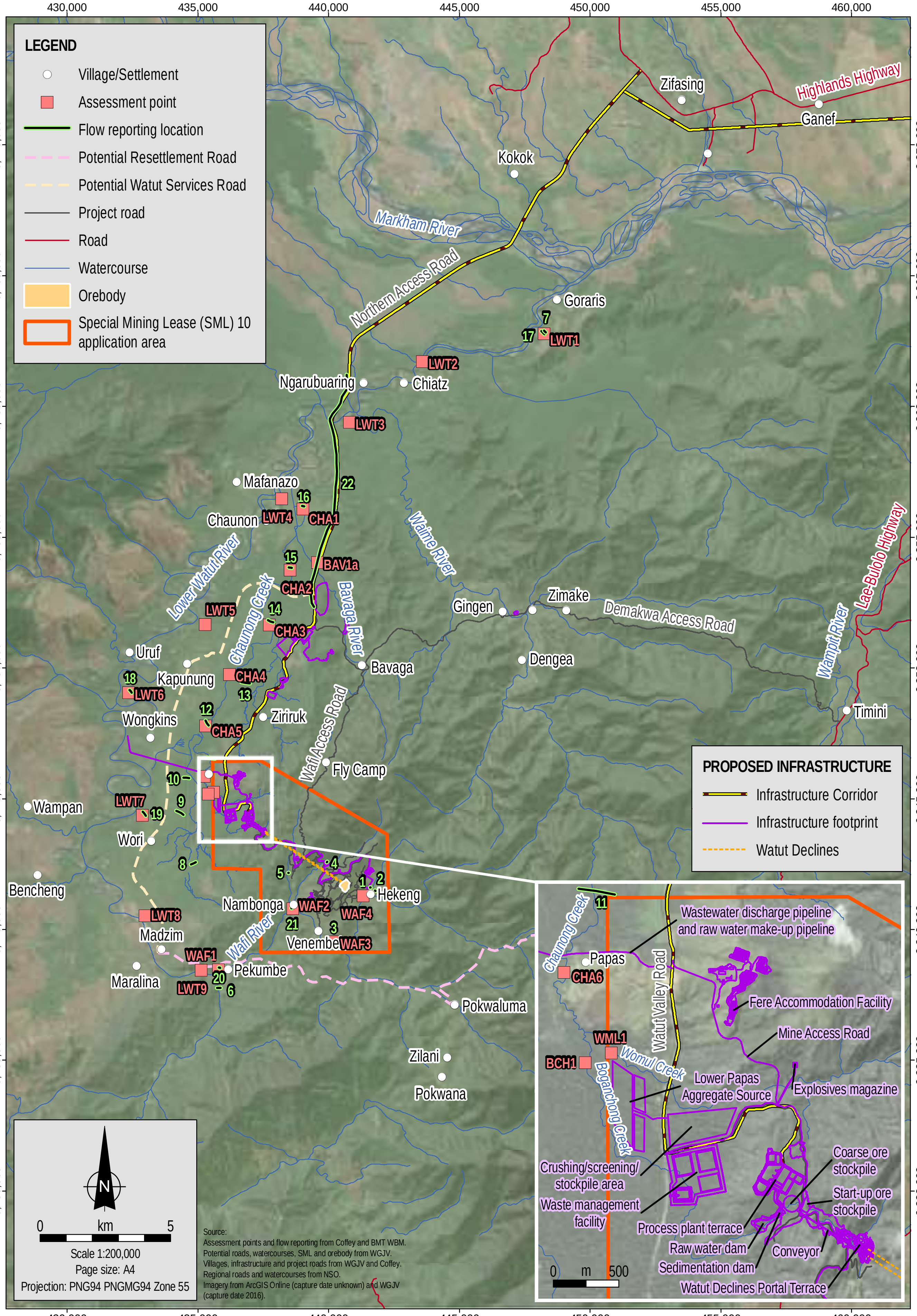
- Development of proposed management measures to mitigate or limit the impacts on the downstream receiving environment.
- Assessment of the residual impacts that these stressors are predicted to have on the downstream receiving environment, assuming the adoption of proposed management measures.

### 15.1.1. 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 15.1. Figure 15.2 shows watercourses in the southern portion of the Mine 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 (see Figure 9.1, Figure 15.1 and Figure 15.2):
  - Lower Watut River (main channel) down to the Markham River confluence 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, which includes (see Figure 9.2 and Appendix Y, Freshwater Ecology Impact Assessment):
  - 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 which include (see Figure 9.2 and Appendix Y, Freshwater Ecology Impact Assessment):
  - Bumbu River and Gaison, Bugalang and Bupeli creeks




MXD Reference: 0520DD_10_GIS028_v0_8

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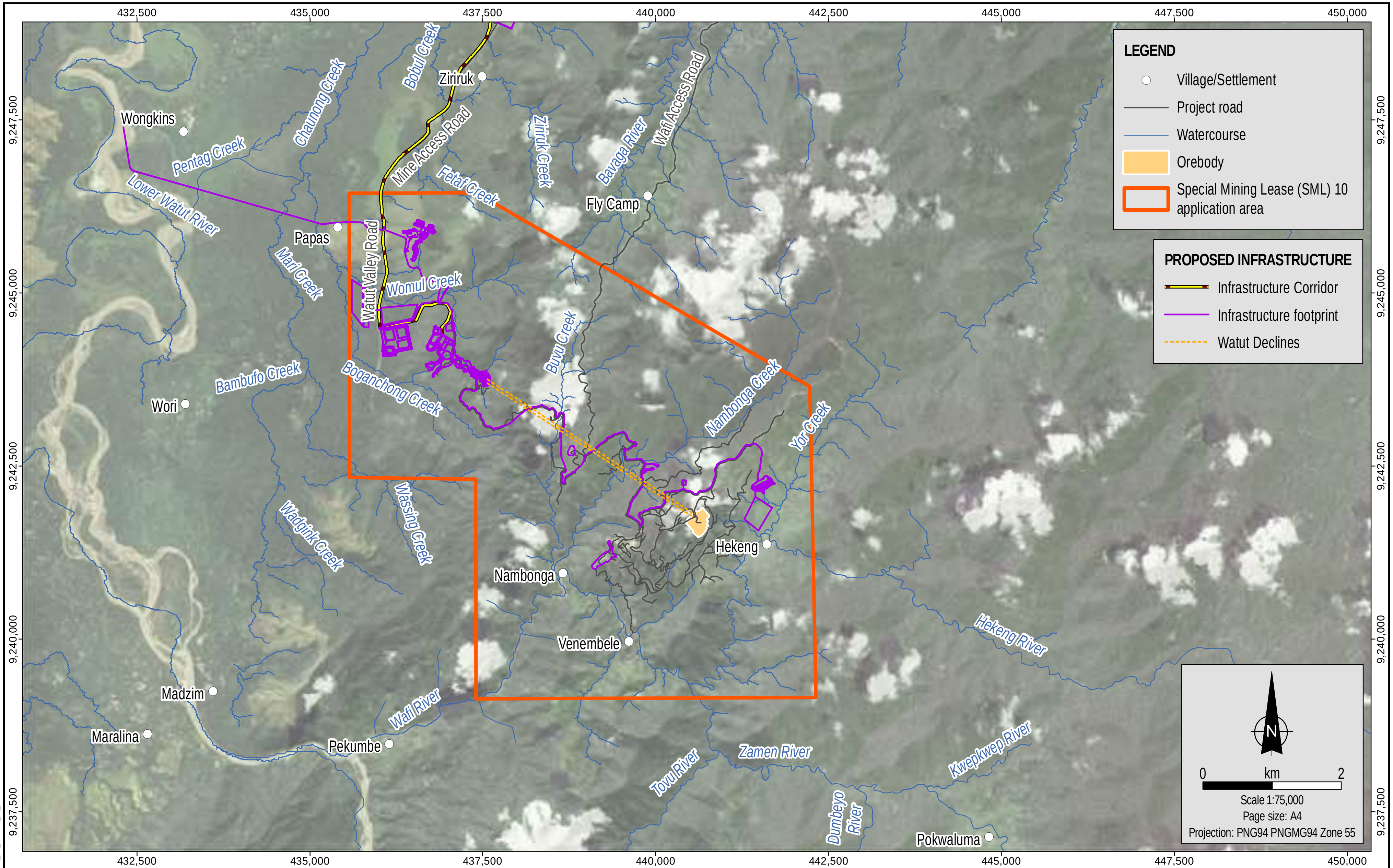
Date: 12.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F15.01_GIS

WAFI-GOLPU JOINT VENTURE
Wafi-Golpu Project

Assessment points

Figure No: 15.1

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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).

coffey
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Date:
23.04.2018
Project:
754-ENAUABTF100520DD
File Name:
0520DD_10_F15.02_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Watercourses in the Mine Area

Figure No:
15.2

The temporal extent of the assessments for each of the surface water and aquatic ecology aspects are:

- **Hydrology and sediment transport**: Scenarios for the five-year construction period and the operational period (27 years[1]) are presented.
- **Water quality**: The temporal extent of the assessment considers the five-year construction period during which time mine wastewater will be discharged via a pipeline to the Watut River near Wongkins Village (see Figure 1.2). During operations, mine wastewater will be captured and used in the Watut Process Plant. During operations, the Project water demand is predicted to exceed supply and therefore discharge of mine wastewater is not anticipated during normal operating conditions. An operations scenario for prediction of water quality downstream was therefore not undertaken based on the assumption that the requirement for any discharge of wastewater will be sporadic and of smaller volume and of similar quality than that during construction.
- Post-closure modelling for the water quality of the subsidence zone lake was undertaken by Piteau Associates (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). The results of this work are reported below and used for input to the freshwater ecology impact assessment. A detailed impact assessment of the post-closure subsidence zone lake is provided in Section 14.3, Groundwater.
- **Aquatic ecology**: Assessments for the five-year construction period and the operational period (28 years) are presented.

### 15.1.2. Assessment Approach

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

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.

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 proposed management measures as it only considers credible impacts with a likelihood of occurring. Potential 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 15.6.7. 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 species. Therefore,

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

an aquatic species having conservation significance does not confer additional sensitivity compared to other introduced or native fish species within an area.

To support these assessments, numerical modelling, as well as semi-quantitative assessments predicted the physico-chemical changes in the Project Area due to Project activities to:

- Hydrology
- Sediment transport
- Water quality

The study methods and a summary of these results are provided in Sections 15.4 and 15.5 followed by the residual impact assessment to aquatic ecology presented in Section 15.6.

Impact assessments presented in other sections of this EIS that may be indirectly related to the freshwater environment include:

- Effects to stream flow resulting from changes to baseflow (i.e., due to impacts of dewatering and groundwater drawdown), which are assessed in Section 14.3, Groundwater and discussed briefly in Section 15.5.1.1. Post-closure drawdown impacts on freshwater ecology is assessed in Section 15.6.9.2.
- Potential impacts of sedimentation on vegetation are assessed in Section 14.4, Terrestrial Ecology.
- Potential impacts on water resources are addressed in Chapter 18, Socioeconomic Impact Assessment.

An overview of proposed management measures to address these potential impacts is presented in Section 15.3 and the subsequent assessment of residual impacts assumes the successful implementation of these measures. The assessment of residual impacts also includes consideration of the proposed management measures contained within the Wafi-Golpu Project (the Project) Environmental Management Plan (EMP) provided in Attachment 3.

Similarly, while listed as potential impacts to the freshwater environment, the potential for accidental events (e.g., hydrocarbon or chemical spillage into watercourses from a road transport vehicle accident) or natural hazards during operations are addressed separately in Chapter 21, Unplanned Events (Natural Hazards and Accident Events) and have not been considered in this chapter.

#### 15.1.2.1. 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. As described in Chapter 4, Overview of Impact Assessment Methods, where PNG has no such published limits or thresholds then surrogate limits or thresholds from other jurisdictions or guidelines have been adopted.

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

As described in Section 9.1.1.3, water quality guidelines developed to protect aquatic ecosystems, drinking water and recreational use, drive the compliance criteria for contaminants in the aquatic environment. These include:

- Ambient water quality criteria 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.
- Drinking water guidelines applicable to total metals:
  - State of PNG Public Health (Drinking Water) Regulation 1984. This regulation contains legally enforceable standards for drinking water quality.
  - World Health Organization (WHO) Guidelines for Drinking Water Quality (WHO, 2017). While these guidelines are not legally enforceable, the current version of the WHO (2017) are considered in the assessment for protection of human health in Chapter 19, Health Risk Assessment.

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.

Guidelines for human consumption (i.e., drinking water guidelines) have been compared to total metals concentrations in Chapter 19, Health Risk Assessment. This is a conservative approach as it is likely that water taken from rivers or creeks in the Project Area would be allowed to settle before consumption, reducing the sediment, and therefore total metals content, of the water.

Where maximum background dissolved and total concentrations of parameters measured in the Mine Area rivers in the Lower Watut River catchment exceed the ANZECC/ARMCANZ (2000) or WHO (2017) guidelines, the background concentrations have been adopted as the site-specific criteria for comparison with predicted concentrations.

#### 15.1.2.2. Significance Assessment Method

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

Sensitivity is defined as the susceptibility of 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 value to the environment.

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

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

Specific definitions have been developed for sensitivity and magnitude used to derive residual impact ratings. In Table 15.1, 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 15.1: Sensitivity of an aquatic environmental value or receptor**

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

Table 15.2 presents the definitions for impact magnitudes.

**Table 15.2: 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).<br>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 biological 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) or be detectable for the life of the Project or beyond. |
| 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 highly unlikely. |
| | 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 very low barely detectable with respect to natural variability, regardless of the geographic extent or duration of the impact. |

For the significance assessment of predicted residual impacts, the magnitude of the residual impact was determined and considered with respect to the sensitivity of the identified values impacted using the significance assessment matrix (Table 15.3).

**Table 15.3: Matrix for assessing the level of significance of a residual impact**

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

## 15.1.3. Summary of Freshwater Environment 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 can be split into two main areas: aquatic ecosystem health and social values, where protection of aquatic ecosystem health generally protects human health. The discussion below focusses on aquatic ecological aspects only. Social values of the downstream receiving environment are addressed in Chapter 18, Socioeconomic Impact Assessment and have not been considered here.

Ecological values of the downstream receiving environment were defined through surveys of the Project Area as discussed in Chapter 9, 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.

### 15.1.3.1. Aquatic Habitats

Four broad aquatic ecosystem types in the Project Area were identified by BMT WBM in Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River, which were analogous to those described by Polhemus and Allen (2006) and IUCN (2017). Table 15.4 presents the main aquatic ecosystem types and habitat ecological values and their assessed sensitivity.

**Table 15.4: 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<br>• Lotic flowing springs<br>• Palustrine: Lowland march (non-forested)<br>• Palustrine: Lowland swamp (forested) | 5.1 Permanent Rivers, Streams, Creeks [includes waterfalls]<br>5.2 Seasonal/Intermittent/Irregular Rivers, Streams, Creeks<br>5.3 Shrub Dominated Wetlands<br>5.4 Bogs, Marshes, Swamps, Fens, Peatlands [> 8ha]<br>5.7 Permanent Freshwater Marshes/Pools [< 8ha]<br>5.8 Seasonal/Intermittent Freshwater Marshes/Pools [< 8ha]<br>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 water bodies (ORWB) | • Lentic: Oxbow lake<br>• Palustrine: Lowland marsh (non- forested) | 5.6 Seasonal/Intermittent Freshwater Lakes [> 8ha]<br>5.7 Permanent Freshwater Marshes/Pools [< 8ha] | High |

Source: Polhemus and Allen (2000); *BMT WBM (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River).

The key aquatic habitats of the Project Area are predominantly riverine. Away from rivers, the predominant water bodies 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 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 substratum of the lower reaches of the escarpment streams become progressively finer with silts and clays as the streams enter the low gradient 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 water bodies 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.

#### 15.1.3.2. 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 turbidity) with nutrients at concentrations sufficient to support plant growth.

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 as described in Chapter 9, Freshwater Environment Characterisation.

Periphyton and macrophytes in the study area have been assessed as having a low sensitivity given their wide distribution and that multiple sources of recruitment are available.

### 15.1.3.3. 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, Aquatic Ecology describes the aquatic macroinvertebrate fauna of the Project Area 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 (see described in Section 15.1.1).

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 15.1.3.6.

### 15.1.3.4. Fish Fauna

The fish fauna of rivers, streams and floodplain water bodies of the Project Area are described in Section 9.6, Aquatic Ecology. 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 (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River).

Typically, fast-flowing, 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. Surveys by EMPS (1993) recorded only one introduced fish species (tilapia), and then only in the Watut River. Independently 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, they 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 15.1.3.6.

#### 15.1.3.5. 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 water bodies and oxbow lakes and have therefore been assessed to have a low sensitivity.

Semi-aquatic species of conservation significance are summarised in Section 15.1.3.6.

#### 15.1.3.6. Aquatic Species of Conservation Significance

This section describes species of aquatic fauna of conservation significance that are known to be present or expected to occur within the Project Area and surrounds (see Section 15.1.1).

