Chapter 19

Health Risk Assessment

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

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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.

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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.

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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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This chapter addresses the human health risk assessment (HHRA) for the Wafi-Golpu Project (the Project) undertaken by Coffey Environments Australia Pty Ltd (Coffey) and presented in Appendix W, Human Health Risk Assessment. It also draws on the information presented in the Assessment of Metal Bioaccumulation and Biomagnification from DSTP in the Huon Gulf (Appendix N), the Socioeconomic Baseline (Appendix T) and Chapter 18, Socioeconomic Impact Assessment.

The HHRA identifies potential human health risks to receptor populations associated with Project activities. Potential exposures to Wafi-Golpu Joint Venture (WGJV) employees and contractors are not the subject of the EIS and will be assessed separately by WGJV in accordance with its work place health and safety requirements. The evaluation of potential impacts of Project activities on lifestyle-related illnesses is addressed in Chapter 18, Socioeconomic Impact Assessment.

19.1. Approach to Risk Assessment

The HHRA followed four steps in accordance with the Australian National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (NEPC, 2013), referred to herein as the NEPM, comprising:

- Identifying the key study areas
- Developing a conceptual site model to identify potential exposure pathways (i.e., ways in which humans could be exposed to contaminants)
- Identifying the appropriate assessment criteria
- A two-tiered risk assessment for both baseline and Project conditions

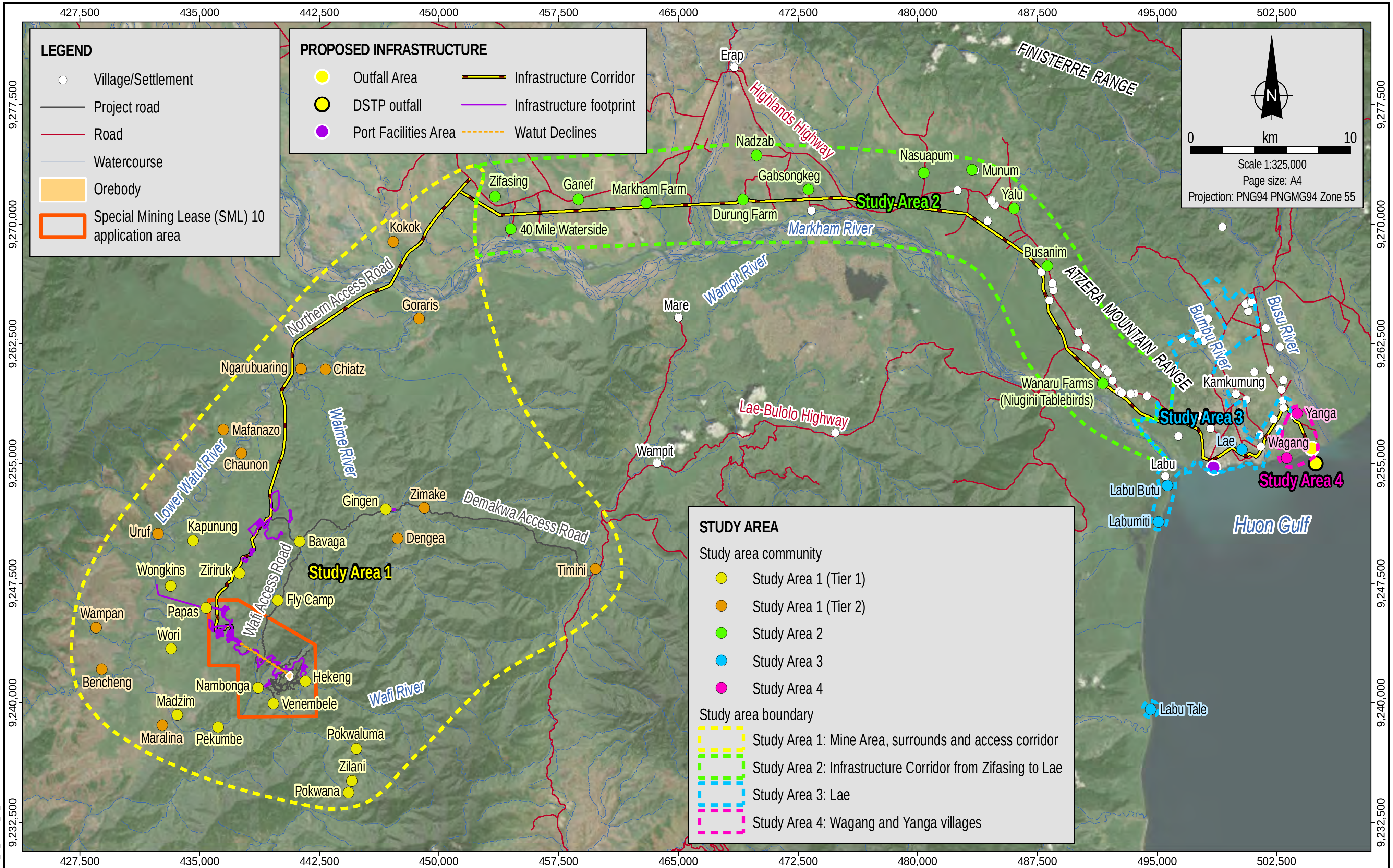
Impacts to ecological receptors (such as terrestrial or aquatic flora and fauna) have been assessed separately in: Chapter 14, Physical and Biological Environment Impact Assessment; Chapter 15, Freshwater Environment Impact Assessment; Chapter 16, Nearshore Marine Environment Impact Assessment; and Chapter 17, Offshore Marine Environment Impact Assessment.

19.1.1. Study Areas

The Socioeconomic Baseline (Appendix T) defined four geographic study areas to characterise groups of people that may be subject to impacts associated with the Project. Potential Project impacts to people’s health are identified and assessed for each of the same four study areas, which broadly group together people and communities who may experience qualitatively similar impacts should the Project be developed (Figure 19.1):

- Study Area 1: Mine Area, surrounds and access corridors
- Study Area 2: Infrastructure Corridor from Zifasing to Lae
- Study Area 3: Lae (including the Infrastructure Corridor and Port Facilities Area)
- Study Area 4: Wagang and Yanga villages (including Outfall Area and Infrastructure Corridor)

As defined in Chapter 12, Socioeconomic Environment Characterisation, the term ‘village’ refers to customary landowners living in a self-identified group of households. ‘Settlement’ refers to non-landowners living in a self-identified group of households, either under an arrangement with customary landowners (formal settlements) or with no customary arrangement or other entitlement (informal settlements). ‘Community’ is used generically to include villages and settlements, and refers to a set of people who interact socially.



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

coffey
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Date: 13.06.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_23_F19.01_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

HHRA study areas

Figure No: 19.1

MXD Reference: 0520DD_10_GIS053_v0_3

For the purposes of the HHRA, people located near the Labu Lakes were also included in Study Area 3 because the villages of Labu Butu, Labumiti and Labu Tale provide representative baseline information for coastal community diets. Communities in Study Area 2 will be impacted during the construction phase of the Project only and given management measures are proposed to manage the release of contaminants via soil or surface water runoff, chronic exposures posing health risks are not considered likely. As such, Study Area 2 is not considered further in the HHRA.

19.1.2. HHRA Study Method

The HHRA was conducted using a two-tiered assessment approach involving a progressively more detailed level of analysis to evaluate both the baseline conditions and the potential human health risks associated with the Project.

The terms Tier 1 and Tier 2, as relevant to the HHRA, relate to the location and land ownership of certain villages within Study Area 1, as defined in the Socioeconomic Baseline (Appendix T), and also to the staged approach adopted in the risk assessment process. In order to avoid confusion, the study area tiers have been presented as Study Area 1 (Tier 1) and Study Area 1 (Tier 2). The tiered process used in the HHRA approach is referred to as the Tier 1 (T1) and Tier 2 (T2) assessments, and are defined in this chapter as follows:

- **Tier 1 (T1) screening assessment.** The Tier 1 (T1) screening assessment of baseline exposures to human receptors was undertaken based on a comparison of concentrations measured in media (i.e., air, sediment, water and food) with adopted screening criteria protective of human health, based on Independent State of Papua New Guinea (PNG) and international guidelines and standards. The Tier 1 (T1) screening assessment of baseline or modelled existing conditions for the Project identified whether further assessment was warranted for any of the contaminants of potential concern (COPC) identified in the conceptual site model discussed in Section 19.2. Tier 1 (T1) screening levels are conservative as they are typically derived to protect the most vulnerable populations under a variety of circumstances. Exceedance of Tier 1 (T1) screening criteria is generally used as the trigger for determining which COPC progress to the Tier 2 (T2) assessment and which exposure pathways require more detailed evaluation. However, in instances where criteria are not proposed or where there are no appropriate risk-based guidance levels, the requirement for a Tier 2 (T2) assessment is also triggered.
- **Tier 2 (T2) quantitative assessment.** Progression from Tier 1 (T1) to Tier 2 (T2) assessment was undertaken when screening levels were exceeded, screening levels were not available, or when uncertainty remained and the risks were not well understood. In the Tier 2 (T2) assessment, risks to potentially exposed human populations were assessed using site-specific data for exposure pathways, land uses and the characteristics of the exposed populations.