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 (see Chapter 9, Freshwater Environment Characterisation).
- 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 State of 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.
- 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. Not 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 and the northern New Guinea giant softshell turtle (*Pelochelys signifera*) has a Vulnerable classification (IUCN, 2017)[2].

### 15.1.4. Model Inclusions and Exclusions

The following points summarise the key inclusions and exclusions in the model outputs used to inform the assessment of potential impacts to the downstream receiving environment:

- In the site water and load balance modelling:
  - While the construction of the Nambonga Decline Portal is proposed to be developed approximately eighteen months to two years earlier than the Watut Declines Portal, in the model, the development of the Nambonga Decline Portal has been assumed to occur approximately three months prior to the development of the Watut Declines Portal and subsequent block cave development. This is likely to have little bearing on the water quality results and would represent a conservative worst-case scenario.
  - Based on an earlier Project design, for modelling purposes it was assumed that waste rock from the Nambonga Decline Portal would be stored in the Watut Waste Rock Dump. Discharge of treated underground dewatering flows, and runoff and seepage from the Miapilli Waste Rock Dump (proposed to store waste rock from the Nambonga Decline Portal in the current Project design), to Nambonga Creek has not been modelled. While underground dewatering flows, and waste rock dump runoff and seepage will be collected and treated prior to discharge, water quality impacts in Nambonga Creek are expected due to the low dilution provided by this creek, as discussed in Sections 15.5.3.1 and 15.6.5.1.2.
- In the surface water hydrology, water quality and sediment transport modelling:
  - The Watut Services Road, Resettlement Road and Lower Papas Aggregate Source were not included in the numerical modelling outputs due to engineering design being only at a conceptual level. To address this:

[2] The IUCN rating of *P. signifera* was recently (March 2018) reassessed by the IUCN and will soon be listed as Vulnerable. See Chapter 9, Freshwater Environment Characterisation.

    - A semi-quantitative assessment has been performed for the Resettlement Road construction that will traverse watercourses within the Wafi River catchment. A qualitative assessment has been completed for construction of the Watut Services Road.
    - The Lower Papas Aggregate Source, located on the floodplain between the lower Boganchong and Womul creeks, has been assessed qualitatively. Given that the gravel extraction site is located on very flat terrain within the Lower Watut River's eastern floodplain it is not expected to result in changes to hydrology or significantly increased sediment loads or suspended solids in downstream watercourses.
  - The sediment transport model includes a presumed Project disturbance for the Madzim gravel pit; Project design evolutions subsequent to modelling completion mean that this site will no longer be developed. Consequently, associated impacts will not manifest.
  - The models predict results within the model mesh extent only, which broadly covers the Lower Watut River floodplain approximately from the Wafi River confluence down to upstream of the Markham River confluence. Further, due to the coarseness of the model mesh, the resolution of the data outputs is expected to be relatively accurate on a regional scale; however, it is less reliable for local scale predictions.
  - Total metals predictions have not been undertaken in the modelling. It is assumed that mine water that will be discharged to the Watut River will be relatively low in solids content and therefore will not contribute significantly to the total metals concentrations in the Watut River. Data is only presented for construction in Boganchong Creek catchment, with natural background soil concentrations at average crustal abundance based on soils metal analyses from alluvial floodplain soil analyses in Boganchong Creek floodplain, which is representative of catchment soils (see Section 15.5.2.2).
  - Mine-related sediment deposition extent and depth has not yet been modelled.

## 15.2. Potential Impacts

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

- 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 pre-existing stresses, resulting in selective survival favouring introduced species.

Potential effects of the Project on surface water and freshwater ecology are summarised in Table 15.5. Stressors and potential impacts on the freshwater aquatic ecological values due to Project activities are discussed in the following sections.

### 15.2.1. Potential Impacts from Physical Disturbance

Direct disturbance of watercourses located within Project infrastructure footprints and along linear infrastructure (e.g., Infrastructure Corridor) will occur. 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 4.5m high, are located immediately downstream of the proposed raw water dam, which forms an existing natural barrier in this creek.

**Table 15.5: 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.<br>• Increased concentrations of dissolved/particulate-associated metals and metalloids in downstream drainage.<br>• Changes in water quality due to increased concentrations of TSS and turbidity. | • Loss or reduction in structural diversity and quality of streambed habitats.<br>• Loss or degradation of riparian habitat.<br>• Potential TSS and turbidity effects on aquatic flora and fauna.<br>• Potential toxic effects of dissolved and particulate-associated metals to aquatic flora and fauna.<br>• Changes to aquatic flora and fauna diversity and abundance. |
| Diversion of watercourses, in-stream works (i.e., gravel extraction) and construction of bridges | Construction and operations | • Altered hydrology and changed stream flow regimes.<br>• In-stream construction (diversion channels, raw water dam embankment, sedimentation ponds, gravel extraction and road and pipeline watercourse crossings) leading to increased coarse and fine-grained sediment loading.<br>• Localised increased turbidity and TSS. | • Loss or reduction in structural diversity and quality of streambed habitats.<br>• Loss or degradation of riparian habitat.<br>• Potential TSS and turbidity effects on aquatic flora and fauna.<br>• Changes to aquatic flora and fauna diversity and abundance. |
| Track and road construction to access major sites (Watut and Nambonga Decline Portals, 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.<br>• Road surface runoff from road usage by construction traffic increasing fine sediment loads to natural drainage.<br>• Exacerbate the spread of weeds and/or invasive fauna species to new catchments. | • Loss or reduction in structural diversity and quality of streambed habitats.<br>• Potential TSS and turbidity effects on aquatic flora and fauna.<br>• Potential changes to the 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.<br>• Changes in water quality due to variable dilution conditions brought about by altered flow regimes.<br>• Aggradation or scour of creek and river beds. | • Potential impacts on flow-sensitive aquatic species.<br>• Potential effects on aquatic flora and fauna as a result of water quality changes.<br>• 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.<br>• Changes in water quality caused by increased concentrations of petroleum hydrocarbons, solvents, flocculants and other processing chemicals transported on roads.<br>• Road surface runoff from road usage by operations traffic increasing fine sediment loads to natural drainage.<br>• Changes in water quality due to increased concentrations of TSS and turbidity.<br>• 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.<br>• Potential toxicity effects of spilled hydrocarbons to aquatic flora and fauna.<br>• Potential toxicity effects of mine chemicals to aquatic flora and fauna.<br>• Potential changes to the aquatic flora and fauna diversity and abundance. |
| Construction and operation of the Northern Access Road Borrow Pit and Mt Bemeana quarry operation | Construction and operations | • Erosion-derived increased coarse- and fine-grained sediments in runoff entering waterways.<br>• Localised sediment deposition and streambed aggradation.<br>• Changes in water quality due to increased concentrations of TSS and turbidity. | • Loss or reduction in structural diversity and quality of streambed habitats.<br>• Loss or degradation of riparian habitat.<br>• Potential impacts of increased concentrations of TSS and turbidity on aquatic flora and fauna.<br>• Potential changes to the aquatic flora and fauna diversity and abundance. |
| 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<br>• 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.<br>• Potential effects on aquatic flora and fauna as a result of water quality changes.<br>• Loss or reduction in structural diversity and quality of streambed 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.<br>• 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. |

| Activity | Project Stage | Potential Stressor | Potential Impact |
|---|---|---|---|
| Ore processing | Operations | • Runoff/spills/seepage. | • Potential toxic effects of dissolved and particulate-associated metals to aquatic flora and fauna.<br>• Potential TSS and turbidity effects on aquatic flora and fauna. |
| 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.<br>• Watut Decline Portal Terrace, raw water dam and sedimentation pond replaces natural creek drainage of Boganchong Creek catchment.<br>• 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.<br>• Loss of running water (lotic) habitats of Boganchong Creek catchment.<br>• 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.<br>• 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.<br>• 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 the 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.<br>• 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.<br>• Potential impacts of increased nutrient loading from sewage treatment plant effluent on aquatic flora and fauna.<br>• Potential toxicity of chemicals and landfill leachate to aquatic flora and fauna. |

| Activity | Project Stage | Potential Stressor | Potential Impact |
|---|---|---|---|
| Construction and operations of waste management facility | Construction and operations | • Potential for landfill leachate to infiltrate to surface water.<br>• Potential for increased TSS and turbidity from stockpiles. | • Potential toxicity of chemicals and landfill leachate to aquatic flora and fauna.<br>• Potential impacts of in-stream sedimentation and increased TSS concentrations and turbidity on aquatic flora and fauna. |
| Mine closure and formation of subsidence zone lake | Post-closure | • Cessation of mining results in flooding of the block caves and underground workings.<br>• Exposure of potentially acid forming material to water and oxygen leading to AMD and poor water quality.<br>• 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.<br>• Impacts on aquatic flora and fauna as a result of changes to baseflow affecting stream recharge. |

### 15.2.2. 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 Section 14.3, Groundwater, and the implications of this for surface water recharge from baseflow and for freshwater ecology are discussed in Section 15.5.1.1 and in Section 15.6.9.2, respectively.

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 can impede drainage, especially during heavy wet-season rainfall. This can lead to localised but temporary flooding on the upstream (upslope) side of the road, altering flood levels, water flow and velocities, which present a physical stressor to flood-sensitive or flow-sensitive aquatic flora and fauna, as well as potential 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. Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River, and Appendix I, Catchment and Receiving Water Quality Modelling, 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 (Appendix I of Appendix I, Catchment and Receiving Water Quality Modelling) has provided additional context for this behaviour, which is explained in further detail in Section 15.5.1.

The presence of the proposed nominally 2m 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.

### 15.2.3. Potential Impacts from Erosion and Sedimentation

#### 15.2.3.1. 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 this 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 velocities of surface runoff. This is further discussed in Section 14.2, Landform and Soils.

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 15.2.4), and; changes to aquatic flora and fauna diversity and abundance.

#### 15.2.3.2. 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.

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 in Section 15.2.1, 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 and 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 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, Lower Bavaga River and sub-catchment rivers and creeks in the Wafi River catchment.

### 15.2.4. Potential Impacts to Water Quality

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

During the construction phase, delivery of fine-grained sediments to downstream watercourses, which will report as suspended load and are measured gravimetrically as concentrations of TSS, will be the primary water quality stressor.

Erosion of disturbed or displaced natural soils during construction 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 pH and increase the concentrations of metals and metalloids delivered to the natural drainage. Increased concentrations of metals and metalloids present 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.

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-chemcial stressors can be assessed using well-established receiving water quality criteria or guidelines for the protection of aquatic life (e.g., ANZECC/ARMCANZ, 2000). However, there are few criteria or guidelines for TSS which, as a potential physical water quality stressor, therefore 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 on aquatic organisms include:

- Lethal effects (mortality of adult, larval life stages)
- Sublethal effects (suppression of growth and productivity)
- 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 on aquatic organisms 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.

### 15.2.5. 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., Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River) 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 to adversely affect aquatic habitats and native fish species elsewhere. 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 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.

### 15.2.6. Existing Stressors and Adaptations

The freshwater aquatic biological communities of rivers, streams and floodplain water bodies 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.

## 15.3. 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 provided in Attachment 3.

### 15.3.1. 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 infrastructure footprints and access routes and restore disturbed primary drainage paths, where practicable
- Install and maintain sediment control measures where required such as drainage diversion into surrounding vegetation, rip-rap aprons, sediment control ponds and sediment fences.
- 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.

### 15.3.2. Water Quality

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

- Capture and treat mine wastewater where necessary prior to discharge, to meet environment permit conditions
- Treat sewage in accordance with environment permit conditions

- Stabilise exposed areas susceptible to erosion using appropriate methods. For example, 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
- Ensure water and wastewater treatment facilities are properly maintained
- Actively manage potentially acid forming (PAF) materials and control runoff and potential leachate from areas containing PAF material. For example:
    - 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 Watut Process Plant
    - Diversion of clean surface water where required
    - Interception of potential leachate from the site and applying appropriate treatment methods if required prior to discharge
    - Treat contaminated runoff and leachate prior to discharge to meet environment permit conditions

### 15.3.3. 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
- 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 15.7.

## 15.4. Residual Impact Assessment Methods

Study methods for assessing residual impacts on hydrology, flooding, sediment transport and water quality are described below.

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 Appendix I, Catchment and Receiving Water Quality Modelling. 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 (Appendix V, Site-wide Water and Mass Balance Modelling), 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 (see Chapter 6, Project Description).

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

Sediment transport impacts along the Resettlement Road originating near Madzim Village, traversing watercourses in the Wafi River catchment and terminating near Old Hengambu Village were 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 15.5.2).

Qualitative assessments based on literature, case studies 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 in CSIRO, 2016 (Angel et al., 2016, Appendix G of Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River). 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 lake. Water and load balance modelling results for the post-closure period was undertaken by Piteau (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). A detailed discussion of the post-closure water quality results are provided in Section 14.3, Groundwater. The resultant impacts (water quality and baseflow) are discussed briefly in sections 15.5.1.1, 15.5.3 and 15.6.

### 15.4.1. Hydrology and Flooding

Based on the integrated nature of the BMT WBM models, the study method for the hydrology modelling, along with sediment transport and water quality are presented together.

The assessment of potential impacts of the Project to the downstream receiving environment was based on an integrated catchment and receiving water quality modelling framework. The framework comprised two primary models: a catchment (rainfall-runoff) model using the Source[3] model platform and a receiving water quality model of riverine systems using TUFLOW FV[4]. The framework was applied to the Lower Watut River system.

[3] The eWater Source Modelling Framework (Source) was developed by eWater CRC, a Federally (Australian) funded Cooperative Research Centre.

[4] TUFLOW FV is a flexible mesh finite volume numerical model capable of simulating hydrodynamic, sediment transport and water quality processes in oceans, coastal waters, estuaries and rivers.

The models were linked in terms of water flows and constituent loads (including sediments and dissolved metals) generated by surface runoff in each catchment.

The receiving water quality model assessed the hydraulics, hydrodynamics, mass transport of dissolved metals, and sediment transport within the riverine systems of the Lower Watut River area. The sediment transport module of TUFLOW FV was used to model TSS concentrations, while the transport of dissolved metals was simulated using passive tracers.

Some aspects of the model input data (including hydrology, TSS concentration and water quality parameters) are limited for the full range of flows that occur in the receiving environment, which place constraints on the modelled outputs. The models are expected to provide a reasonable description of the general environmental conditions for the highly complex and dynamic lowland river floodplain system. The modelling and subsequent impact assessment adopted a precautionary or conservative approach and, in most instances, impacts are likely over-stated.

The assessment points shown in Figure 15.1 were selected as reporting locations downstream of Project activities and near selected villages to provide predicted mine-related changes to hydrology, sediment transport and water quality. The most relevant assessment point is a site on the Lower Watut River (LTW6) downstream of the treated mine water discharge point, which has been discussed detail in Section 15.5.3.

The scenarios detailed below have been modelled over a six-month period, which include a three-month period representative of the dry season (July to September) and a three-month period representative of the wet season (October to December). For the purposes of modelling, it has been conservatively assumed that all of the construction activities are occurring simultaneously. However, in reality, the construction of individual facilities will be staged. As such, the model overestimates the intensity of construction-related disturbance at any one time.

A flood model was developed using TUFLOW classic (SKM, 2012b) and TUFLOW-GPU based on a flood frequency analysis (FFA) undertaken by SKM (2012a) (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River and Appendix I, Catchment and Receiving Water Quality Modelling).

The highly variable and dynamic nature of the Watut River has resulted in a number of periods where gauging stations have been washed away or compromised by changes in channel morphology. These factors have introduced uncertainty in the estimated design discharges at longer recurrence intervals (1:10 year AEP event and above) due to the recurrence interval of the design event being more than the length of the data record used to generate the design discharge. Given this uncertainty, the modelling adopted a precautionary or conservative approach, and as such flood modelling likely overestimates the frequency of flooding and flood breakouts from the Watut River main channel onto the floodplain. This has been supported by an independent peer review of BMT WBM's hydrological, flood and sediment modelling report, which was completed by Hydrobiology (Appendix I of Appendix I, Catchment and Receiving Water Quality Modelling). This review, facilitated by a site inspection, provided additional insights on the fluvial processes in the Watut River and its floodplain. The findings of this review have been added to relevant hydrology, flooding and sediment transport sections below. The flood scenarios modelled included:

- Existing conditions (at 2-year, 10-year, 20-year, 50-year and 100-year average recurrence intervals (ARI))

- Presence of the Northern Access Road (at 20-year and 100-year ARIs)[5]
- Climate change scenarios (at a 100-year ARI):
  - 10% increase in runoff
  - 20% increase in runoff

The changes to the flows in the Watut River as a result of water abstraction to accommodate the predicted water deficiency for most of the operational phase were also calculated. This raw water will be used to supplement the varying operational requirements of facilities within the Watut Process Plant and the Watut Declines Portal Terrace.

Changes to the Watut River flow during operations considered the following raw water abstraction rates during both the dry and wet seasons:

- 10-percentile abstraction rate – 0.15$m^3/s$
- 50-percentile abstraction rate – 0.37$m^3/s$
- 90-percentile abstraction rate – 0.39$m^3/s$

The 90-percentile raw water abstraction rate of 0.39$m^3/s$ was assessed as the worst-case scenario to provide a conservative assessment.