The investigations used to inform the baseline Tier 1 (T1) and Tier 2 (T2) assessments included field sampling of freshwater and marine waters, sediments, air, and terrestrial and aquatic biota. The data collected during the surveys generally focussed on areas downstream of the Mine Area and the Huon Gulf.

The Tier 1 (T1) assessment for Project conditions was based on environmental data modelling results that informed this EIS, cited as applicable throughout this chapter. If the modelling data had indicated COPC levels in the environmental media were likely to be higher than those in baseline conditions, then the HHRA would have proceeded with the Tier 2 (T2) assessment for Project conditions.

The Tier 2 (T2) assessment identified potentially complete exposure pathways by which COPC in air, soil or water could reach human health receptors, either directly or indirectly. An exposure pathway is only considered complete when all four of the following elements can be linked: a contaminant source (such as disturbed soil), transport/migration of the contaminant (such as in surface water runoff discharging to a creek) to a receptor (in this case a person) who is then exposed via an exposure route (such as ingestion of water). The following exposure pathways were considered:

- Ingestion or dermal (i.e., skin) contact through bathing, cleaning or recreational activities (such as swimming or fishing)
- Ingestion of food sources, including drinking water (from primary and secondary water sources) and aquatic and terrestrial foods
- Inhalation of ambient air

The Tier 2 (T2) quantitative risk assessment was conducted in accordance with the NEPM (2013). The risk assessment approach provided in the NEPM is consistent with international guidance published by environmental agencies such as the United States Environmental Protection Authority (USEPA), United Kingdom Environment Agency and Canadian Council of Ministries for the Environment (CCME). Additional guidance documents and international sources were also consulted where information was lacking from NEPM (2013).

The Tier 2 (T2) quantitative risk assessment also involved calculations to determine which COPC are potential risks to human health as a result of the Project. Further details on all calculations are provided in Appendix W, Human Health Risk Assessment. The following calculations were completed:

- **Estimated intake dose:** the estimated human intake dose of COPC via exposure routes such as dermal contact and ingestion pathways, using methods provided in NEPM (NEPC, 2013) and the USEPA Risk Assessment Guidance for Superfund sites (USEPA, 1989, 2004, 2009). These calculations account for parameters such as age (young children and adults), area of exposed skin, average exposure time per day, duration and frequency, bioavailability factors, body weight, ingestion rates and contaminant concentration.
- **Food ingestion calculation:** calculation based on food types ingested, and quantity and frequency of ingestion, for a child (0 to 5 years) and an adult. The estimated food intake was based on information collected from Market Basket surveys from the communities in the vicinity of the Lower Watut River and Huon Gulf (Bentley, 2011), supplemented with food diary surveys from the Ok Tedi and Fly River community studies (Bentley, 2007). While some data from the Bentley (2007 and 2011) studies was collected from people within the Project Area, surrogate data from similar mining communities in PNG (i.e., data that is relevant considering the location and characteristics of the community, but is not collected from Project Area communities) was also used. Data sources are discussed further in Section 19.1.3, and Appendix W, Human Health Risk Assessment, provides a full discussion on surrogate data used in the calculations.
- **Human health toxicity assessment:** the determination of whether human exposure to a contaminant could cause an increase in the incidence of an adverse health condition, either threshold (non-carcinogenic) or non-threshold (carcinogenic) in nature. This assessment is consistent with the International Agency for Research on Cancer (IARC, 2017) and USEPA cancer classifications (USEPA, 2005) and was based on NEPM toxicity reference value recommendations for the identified COPC in the Tier 2 (T2) assessment.

- **Risk assessment:** quantitative risk assessment of contaminants that presented threshold (non-carcinogenic) health effects (that in some instances were also protective of non-threshold health effects) through calculation of a hazard quotient (HQ) for each COPC for each exposure pathway. Threshold contaminants have a specific dose at which no health effects are observed. A HQ is based on a comparison of the estimated intake from each pathway (i.e., the level of exposure to a contaminant at which no adverse effects are expected). To estimate the additive effect of exposure to a contaminant via multiple pathways, the HQs were summed to obtain a hazard index (HI) for exposures to a particular receptor population. Where the HI is less than one (1), the risk of adverse health effects associated with exposure to the contaminant is considered low. However, HI exceeding one (1) does not necessarily indicate an actual risk but rather a potential adverse health outcome requiring additional assessment.

19.1.3. Data Sources

Data to inform the HHRA has been sourced from Project-specific data in the first instance. Where Project-specific data was not available (i.e., detailed food studies), data from a 2011 Market Basket survey (Bentley, 2011) was used. The Market Basket survey included the assessment of fish, molluscs and prawns in several villages around Labu (assumed to be Labu Butu and Labu Tale) within Study Area 3. While the data collected for the Market Basket study was obtained several years ago, villagers are likely to still be consuming the same types of foods as the conditions in Study Area 3 have not undergone major demographic, environmental or economic change. The concentrations of metals in foods are unlikely to have changed significantly over this period; however, further data will be obtained closer to construction to confirm baseline conditions for foods, particularly terrestrial and aquatic plants not sampled in the more recent studies, or where data sets are considered small.

Where site-specific information had not yet been collected or was considered insufficient, surrogate data relating to selected exposure parameters was used from the Ok Tedi and Fly River studies (Bentley, 2007). Extensive data was collected from the studies of control and impacted village communities within five defined highland, lowland and estuarine/marine regions in Western Province, PNG. The studies included both control and impacted villages that were selected based on their locations in relation to the Ok Tedi Mining operations and their potential to have been impacted by chemicals in local foods that may have been released to the environment as a result of mining related activities.

It is possible that some foods will be over-represented and others under-represented given some differences in food sources in the Ok Tedi and proposed Project areas. Some foods will be substituted for others but unless the substitution involves foods with widely divergent contaminant levels it is unlikely to make a significant difference to the intake calculations.

While the use of data from Bentley (2007 and 2011) is considered useful in this HHRA, further data collection from the Project study areas will be undertaken prior to construction, including an updated Market Basket survey, a time-activity study, expanded baseline air quality monitoring and expanded sample collection for garden soil, drinking water and other potential sources of exposure to COPC. At that time the HHRA will be revised and implications for any change to risk to human health will be addressed.

19.2. Conceptual Site Model

The development of the conceptual site model is critical as part of the baseline assessment to determining which communities may currently be exposed to contaminants and as a result of Project activities during construction, operations and closure.

The conceptual site model identifies:

- Contaminant sources:
  - Media such as air, soil, surface water, sediment, groundwater and local human food sources such as aquatic biota (e.g., fish) and terrestrial biota (e.g., edible plants) containing contaminants based on the available baseline study data
  - Media to which contaminants may be introduced as a result of Project activities
- Transport pathways: the potential transport mechanisms following contaminant release
- Receptors: human populations potentially exposed to these contaminants
- Exposure routes: the routes of exposure whereby a contaminant may enter the body

These four components together represent the exposure pathway, which is the course a contaminant takes from the source to the point via the transport pathway(s) to the point where a person (receptor) may be exposed and the route by which the exposure occurs. The components of the conceptual site model are described further below.

19.2.1. Source

The following key features and activities have been identified as potential sources of contaminants for further evaluation in the HHRA:

- Disturbed soil and exposed soil surfaces (contaminant: metals and metalloids)
- Air emissions from vehicles, power generators and the power generation facility (contaminant: particulate matter less than 10 microns in aerodynamic diameter (PM_{10}), particulate matter less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2))
- Wastewater discharges (contaminant: metals and metalloids, other chemical mixtures)
- Acid and metalliferous drainage via rainwater and/or groundwater infiltration (contaminant: low pH, metals and metalloids)
- Discharge of tailings to Huon Gulf at a depth of approximately 200m (deep sea tailings placement (DSTP))

Other low volume contaminant sources associated with ancillary infrastructure such as workshops, offices, construction camp, laboratories, flocculants and reagent storage, sewage treatment plants, general waste disposal storage and the explosives magazine are generally expected to be managed via the implementation of environmental management plans and have not been considered further in the HHRA.