### 15.4.2. Sediment Transport

Sediment transport modelling considered mine-related sediment point sources primarily from construction of infrastructure for the Project. The sediment loads were calculated at two scales; namely, at the regional scale for the whole of the Lower Watut River catchment and at the local scale for the individual sub-catchments of the Boganchong and Womul creeks and the lower Bavaga and Wafi rivers as described below.

The catchment model developed by BMT WBM (Appendix I, Catchment and Receiving Water Quality Modelling) estimates sediment transport at a coarse scale and conservatively does not assume that mitigation measures are implemented.

The catchment modelled scenarios for sediment transport included:

- Existing conditions
- Construction phase (nominally 5 years[6]), wet and dry season – sediment loads from disturbed areas during construction
- Operations phase (nominally 27 years[7]), wet and dry season – sediment loads from disturbed areas during operation

A semi-quantitative assessment of the loads and concentrations of particulate-associated metals and metalloids for Boganchong Creek (extrapolated to other catchments in the Mine Area) was also conducted using soils data reported by KCB (2013).

[5] The Watut Services Road and the Resettlement Road were not included in the numerical flood modelling but have been considered qualitatively and semi-quantitatively in the residual aquatic ecology impact assessment.

[6] In Appendix I, the construction period is referred to as being 7 years, which is related to a previous construction schedule. This discrepancy is immaterial to the predicted model outputs.

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

### 15.4.3. Water Quality

#### 15.4.3.1. Construction and Operations

The integration of the numerical models for assessment of hydrology and flooding, sediment transport and water quality is described in Section 15.4.1.

Water quality modelling considered the effects of mine-related point source discharges (dissolved metals/metalloids and TSS) from the Project on the downriver receiving environment. Inputs to the models included:

- Flow rates and water quality for mine dewatering and other runoff sources obtained from the water and load mine water balance (Appendix V, Site-wide Water and Mass Balance Modelling). Piteau's water modelling outputs assumed water treatment performance as per the Clean TeQ (2017) report.
- Suspended sediment concentrations from BMT WBM's catchment modelling based on Project disturbance areas (Appendix I, Catchment and Receiving Water Quality Modelling).

Selection of the metals and metalloids for modelling (arsenic, cadmium, copper, nickel, zinc, manganese and selenium) was informed by the predicted water quality of discharges for the mine during construction and operations, along with PNG and international ambient water quality guidelines, and consideration of the potential impacts to surface water values in the Project Area.

Semi-quantitative assessments for chromium, iron, lead, mercury, sulphate and total dissolved solids were also undertaken involving use of a tracer in the BMT WBM catchment model to determine approximate dilution rates achieved at a certain point in the model. The approximate dilution rate was calculated assuming a nominal point approximately 3km from the discharge point in the Watut River. The dilution rate at this point was conservatively calculated to be approximately 1:45 (this is conservative because it represents the 95-percentile concentration from the tracer in the model).

A detailed description of water management for the Project is described in Chapter 6, Project Description. However, a summary is provided below for context to the design and operating philosophy on which the prediction of residual impacts to water quality is based.

During construction, mine wastewater will be treated if necessary to meet environment permit criteria and then be discharged to the Watut River via a wastewater discharge pipeline. Clean surface water runoff will be diverted where possible to minimise the volume of water requiring capture and possible treatment. The key sources of mine wastewater that will be treated if necessary prior to discharge include:

- Groundwater and surface water inflow to the declines and block caves (which will require dewatering)
- Runoff and seepage from the waste rock dumps and stockpiles
- Treated sewage wastewater
- Exudate from sludge produced from the waste water treatment plant stored in geotubes located on the Watut Decline Portal Terrace

During operations, the Project water demand is predicted to exceed the supply for most of the time and therefore discharge of mine wastewater will be limited during this phase of the Project. Mine wastewater runoff from the portal and plant terraces will continue be captured (and treated if necessary) and used in the Watut Process Plant rather than discharged. Clean water diversions and runoff will continue to be directed to Boganchong Creek downstream of the raw water dam. Sludge produced from the treatment of wastewater will be directed through the Watut Process Plant.

The Watut and Miapilli Waste Rock Dumps will be designed and constructed to appropriately manage PAF material (by encapsulating in NAF and clay material) and the seepage and runoff will be captured and treated if necessary prior to discharge. The Miapilli Waste Rock Dump in Yor Creek catchment will store approximately 0.9Mt of waste rock from the Nambonga and Watut declines portals. During construction, underground dewatering flows from the Nambonga Decline Portal, and runoff 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. Potentially contaminated runoff and seepage from the Watut Waste Rock Dump will be collected for testing and treatment (if necessary) at the water treatment plant north of the Watut Process Plant. This water will either be used to fulfil process plant water demands or discharged to the Lower Watut River. Management of these facilities will continue throughout construction and operations as required.

Competent NAF material will be used during construction of the waste rock dumps as lining and capping for the PAF waste rock cells within the waste rock dumps. In addition, clay will be extracted from the Miapilli Clay Borrow Pit to aid in isolating the cells of PAF waste rock cells within the Miapilli Waste Rock Dump.

Based on the assumptions above, water quality modelling considered the following scenario:

- Construction phase (nominally 5 years), wet season and dry season – treated mine dewatering water is discharged directly to the Watut River via pipeline[8]

An operational scenario for prediction of water quality in the downstream receiving environment was not required based on the assumption that all mine wastewater will be captured and used for the Project and that there will be a limited requirement (two occurrences associated with transition between mining of the block caves) for discharge of wastewater during operations.

The water quality modelling outputs were generated using the integrated catchment and receiving water quality modelling framework, as described in Section 15.4.1.

Details in relation to the treatment process of mine wastewater is described in Chapter 6, Project Description.

[8] While the construction of the Nambonga Decline Portal is proposed to be developed approximately eighteen months to two years earlier than the Watut Declines Portal, in the model, the development of the Nambonga Decline Portal has been assumed to occur approximately three months prior to the development of the Watut Declines Portal and subsequent block cave development. This is likely to have little bearing on the water quality results and would represent a conservative worst-case scenario. Further, based on an earlier Project design, for modelling purposes it was assumed that waste rock from the Nambonga Decline Portal would be stored in the Watut Waste Rock Dump. Discharge of treated underground dewatering flows, and runoff and seepage from the Miapilli Waste Rock Dump (proposed to store waste rock from the Nambonga Decline Portal in the current Project design), to Nambonga Creek has not been modelled. Water quality impacts in Nambonga Creek are not anticipated given that underground dewatering flows, and waste rock dump runoff and seepage will be collected and treated prior to discharge.

#### 15.4.3.2. Post-Closure

As described above, Piteau (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone) conducted numerical modelling to simulate the groundwater inflows, surface water balance and water quality upon mine closure.

Impacts associated with the intended closure scenario are discussed in detail in Section 14.3, Groundwater, but implications for surface water quality and aquatic ecology impacts are presented in Sections 15.5.1.1, 15.5.3 and 15.6. These are premised on the following scenario:

- Accelerated cave flooding rate at 500L/s with added hydrated lime slurry ($Ca(OH)_2$): Modelling assumed that block cave inflows will be artificially filled at a rate of 500L/s to increase the flooding rate with concurrent addition of a hydrated lime slurry, administered to maintain a nominal pH of 7.

## 15.5. Residual Impacts to Surface Water

The residual hydrology, flooding, sediment transport and water quality impact assessments revealed that of all the catchments assessed in the Project Area, the only catchments likely to be subject to material Project-related impacts (primarily associated with the construction of Project infrastructure) included Boganchong Creek, Womul Creek, Lower Bavaga River, Wafi River and the Lower Watut River eastern floodplain[9]. Therefore, the focus of the impact assessment discussion in the following sections is placed on these sub-catchments. The Project components within these catchments are described below. Discussion of some catchments within which low impacts are predicted are provided for context or may be of particular interest to stakeholders (i.e., the Lower Watut River catchment on a regional scale).

Project activities expected to result in residual impacts to surface water within Mine Area sub-catchments are listed below.

**Boganchong Creek.** The Boganchong Creek upper catchment will contain a major concentration in space and time of Project infrastructure. 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)

**Womul Creek.** Womul Creek drains a small catchment (approximately 2.2km$^2$) that is located within the Mine Area. This ephemeral creek flows westwards to the eastern

[9] The Freshwater Ecological Impact Assessment report (Appendix Y) details the impacts for all credible impacts for all sub-catchments for completeness.

backplain of the Lower Watut River's eastern floodplain. Womul Creek and Boganchong Creek join to form the start of Chaunong Creek. Project infrastructure within the Womul Creek upper catchment includes:

- Northern part of the Watut Process Plant and terrace
- A section of the Northern Access Road and Infrastructure Corridor
- The waste management facility and stockpiles
- The water treatment plant
- The explosives magazine and its access road
- A major part of the Fere Accommodation Facility
- A 1.4km-long section of the Mine Access Road that passes to the west of the Fere Accommodation Facility

**Wafi River.** The Wafi River catchment (121km$^2$) is a sub-catchment of the Watut River and covers the southern and eastern portions of the Mine Area. Project infrastructure to be constructed within this catchment includes:

- Migiki Borrow Pit and a section of the Portal Haul Road within Buvu Creek catchment
- Nambonga Decline Portal, ventilation shaft terrace, associated Nambonga Haul Road in the Nambonga Creek catchment
- Miapilli Waste Rock Dump and Miapilli Clay Borrow Pit within Yor Creek catchment
- The Resettlement Road, which crosses several tributary rivers of the southern Wafi River catchment

**Bavaga River.** Proposed Project and existing infrastructure within the lower Bavaga River catchment includes:

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

**Lower Watut River Eastern Floodplain.** Project infrastructure within the western part of the Lower Watut River's eastern floodplain includes:

- Construction of the entire length (18.5km) of the Watut Services Road (a community access road) across the floodplain from north to south
- Construction and installation of a 4.4km-long section of the buried wastewater discharge and water extraction pipelines and pump service track across the floodplain from east to west from the water treatment plant on the process plant terrace to the Lower Watut River main channel upstream of Wongkins Village

- Floodplain gravel extraction area (Lower Papas Aggregate Source) located on the floodplain between the lower reaches of Womul and Boganchong creeks, and 1km southeast of Papas Village. This area comprises:
  - Lower Papas Aggregate Source
  - A 0.2km-long access spur road from the Northern Access Road
  - Overburden storage area
  - Crushing/screening and stockpile area

Residual hydrology, sediment transport and water quality impacts (as well as subsequent aquatic ecology impacts) within watercourses of the Markham River floodplain and Coastal Area (that will contain sections of the Northern Access Road and Infrastructure Corridor) are predicted to be low and can be managed by implementation of the Project's Environmental Management Plan provided in Attachment 3, particularly those measures that relate to erosion and sediment control. Impacts within these catchments are therefore not discussed further within this chapter; a detailed assessment of impacts within these catchments is provided in Appendix Y, Freshwater Ecology Impact Assessment. Impacts associated with the 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, Nearshore Marine Environment Impact Assessment.

### 15.5.1. Hydrology and Flooding

#### 15.5.1.1. Hydrology

Large modifications to the flow regimes within the Lower Watut River catchment as a whole due to construction and operation of the Project are not expected. There will, however, be significant local-scale changes to hydrology within watercourses in the Mine Area. This is discussed further below.

**Bogangchong Creek**. Interception of surface runoff from Boganchong Creek catchment, due to construction and operation of facilities on the Watut Process Plant and Watut Declines Portal terraces (see Chapter 6, Project Description), will result in reduced frequency and magnitude of all flow regime types (low, median and high) within these catchments. These changes are expected to result from:

- Land clearing and construction of access roads with hard impermeable surfaces, which may lead to an increase in catchment water yield that may affect peak flows
- Construction of sedimentation dams, which may result in delayed storage of overland flows, reducing the magnitude of peak flow 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
- Construction of the subterranean drains (or underdrains) under the Watut Decline Portal Terrace, which will likely experience high flow velocities
- Diversion of Boganchong Creek from the sedimentation pond around the raw water dam construction site, resulting in minor spillway flows from the sedimentation pond

These changes will result in highly localised changes to flow regimes in receiving environments immediately downstream of the infrastructure. While Boganchong Creek is naturally ephemeral (i.e., flows within the creek are not continuous and may not receive flows at all times of the year) and flow-related impacts are not expected to be recognised in the dry season, Project infrastructure will permanently alter the natural flow regime in this catchment during the wet season.

**Womul Creek**. Based on the absence of sedimentation dams within the creek, water detention or abstraction as process plant make-up water in Womul Creek, major hydrological changes within its catchment are not expected.

**Wafi River.** During construction and operations, none of the surface Project activities within the Wafi river catchment are expected to materially impact on the hydrology of the Wafi River and sub-catchments, with any impacts anticipated to be minor and localised. While the majority of the Resettlement Road is located within this catchment, the road will be designed and constructed so that the appropriate frequency of culverts is installed and filled areas do not impede drainage, especially during heavy wet-season rainfall.

As described in Section 14.3, Groundwater, numerical modelling indicates that groundwater drawdown is likely to result in reduced baseflow contributions to Buvu Creek, Nambonga Creek, Hekeng River and the Wafi River to varying degrees. The smaller catchments (Nambonga and Buvu Creek catchments) will be the most affected during construction and operations with predicted baseflow reductions ranging from 26 to 34%, respectively (see Section 14.3, Groundwater, and Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine). This could translate to a similar reduction to the total stream flow rate during dry periods where baseflow accounts for most stream flow. A smaller baseflow reduction of 5% across the Hekeng River catchment reflects a greater portion of the catchment falling outside of the predicted zone of groundwater drawdown.

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

As discussed in Section 14.3, Groundwater, reduction in baseflow to these catchments is predicted to be temporary. Recovery of baseflow will take approximately 20 years for Buvu Creek catchment and 80 years for Nambonga Creek, Hekeng River and the Wafi River catchments, with small permanent reductions in predicted baseflow to these catchments ranging from 1 to 2%.

**Bavaga River.** Surface water management of the Northern Access Road Borrow Pit includes directing approximately 70% of the 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. These changes in flow, however, are not expected to affect the flow regime in the Lower Bavaga River due to its proportionally large catchment size (27.5km$^2$).

**Lower Watut River Eastern Floodplain.** During the construction phase, the physical presence of completed sections of the Watut Services Road (see Figure 15.1), which will be elevated above the floodplain (nominally 2m above ground level), has the potential to impede surface water and flood flows. The potential for impeding flows and detention of flood water will be reduced by installing an appropriate number and density of road culverts or underdrains where flood flow paths are known (e.g., along creek lines) or identified by pre-construction grade surveys along the road's proposed alignment.

For most of its length, the road route follows high ground across the floodplain that is known from the tracks and paths used by villagers during the wet season when the Lower Watut River overtops its banks during flood flows (Section 15.4.1). The middle section of the road (approximately 2km either side of Pentag Creek) is a low-lying part of the floodplain that is subject to more regular flooding at the breakout location of the Lower Watut River. A bridge will be installed over Pentag Creek in this section of the Watut Services Road, and hence breakout flood flows from the Lower Watut River across the floodplain are not predicted to be impeded in this section of the road or modify flows to the floodplain watercourses it traverses.

The wastewater discharge and raw water make-up pipelines will be co-located within a trench and will cross the Chaunong, Mari and Pentag creeks. The proposed watercourse crossing methods will include trenching and the direct pipe trenchless method. 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. If construction occurs 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 provide access to the pumps for water extraction from the Watut River. 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.

No significant impacts on floodplain surface flows or the Lower Watut River flood flows across the floodplain are anticipated as a result of road or pipeline construction.

The Lower Papas Aggregate Source will be located on very flat terrain adjacent to the confluence of the Boganchong and Womul creeks on the Lower Watut River's eastern floodplain. Contour drains or berms will be constructed around the perimeters of the Lower Papas Aggregate Source, overburden storage area, crushing/screening and gravel stockpiles to prevent the inflow of surface water. Sedimentation ponds will be constructed to allow the settling of suspended fine sediments and subsequent discharge offsite to the natural drainage. The gravel extraction pits will also fill with groundwater inflows given the shallow water table (1 to 2m below ground level). Significant alteration of the hydrology of surface flows in natural drainage channels in the vicinity, or downstream, of the gravel extraction site is not anticipated, considering implementation of the Project's Erosion and Sediment Control Plan, surface water management system and the recycling of washwater.

**Lower Watut River.** During the construction period (and for two occurrences during operations[10]), mine-wastewater will be discharged via a pipeline to the Lower Watut River upstream of Wongkins Village (see Figure 15.1). The volume of the discharge is predicted to be a fraction (0.065% during the wet season and 0.15% during the dry season) of the existing flows in the Lower Watut River and is not expected to result in any measurable change to river levels or hydrology.