19.2.2. Transport Pathways

The potential transport of contaminants from the source areas is via:

- **Air**: where transportation of contaminants could be in the form of particulate matter or gas emissions resulting from clearing and construction, transport, ore stockpiles and the operation of onsite diesel generators (construction), power generation facilities (operations), machinery and vehicles.
- **Water**: where dissolved contaminants or suspended solids from exposed soils, mining processes, waste rock, waste waters, tailings disposal and run-off waters are discharged to downgradient surface waters such as creeks, rivers or marine waters, and/or are deposited in the terrestrial environment (i.e., floodplains).

19.2.3. Receptors

In Study Area 1 (Mine Area, surrounds and access corridors), people may be directly impacted by Project activities through their proximal location to Project infrastructure and access corridors and uses of land and waterways potentially impacted by the Project.

People in Study Area 3 (Lae) and Study Area 4 (Wagang and Yanga) are closest to the Outfall Area for DSTP and are known to regularly consume locally caught seafood.

Both Lae and Labu populations (Study Area 3) have been considered in the HHRA, however the Labu villages (Labu Butu, Labumiti and Labu Tale) are likely to have greater potential exposures as their diets are primarily from local food sources. The Labu villages have also been included as no dietary data was available from Lae (nor the Study Area 4 villages). As such the Labu villages have been used to assess the potential baseline health impacts in Study Area 4. The population of Lae is assumed to obtain the majority of their food from stores and to generally obtain their drinking water via a reticulated water supply, and as such would be less impacted by Project activities.

As described in Section 19.1.1, Study Area 2 (Infrastructure Corridor from Zifasing to Lae) is not considered to be a receptor for the HHRA.

Young children are considered to be the most sensitive age group as the relative intake for young children (aged 0 to 5 years) has been demonstrated to differ from older children and adults based on weight to food intake ratios and hygiene behaviours. Consequently, receptors have been split into two age groups as consistent with the NEPM (2013) and FSANZ (2016) calculations: adults and young children 0 to 5 years.

19.2.4. Exposure Routes

Routes of exposure whereby a contaminant may enter the body are via inhalation, ingestion and dermal contact. Examples of exposure routes relevant to the HHRA include:

- Inhalation of gases such as those emanating from fuels or exhaust emissions
- Inhalation of contaminants in airborne particulate matter
- Ingestion of contaminants in food and water (and incidental ingestion of contaminants in other forms such as dust, soil and aerosols)
- Dermal contact with contaminants in media such as soil, sediment and water

19.2.5. Exposure Pathways

The exposure pathways for human receptors in the selected study areas to COPC associated with Project activities are presented in Table 19.1.

Table 19.1: Plausible exposure pathway evaluation – human receptors

Transport Pathway	Point of Exposure	Exposure Route	Potential Receptors Affected (by Study Area)	Selected for Baseline/ Project Impact Evaluation
Potential Project COPC Source: air emissions				
Volatiles in air	Outdoor air	Inhalation of volatiles	Study Area 1	Yes
			Study Area 3	No
			Study Area 4	No
Particulates transported in air	Plant via foliage or soil deposition and uptake	Ingestion of contaminated food	Study Area 1	Yes
			Study Area 3	No
			Study Area 4	No

Transport Pathway	Point of Exposure	Exposure Route	Potential Receptors Affected (by Study Area)	Selected for Baseline/ Project Impact Evaluation
	Terrestrial animal uptake		Study Area 1	Yes
			Study Area 3	No
			Study Area 4	No
	Direct contact pathways	Incidental ingestion Particulate inhalation Dermal contact	Study Area 1	Yes
			Study Area 3	No
			Study Area 4	No
Potential Project COPC Source: water				
Surface water, freshwater and marine(1)	Domestic purposes	Direct ingestion Dermal contact	Study Area 1	Yes
			Study Area 3	No
			Study Area 4	No
	Recreation	Incidental ingestion Dermal contact	Study Area 1	Yes
			Study Area 3	Yes
			Study Area 4	Yes
	Soils or sediments in areas associated with sediment deposits from flooding events	Ingestion of garden/crop plants grown in floodplain Dermal contact	Study Area 1	Yes
			Study Area 3	No
			Study Area 4	No
	Fishing, hunting	Ingestion of animals (including animal products) inhabiting/utilising surface and marine waters	Study Area 1	Yes
			Study Area 3	Yes
			Study Area 4	Yes
Ground water	Bore or spring	Direct ingestion Dermal contact	Study Area 1	Yes
			Study Area 3	No
			Study Area 4	No

[1] Assumed to be freshwater in Study Area 1, and marine water in Study Area 3 and Study Area 4.

The source and transport pathways selected for further consideration include:

Baseline

- Air emissions: transportation of contaminants in the form of particulate matter or gas emissions resulting from clearing, burning and cooking activities or local traffic and industry in more urban areas.
- Freshwater sources (including groundwater) and associated sediments: contaminants dissolved in water or in sediments as a result of natural transport and deposition of sediments particularly during the wet season, via landslides or anthropogenic sources such as artisanal mining.
- Marine waters and sediments: contaminants dissolved in water or in sediments as a result of transport via Markham River and other rivers discharging to Huon Gulf, as well as other activities that potentially impact on water quality (e.g., commercial or municipal discharges in Lae).

Project

- Air emissions: where the transport pathway for contaminants could be in the form of particulate matter resulting from dust generation during clearing and construction, transport, rock stockpiles and gas emissions due to operation of the power generation facilities, machinery, vehicles and underground blasting residues.
- Wastewater discharge and sediment discharge: where dissolved contaminants or suspended solids from wastewaters are discharged to the downstream receiving environment, such as the Lower Watut River.
- Discharge of mine tailings to the Huon Gulf at a depth of approximately 200m: where dissolved contaminants or suspended solids from DSTP are discharged to marine waters in the Huon Gulf.
- Infiltration of acid and metalliferous drainage (AMD) to groundwater: where groundwater pH is low and dissolved contaminants are discharged to springs or waterways after mine closure.

19.2.6. Selection of Contaminants of Potential Concern

Based on the above discussion, the following COPC were identified for the Tier 1 (T1) screening assessment for baseline and Project conditions:

- Metals: antimony, arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium and zinc
- Particulates (PM_{10}), NO_2 and SO_2

The COPC selected for quantitative evaluation in the Tier 2 (T2) assessment (baseline and Project conditions) were further refined based on the outcomes of the Tier 1 (T1) assessment. This refinement considered:

- Antimony was identified in soils from the Mine Area as being relatively elevated when compared to the average crustal abundance in natural soils. Neither the mean nor 50th percentile concentrations of antimony in water, sediment or foods exceeded any screening criteria in the Tier 1 (T1) assessment (the higher of the two concentrations was selected). On the basis antimony is not readily absorbed following ingestion or dermal contact, it was not considered further.
- Arsenic and lead were not identified as COPC in the Tier 1 (T1) assessment as no exceedances of screening criteria for water, sediment or foods were observed. The Tier 1 (T1) screening evaluation was based on average concentrations of the metals. Arsenic exceedances were noted in fish tissue in the Assessment of Metal Bioaccumulation and Biomagnification from DSTP in the Huon Gulf (Appendix N), where the reported concentration ranges were used rather than the average concentration. However as both were noted to have elevated Geochemical Abundance Indices (a measure of the enrichment of elements) (INAP, 2018) and were measured in the blood or urine of some people at levels exceeding the health limits, they were selected as COPC.
- Cadmium, chromium, copper, molybdenum and nickel not did exceed criteria in the Tier 1 (T1) assessment and were not identified as a potentially elevated in the Geochemical Abundance Indices. These metals were not assessed further in this assessment.
- Mercury, assumed to be in organic form, exceeded criteria in fish from the deep-slope area of the Huon Golf. Mercury was measured in blood at levels exceeding the health limit in more than 15% of villagers surveyed in Labu 1 (assumed to be Labu Butu in Study Area 3) and hence was selected as a COPC.