For the majority of the operational phase, the Project is predicted to have a water deficit, i.e., water demand exceeds supply. To accommodate the expected water deficit, water will be abstracted from the Lower Watut River to supply raw water for the Watut Process Plant. As shown in Table 15.6, the conservative 90-percentile abstraction rates ($0.39m^3/s$) represent a small proportion (less than 1%) of the flow rate of the Lower Watut River, even during the dry season.

[10] As shown in Figure 6.16, the discharges during operations are related to reduced mill feeds caused from the transition between the block caves.

**Table 15.6: Modelled Lower Watut River flows and predicted water abstraction during operations**

| Watercourse | Season | Discharge ($m^3/s$) | | |
|---|---|---|---|---|
| | | 10%ile | 50%ile | 95%ile |
| Modelled baseline Lower Watut River flow (at LWT6) | Dry | 54 | 76 | 118 |
| | Wet | 102 | 191 | 269 |
| Predicted water abstraction during operations (90%ile water abstraction) | Dry | 0.39 | | |
| | Wet | 0.39 | | |
| Proportion of water abstraction | Dry | 0.70% | 0.50% | 0.30% |
| | Wet | 0.40% | 0.20% | 0.10% |

During the post-closure period, water from the Lower Watut River may be used to expedite flooding of the underground workings at a nominal rate of 500L/s (or $0.5m^3/s$). This would again represent a small fraction of the flows in the Lower Watut River (<1%) and is not expected to impact the hydrology of the Lower Watut River during this time.

#### 15.5.1.2. Predicted Flooding Impacts

A number of scenarios and flood events were modelled to simulate flooding conditions for the Project. The outputs of these models are described below, with full details provided in Appendix I, Catchment and Receiving Water Quality Modelling.

**Existing conditions**. As described in Chapter 9, Freshwater Environment Characterisation, the existing conditions flooding results indicate that:

- Flood waters can break out from the eastern bank of the Watut River at two main locations (see Figures 9.11 and 9.12) including immediately downstream of the Wafi and Watut river confluence, and near Wongkins Village.
- The breakouts described above form an overbank flow path on the eastern side of the Watut River and are predicted to inundate a large area of the floodplain.
- During events of 50-year ARI or greater, much of the Lower Watut River floodplain is inundated.
- High flow velocities are predicted along the main Watut River channel with values in excess of 2m/s at a number of locations. Velocities more than 1m/s are predicted along much of the watercourse in the 2-year ARI event.
- While flow velocities of up to 0.75m/s are predicted over large sections of the eastern Watut floodplain in events greater than the 50-year ARI, the area is heavily forested which could result in flows being slower than predicted.

Following review of the modelling results described above, the independent peer review (Appendix I of Appendix I, Catchment and Receiving Water Quality Modelling) concluded that:

- The flow breakouts between the Wafi River and Wongkins Village are expected to occur less frequently than the extent depicted on the flood maps in figures 9.11 and 9.12 (i.e., greater than 2-year ARI frequency).
- Predictions of velocity of wet season flows across the eastern floodplain are most likely too high and unlikely to occur on a 2-year ARI frequency. Although flow in the defined channels (e.g., Chaunong Creek, Bobul Creek) may be of the order of up to 0.5m/s in certain circumstances, floodplain flow rates are likely to be significantly slower; the

density of vegetation throughout the floodplain appears too high to allow flow velocities of the predicted magnitude to occur. A review of available recent satellite imagery shows little evidence of significant overspill from the Lower Watut River that would result in floodplain flows of between 0.15 and 0.5m/s over a flow width of approximately 1km.

- During the wet season, inundation of the Lower Watut River eastern floodplain due to high river levels is expected to be more gradual and the contribution of local runoff to be more significant. Filling of the floodplain basins is expected to occur from both upstream and downstream connection points, and from local runoff (i.e., rather than from overflow from the Watut River).

As a result of the review findings, it is expected that the BMT WBM modelling results depict a worst-case scenario in terms of flooding and sediment loads and TSS concentrations in Project Area watercourses. Therefore, the flooding and sedimentation impacts are likely to be less than those described below.

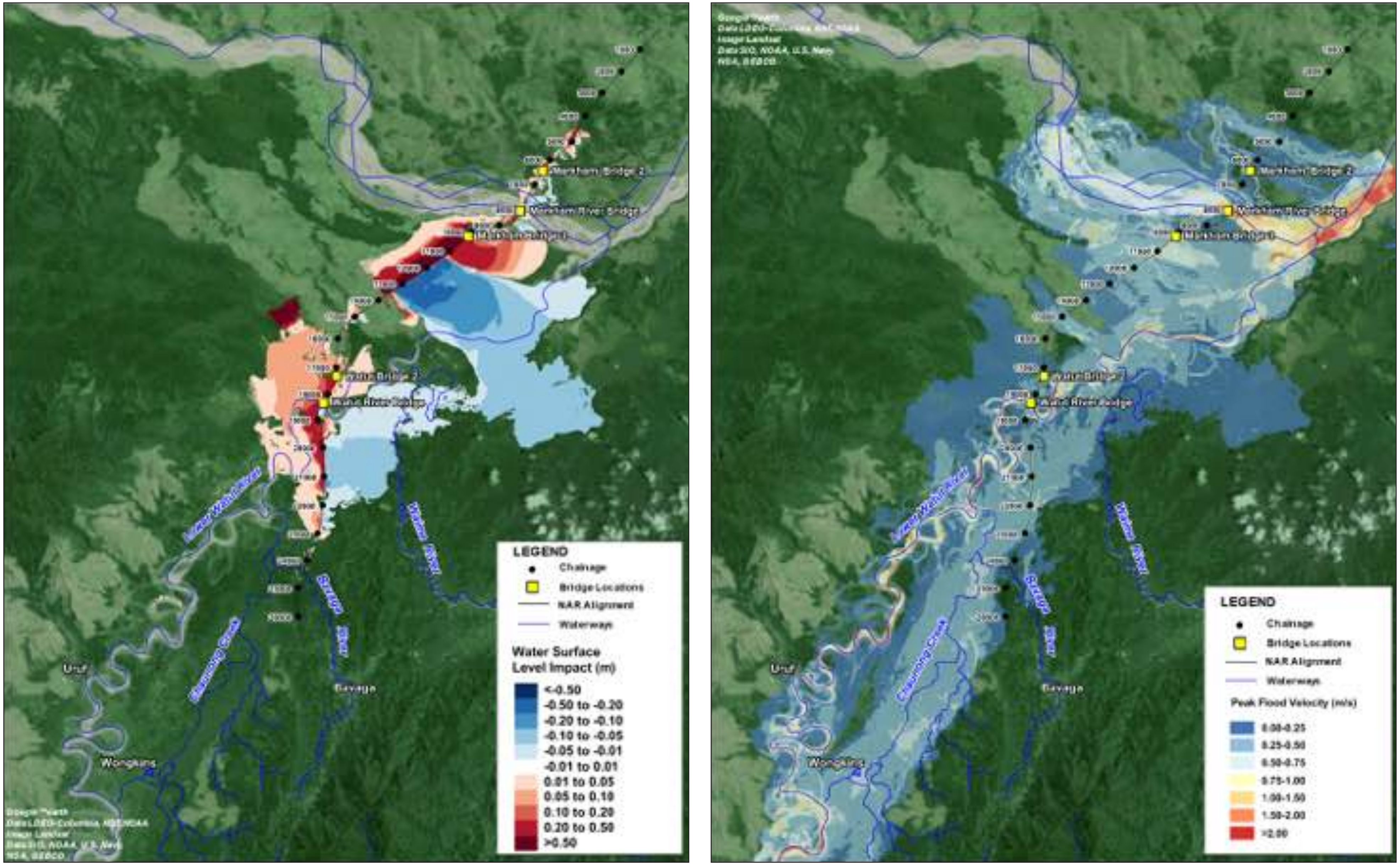
**Project infrastructure in place scenario.** Construction of the Project is not expected to change the flooding regimes at the existing two main breakout points on the Lower Watut River or the overbank flow path on the eastern side of the Lower Watut River. There are likely to be changes to flooding regimes in downstream sections of the Lower Watut River and Bavaga River in addition to other watercourses on the Lower Watut River floodplain due to construction of the Infrastructure Corridor as described below.

Notwithstanding the findings of the modelling peer review (Appendix I of Appendix I, Catchment and Receiving Water Quality Modelling), the modelled flood depths and velocities for a 20-Year ARI event (adopted to align with engineering design parameters) considering the presence of the Northern Access Road are shown in Figure 15.3 and indicate:

- Locations where the model showed the greatest change in peak flood level are predicted to be subject to the greatest velocities.
- The highest velocity predicted by the model along the alignment was on the Lower Watut River floodplain on the southern side of the Markham River, with peak velocities crossing the road and down the downstream embankment of approximately 2.2m/s.
- During a 20-year ARI flood event, velocities predicted across the road at some locations will reduce the trafficability of the Northern Access Road. This may also result in changes to natural flow and sediment transport regimes, which could potentially impact aquatic ecology values (see Section 15.1.3).
- Additional crossings and culverts may reduce peak flood levels along the Northern Access Road alignment.

**Climate change assessment.** Flood modelling assessed changes of a 10% and 20% increase in peak flow rate to simulate climate change. Results indicated that:

- Peak flood levels generally increased in both climate change scenarios compared to the baseline.
- Peak flood levels are predicted to increase along the Watut River floodplain by between 0.01 and 0.1m in the 10% increase scenario and by up to 0.5m in the 20% increase scenario.
- Localised water surface level impacts of up to 0.5m are predicted in the upper extent of the model (adjacent to the Wafi River confluence) in the 10% increase scenario.




Source:
BMT WBM, Appendix I, Catchment and Receiving Water Quality Modelling

coffey
A TETRA TECH COMPANY

Date: 26.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F15.03_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Modelled flood depth and velocity for a 20-Year ARI for the Northern Access Road

Figure No: 15.3

#### 15.5.1.3. Residual Impact Summary

On a regional scale, mine-derived hydrology impacts to the Lower Watut River are expected to be low due to the incremental Project-related effects within a very large catchment.

The residual impacts associated with hydrology and natural flow regimes are predicted to be high on a sub-local scale (within 2 to 4km) and are associated with permanent modifications (i.e., that will persist post-closure) to the middle and upper Boganchong Creek due to construction and operation of the process plant and portal terrace facilities.

Surface Project activities in the Wafi and Bavaga rivers and eastern floodplain creeks (due to construction of the borrow pits, quarries, laydown areas, access roads and gravel extraction) are predicted to result in localised and minor hydrological changes.

During decline and block cave dewatering (construction, operations and post-closure), baseflow recharge to streams may be reduced in the smaller catchments of Buvu and Nambonga Creek, and to a lesser degree in Hekeng River and Wafi River catchments.

### 15.5.2. Sediment Transport

Impacts of sedimentation and particulate-associated metals and metalloids are presented below.

#### 15.5.2.1. Sedimentation Impacts

The main sediment-related impacts are predicted to occur during construction, when land clearing activities such as tree felling, vegetation removal, grubbing and topsoil stockpiling are required followed by construction of major Project infrastructure. Based on the proposed location of key Project infrastructure, the majority of sediment deposition associated with construction will be restricted to the eastern Lower Watut River floodplain sub-catchment areas, in particular Boganchong and Womul creeks and the Bavaga River. Assessments of existing (baseline) and predicted (unmitigated) sediment loads were conducted for the whole Lower Watut River catchment and at a more localised scale for the Boganchong and Womul creeks and the Bavaga River, as described in the sections below and presented in Table 15.7.

**Table 15.7: Modelled existing and predicted (unmitigated) sediment loads for construction in Boganchong and Womul creeks and the Wafi and Bavaga rivers**

| Watercourse | Season | Construction | | Operations | | Mine-derived Sediment Increase Factor | |
|---|---|---|---|---|---|---|---|
| | | Natural Sediment Load (tonnes) | Mine-derived Sediment Load (tonnes) | Natural Sediment Load (tonnes) | Mine-derived Sediment Load (tonnes) | Construction | Operations |
| Boganchong Creek | Dry | 1.9 | 471 | 1.9 | 167 | 248 | 88 |
| | Wet | 59.7 | 3,434 | 59.7 | 1,215 | 58 | 20 |
| Womul Creek | Dry | 1.3 | 278 | 1.3 | 98 | 214 | 75 |
| | Wet | 39.4 | 2,024 | 39.4 | 716 | 51 | 18 |
| Bavaga River | Dry | 29.5 | 862 | 29.5 | 306 | 29 | 10 |
| | Wet | 915.8 | 6,288 | 916 | 2,225 | 7 | 2 |
| Wafi River* | Dry | 1,085 | 187 | 1,085 | 66 | 0.17 | 0.06 |
| | Wet | 33,960 | 1,360 | 33,960 | 481 | 0.04 | 0.01 |

* Modelling does not capture the resettlement proposed to be constructed within this catchment.

**Boganchong Creek.** On a local scale, sediment loads generated in the vicinity of key construction activities are predicted to be many times higher than the existing natural loads in Boganchong Creek (see Table 15.7).

For the modelled construction period, Project activities (refer Section 15.1) (if unmanaged) will result in an increase to the natural sediment loads in Boganchong Creek by approximately 60 times during the wet season and approximately 250 times during the dry season. Construction of both the sedimentation pond and raw water dam downstream of the portal and process plant terrace will limit sediment reporting to downstream reaches of Boganchong Creek.

Below the two natural waterfalls on Boganchong Creek, the main channel fans out into several distributary channels within an alluvial fan. Overbank flows then spread in a northerly direction across the inner floodplain of the Lower Watut River's eastern floodplain (i.e., its eastern backplain). BMT WBM (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River), Pickup (2015a,b) and Hydrobiology (Appendix I of Appendix I, Catchment and Receiving Water Quality Modelling) observed that coarse sediments do not reach Chaunong Creek main channel (nor the receiving Bavaga River and Lower Watut River) but settle on the outer backplain of the Lower Watut River's eastern floodplain between Chaunong Creek and the escarpment. The flow of sediment-laden high or flood flows across backplain vegetation results in a dropping out (sedimentation) of coarse-grained sediment particles by reduced water velocities and the trapping efficiency of vegetation.

Sediment deposition is expected to decrease exponentially with distance from Boganchong Creek main channel or its distributary channels on the floodplain (Pickup, 2015a,b).

During operations, sediment loads are predicted to reduce compared to construction sediment loads, facilitated by implementation of measures in the Erosion and Sediment Control Plan.

**Womul Creek.** For the modelled construction period, construction activities for Project facilities (refer to Section 15.5) (if unmanaged) will result in an increase to the natural sediment loads in Womul Creek by approximately 50 times during the wet season and approximately 200 times during the dry season (see Table 15.7). This is slightly less that that predicted in Boganchong Creek.

During construction, 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 (the northern area of which is within the Womul Creek catchment), the water treatment plant and southern part of the Fere Accommodation Facility will be constructed in Construction Years 2 and 3.

Sediment loads to the natural drainage and Womul Creek are predicted to progressively diminish following construction over an 18-month to two-year period to comparable to pre-disturbance levels due to natural or assisted revegetation and stabilisation of exposed areas. 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.

**Bavaga River catchment.** Proposed construction activities in the Bavaga River catchment (Section 15.5) are predicted to increase unmitigated mine derived sediment loads by 7 times above the natural sediment loads during the dry season and by almost 30 times during the wet season (Table 15.7). The proportional mine-derived increase in sediment loading was greater in the Bavaga River during the wet season possibly due to the small catchment size and comparatively large area of disturbance influencing sediment loads within the catchment.

During operations, these sediment loads are expected to reduce as working areas are rehabilitated.

Further detail for each of the key proposed Project facilities within the Bavaga River catchment are discussed below.

During development of the Bavaga River gravel extraction pit, 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 is not expected to add any sediments that were not already a part of the natural bed or suspended sediment load in the river.

During early construction of the Northern Access Road, 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 working areas. Temporarily deposited material will resuspend and be transported downstream mainly as suspended load towards the Lower Bavaga River during high flows. The steep upper catchment creeks draining the eastern slopes of Northern Access Road Borrow Pit area are flashy (i.e., water levels rise and fall rapidly) and have high sediment transport capacity, which will lead to increased sediment loads downstream. During the later development phase of the borrow pit (e.g., late construction phase and early operations), there will a greater emphasis on within-pit surface water and stormwater management, resulting in a major reduction of coarse-grained sediment delivery to the natural drainage.

While in-quarry erosion and sediment control will be implemented under the Project Erosion and Sediment Control Plan, construction of the Mt Beamena Quarry will contribute some coarse-grained sediment to the Lower Bavaga River. The Mt Beamena Quarry access road, which is located in steep terrain, is expected to result in short-term (6 to 8 months) and highly localised delivery of coarse-grained sediments entering the upper catchment creeks. Subsequent rising and flood flows are expected to resuspend the deposited sediments and transport them downstream as either bedload or suspended load to resettle on the lower creek reaches.

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, provided access road maintenance and erosion and sediment control measures are implemented.

**Wafi River catchment.** As described in Section 15.5.1, mine facilities within the Wafi River catchment will affect the three sub-catchments of Nambonga, Buvu and Yor creeks. These creeks are deeply incised in the upper reaches and have high sediment transport capacity. The Resettlement Road will also traverse several tributary rivers of the southern Wafi River catchment.