- Elevated average levels of zinc were measured in freshwater fish. Zinc was also identified as being elevated in relation to the average crustal abundance and therefore selected as a COPC for further evaluation.
- Air quality modelling (Appendix A, Air Quality and Greenhouse Gas Impact Assessment) predicted that emissions during operation of the intermediate fuel oil power generation facility may exceed the SO_2 screening criteria at two locations, Ziriruk and Fly Camp. The modelling outcomes indicate that people at these locations are potentially exposed to elevated levels of SO_2 for chronic exposure periods during the operation phase of the mine.

After refinement of the COPC, the COPC remaining for further assessment were: arsenic, lead, mercury, zinc and SO_2.

19.2.7. Assessment Criteria

The HHRA criteria were developed based on the standards and guidelines discussed below.

19.2.7.1. Air

The State of PNG regulations do not include specific air quality criteria. International guidelines were therefore reviewed to select appropriate screening criteria for total suspended particles, PM_{10}, $PM_{2.5}$, NO_2, SO_2 and carbon monoxide (CO). In addition to these standard air contaminants, the deposition of dust is also considered to be a nuisance and dust deposition monitoring stations have been in place at a number of villages since 2011. Screening criteria from these stations were also included.

Screening criteria have been selected from the following sources:

- World Health Organization (WHO) Air Quality Guidelines: WHO Air Quality Guideline - Global Update – Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide (WHO, 2005)
- United States Environmental Protection Agency (USEPA) Office of Air Quality Planning and Standards: National Ambient Air Quality Standards (USEPA, 2010)
- USEPA Integrated Science Assessment (2017)
- European Union: European Commission Air Quality Directives (1999)
- Australian Regulatory Guidelines: Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW OEH, 2005)

The adopted screening criteria are consistent with those used in the air quality baseline assessment (Appendix A, Air Quality and Greenhouse Gas Impact Assessment). The WHO sourced guidelines were selected where available on the basis that these air quality guidelines are generally more conservative than other international screening criteria. The WHO has not set a total suspended particulates guideline and only Australia has derived a dust deposition guideline. In addition, following review of initial SO_2 emission estimates, there was potential for elevated concentrations to arise from the power generation facilities. An in-depth appraisal of international air quality standards was subsequently undertaken for SO_2 (presented in Appendix W, Human Health Risk Assessment). The review noted many countries directly adopted or derived their air quality standards from either the WHO or USEPA. On the basis a 1-hour standard is considered the most appropriate (based on the 2017 assessment of this standard by the USEPA), and the fact national jurisdictions such as the European Union, United Kingdom, Sweden and New Zealand, all specify a 1-hour SO_2 standard of 350 $\mu g/m^3$, the Project adopted the guideline of 350 $\mu g/m^3$ as derived by the European Union (1999).

19.2.7.2. Soil

To assess risks to human health from COPC in soil or sediments, guideline values were adopted from the Soil Quality Guidelines for the Protection of Environmental and Human Health for Agricultural Land (CCME, 2007).

19.2.7.3. Drinking Water

To assess risks to human health from COPC in drinking water, guideline values were adopted from:

- PNG Public Health (Drinking Water) Regulation 1984
- WHO Guidelines for Drinking-Water Quality, 4th edition (WHO, 2017)

19.2.7.4. Surface Water

The State of PNG has yet to establish recreational water quality guidelines therefore a conservative adjustment of the WHO drinking water guideline values (listed above) was made to account for reduced ingestion rates associated with recreational exposure in surface water. A conservative adjustment of the drinking water guideline was based on 100ml of water being ingested per day (during recreational activity).

19.2.7.5. Food (Aquatic and Terrestrial)

Food standards have been determined by the following regulatory authorities:

- World Health Codex Alimentarius Commission (WHO/JECFA, 2011)
- The European Commission (European Commission, 2010)
- Food Standards Australia and New Zealand Generally Expected Levels (GELS) for Metal Contaminants (FSANZ, 2001)
- Food Standards Australia and New Zealand (FSANZ, 2016)

The food standards established by these authorities are generally focussed on additives to foods (e.g., pesticides) and on those foods that can contribute significantly to the total dietary intake of a particular compound (such as mercury in shellfish). Therefore, guidelines have only been established for cadmium, lead in food plants and arsenic, cadmium, lead and mercury in aquatic biota. It is expected that most foods will also contain essential nutrients that may cause health effects where the recommended guidelines are significantly exceeded.

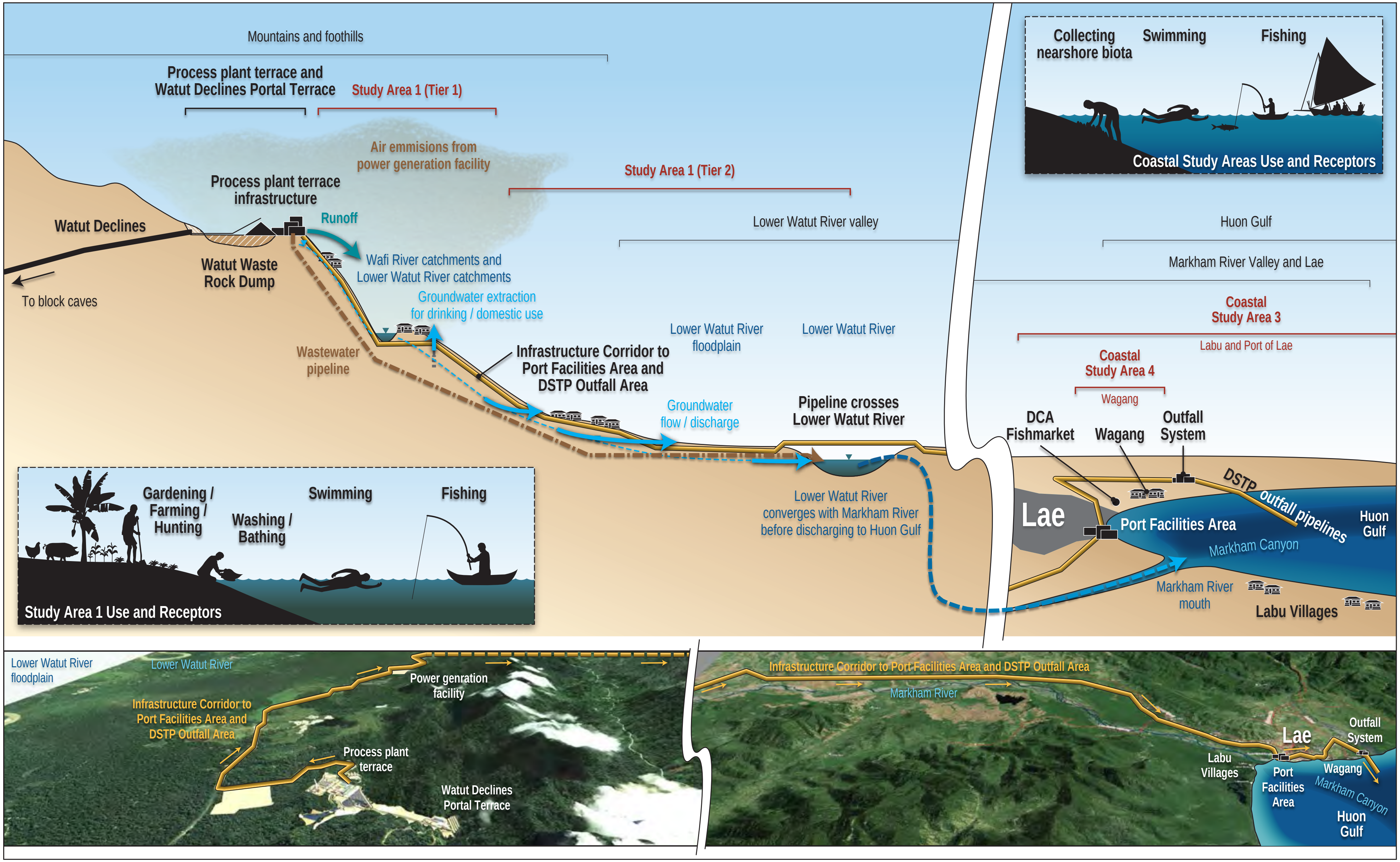
19.2.8. Project Conceptual Site Model

Figure 19.2 shows the conceptual site model applicable to human receptors in the three HHRA study areas.

The conceptual site model shows that the main complete exposure pathways for risks to human health relate to water. The complete exposure pathways identified comprise contaminants being ingested or coming into contact with skin as a result of domestic use of water (i.e., drinking, cleaning or bathing), recreational activities (i.e., swimming and, for the purposes of the HHRA, fishing or hunting) and ingestion of impacted terrestrial and aquatic foods.

19.3. Risk Assessment Results

The results of the Tier 1 (T1) and Tier 2 (T2) assessments for baseline and Project conditions are presented in the following sections.



coffey
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Date: 26.04.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F19.02_GRA

WAFI-GOLPU JOINT VENTURE
Wafi-Golpu Project

Conceptual site model

Figure No: 19.2

INDD Reference: 0520DD_10_GRA100.indd_7

19.3.1. Baseline Conditions

19.3.1.1. Baseline Tier 1 (T1) Assessment

The Tier 1 (T1) assessment involved comparison of baseline concentrations of contaminants (in air, sediment, water and biota) to adopted screening criteria. This process allowed existing contaminants that were in concentrations high enough to be potential risks to human health to be identified, i.e., risks to human health that are already present without the development of the Project. The results of the Tier 1 (T1) assessments are summarised below.

19.3.1.1.1. Air

Table 19.2 shows the available baseline air quality data for villages from Study Area 1 (Tier 1) compared against the adopted screening criteria. The highest baseline ambient PM_{10} concentrations were at Wongkins and Bavaga villages and the lowest concentrations were at Wori and Madzim villages.

Table 19.2: Ambient Air Quality Screening Assessment for Study Area 1 (μg/m³)

Pollutant	Averaging Period	Ambient Air Quality Standard	Baseline Data (Range for Monitored Villages)(1)
Particulate matter (PM_{10})	24 hours	50	4 – 33
	Annual	20	Not available
Dust deposition	Annual (incremental)	2 g/m²/month	1.6 – 2.4(2)
	Annual (cumulative)	4 g/m²/month	

1 Baseline data from Coffey Environments, 2011 and ongoing dust deposition monitoring.
2 Based on averages from each village from June 2011 to May 2015.

While the concentrations of NO_2 and SO_2 have not been measured, for Study Area 1 it was assumed that the levels of these contaminants are negligible given the remote location. Likewise, Study Area 4 (Wagang and Yanga villages) is expected to share a similarly good air quality to that of Study Area 1.

While baseline air quality monitoring data is not available for Study Area 3, vehicle and industrial emissions from sources located in Lae (including ships entering and berthed at the Port of Lae) have the potential to contribute to existing elevated baseline concentrations of NO_2, SO_2 and particulates.

Slightly elevated dust deposition rates have been measured at Wori and Bavaga villages on occasion, however these may have been due to activities occurring in and around the villages such as the burning of vegetation and land clearance for gardens or construction of new dwellings.

As shown in Table 19.2, the baseline air quality monitoring data shows no exceedances compared to the screening criteria.

19.3.1.1.2. Soil and Sediment

Average baseline concentrations of metals in sediment collected from the Lower Watut River are presented in Table 19.3 along with the adopted guideline values for soil and sediment. The samples collected from the Lower Watut River are assumed to provide indicative metal concentrations for the Watut River floodplain garden/crop areas. It has been assumed that sediment data would overestimate contaminant concentrations in this instance, so this provides a conservative assessment.

Table 19.3: Human health soil and sediment screening assessment (mg/kg)

Metal	Agriculture Standard (CCME, 2007)	Mean Sediment Concentration Lower Watut River[1]
Antimony	20	0.5
Arsenic	12	12
Cadmium	1.4	0.1
Chromium	64	44
Copper	63	41
Lead	70	Not analysed
Mercury	6.6	0.1
Molybdenum	5	Not analysed
Nickel	45	34
Selenium	1	*1.6*[2]
Zinc	200	72

[1]Baseline data from Appendix G, Surface Water and Freshwater Aquatic Ecology Characterisation – Mine Area to Markham River. The full data set for Study Area 1 was used to estimate sediment concentrations.

[2] Below the human health screening criteria in an agricultural scenario (CCME, 2007).

The average concentration of selenium detected was found to exceed the established CCME criteria for the protection of ecological and human health, in an agricultural setting. The CCME standard criteria for selenium in an agricultural setting was based on the protection of more sensitive ecological receptors via direct contact rather than human exposures, given ecological receptors are considered the more sensitive in this scenario.

The screening criteria for selenium based on a human health endpoint is 80mg/kg in an agricultural setting, therefore the level of exceedance shown in Table 19.3 is not considered to indicate a potential human health risk under baseline conditions (CCME, 2007).

19.3.1.1.3. Drinking Water

The assessment of baseline surface water quality data includes data collected by WGJV in 2017 as well as water quality data collected between January 2006 and December 2016 (at 47 monitoring sites), and further water quality data from monitoring programs undertaken by BMT WBM in 2015 through 2016.

No exceedances of the drinking water screening criteria were identified for the total metals in the 2017 baseline drinking water investigation conducted by WGJV which sampled drinking water sourced from local waterways and extracted from local groundwater wells. The results show the water sources in Study Area 1 (Tier 1) and groundwater in Study Area 1 (Tier 1) are suitable for drinking as most results were below the laboratory limit of reporting and the average concentrations were below the adopted screening criteria (Table 19.4).

Drinking water source information for most villages in Study Area 1 (Tier 2) is limited. Therefore, the mean surface water concentrations in Study Area 1 obtained from the wider sampling conducted over a decade were adopted, which is discussed further in Appendix W, Human Health Risk Assessment.

No exceedances of the drinking water screening criteria were identified for the COPC in the adopted baseline surface water concentrations associated with the Lower Watut River and its catchments. Comparison of the drinking water screening criteria with the maximum adopted concentration from the mean concentration of total metals in the baseline data (using estimated 50th percentile concentrations to account for data uncertainties, refer to Appendix W, Human Health Risk Assessment) found no exceedances, indicating the primary and secondary water sources in Study Area 1 (Tier 2) are also suitable for drinking.

Table 19.4: Total metals drinking water screening assessment (1)

Metal	Screening Criteria	Average Concentration Drinking Water Study Area 1 (Tier 1)(2)	Average Concentration Extracted Groundwater Study Area 1(3)	Adopted Concentration(4) Sub Catchments(5): Wafi River, Bavaga River, Waime River	Adopted Concentration(4) Lower Watut River and Floodplains(6)
Units	mg/L	mg/L	mg/L	mg/L	mg/L
Antimony	0.02	0.001	0.001	0.0002	0.0002
Arsenic	0.01	0.001	0.001	0.002	0.01
Cadmium	0.003	0.0001	0.0001	0.0002	0.0001
Chromium	0.05	0.003	0.001	0.001	0.01
Copper	2	0.001	0.001	0.002	0.01
Lead	0.01	0.001	0.002	0.001	0.01
Mercury	0.001	0.0001	0.0001	0.0001	0.0001
Molybdenum	0.07	0.001	0.003	0.0002	0.0002
Nickel	0.07	0.003	0.001	0.003	0.01
Selenium	0.01	0.01	0.01	0.01	0.01
Zinc	3.0	0.01	0.18	0.01	0.02

1 Note total metal concentrations have been calculated using the laboratory limit of reporting where non-detects were reported.
2 Mean concentrations in drinking water piped from local streams/creeks in Study Area 1, Tier 1 villages only.
3 Average total metal concentrations in drinking water sourced from locally extracted groundwater at Wori (Tier 1) and Chaunon (Tier 2) villages.
4 Selected based on the maximum of the 50th percentile concentration using WGJV data and the mean concentration from BMT WBM data (the maximum of the two datasets was selected).
5 Selected total metal concentrations in surface water associated with the Study Area 1 villages generally located in the highlands. Calculated median concentrations at the following catchments Wafi River, Bavaga River and Waime River. Refer to the discussion in Appendix W, Human Health Risk Assessment, regarding uncertainties in the dataset.
6 Selected total metal concentrations in surface water associated with the Study Area 1 villages generally located in the lowlands and floodplains. Calculated median concentrations at the following catchments Lower Watut River, Lower Watut River floodplains and Womul River. Refer to the discussion in Appendix W, Human Health Risk Assessment regarding uncertainties in the data set.

19.3.1.1.4. Recreational Water

Table 19.5 presents the adopted screening criteria for water used for recreational purposes (both freshwater and marine water), which have been derived from drinking water criteria adjusted for recreational exposures (see Section 19.2.7).

The adopted concentrations of total metals in freshwaters and nearshore marine water were below the recreational screening criteria. The results show water used for recreational purposes in Study Area 1 and the coastal study areas 3 and 4 are suitable for recreational uses under baseline conditions.