The Nambonga Decline Portal and ancillary infrastructure will be sited on areas of existing disturbance in generally flat terrain within the Nambonga Creek catchment. This, along with a vegetated buffer strip between the terrace and Nambonga Creek main channel, will help to limit sediment associated with construction activities reaching the creek. Further, a new road to the Miapilli Waste Rock Dump (the Nambonga Haul Road), the Miapilli Waste Rock Dump itself and the Miapilli Clay Borrow Pit are located on sloping land with secondary regrowth vegetation, which will provide stability and protection from erosion. This will reduce delivery of coarse and fine-grained sediments as a result of Project activities to the natural drainage.

Any coarse sediments that do reach the Nambonga Creek main channel as a result of the Nambonga Decline Portal construction will be temporary deposits that will be transported downstream during successive rising and flood flows.

An existing small section of an access road will be widened to provide access to the Nambonga Decline Portal. As a result, coarse sediment delivery to the natural drainage is expected to be minimal with most sediments settling on land immediately downslope of the road.

Where the Nambonga Creek enters the Wafi River, construction-derived coarse sediments (e.g., stone and gravels) are expected to accumulate within an existing coarse sediment storage area. These sediments, however, are not expected to cause sedimentation impacts on the Wafi River, as subsequent flood flows would resuspend and transport the coarse sediment downstream to the lower Wafi River and the receiving Watut River.

Waste rock from the Nambonga Decline Portal will be managed in a purpose-built waste rock dump, referred to as the Miapili Waste Rock Dump, adjacent to Yor Creek, a tributary of the Wafi River. Any sediment-laden runoff from the waste rock dump will be captured using sediment ponds limiting coarse-grained sediment from reaching Yor Creek.

The Migiki Borrow Pit 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, so that coarse-grained sediment delivery to the natural drainage in Buvu Creek will be minimal. No significant coarse sediment deposition is anticipated in the steep-gradient reach of Buvu Creek between the Migiki Borrow Pit and its confluence with Nambonga Creek.

In the first year of construction of the Resettlement Road, coarse and fine grained sediment loads are predicted to reach watercourses in the road's vicinity. After approximately 12 months, construction-derived sediment loads will progressively reduce as disturbed soils are stabilised and revegetated. Implementation of the Project Erosion and Sediment Control Plan, including silt fences, surface drainage and sedimentation ponds (if required) is expected to minimise off-site delivery of coarse sediments to Wafi Creek and its tributaries. Erosion of road cut-slopes and fill-slopes will be reduced by the implementation of proposed road construction-related management measures.

Construction-derived sediments entering Nambonga, Buvu and Yor creeks and the receiving Wafi River and its tributaries are not expected to cause significant sedimentation of these creeks and rivers, given their steep gradients and flashy nature (steeply rising and falling flood hydrographs) during high rainfall-runoff events, as well as their high sediment transport capacities. Sediment loads associated with construction are expected to progressively decline following completion of construction works to comparable to pre-disturbance levels within 18 months to two years.

As shown in Table 15.7, during construction, the sediment load increase to the Wafi River (not considering the Resettlement Road construction) was predicted to be negligible (a fraction of 1%) during both the wet and dry seasons.

**Lower Watut Eastern Floodplain**. Sedimentation impacts in the Lower Watut River's eastern floodplain are expected to relate primarily to coarse-grained sediment loading downstream of creek crossings as a result of construction of the Watut Services Road, wastewater discharge pipeline and associated service track and the Lower Papas

Aggregate Source adjacent to the lower Boganchong and Womul creeks. These are assessed below.

Soil erosion along the Watut Services Road and the delivery of coarse-grained sediment to the natural drainage is predicted to be minor given the results of previous studies of sedimentation impacts from roads constructed across floodplains in PNG, 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).

For the Watut Services Road, highly localised and short-term sedimentation impacts are anticipated to occur immediately downstream of the creeks crossed by the road. Well-established environmental proposed management measures will be implemented to reduce potential impacts and to achieve post-construction, long-term stability of the watercourse crossings.

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 buried 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 Lower Papas Aggregate Source will retain coarse-grained sediment on site. Pits which have been exhausted of gravels can be used as settling ponds for trapping coarse-grained sediments in washwater from the crushing and washing plant. 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 (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River; Pickup, 2015a,b; Hydrobiology, 2018). Residual impacts of sedimentation in the floodplain from the gravel extraction operation are expected to be low.

**Lower Watut River catchment.** As shown in Table 15.8, on a whole of catchment scale, the Project-derived sediment loads (unmitigated) generated during construction are predicted to contribute a very small proportion (approximately 0.21% annually) to the natural sediment loads of the Lower Watut River main channel. During operations, the predicted annual sediment load was estimated to contribute 0.07% of the natural sediment load as a result of less bulk earthworks, progressive rehabilitation and revegetation of disturbed areas. The predicted Project-derived contribution during the dry season is slightly higher due to the reduced natural sediment loads being generated by the catchments.

**Table 15.8: Modelled existing and predicted (unmitigated) sediment loads for construction and operations in Lower Watut River catchment**

| Project phase | Duration | Modelled Natural Sediment Loads (tonnes) | Mine–Derived Sediment Loads (tonnes) | Mine Sediment as a Percentage of Natural Catchment Inputs (%) |
|---|---|---|---|---|
| Construction | Dry (3 months) | 308,681 | 2,712 | 0.88% |
| | Wet (3 months) | 5,735,514 | 22,352 | 0.39% |
| | Annual | 12,088,390 | 25,064 | 0.21% |
| Operations | Dry (3 months) | 308,681 | 961 | 0.31% |
| | Wet (3 months) | 5,735,514 | 7,908 | 0.14% |
| | Annual | 12,088,390 | 8,869 | 0.07% |

#### 15.5.2.2. Particulate-Associated Metals and Metalloids Impacts

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

An assessment of the potential for enrichment of metals in Boganchong Creek was investigated using soils data reported in KCB (2013) in Appendix Y, Freshwater Ecology Impact Assessment. As shown in Appendix Y, 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.

Metals data for the <63µm size fraction of creek bed sediments in the Mine Area (Womul Creek) (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River) showed that the median and average metal and metalloid concentrations met ANZECC/ARMCANZ (2000) sediment quality guidelines, with the exception of median total nickel concentration (42mg/kg) being above the Sediment Quality Guideline (SQG) trigger value (21mg/kg), which is common in soils of PNG.

The <63µm size fraction (silts and clays) of creek bed sediments had generally low concentrations of metals and metalloids which supports the contention by BMT WBM (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River), Pickup (2015a,b) and Hydrobiology (Appendix I of Appendix I, Catchment and Receiving Water Quality Modelling) that fine sediments are deposited on the floodplain due to via reduced flow velocities and the trapping efficiency of vegetation.

The implications of these findings for filter-feeding or sediment-ingesting macroinvertebrates and inadvertent sediment-ingestion by bottom-feeding fish is presented in Appendix Y, Freshwater Ecology Impact Assessment, and summarised in Section 15.6.

#### 15.5.2.3. Residual Impact Summary

The main sediment-related impacts are predicted to be associated with the construction of major Project infrastructure. The majority of Project-related sediment deposition will be restricted to Boganchong and Womul creeks and the Bavaga River. Construction of sedimentation ponds downstream of construction works and implementation of the Project Erosion and Sediment Control Plan will limit off-site release of fugitive sediments. Over the course of operations, sedimentation impacts are expected to reduce to within the natural variability of existing conditions.

### 15.5.3. Water Quality

The water quality modelling results for selected dissolved metals/metalloids and TSS for the Watut River are presented below, based on the modelling described in Appendix I, Catchment and Receiving Water Quality Modelling. The results are reported for the assessment point LWT6 in the Lower Watut River shown in Figure 15.1.

#### 15.5.3.1. Dissolved Metals and Metalloids

Water quality impacts relating to dissolved metals and metalloids concentrations in the Lower Watut and Wafi rivers are discussed below.

**Lower Watut River.** Modelled baseline and predicted water quality results (median and 95-percentile) in the Lower Watut River approximately 3km downstream of the discharge point (LWT6) for the construction period are presented in Table 15.9, along with water quality guidelines. The modelling results indicate that there are no predicted concentrations elevated above background variability as a result of the Project, assuming treatment of mine wastewater flows. The degree to which mine water will be treated will be adjusted to meet agreed water quality criteria at an agreed compliance point at the downstream extent of a mixing zone.

All modelled concentrations of dissolved metal and metalloids in the Watut River (i.e., for baseline and after discharge of treated mine wastewater) during both the dry and wet season are below the (hardness corrected) water quality guidelines, including ANZECC/ARMCANZ (2000) freshwater quality guidelines for the protection of 95% of aquatic species in slightly disturbed freshwater ecosystems. This is a result of the concentrations of metals and metalloids in the treated discharge being low (Table 15.9), along with the large dilution factor provided by flows in the Watut River of approximately 45:1.

In addition to the already low predicted concentrations of metals and metalloids, some water quality parameters including hardness, dissolved organic matter, suspended solids and pH can effectively reduce the concentrations of bioavailable and potentially toxic metals in watercourses.

Watercourses in the Project Area, including the Watut River, have a natural capacity to form strongly-bound complexes of dissolved metals with dissolved organic carbon, particularly copper (known as complexing capacity), thereby making them less bioavailable (i.e., less toxic) to aquatic biota than labile metal ions (i.e., free unbound metal ions in solution). In addition, adsorption of dissolved metals onto particulate matter would further reduce the labile (or free) metals that are bioavailable and potentially toxic to aquatic biota. Analysis undertaken by CSIRO (Angel et al., 2016, Appendix G of Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River) indicated that the percentages of copper, nickel and zinc removed from the dissolved phase through adsorption (onto particles or other matter) from the Watut River were in the range 75% to 96%, 53% to 73% and 90% to 99%, respectively. This provides an additional layer of conservatism in terms of assessing potential ecotoxicological effects from the discharge of treated mine wastewater into the Watut River.

**Table 15.9: Modelled baseline and predicted dissolved metal and metalloid concentrations downstream of the discharge point in the Lower Watut River during construction (mg/L)**

| Season | Assessment Point | As | | Cu | | Mn | | Ni | | Se | | Zn | | Cd | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 50%ile | 95%ile | 50%ile | 95%ile | 50%ile | 95%ile | 50%ile | 95%ile | 50%ile | 95%ile | 50%ile | 95%ile | 50%ile | 95%ile |
| **Dry** | LWT6 | 0.0038 | 0.0044 | 0.0020 | 0.0026 | 0.0147 | 0.0197 | 0.0012 | 0.0017 | 0.0050 | 0.0050 | 0.0076 | 0.0101 | 0.0004 | 0.0006 |
| *Modelled baseline: Dry* | | 0.0036 | 0.0039 | 0.0017 | 0.0021 | 0.0133 | 0.0159 | 0.0011 | 0.0013 | 0.0050 | 0.0050 | 0.0067 | 0.0080 | 0.0004 | 0.0006 |
| **Wet** | LWT6 | 0.00461 | 0.0048 | 0.0027 | 0.0033 | 0.0221 | 0.0237 | 0.0016 | 0.0019 | 0.0050 | 0.0050 | 0.0114 | 0.0123 | 0.0007 | 0.0008 |
| *Modelled baseline: Wet* | | 0.0044 | 0.0047 | 0.0028 | 0.0031 | 0.0206 | 0.0231 | 0.0016 | 0.0018 | 0.0050 | 0.0050 | 0.0105 | 0.0117 | 0.0007 | 0.0008 |
| ***Water quality guidelines*** | | | | | | | | | | | | | | | |
| PNG criteria[a] | | 0.05 | | 1 | | 0.5 | | 1 | | 0.01 | | 5 | | 0.01 | |
| PNG ECoP[b] | | 0.05 | | 0.0065-0.012[c] 0.012-0.021[d] | | - | | 0.056-0.096[c] 0.096-0.160[d] | | 0.005 | | 0.180 - 0.320[c] 0.320 - 0.570[d] | | <0.00066 - 0.0011[c] 0.0011 - 0.002[d] | |
| ANZECC/ARMCANZ[e] | | 0.013 | | 0.0014/ 0.0035[f] | | 1.9 | | 0.011/ 0.0275[f] | | 0.005 | | 0.008/ 0.02[f] | | 0.002 /0.0084[f] | |
| PNG raw drinking water[g] | | 0.007 | | 1 | | 0.1 | | 0.02 | | 0.01 | | 3 | | 0.002 | |
| PNG Schedule 2[h] | | 0.05 | | 1.5[i] | | 0.5[i] | | - | | 0.01 | | 15[i] | | 0.01 | |
| WHO (2017)[j] | | 0.01[k] | | 2 | | - | | 0.07 | | 0.04[k] | | - | | 0.003 | |

a Environment (Water Quality Criteria) Regulation 2002 – Schedule 1 Water Quality Criteria for Aquatic Life Protection (PNG, 2002).
b PNG Environmental Code of Practice for the Mining Industry. Criteria for protection of freshwater aquatic life.
c Guideline is applicable to a hardness of 50 to 100 mg/L $CaCO_3$.
d Guideline is applicable to a hardness of 100 to 200 mg/L $CaCO_3$.
e Source: Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000).
f Guideline is a 'hardness modified trigger value' as per Section 3.4.3.2 of ANZECC/ARMCANZ (2000). The first trigger value listed is for a hardness of 30 mg/L (for soft waters such as the Wafi River) and the second value listed takes into account the 'hard' (150mg/L $CaCO_3$) hardness of the water, such as floodplain creeks and rivers and the Watut River water.
g Raw drinking water quality criteria described in OEC (2000).
h PNG Public Health (Drinking Water) Regulation, Schedule 2, 1984.
i Aesthetically-based value.
j World Health Organisation (WHO) drinking water guidelines (2017).
k Provisional guideline value.

The results from the semi-quantitative estimates of concentrations of other contaminants as a result of treated mine wastewater (excluding the beneficial effects of complexation and adsorption) and treated sewage approximately 3km downstream of the discharge point are presented in Table 15.10. These results indicate that there are no expected exceedances of the PNG ER nor the ANZECC/ARMCANZ water quality criteria assuming, as for the modelling, treatment of mine wastewater flows.

**Table 15.10: Semi-quantitative assessment of other parameters (mg/L)**

| Parameter | Mine Dewatering (Construction Phase) | Approximate Concentration (above background) 3km Downstream of Discharge | Approximate Background Concentration in Watut River[a] | PNG ER Receiving Water Quality Criteria | ANZECC/ ARMCANZ |
|---|---|---|---|---|---|
| **Treated mine water discharge** | | | | | |
| Chromium | 0.049 | 0.0001 | 0.002 | 0.05 | 0.001b |
| Iron | 0.034 | 0.0008 | ND | 1 | - |
| Lead | 0.0003 | 0.00001 | 0.001 | 0.005 | 0.0034 |
| Mercury | 0.0001 | 0.000002 | 0.0056 | 0.0002 | 0.00006c |
| Sulphate | 1,090 | 24 | 18 | 400 | - |
| **Treated sewage discharge** | | | | | |
| Total Dissolved Solids | 468 | 10 | ND | - | - |
| Total nitrogen | 10 | 0.22 | 0.4 | - | - |
| Total phosphorus | 3 | 0.07 | 0.35 | - | - |
| Ammonia | 4 | 0.09 | 0.07 | 3.6 | - |
| Nitrate | 0.7 | 0.02 | 0.06 | 45 | - |
| Faecal Coliforms cfu/100 ml | <10 | 0.22 | ND | 200 | - |

[a] Background concentrations sourced from WGJV monitoring data (median values from site 'B30') and BMT WBM monitoring data (site 'Watut River@Uruf') in Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River
ND – no data available
[b] Chromium IV.
[c] Mercury values are for protection of 99% of species in typical slightly–moderately disturbed systems.

**Wafi River.** Within the Wafi River catchment, underground dewatering flows from the Nambonga Decline Portal, and runoff 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 1.6km downstream of the discharge point and 0.7km upstream of Nambonga Village. While no modelling of the 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 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 of 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.

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. 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 and ensure that PNG ER criteria are met at the compliance point at end of the mixing zone.

As described in Chapter 9, 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 (2000) 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 (Clean TeQ, 2017), to meet the site-specific criteria in Nambonga Creek:

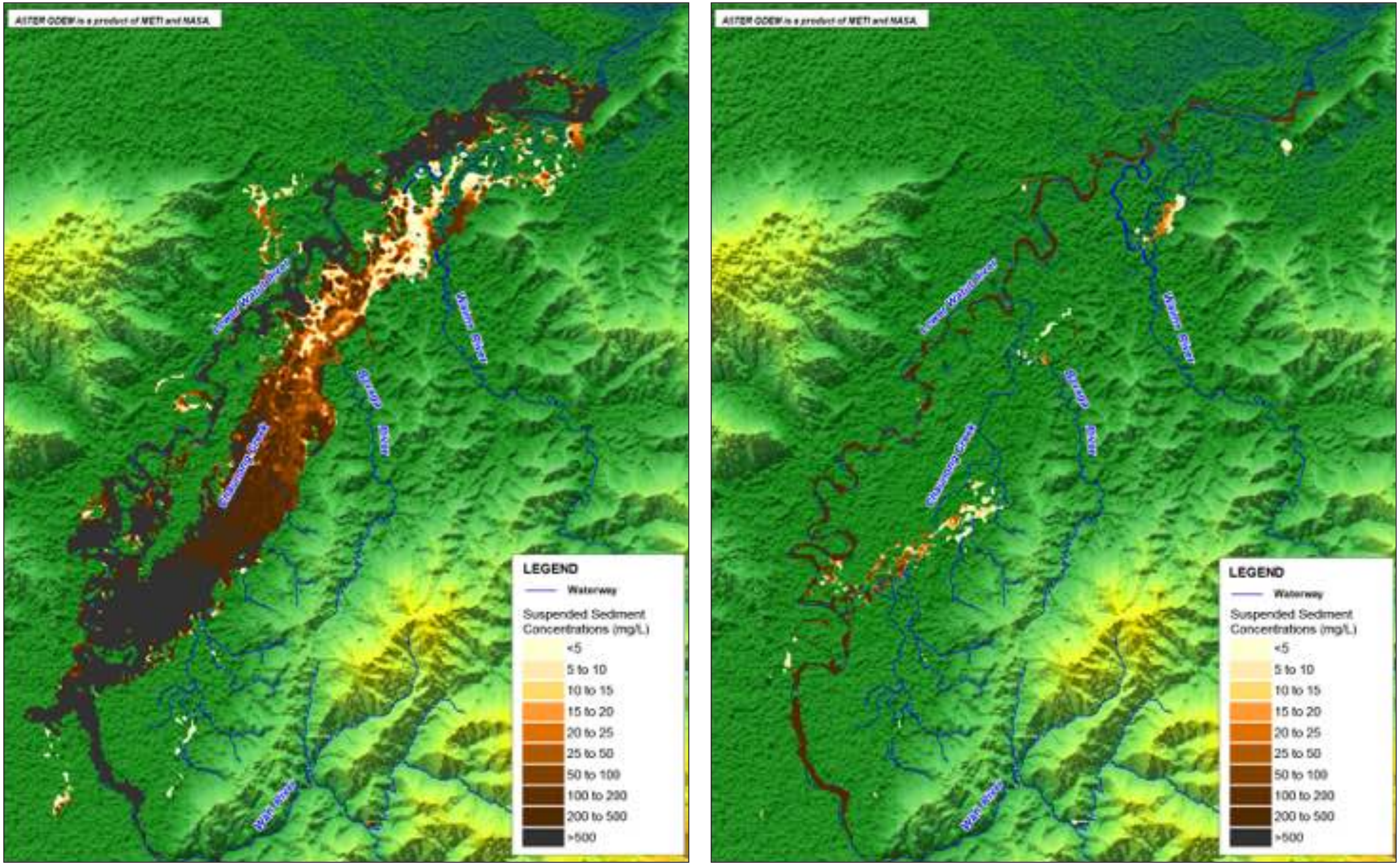
- Copper concentrations in the discharge (0.05mg/L) would require 5 dilutions, based on a site-specific copper criterion of 0.01mg/L
- Zinc concentrations in the discharge (0.06mg/L) would require 2 dilutions, based on a site-specific zinc criterion of 0.03mg/L

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 to improve discharge water quality and ensure that the site-specific copper and zinc criteria are met at the compliance point at end of the mixing zone.

Therefore, water quality impacts in Nambonga Creek are predicted to be low based on the plan to capture and treat (if required) potentially contaminated water prior to discharge to the environment, and directing a larger proportion of the mine wastewater feed to the DeSALx® component of the water treatment plant during low flows. This will ensure that PNG ER criteria and site-specific (i.e., ANZECC/ARMCANZ, 2000) copper and zinc criteria are met at the compliance point for the three year discharge period.

#### 15.5.3.2. Total Suspended Solids

Figure 15.4, Figure 15.5 and Figure 15.6 show spatially distributed existing and Project-derived (construction and operations) median TSS concentrations, respectively, during the dry and wet seasons. During operations, while predicted sediment delivery flowpaths and extents are similar to the construction period, concentrations of mine-derived TSS are predicted to be less than those predicted during construction. This is due to a reduction in delivery of sediments to the natural drainage as a result of stabilisation of disturbed areas, progressive rehabilitation and natural revegetation.




Source:
BMT WBM, Appendix I, Catchment and Receiving Water Quality Modelling

coffey
A TETRA TECH COMPANY

Date: 26.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F15.04_GRA

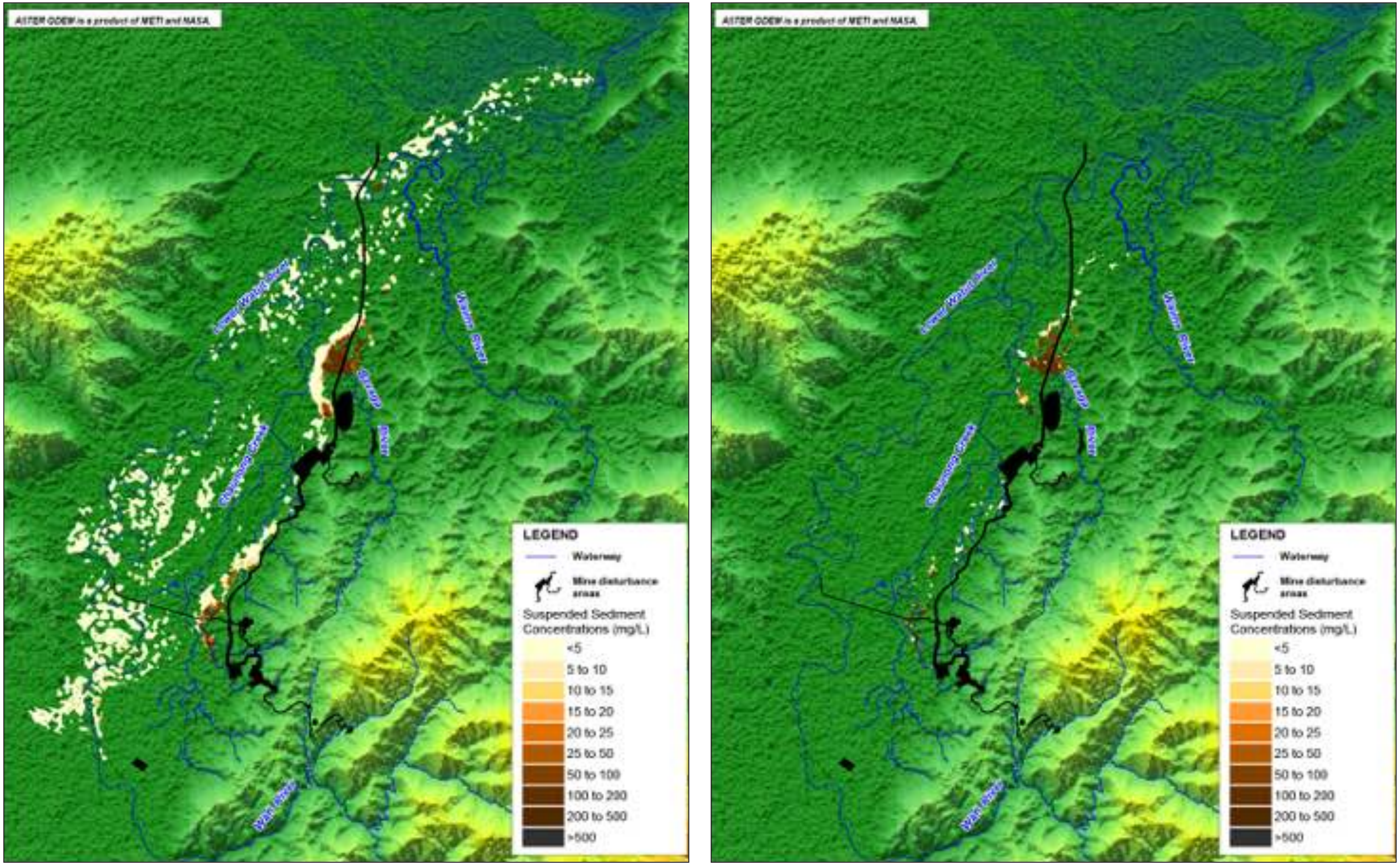
WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Existing modelled TSS concentrations in the wet (left) and dry (right) seasons

Figure No: 15.4

INDD Reference: 0520DD_10_GRA111.indd_5




Source:
BMT WBM, Appendix I, Catchment and Receiving Water Quality Modelling

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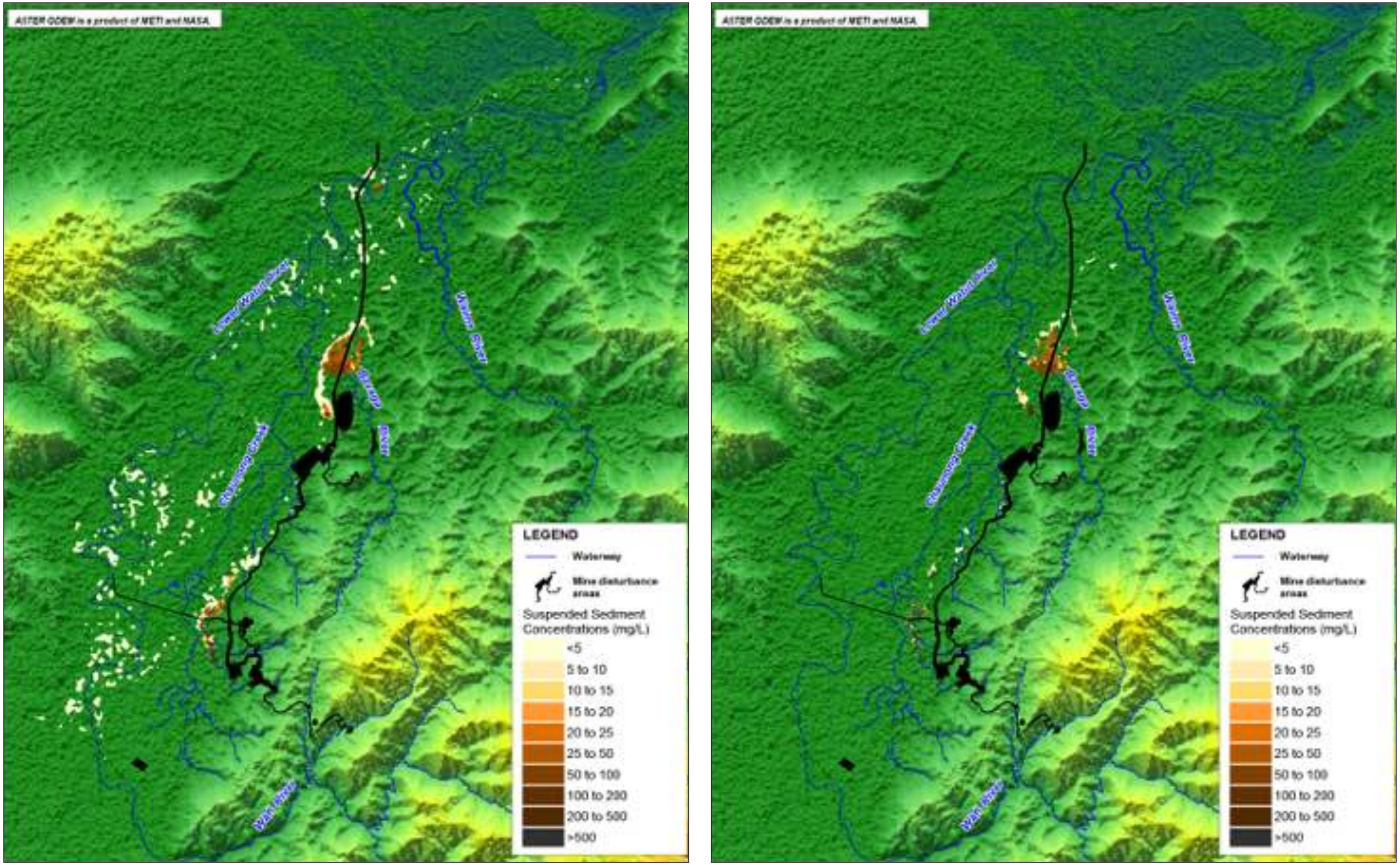
Date: 26.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F15.05_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Predicted mine-derived incremental TSS concentrations during construction in the wet (left) and dry (right) seasons (unmitigated)

Figure No: 15.5




Source:
BMT WBM, Appendix I, Catchment and Receiving Water Quality Modelling

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Date: 26.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F15.03_GRA

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

**Predicted mine-derived incremental TSS concentrations increment during operations in the wet (left) and dry (right) seasons (unmitigated)**

Figure No: **15.6**

INDD Reference: 0520DD_10_GRA113.indd_5

During the dry season, construction-derived TSS concentrations are predicted to be minor in Mine Area watercourses, with some increases in TSS downstream of construction activities. During the wet season, predicted TSS concentrations are predicted to be most elevated compared to existing levels near construction activities (i.e., Watut Process Plant, portal terrace and Fere Accommodation Facility) on the Chaunong Creek eastern floodplain and downstream of the construction activities in the Bavaga River catchment. These TSS concentrations are predicted to decrease progressively downstream.

Natural flooding of the eastern floodplain of the Lower Watut River, however, carries high background sediment loads to the floodplain creeks, independently of any significant Project inputs. Mine-derived TSS concentrations are predicted to be a minor component of natural TSS concentrations during the wet and dry seasons during construction. With implementation of sediment control measures, predicted TSS concentrations are expected to be reduced and impacts of elevated TSS are likely to be localised to construction sites in key catchments including Boganchong and Womul creeks, Bavaga River and the Wafi River.

Mine-derived TSS concentrations within individual catchments are described below.

**Boganchong Creek.** During early construction activity, there will be little latitude for limiting the amount of rainfall-based erosion and scour of disturbed or displaced soils and subsequent delivery of fine sediments (<125μm size fraction) reporting as TSS load to the creek, especially during the construction of the 385m-long access road from the existing Watut Valley Road to the sedimentation dam, as well as in-channel works associated with the construction of the sedimentation dam. However, during subsequent construction activities (e.g., Watut Process Plant terrace and Watut Declines Portal Terrace), the presence of the sedimentation pond is anticipated to reduce the fine sediment load (>63μm size fraction) transported downstream of the sedimentation dam, owing to the assumed trap efficiency of the sedimentation pond, which would be engineered to retain the >63μm size fraction due to reduced water velocities in the sedimentation pond. Wash load (<20μm size fraction) will pass over the sedimentation dam spillway and report to the floodplain distributaries of Boganchong Creek, as well as to the eastern floodplain of Chaunong Creek.

No or minimal mine-derived TSS concentrations are predicted to reach the Chaunong Creek main channel; however, elevated TSS concentrations are predicted on the eastern side of the floodplain (Appendix I, Catchment and Receiving Water Quality Modelling). It would be reasonable to assume that during the construction period some elevated mine-derived TSS concentrations may reach Chaunong Creek during the wet season. This is supported by the findings of the modelling independent peer review (Appendix I of Appendix I, Catchment and Receiving Water Quality Modelling) that indicated that while a proportion of fugitive sediments generated by the Project could reach Chaunong Creek by direct hydraulic connection and be transported downstream, a proportion would remain in stores along the tributary networks and on the distal floodplain/backswamp areas.

**Womul Creek**. Impacts of TSS concentrations in Womul Creek during construction and operation are predicted to be of similar (but slightly less) magnitude and duration as the TSS impacts in Boganchong Creek.

The most intense period of construction will be during Construction Year 1 involving the construction of segments of the Mine Access Road and the Northern Access Road in steep terrain. During the wet season, it is estimated that 50% of the coarse-grained sediment may reach the creek, based on experience in other mining projects and operating mines in PNG. In construction areas located on low gradient landforms, such as access road segments and the waste management facility on the floodplain and ridge top locations (e.g., Fere Accommodation Facility, northern part of Watut Process Plant and terrace, and hill top access road segments), coarse-grained sediment loading of the natural drainage will be much less.

A large proportion of coarse-grained sediments will transport a short distance downslope of Project construction sites within the catchment and deposit in concave areas, forming sediment 'tongues' below construction areas. A proportion of the coarse-grained sediment fraction (>125µm particle diameter) comprising mainly fine sands will be transported in overland flows (via sheetflow and rills) in rainfall runoff to the Womul Creek main channel. From there it will be transported downstream as suspended load to settle out on the lower gradient reach of the creek and its distributaries on the floodplain (via reduced water velocities), as well as the floodplain itself. The lower Womul Creek bed substratum is comprised mainly of sand-sized sediments that will be augmented by the increment of fine sands due to construction-derived sediment.

**Bavaga River.** Mine-derived TSS concentrations in the Bavaga River are predicted to increase during construction in the wet season and to a lesser degree during the dry season.