Table 19.5: Surface water screening assessment for recreational use

Metal	Screening Criteria(1)	Adopted Concentration Freshwater(2,3)		Mean Concentration Nearshore Marine Water(2,6)
		Sub Catchments(4): Wafi River, Bavaga River, Waime River	Lower Watut River and Floodplains(5)	
Units	mg/L	mg/L	mg/L	mg/L
Antimony	0.4	0.0002	0.0002	Not analysed

Metal	Screening Criteria(1)	Adopted Concentration Freshwater(2,3)		Mean Concentration Nearshore Marine Water(2,6)
		Sub Catchments(4): Wafi River, Bavaga River, Waime River	Lower Watut River and Floodplains(5)	
Arsenic	0.2	0.002	0.01	0.002
Cadmium	0.06	0.0002	0.0001	<0.001
Chromium	1	0.001	0.01	<0.001
Copper	40	0.002	0.01	0.001
Lead	0.2	0.001	0.01	<0.001
Mercury	0.02	0.0001	0.0001	<0.001
Molybdenum	1.4	0.0002	0.0002	Not analysed
Nickel	1.4	0.003	0.01	0.011
Selenium	0.2	0.01	0.01	0.003
Zinc	60	0.01	0.02	0.002

[1] 20 fold increase of the adopted drinking water criteria based on recreational use adjustment.
[2] The laboratory limit of reporting concentration was adopted for samples that reported a non-detect result.
[3] Selected based on the maximum of the 50th percentile concentration using WGJV data and the mean concentration from BMT WBM data.
[4] Selected total metal concentrations in surface water associated with the Study Area 1 villages generally located in the highlands. Calculated median concentrations at the following catchments Wafi River, Bavaga River and Waime River. Refer to the discussion in the text below regarding uncertainties in the data set.
[5] Selected total metal concentrations in surface water associated with the Study Area 1 villages generally located in the lowlands and floodplains. Calculated median concentrations at the following catchments Lower Watut River, Lower Watut River floodplains and Womul River. Refer to the discussion in the text below regarding uncertainties in the data set.
[6] Marine waters in the vicinity of the Study Area 3 and Study Area 4 based on concentrations measured at 1.5m depth at L4, M1, V1, V2, B1, LA1, LA2, LA3, LA4 and LA5 (Chapter 10, Nearshore Marine Environment Characterisation). Concentrations for dissolved metals only.

19.3.1.1.5. Food

This section presents a summary of the Tier 1 (T1) baseline assessment for food.

Marine aquatic food. The average mercury concentration in the deep-slope bony fish exceeded the screening criteria adopted for bony fish. However, the dwarf gulper shark was the main species caught during the Coffey 2017 study (Appendix P, Deep-slope and Pelagic Fish Characterisation), and the average mercury concentration was below the screening criteria for predatory fish (such as gulper shark). All other contaminants in market fish (marine) (Appendix P, Deep-slope and Pelagic Fish Characterisation) were below the adopted screening criteria. Contaminants in food in the Market Basket survey (marine) (Bentley, 2011) were below the adopted screening criteria.

Freshwater aquatic food. The average concentrations of zinc in freshwater fish exceeded the adopted screening criteria in both the 2015 investigation (BMT WBM, 2016) and the 2011 Market Basket Survey (Bentley, 2011) for Study Area 1 (includes both Tier 1 and Tier 2 sample locations). Section 19.1.3 provides a discussion on data used in the HHRA. All other average contaminant concentrations were below the adopted screening criteria in both surveys.

Terrestrial food plants. Terrestrial food plants commonly consumed by local communities were analysed for the presence of seven metals. All metals, with the exception of mercury, were detected above the laboratory limit of reporting but none exceeded the adopted screening criteria for these foods in Study Area 1 or Study Area 3.

Animal foods. No exceedances were noted in terrestrial animal foods including livestock and wild animals consumed in the study areas (Bentley, 2011).

19.3.1.1.6. Human Biological Specimen Analysis

Table 19.6 presents the results of human biological screening conducted as part of a public health and biomedical survey for the Project by Abt JTA in 2013. Capillary blood samples were collected from people aged 6 to 35 years, and all other samples were collected from people aged 16 to 65 years.

Exceedances of blood lead and mercury were reported at Labu 1, which has been incorporated into Study Area 3 for the purposes of the baseline assessment. Elevated levels of these metals in blood in some people are likely to be due to the high consumption of fish and shellfish by this coastal community. It is not known if any individuals' blood lead levels exceeded the lower screening criteria of 50 micrograms per decilitre of blood (µg/DL) recently adopted in some countries (CDC, 2012 and NHMRC, 2015).

Arsenic screening levels in urine were exceeded in some villages in Study Area 1 and were also noted to potentially be related to high levels of fish consumption by some villagers.

Table 19.6: Human biological specimen – Tier 1 (T1) screening assessment

<table>
<tr><th rowspan="3">Contaminant</th><th rowspan="3">Study Area</th><th rowspan="3">Location</th><th colspan="4">Specimen type</th></tr>
<tr><th>Whole Blood</th><th colspan="2">Urine</th><th>Hair</th></tr>
<tr><th>µg/L</th><th>µg/g of Creatinine</th><th>µg/L</th><th>µg/g</th></tr>
<tr><td rowspan="5">Arsenic</td><td colspan="2">Screening criteria</td><td>-</td><td>-</td><td>100 (1)</td><td>-</td></tr>
<tr><td rowspan="2">Study Area 1</td><td>Tier 1</td><td rowspan="4">Not analysed</td><td rowspan="4">Not analysed</td><td>20 - 30% people surveyed exceeded (2)</td><td rowspan="4">Not analysed</td></tr>
<tr><td>Tier 2</td><td>12 - 43% people surveyed exceeded</td></tr>
<tr><td rowspan="2">Study Area 3</td><td>Labu 1</td><td>79% people surveyed exceeded</td></tr>
<tr><td>Labu 2</td><td>51% people surveyed exceeded</td></tr>
<tr><td rowspan="5">Cadmium (3)</td><td colspan="2">Screening criteria</td><td>5</td><td>5</td><td>-</td><td>2</td></tr>
<tr><td rowspan="2">Study Area 1</td><td>Tier 1</td><td>0 – 0.56</td><td>0 - 0.05</td><td rowspan="4">Not analysed</td><td rowspan="4">Not analysed</td></tr>
<tr><td>Tier 2</td><td>0 – 0.07</td><td>0 - 0.05</td></tr>
<tr><td rowspan="2">Study Area 3</td><td>Labu 1</td><td>0</td><td>0.2</td></tr>
<tr><td>Labu 2</td><td>0.06</td><td>0.03</td></tr>
<tr><td rowspan="5">Lead</td><td colspan="2">Screening criteria</td><td>100 (1)</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Study Area 1</td><td>Tier 1</td><td>No exceedances</td><td rowspan="4">Not analysed</td><td rowspan="4">Not analysed</td><td rowspan="4">Not analysed</td></tr>
<tr><td>Tier 2</td><td>No exceedances</td></tr>
<tr><td rowspan="2">Study Area 3</td><td>Labu 1</td><td>11% people surveyed exceeded</td></tr>
<tr><td>Labu 2</td><td>No exceedances</td></tr>
<tr><td rowspan="5">Mercury (3)</td><td colspan="2">Screening criteria</td><td>10</td><td>20</td><td>Not established</td><td>2</td></tr>
<tr><td rowspan="2">Study Area 1</td><td>Tier 1</td><td>No exceedances</td><td>0.2 – 1.1</td><td rowspan="4">Not analysed</td><td>0.3 – 0.8</td></tr>
<tr><td>Tier 2</td><td>No exceedances</td><td>0.5 – 2.2</td><td>0.5 – 0.7</td></tr>
<tr><td rowspan="2">Study Area 3</td><td>Labu 1</td><td>17% people surveyed exceeded</td><td>0.5</td><td>0.6</td></tr>
<tr><td>Labu 2</td><td>No exceedances</td><td>0.7</td><td>1.1</td></tr>
</table>

Contaminant	Study Area	Location	Specimen type			
			Whole Blood	Urine		Hair
			μg/L	μg/g of Creatinine	μg/L	μg/g
Selenium [(3)]	Screening criteria		1000	-	-	-
	Study Area 1	Tier 1	124 – 269	Not analysed	Not analysed	Not analysed
		Tier 2	237 – 436			
	Study Area 3	Labu 1	208			
		Labu 2	280			

'–': Biological samples were not collected for this contaminant.
[1] Blood lead levels less than 50g/L are now considered unlikely to pose a potential health risk to children by health or environmental agencies in Australia and the United States (CDC, 2012 and NHMRC, 2015).
[2] Zilani did not report any exceedances.
[3] Average concentrations.