During the wet season, the predicted 10-, 50- and 95-percentile TSS concentrations at a modelling site (BAV1a) downstream of all the combined unmitigated construction disturbed areas were 16, 110 and 259mg/L respectively. Compared with the respective modelled background TSS concentrations of 11, 28 and 134mg/L, these data represent a 1.4-fold, 3.9-fold and 1.9-fold increase over the respective background TSS concentration levels.

Examples in the literature (Naiova (2007); James (2015)) reviewed the impacts of active in-river gravel operations on the freshwater ecology (in Fiji and New Zealand, respectively) and concluded that, while it appeared that river works did not increase TSS or turbidity to levels any greater than recorded during floods, the important difference was that river works were generally undertaken at lower flow periods, such that any generated suspended sediment relatively rapidly settles out and is deposited on the riverbed in low velocity environments.

The construction activities within the Bavaga River will be relatively short term and TSS concentrations are expected to reduce upon stabilisation of exposed areas following the construction period.

**Wafi River.** The proposed Resettlement Road from Madzim to Old Hengambu villages is approximately 18.9km, of which a 16.5km-long segment (87%) is located in the Wafi River catchment. This segment of the road is mostly along mountainous terrain and crosses six rivers and therefore its construction has the greatest potential for TSS-related water quality impacts to the Wafi River.

The TSS impacts of the proposed Resettlement Road within the Wafi River have been assessed on a whole-of-catchment basis using a semi-quantitative method (see Appendix Y, Freshwater Ecology Impact Assessment), with impacts being assessed and related to the lower Wafi River at Pekumbe (see Figure 15.1 and Figure 15.2).

Based on sediment production rates of 500m$^3$/ha/year for road construction in high rainfall areas of PNG (NSR, 1999; Hydrobiology, 2008; DBA, 2005), a maximum total fine-grained sediment load of 8,538t of sediment is predicted to report as suspended load in the Wafi River catchment. In the Lower Wafi River at Pekumbe Village, it is estimated that in the first year of construction of the Resettlement Road, construction-derived TSS concentrations increase by a factor of 2.6 (see Appendix Y, Freshwater Ecology Impact Assessment). These loads will progressively reduce as disturbed soils are stabilised and revegetated and the measures in the Project Erosion and Sediment Control Plan are implemented. Road construction-derived TSS loads and concentrations in the Wafi River main channel are expected to progressively decline toward pre-disturbance levels after approximately 18 months to two years.

**Lower Watut Eastern Floodplain**. The residual impacts of increased TSS concentrations and associated turbidity on the floodplain as a result of the Watut Services Road, wastewater discharge pipeline (including the co-buried return make-up water pipelines and service track and the Lower Papas Aggregate Source extraction area) are discussed below.

At the three creek crossings (Chaunong, Mari and Pentag creeks), the wastewater discharge and raw water make-up pipeline will be installed using trenching or direct pipe trenchless method. If constructed 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.

At creek crossings, 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 revegetated. Concentrations of TSS are expected to be comparable to the wide range of TSS concentrations that floodplain creeks naturally experience. 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.

The supporting service track adjacent to the buried 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.

The Lower Papas Aggregate Source extraction operation is predicted to have little or no impact on floodplain and creek water quality (i.e., increased TSS concentrations and turbidity), owing to its prudent siting on a flat area of the floodplain. Sedimentation ponds will be constructed to allow the settling of fine-grained washwater sediments and the settled water (typically below 50 to 100mg/L) discharged offsite to the natural drainage. Loading of TSS in the Lower Watut River floodplain will be minor and within the natural range of TSS concentration variability of the receiving Lower Watut River main channel.

During the operations phase, there will be no physical impacts of the wastewater discharge pipeline and return make-up water pipelines as the natural ground level will be reinstated over the buried pipelines, and the service track will become compacted by traffic, thereby reducing TSS to local surface water drainage. Surface runoff from the Watut Access Road will continue to be a minor source of fine sediment loading to the floodplain.

The Lower Papas Aggregate Source operation will have ceased once the roads have been constructed, and therefore will not generate any water quality impacts.

**Lower Watut River.** In general, there are predicted to be minimal (unmitigated) TSS impacts on the Lower Watut River during the dry season, owing mainly to the low levels of rainfall-based erosion and scour of disturbed soils with consequential low amounts of fugitive, fine-grained sediment delivery to the natural drainage (see Figure 15.4 and Figure 15.5). In addition, Project-derived TSS impacts in the Lower Watut River main channel are predicted to be negligible during the dry season. During the wet season, the unmitigated Project-derived TSS distribution figures for the construction and operations periods indicate that TSS concentrations are predicted to be slightly elevated (around 5 to 10mg/L above baseline) in the Watut River and in the adjacent floodplain areas as a result of the modelling including gravel extraction at Madzim. Impacts of the Madzim gravel pit will not be realised due to Project refinement and exclusion of this facility from the currently-proposed Project.

#### 15.5.3.3. Post-Closure Subsidence Lake

Based on the assessment in Section 14.3, Groundwater, discharges from the subsidence zone lake are predicted to be acidic with elevated concentrations of metals and metalloids and are expected to exceed PNG ER Criteria and ANZECC/ARMCANZ guidelines. Water in, and seeping and/or spilling from, the subsidence zone lake will be monitored and will be treated during the post-closure period until water quality closure objectives are met as described in the Conceptual Closure and Rehabilitation Plan (Attachment 2).

Post-closure, engineered hydraulic plugs / bulkheads will be installed in the decline portals and ventilation shaft, preventing convective oxygen supply to the sulphides within the subsidence zone and also to prevent or minimise water discharge. 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 hydrated lime to increase pH and reduce dissolved metals concentrations via solids precipitation.

With lime treatment, the pH is predicted remain acidic (pH 5.5) and the following concentrations are predicted to exceed the PNG ER criteria 50 years post-closure:

- Manganese concentrations (3.2mg/L) are predicted to exceed the PNG ER criterion (0.05mg/L).
- Iron concentrations (2.9mg/L) are predicted to exceed the PNG ER criterion (1mg/L).

Concentrations of copper (0.2 mg/L) and aluminium (1.6 mg/L) are predicted to 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 (of at least 50 years).

Modelling of final pit lake water quality and engineering solutions will be progressively improved as actual data is accumulated during operations. 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 downstream impacts to the freshwater environment may be higher than predicted.

#### 15.5.3.4. Impact Summary

Residual contaminant impacts to surface water quality are predicted to be low based on the plan to capture and treat (if required) potentially contaminated water prior to discharge to the environment. There are predicted to be no residual water quality impacts downstream of the treated wastewater discharge in the Watut River near Wongkins Village, as all dissolved metal/metalloid predictions are predicted to be below the PNG ER and (hardness corrected) ANZECC/ARMCANZ guidelines (2000) and within natural background variability.

Should any contaminants from seepage from the Watut Waste Rock Dump reach the sedimentation pond and/or raw water dam downstream of the process plant terrace, this water will be reused as a part of the Project water supply or treated and released if required. Any seepage and runoff from the Miapilli Waste Rock Dump will be captured and treated prior to discharge (if necessary) to Nambonga Creek. It is expected that PNG ER ambient water quality criteria will be met in Nambonga Creek at the proposed compliance point downstream of the mixing zone.

To achieve compliance with the PNG ER sulphate criterion 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 water quality and ensure that all PNG ER criteria are met at the compliance point at end of the mixing zone.

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. As indicated above, during low flows, a larger proportion of mine wastewater will be fed to the DeSALx® treatment facility of the water treatment plant to ensure that site-specific criteria for copper and zinc are met at the compliance point at end of the mixing zone.

The residual impacts associated with TSS are predicted to be high on a sub-local scale (within 2 to 4km) in the vicinity of Boganchong Creek (due to construction of the process plant and portal terrace facilities) and the Bavaga River (due to construction of the borrow pits, quarries, laydown areas, access roads and gravel extraction). These elevated TSS loads are predicted to occur for the construction period only and are not predicted to persevere at such levels during operations once exposed surfaces are rehabilitated and revegetated; hence, residual impacts are expected to lessen over time.

The subsidence zone lake is predicted to have poor water quality such as low pH and elevated sulphate and metals concentrations for at least 50 years after closure (Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone). This is currently predicted to require the active treatment of water prior to its release to the environment if water quality criteria are to be met (pending the results of further study during operations). Further information about this is provided in Section 14.3, Groundwater.

#### 15.5.3.5. Surface Water Mixing Zone and Compliance Points

In PNG, a mixing zone can be included in an environment permit under the *Environment Act 2000*. The downstream end of the mixing zone is normally the first location downstream of the proposed discharge point where local people use the river and is likely to be the compliance point under the environment permit.

Two compliance points are proposed in the Mine Area for the Project:

- Located on the Lower Watut River approximately 0.5km upstream of the Wongkins Village and approximately 3km downstream from the outfall of the wastewater discharge pipeline.
- In Nambonga Creek, approximately 1.6km downstream of the wastewater discharge point (adjacent to the Nambonga Decline Portal Terrace) and approximately 0.7km upstream of Nambonga Village.

The WGJV proposes that these compliance points shall be the downstream boundaries of the mixing zones and the waters between the wastewater discharge pipeline and the compliance points shall be mixing zones where PNG ER water quality standards shall not be required to be met. The degree to which mine water will be treated will be adjusted to meet agreed water quality criteria at the agreed compliance points at the downstream extents of the mixing zones.

Compliance with the PNG ambient and drinking water regulatory criteria may not provide adequate protection for aquatic ecosystems or human health based on the current state of knowledge of toxicant exposure to biota and people. As such, the ANZECC/ARMCANZ (2000) guidelines for 95% aquatic ecosystem protection and site-specific criteria will provide trigger values for further action (which could include further site-specific investigations and/or additional management measures), where background concentrations do not exceed these guidelines.

## 15.6. Residual Impacts to Freshwater Ecology

This section summarises the predicted residual impacts of the Project on the freshwater ecology of the creeks, rivers and floodplain watercourses in the Project Area and downriver environment based on a detailed assessment provided in Appendix Y, Freshwater Ecology Impact Assessment.

The residual impact assessment assumes that proposed management measures have been successfully implemented to avoid, reduce or ameliorate potential impacts.

As described in Section 15.1, 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 Section 15.5, which involved combination of quantitative modelling, 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.

Via a thorough step-by-step process (Appendix Y, Freshwater Ecology Impact Assessment), the assessment of impacts on aquatic ecological values were evaluated in each of the sub-catchments listed in Table 15.11. 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

As such, the focus of the discussion of the impact assessment in the following sections is placed on the sub-catchments in the Mine Area most likely to be impacted by the Project (i.e., containing the greatest concentration of Project infrastructure and construction intensity), comprising:

- Boganchong Creek
- Womul Creek
- Lower Bavaga River
- Lower Watut River Eastern Floodplain
- Wafi River
- Lower Watut River

In some cases, however, sub-catchments that were assessed as having low residual impacts are discussed for contextual purposes or because they are likely to be of particular interest to stakeholders (i.e., the Lower Watut River on a regional scale). The impact assessments for other eastern creeks in the Lower Watut River floodplain, and watercourses in the Markham River floodplain and the Coastal Area are not presented in this chapter but provided in Appendix Y, Freshwater Ecology Impact Assessment.

**Table 15.11: High-level summary of residual freshwater aquatic ecological 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 |

## 15.6.1. Boganchong Creek

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

### 15.6.1.1. Construction

#### 15.6.1.1.1. Loss of Aquatic Habitat

The main channel aquatic habitats of a 1.4km-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. While upper Boganchong Creek is an ephemeral creek and ceases to flow during the dry season, surface water flows during the wet season 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 relates 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 4.5m high located 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 1.4km-long loss of microalgal and macroinvertebrate habitats represents about 58% of the upper Boganchong Creek main channel. The residual impacts of this habitat loss in the wet season are assessed as **moderate** 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 unaffected 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** based on a **very low** magnitude of impact and a **low** sensitivity.

#### 15.6.1.1.2. 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. Implementation of the Project Erosion and Sediment Control Plan is also expected to facilitate reduction of sedimentation rates. 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** based on a **high** magnitude of impact and a **low** sensitivity.

#### 15.6.1.1.3. 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 Watut Declines Portal Terrace, fine-grained sediments comprising very fine sands, silts and clays (<125µm diameter) will enter the natural drainage via overland flow during and following rainfall.

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, Freshwater Environment Characterisation) are sediment-tolerant species and experience naturally high TSS concentrations intermittently, 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.

Background TSS concentrations in Boganchong Creek during low to average flows are low (<5mg/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).

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

#### 15.6.1.1.4. Impacts Arising from Altered Hydrology

The residual impact on peak flow events and the overall flow regime of Boganchong Creek downstream of the Mine Area as a result of the effects of construction of Project infrastructure within its catchment is not predicted to be significant. A southern unnamed tributary of the Boganchong Creek enters the creek's main channel about 280m downstream of the waterfall, which drains a comparable sub-catchment area of $1.1km^2$ that is 87% of the sub-catchment with mine infrastructure ($1.3km^2$) and augments the flow in Boganchong Creek in its floodplain reach.

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** 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.

#### 15.6.1.1.5. Increased Particulate and Dissolved Contaminant Impacts

As described in Section 15.5.2.2 and Appendix Y, Freshwater Ecology Impact Assessment, metals and metalloids concentrations in Mine Area soils meet ANZECC/ARMCANZ (2000) sediment quality criteria with the exception of nickel. 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** 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.

### 15.6.1.2. Operations

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 (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River, Pickup (2015a, 2015b) and Hydrobiology (Appendix I of Appendix I, Catchment and Receiving Water Quality Modelling)).

Drainage from the process plant terrace, the Watut Declines Portal Terrace, and seepage from the Watut Waste Rock Dump are proposed to be intercepted and treated, so 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 at the end of a mixing zone (see Section 15.5.3). This will ensure that aquatic flora and fauna are protected. Significant levels (i.e., concentrations above water quality criteria) of dissolved or particulate-associated metals or metalloids are not anticipated in Boganchong Creek as treated mine wastewater is being directed to the Lower Watut River via the wastewater discharge pipeline.

Residual impacts during operations on the aquatic flora and fauna of Boganchong Creek downstream of the raw water dam are assessed as **low** 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.

### 15.6.2. Womul Creek

The residual impacts on freshwater ecology in Womul Creek are assessed below.

#### 15.6.2.1. Construction

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.

##### 15.6.2.1.1. 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 1-in-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.

The loss or alteration of creek bed habitat at these two road crossings is therefore assessed to be **low** based on a magnitude of impact of **low** and a sensitivity of **low**.

##### 15.6.2.1.2. Sedimentation Impacts on Freshwater Aquatic Habitats

Womul Creek will receive construction-derived sediment loads resulting from rainfall-based erosion and scour of disturbed or displaced soils from construction sites including mine access roads, the waste management facility, stockpiles and the Fere Accommodation Facility during the first the first three years of construction

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

The aquatic biological communities resident in 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 the creek is flowing. Construction-derived sediments are expected to increase sedimentation rates, 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. Residual impacts on the aquatic biological communities (principally benthic macroinvertebrates and fish) during the wet season are assessed to be **low** based on a **moderate** magnitude of impact and a **low** sensitivity. 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.

#### 15.6.2.1.3. 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) (see Section 15.5.2). 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 residual impact assessment on aquatic ecology related to increases in TSS concentrations and associated turbidities in 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 (2.9km) of access road to be built within its catchment. Most infrastructure components will be built in the first two years of construction, 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. The residual impacts of construction-derived increased TSS concentrations on downstream aquatic macroinvertebrates and fish fauna of Womul Creek are assessed as **low**, based on a **moderate** magnitude of impact and a **low** sensitivity.

### 15.6.2.2. Operations

During operations, soils of most construction-disturbed areas in the Womul Creek catchment 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 of 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** based on a **very low** magnitude of impacts and **low** sensitivity.

## 15.6.3. Lower Bavaga River

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

### 15.6.3.1. Construction

#### 15.6.3.1.1. 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 1.5km-long reach of the Lower Bavaga River, located 2km downstream of Bavaga Village.

The extraction of river gravel from bars has a direct impact on the existing gravel bed freshwater aquatic habitat. 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[11] 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).

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**, 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 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.

#### 15.6.3.1.2. Altered Hydrology Impacts

As described in Section 15.4.1, residual impacts of altered hydrology as a result of diversion of flows for the Northern Access Road Borrow Pit and water use for the gravel pit on the freshwater aquatic habitats and biological communities of the Lower Bavaga River are assessed as **low**, 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).

#### 15.6.3.1.3. Sedimentation Impacts

As described in Section 15.5.2.1, in-river sedimentation may occur as a result of Bavaga River gravel extraction, the Northern Access Road Borrow Pit, Mt Beamena Quarry and their associated access roads.

Considering the implementation of proposed management measures, residual impacts of sedimentation on the aquatic habitats of the Lower Bavaga River derived from coarse-grained sediment delivery as a result of these Project activities are assessed to be **low**, based on a **moderate** magnitude of impacts and **low** sensitivity. This is based on the relatively localised and temporary nature of the predicted impacts.