19.3.1.1.7. Summary of Baseline Tier 1 (T1) Assessment

Based on the available data, the Tier 1 (T1) baseline assessment indicates people living in communities located within Study Areas 1, 3 and 4 are likely to be exposed to levels of contaminants below health based guidelines in air, drinking water, surface water and terrestrial plants and meats.

Freshwater fish and deep sea fish exceeded screening criteria for zinc and mercury, respectively. The analysis of human biological specimens indicated that people in Study Area 1 and Study Area 3 are currently exposed to elevated levels of mercury, lead and arsenic. The elevated concentrations of metals in human specimens is likely due to the high consumption of fish and/or shellfish.

The exceedances of screening criteria are discussed further in the baseline Tier 2 (T2) health risk assessment.

19.3.1.2. Baseline Tier 2 (T2) Assessment

The selection of contaminants of concern for the Tier 2 (T2) assessment is determined by the Tier 1 (T1) evaluation of measured concentrations in baseline media, known chronic human toxicity, presence in human biological specimens at elevated levels (Abt JTA, 2013) and potential Project related contaminants. The potential baseline intakes of arsenic, lead, mercury and zinc by receptors in Study Area 1, Study Area 3 and Study Area 4 were estimated for the following exposure pathways:

- Incidental ingestion of COPC in water while undertaking bathing, washing, irrigating or recreational activities such as swimming or, for the purposes of the HHRA, fishing
- Dermal contact with COPC in water while undertaking bathing, washing, irrigating or recreational activities such as swimming or, for the purposes of the HHRA, fishing
- Ingestion of COPC in drinking water from primary and secondary water sources
- Ingestion of COPC in freshwater or marine fish, crustaceans or molluscs
- Ingestion of COPC in terrestrial foods including locally sourced fruits, vegetables, nuts, grains, meat and animal products

The general approach taken for the exposure assessment was to adopt exposure parameters (these are inputs such as how many hours per day or days per year someone is exposed) that would reflect the typical experiences of the majority of the receptor group.

Consistent with the NEPM (2013) and FSANZ (2016), adults and young children were evaluated separately due to their behaviour, size and other developmental factors. The exposure parameters and adopted COPC concentrations were based on a mixture of average or maximum (i.e., 365 days per year) exposure parameters and average exposure concentrations. This results in a conservative estimate of the average population exposure and is likely to represent most of the population.

19.3.1.3. Baseline Tier 2 (T2) Contaminants of Potential Concern

The rationale for the COPC selected for Tier 2 (T2) evaluation is:

- Arsenic and lead were noted to potentially be present in the environment at elevated levels and were measured in the blood or urine of some people at levels exceeding the health limits.
- Mercury, assumed to be in organic form, exceeded screening criteria in fish from the deep-slope area of the Huon Golf. Mercury was also measured in blood at levels exceeding the health limit in more than 15% of villagers surveyed in Labu 1 (within Study Area 3).
- Elevated average levels of zinc were measured in freshwater fish. Zinc was also identified as being elevated in relation to the average crustal abundance.

19.3.1.4. Baseline Human Intake Dose

The estimated human intake dose of contaminants via ingestion and dermal contact was calculated assuming exposure parameters reflective of the typical experiences of the population, combined with toxicological reference values which aim to protect sensitive members of the population. Since young children are considered to be the most sensitive age group based on their behaviour, size and other developmental factors, the age of people assessed has been split into two groups: adults and children 0 to 5 years. As a conservative approach, the parameters for children were generally selected to represent a child aged 2 to 3 years as they are considered to be the more sensitive group in this age range (consistent with the NEPM (2013) and FSANZ (2016)). These exposure parameters are detailed in Appendix W, Human Health Risk Assessment.

The assessment then estimated the amount and type of aquatic and terrestrial food that would be ingested, and how regularly, using the Market Basket survey (Bentley, 2011) supplemented with food diary data collected from relevant Ok Tedi and Fly River community studies (Bentley, 2007). Surrogate data collected from Ok Tedi and Fly River community studies (Bentley, 2007) was used to estimate the amount of each type of food consumed per day as this data was not available for the Project Area. Appendix W, Health Risk Assessment provides a full discussion of the use of surrogate data. The input exposure parameters are listed in Table 19.7.

Table 19.7: Exposure parameters – dermal, ingestion and incidental ingestion of water

Exposure Parameters		Value Adopted		Reference
		Young Child	Adult	
Body weight [kg]		12	57.4	Young children based on 1 to 5 years Ok Tedi and Fly River regions (Bentley, 2007)
Exposure frequency [days/year]	Drinking water (primary source)	365		Maximum possible enHealth (2012)
	Washing/bathing activities			

Exposure Parameters		Value Adopted		Reference
		Young Child	Adult	
	Recreation activities	150		enHealth (2012) data for adults assumed for children also
	Drinking water (secondary source)	60		Assumed duration in dry season when the secondary water source may be utilised
Exposure time [hours/day]	Washing/bathing/ domestic activities	0.13	0.9	Young child based on one bath per day. Adults based on food/drink preparation and cleaning, laundry, grounds and animal care activities. Assumed a third of the activity time respectively was directly associated with water. enHealth (2012)
	Recreation activities	0.5	1	enHealth (2012)
Bioavailability - oral ingestion [no units]		1		Conservatively assumed to be 100%
Exposed skin area [cm^2]	Recreation	7,545	18,200	Ok Tedi and Fly River regions (Bentley, 2007)
	Washing/bathing			
Water ingestion rate [L/d]	Drinking water	1	2	WHO (2017), enHealth (2012)
	Washing activities	0.025	0.0125	Limited information available - assumed to be half the ingestion rate of swimming enHealth (2012)
	Recreation activities	0.05	0.025	enHealth (2012)
Exposure duration [years]		5	65	Based on average lifespan and assumed residency time in the same location
Averaging time [years]		5 (1) 70 (2)	65 (1) 70 (2)	Based on exposure duration

[1] Averaging time for threshold contaminants with a tolerable concentration.
[2] Averaging time for non-threshold contaminants with a unit risk, assumed to be over a 70-year lifetime.

19.3.1.5. Baseline Human Health Toxicity Assessment

The human health toxicity assessment evaluates the inherent toxicity of potential contaminants and establishes the baseline with consideration for those contaminants that are potentially associated with the Project. The assessment considered factors including:

- Nature of adverse effects related to the exposure to a contaminant
- Dose-response relationships
- Weight of evidence for effects such as carcinogenicity (i.e., capacity for being cancer causing)
- How applicable animal data is to humans

Of the contaminants selected for the Tier 2 (T2) assessment, only arsenic (in its inorganic form) is known to have both carcinogenic and non-carcinogenic health effects. There is not enough evidence to suggest that lead, mercury and zinc are carcinogens. As such, inorganic arsenic has been assessed using a threshold dose response approach that is protective of carcinogenic effects.

19.3.1.6. Baseline Human Health Risk Assessment

The risk of health effects caused by exposure to contaminants was expressed as a HQ (i.e., the ratio of the estimated exposure concentration or chronic daily intake to the tolerable daily intake). To estimate the additive effect of exposure to Tier 2 (T2) contaminants via multiple exposure pathways, the HQs for each selected contaminant were summed to obtain a HI (recalling that where the HI is less than one (1), adverse health effects associated with exposure to the contaminant are unlikely). However, an HI exceeding 1 does not necessarily indicate an actual risk but rather a potential adverse health outcome that may require additional assessment.

The calculated HI for each COPC for all exposure pathways evaluated for each study area and receptor group are presented in Table 19.8. Table 19.8 summarises the outcome of the baseline (i.e., without Project) risk assessment.

Table 19.8: Total Hazard Index calculated for exposure to COPC by receptors in selected study areas (baseline conditions)

Exposure Pathway	COPC	Total HI All Exposure Pathways Young Child	Total HI All Exposure Pathways Adult
Study Area 1 (Tier 1)	Arsenic	0.15	0.03
	Lead	0.62	0.18
	Mercury	***3.80***	***1.21***
	Zinc	***1.68***	0.52
Study Area 1 (Tier 2)	Arsenic	0.18	0.03
	Lead	0.96	0.30
	Mercury	***4.05***	***1.26***
	Zinc	***1.18***	0.33
Study Area 3	Arsenic	0.45	0.18
	Lead	0.55	0.13
	Mercury	***4.17***	***1.96***
	Zinc	0.92	0.20
Study Area 4	Arsenic	0.40	0.20
	Lead	0.47	0.12
	Mercury	***3.85***	***1.99***
	Zinc	0.62	0.14

Notes: **Italicised bolded text** indicates HI >1.