#### 15.6.3.1.4. 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. The Lower Bavaga River gravel extraction, the Northern Access Road Borrow Pit, the Mt Beamena Quarry and its access road have the potential to deliver fine grained sediment to the natural drainage. Minor fine-grained sediment delivery is also expected from the Infrastructure Corridor crossing of the

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

floodplain reach of the Lower Bavaga River but is not assessed given the expected very short term and highly localised impact on water quality.

Among the ten species of fish caught in the Lower Bavaga River (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River), 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 naturally experience regularly in the Lower Bavaga River during rising and flood flows.

Given the in-borrow pit management of surface and stormwater, as well as implementation of the proposed management measures for the borrow pit 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.

The residual impacts of deteriorated water quality (i.e., increased TSS concentrations and turbidity) on the aquatic biological communities of the Lower Bavaga River are assessed to **low**, based on a **low** magnitude of impact and a **low** sensitivity.

#### 15.6.3.2. Operations

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

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 are also assessed to be **low**, based on a **low** magnitude of impact and a **low** sensitivity.

### 15.6.4. 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.

#### 15.6.4.1. Construction

##### 15.6.4.1.1. Altered Hydrology Impacts

The potential for altered hydrology relates to the construction of the Lower Papas Aggregate Source, the Watut Services Road, access roads, the wastewater discharge and raw water make-up pipelines, and service track traversing watercourses of the floodplain.

Measures to manage flow impedance along the Watut Services Road 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.

Given that the Lower Papas Aggregate Source will be located in flat terrain, changes to the natural flow regime will be limited.

Short term and highly localised impacts on hydrology are anticipated as a result of construction of the buried wastewater discharge and raw water make-up pipelines. Similar to the Watut Services Road, the service track will be constructed with the appropriate number and density of culverts to avoid impedance of flows and watercourse crossings.

The residual impacts of changes to hydrology, flow impedance and temporary areas of detained flood waters due to road and pipeline construction and gravel extraction are short-term impacts that has been assessed as **low** based on a **low** magnitude of impact and **low** sensitivity for aquatic habitats and biological communities.

#### 15.6.4.1.2. Sedimentation Impacts on Aquatic Ecology

For the Watut Services Road, very short-term sedimentation impacts are anticipated to occur immediately downstream of the three 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.

With implementation of proposed management measures such as installation of a contour drain around the Lower Papas Aggregate Source perimeter or berm to prevent the inflow of surface water and the use of sedimentation ponds, suspended fine sediments and subsequent discharge offsite to the natural drainage will be limited. Given the flat terrain and implementation of management measures along the wastewater discharge and raw water make-up pipelines and service track route, 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 residual impacts of predicted short-term and minor sedimentation of floodplain aquatic habitats associated with the construction of the Lower Papas Aggregate Source, Watut Services Road and construction, installation and burial and infilling of the wastewater discharge pipeline are assessed as **low**, based on a **very low** magnitude of impact and **low** sensitivity (common and widespread aquatic type within the Lower Watut River's eastern floodplain).

#### 15.6.4.1.3. Water Quality Impacts to Aquatic Biota

As discussed in the previous section, predicted increased TSS concentrations downstream of the Watut Services Road, the wastewater discharge and raw water make-up pipelines, and the associated service track are expected to be of short duration, basically for the period of active in-creek construction works. The floodplain gravel extraction operation is predicted to have little or no impact on floodplain and creek water quality based on the reasons described in the preceding sections.

Given that sediment-laden surface runoff drains to vegetated areas, and as assuming implementation of proposed management measures will reduce TSS concentrations, residual impacts of altered water quality on the aquatic biological communities of the affected floodplain creeks are assessed to be **low**, 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.

Further, floodplain fish and macroinvertebrates are naturally frequently exposed to short-term sustained high TSS concentrations and turbidity occasioning floodplain inundation as a result of Lower Watut River overbank flood flows.

##### 15.6.4.2. Operations

During the operations phase only surface runoff from the Watut Access Road will continue to be a minor source of fine sediment loading to the floodplain. The residual impacts of this are assessed to be **low**, based on a **very low** magnitude of impact given the flat terrain and a **low** sensitivity.

### 15.6.5. Wafi River

Within the Wafi River catchment, Project infrastructure is located in Buvu, Nambonga, Buvu and Yor creek sub-catchments. Tributary rivers of the southern Wafi River catchment crossed by the Resettlement Road include the Zamen, Tovu, Dumbeyo and Kwepkwep rivers.

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

#### 15.6.5.1. Construction

##### 15.6.5.1.1. Buvu Creek

###### 15.6.5.1.1.1. Sedimentation Impacts on Freshwater Aquatic Habitats

Coarse-grained sediment delivery to the local drainage lines as a result of Migiki Borrow Pit and access road is expected to be minimal as described in Section 15.5.2. 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.

The existing freshwater aquatic habitats of Buvu Creek, as well as Nambonga Creek discussed below, 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).

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.

###### 15.6.5.1.1.2. Water Quality Impacts on Freshwater Aquatic Biota

The implementation of the Project Erosion and Sediment Control Plan for the Migiki Borrow Pit and access road within Buvu Creek catchment is expected to reduce sediment delivery to the natural drainage.

During freshwater ecology surveys of the Project Area by BMT WBM (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River) 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 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.

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**, based on a **low** magnitude of impact and a **low** sensitivity (common and widespread macroinvertebrate and fish fauna).

#### 15.6.5.1.2. Nambonga Creek Impacts

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

#### 15.6.5.1.2.1. Sedimentation Impacts on Freshwater Aquatic Habitats

Offsite coarse-grained sediment from the Nambonga Decline Portal Terrace is expected to be low given the small area of the portal terrace (0.45ha), 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.

An 0.2km-long section of the Nambonga Haul Road up to the Nambonga Decline Portal is an upgrade of the existing access road and is not expected to result in significant coarse sediment delivery to the natural drainage, with most sediments settling on land immediately downslope of the road. Construction of the remaining section of the Nambonga Access Road will result in short-term coarse-grained sediment delivery to the local drainage lines; however, this will be reduced with implementation of measures in the Project Erosion and Sediment Control Plan.

Residual impacts of sedimentation on the freshwater aquatic habitats of Nambonga Creek main channel from Project construction are assessed as **low**, based on a **low** magnitude of impact and **low** sensitivity (due to the common and widespread freshwater aquatic habitat type in the Project Area and beyond).

#### 15.6.5.1.2.2. Water Quality Impacts on Aquatic Biota

Fine-grained sediments (<125µm) carried in overland flow from construction areas will report as suspended load to Nambonga Creek. 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). Delivery of fine-grained sediments is 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 the same species matrix. Given that the effects of TSS concentrations on fish, for example, are time duration-concentration dependent (NSR, 1986; Newcombe and MacDonald, 1991; Newcombe, 1994; DBA, 2005), intermittent exposure to such high concentrations is of short duration, readily tolerated and inconsequential.

Underground dewatering flows from the Nambonga Decline Portal, and runoff and seepage waters from the Miapilli Waste Rock Dump will be captured, treated if necessary using a water treatment plant located at the Nambonga Decline Portal Terrace, and discharged to Nambonga Creek adjacent to the terrace.

**Sulphate.** As discussed in Section 15.5.3.1, most of the PNG ER ambient water quality criteria, with the exception of sulphate at low flows, are expected to be met in Nambonga Creek downstream of a 1.6km-long mixing zone beyond the discharge point at the proposed compliance point downstream.

The concentration of sulphate in the treated discharge (695mg/L, Clean Teq, 2017) will require approximately 1.7 dilutions to meet the PNG ER criterion for sulphate (400mg/L). At average flows in Nambonga Creek, sulphate concentrations will meet the PNG ER criterion based on dilution. At low flows, however, a larger proportion of mine wastewater will be fed to the DeSALx® treatment facility of the water treatment plant to improve water quality and ensure that PNG ER criteria are met at the compliance point at end of the mixing zone.

**Copper and zinc.** At low or treated water discharge flow only in Nambonga Creek, copper and zinc may not meet site-specific criteria between the discharge point to the confluence of Nambonga Creek with the Wafi River (2.4km), exceeding the criteria by 5 and 2-fold, respectively. During the average flow range in Nambonga Creek (250 to 500L/s, offering between 4.3 and 8.6 dilutions), 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, to ensure compliance site-specific copper and zinc criteria at the end of the mixing zone, the proportion of mine wastewater feed to the DeSALx® treatment facility of the water treatment plant will be increased to improve the treated water quality.

The residual impacts of deteriorated water quality (increased TSS concentrations and treated water discharges) 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**, based on a **low** magnitude of impact and a **low** sensitivity.

#### 15.6.5.1.3. Yor Creek

##### 15.6.5.1.3.1. Sedimentation Impacts on Aquatic Habitats

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

With implementation of erosion and sediment control measures (to be designed for the Miapilli Waste Rock Dump during the detailed design phase), residual sedimentation impacts on the aquatic habitats of Yor Creek downstream of Project infrastructure are assessed to be **low**, based on a **low** magnitude of impact and **low** sensitivity (common and widespread upland aquatic habitat type).

##### 15.6.5.1.3.2. 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 are not expected on the assumption that this seepage will be collected and treated, if required, prior to discharge within the Nambonga Creek catchment.

In terms of residual impacts on aquatic macroinvertebrates 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 construction phase and active placement of waste rock within the waste rock dump, TSS concentrations are expected to diminish as soils stabilise and revegetate with minimal erosion.

Overall, the residual impacts of deteriorated water quality (increased TSS concentrations and contaminants associated with waste rock dump leachate) associated with Project construction in Yor Creek catchment on aquatic macroinvertebrate and fish fauna are assessed to be **low**, based on a **low** magnitude of impact and a **low** sensitivity (due to the common and widespread macroinvertebrate and fish fauna of Wafi River upper catchment tributaries).

#### 15.6.5.1.4. Resettlement Road Impacts

There is predicted to be 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 are revegetated (Section 15.5.3.2).

Most of the macroinvertebrate and fish assemblages of the Wafi River system (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River) 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 (*Clarias 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**, based on a **moderate** magnitude of impact and a **low** sensitivity.

#### 15.6.5.2. Operations

During operations, impacts on freshwater ecology in the Wafi River catchment are predicted to be minor, since 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. Sediment generation from this sort of road usage is typically 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** based on a **very low** magnitude of impacts and **low** sensitivity.

### 15.6.6. 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.

#### 15.6.6.1. Construction

##### 15.6.6.1.1. Sedimentation Impacts to Freshwater Aquatic Habitats

On a whole-of-catchment basis, the construction sediment loads are predicted to 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** based on a **low** magnitude of impact and **low** sensitivity (due to the common and widespread turbid river aquatic habitat type).

Furthermore, during the latter years of construction and early operations, sediment loading is expected to decrease progressively toward pre-disturbance levels 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).

##### 15.6.6.1.2. Treated Wastewater Discharge Impacts

During construction, all dissolved metal/metalloid predictions in the Lower Watut River downstream of the mixing zone and agreed compliance point are predicted to be below the PNG ER and (hardness corrected) ANZECC/ARMCANZ (2000) guidelines, as well as within natural background variability (see Section 15.5.3).

Residual contaminant impacts on the aquatic biological communities of the Lower Watut River during operations are therefore assessed to be **low**, based a **low** magnitude of impact and **low** sensitivity.

#### 15.6.6.2. Operations

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 as, or less than, for construction above.

During operations, minor sediment loads 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. 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 (Appendix I, Catchment and Receiving Water Quality Modelling), the operations phase sediment loads are predicted to contribute a very small proportion (approximately less than 0.1% annually) to the high natural loads of the Lower Watut River main channel.

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** based on a **low** magnitude of impacts and **low** sensitivity.

### 15.6.7. Species of Conservation Significance

Impacts on species of conservation significance, such as IUCN-listed and 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 to occur in the Mine Area and Infrastructure Corridor. There is a low likelihood of adult individuals of the Indo-Pacific subpopulation of the largetooth sawfish (*Pristis 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**, based on a **low** magnitude of impact and a **low** sensitivity (due to it being a known sediment-tolerant fish species).

### 15.6.8. Invasive Aquatic Flora and Fauna

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 are assessed below.

#### 15.6.8.1. Invasive Aquatic Macrophytes

Only one species of aquatic weed, the water lettuce (*Pistia 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 (*Eichhornia crassipes*), which was not observed in field surveys undertaken by BMT WBM (2013a,b; Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River). 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. 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.

There are no Project construction or operational activities that physically impinge directly on oxbow lakes where species such as the water lettuce were recorded; therefore, the likelihood of accidental dispersal by the Project is very low.

As potential aquatic macrophytes could be encountered in floodplain tributaries at watercourse crossings, the risk of spreading invasive species can be reduced by the hosing-down of construction plant equipment as a mitigation measure, following completion of watercourse crossings.

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

#### 15.6.8.2. Invasive Exotic Fish Species

Aquatic ecology surveys by BMT WBM (2013a,b; Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River) 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, *Gambusia holbrooki*) or to provide a food source of protein to local communities across the country.

Many species such as European carp (*Cyprinus carpio*), swordtails (*Xiphophorus helleri*), mosquitofish and Mozambique tilapia (*Oreochromis 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 Project construction or operational impacts on the floodplain swamps and tributaries.

Some species of introduced fish such as the golden mahseer (*Tor 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 (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River) 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 (*Clarias batrachus*), which was found in Boganchong and Womul creeks and floodplain swamps (Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation - Mine Area to Markham River).

Overall the residual impacts of the Project of introduced fish species are assessed to be **low** 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.

### 15.6.9. Post-closure Aquatic 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 subsidence zone lake, and post-closure seepage waters from the Watut Declines Portal Terrace, the Nambonga Decline Portal Terrace and the Watut and Miapilli Waste Rock Dumps. Post-closure impacts of the subsidence zone lake are assessed in detail in Section 14.3, Groundwater, with baseflow surface water recharge and water quality impacts briefly discussed above in Section 15.5.1.1 and Section 15.5.3.

#### 15.6.9.1. Post-Closure Subsidence Zone Lake Outflows

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 guidelines (2000) receiving water guidelines for the protection of 95% of aquatic species. As discussed in Section 8.3, Groundwater, however, existing groundwater quality in the vicinity of the proposed block caves has acidic pH and concentrations of aluminium, cadmium, cobalt, copper, iron, mercury and zinc in exceedance of guidelines. Lead, chromium and nickel also exceed the guideline values at some locations. The concentrations of these parameters are considered to be representative of the baseline conditions associated with mineralisation in the Mine Area.

With accelerated flooding of the block caves and declines and application of lime treatment, the predicted concentrations of manganese (3.2mg/L) and iron (2.9mg/L), are predicted to still exceed the PNG ER criteria (0.05mg/L and 1mg/L, respectively) 50 years post-closure. Concentrations of copper (0.2 mg/L) and aluminium (1.6 mg/L) are predicted to 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.

Water from the subsidence zone lake, and associated products of AMD, could potentially affect the water quality downstream of the lake through discharge via groundwater springs and the lake's spill point.

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 (as currently modelled at least 50 years).

In the Project Environmental Management Plan (Attachment 3), it is proposed to monitor the quality of seepage and spill from the subsidence zone lake and treat any contaminated water during the post-closure period until water quality closure objectives are met.

At this juncture, the residual impacts of treated seepage and/or subsidence zone lake overtopping discharges to the Wafi River system are assessed to be **low**, based on a **low** magnitude of impact and a **low** sensitivity (common and widespread aquatic flora and fauna) and the assumption that such metal- and metalloid-contaminated waters will be treated to meet water quality guidelines.

As indicated in Section 15.5.3.1, 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 downstream impacts to the freshwater environment may be higher than predicted. Modelling of final pit lake water quality and engineering solutions will be progressively improved as actual data is accumulated during operations.

#### 15.6.9.2. Post-closure Drawdown Impacts on Baseflows in Creeks

Piteau, in Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone and Appendix F, Groundwater Management and Modelling of Inflows to Golpu Underground Mine, modelled the effects of groundwater drawdown and mine dewatering on baseflows in creeks draining the Mt Golpu area. The main affected creeks are predicted to be Buvu and Nambonga creek catchments with reduced effects in Hekeng River and Wafi River catchments (see Section 15.5.1.1).

While reduced baseflows could add stress to the aquatic ecosystems, the residual effects on aquatic biological communities of these creeks are predicted to be 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, including if they are reduced in flow/duration as a result of the Project).

The residual impacts of 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**, based on a magnitude of impact of **low** and a sensitivity of **low**.

### 15.6.10. Residual Impact Summary

Most of the Project's residual impacts on aquatic 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 improve toward pre-disturbance levels. This pattern and duration of recovery has been observed at many other mines in PNG (e.g., NSR, 1988 and 1999).

## 15.7. Monitoring

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

Monitoring potential impacts of the Project on the freshwater aquatic environment and the performance of the proposed management measures will 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) that will not be impacted by Project construction and operation.
- Continued use of gauging stations to monitor water level and flow.
- Monitoring of aquatic ecology (flora and fauna) in watercourses downstream of the Project Area, as well as at already-established baseline sites (see Figure 9.1), 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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