The COPC associated with exposure from all pathways evaluated for each study area, where the HI exceeded 1, primarily relate to the ingestion of local terrestrial and aquatic biota associated with mercury in fish. Young child receptors in all study areas potentially ingest elevated levels of mercury (conservatively assumed to be present in the form of methylmercury which is the more toxic organic form of mercury) and zinc in locally obtained terrestrial and aquatic foods under baseline conditions, i.e., without the Project. Adult receptors in coastal study areas potentially already ingest elevated levels of mercury (assumed to be present in the form of methylmercury) in locally obtained terrestrial and aquatic foods under baseline conditions. Mercury ingestion from locally sourced fish was the largest contributor associated with predicted exposures to both young children and adults in all study areas.

The risk characterisation outcomes are based on the available information and limitations of the exposure modelling should be considered as relative indicators of baseline conditions in Study Area 1, Study Area 3 and Study Area 4 in conjunction with the uncertainties discussed in Appendix W, Human Health Risk Assessment.

19.3.2. Predicted Project Conditions

Considering the results from the baseline Tier 1 (T1) and Tier 2 (T2) assessments, the predicted Project conditions were assessed using a Tier 1 (T1) screening level evaluation and a qualitative assessment for predicted Project-related effects for human health.

19.3.2.1. Air Emissions

Dust and air emission modelling was undertaken by SLR (Appendix A, Air Quality and Greenhouse Gas Impact Assessment) to determine whether Project emissions of air pollutants would result in ambient air quality predicted to exceed the adopted health screening criteria (refer to Section 19.2.7). The contaminants modelled included:

- The products of fossil fuel combustion: NO_2, SO_2 and CO
- Total suspended particulates (PM_{10} and $PM_{2.5}$) and dust deposition

19.3.2.1.1. Mine Area

Modelling of emissions from the on-site diesel generators in the Mine Area during the construction phase predicted that NO_2, SO_2 and CO concentrations will be below the adopted screening criteria (refer to Section 19.2.7) at the surrounding villages.

Modelling of emissions from the proposed intermediate fuel oil power generation facilities during the operations phase (when the power generation facility is operating near maximum capacity which is estimated to occur from year 16 of operations onwards) predicted exceedances of the SO_2 screening criteria at two locations, Ziriruk and Fly Camp. The modelling outcomes indicate that people at these locations would be potentially exposed to elevated levels of SO_2 for chronic (i.e., long term) exposure periods during the operation phase of the mine.

To put the predicted exceedances of Project criteria in the context of potential risks to human health:

- The potential human health risks relating to the inhalation of SO_2 in air are generally dependant on the susceptibility of an individual, the activities they undertake and the climatic conditions.
- Potential human health risks are likely to be most significant in individuals with asthma, particularly children, who may experience changes in lung function.
- The USEPA (2017) concludes that there is a causal relationship between short-term SO_2 exposure and respiratory effects, particularly in individuals with asthma, and changes in lung function generally occur at concentrations an order of magnitude lower than similar changes in non-asthmatic individuals.

Epidemiological and clinical studies demonstrate that temperature and humidity within the range of ambient environmental conditions can affect the health risk of asthma (USEPA, 2017). In general, cooler, dry conditions have an increased adverse response in comparison with hotter humid conditions (WHO, 2018), such as would be generally experienced at Ziriruk and Fly Camp.

Information relating to the incidence of asthma in PNG, reported by WHO (2018) was “virtually zero” in children. The WHO Global Burden of Disease report shows the Annual Mortality Rate per 100,000 head of population associated with asthma rises steeply from age 55 and 65 in adult males and females respectively. However, in PNG, risks to human health from asthma need to be considered in the context of the morbidity and mortality due to smoking and vector-borne and infectious diseases, which far exceeds that from asthma.

The WGJV is committed to achieving compliance with the adopted air quality criteria, and management measures such as scrubbers on the power generation facilities' stacks or increasing the exhaust gas exit velocity will be implemented to achieve compliance. Such investigations can be conducted using actual data when the power generation facility is in operation but before it is at near peak capacity when it was estimated from modelling that SO_2 conditions will exceed criteria.

Air modelling of fugitive dust emissions to air indicated that maximum ground level suspended particulate concentrations and dust deposition rates were predicted to comply with the adopted screening criteria at surrounding Study Area 1 (Tier 1) villages for both the construction and operational scenarios. Based on conservative background inputs adopted in the modelling, no health-related risks were anticipated as a result of particulate emissions from mining operations.

19.3.2.1.2. Other Project Areas

Emissions of combustion products from mobile plant and machinery were qualitatively evaluated by SLR with emissions expected over a large area that will be well-diluted before they can travel beyond the Mine Area. The potential for elevated off-site concentrations as a result of these emissions is therefore considered to be negligible.

Air emissions from the operation of the Port Facilities Area and Outfall Area were considered minimal. Dust generated during construction activities at both sites was evaluated qualitatively and the risk of potential health impacts was expected to be negligible.

19.3.2.2. Mine Wastewater Discharge

The Tier 1 (T1) screening evaluation for baseline conditions found all metals were below screening criteria for sediments (excluding selenium), water and terrestrial foods. Zinc exceeded screening criteria in freshwater fish sampled by BMT WBM in 2015 (BMT WBM, 2016) and in the Market Basket survey by the Centre for Environmental Health in 2011 (Bentley, 2011). Baseline data for biota located near the shorelines was not available.

The mine wastewater modelling scenario focussed primarily on the potential impacts of mine wastewater piped to the Lower Watut River during the construction phase.

Mine wastewater discharge during the operations phase was not modelled because processing water requirements indicate the Project will have a water deficit during operations (i.e., greater process water requirement than mine water production) and therefore the discharge of process wastewater to the Lower Watut River during the operations phase is not expected for most of the time.

Modelling of sediment loads during the construction and operations phases was also undertaken; however, total metal concentrations associated with the sediment transport were not modelled and therefore this scenario has been assessed qualitatively.

The results of the modelling are presented in Chapter 15, Freshwater Environment Impact Assessment. The maximum concentrations of predicted dissolved metals at assessment points downstream were below the adopted Tier 1 (T1) screening criteria for drinking water and further quantitative Tier 2 (T2) modelling for Project conditions was not warranted. Based on the modelling outcomes, the COPC concentrations estimated in receiving waterways and the health risks associated with the proposed wastewater discharge to the Lower Watut River were considered to be generally consistent with baseline conditions.

19.3.2.3. Sediment Mobilisation in the Mine Area

Sediment transport modelling was also undertaken to evaluate mine related point sources of sediment from the Project (Appendix I, Catchment and Receiving Water Quality Modelling). The modelling considered sediment loads rather than contaminants associated with the sediments. However, coarse-scale catchment modelling of construction disturbance areas by BMT WBM (Appendix I, Catchment and Receiving Water Quality Modelling) assessed that, on a whole-of-catchment basis, sediment loads associated with construction and operational phases would contribute a very small proportion annually (less than 0.5%) to the high natural loads of the Lower Watut River main channel. Furthermore, sediment deposition is predicted to decrease exponentially with distance from Boganchong Creek main channel or its distributary channels on the floodplain (Chapter 15, Freshwater Environment Impact Assessment). Therefore, mine-derived coarse-grained sediments in Boganchong Creek are unlikely to reach Chaunong Creek or the receiving Bavaga and Lower Watut river main channels limiting the potential for contaminants in sediment to impact water sources of downstream villages. The modelling assumptions and results (see Chapter 15, Freshwater Environment Impact Assessment) indicated:

- The majority of sediment deposition associated with construction is predicted to be restricted to the eastern Watut River floodplain sub-catchment areas and floodplain creeks, and particularly the Boganchong, Womul and Chaunong creeks and the Bavaga and Waime rivers.
- Sediment loads are predicted to be elevated for a short period during construction and are expected to recover during operations when the construction sites will stabilise and surface soil erosion will reduce due to both proactive rehabilitation and revegetation.
- Construction of sedimentation ponds downstream of the Watut Declines Portal and process plant terrace facilities will limit sediment transport downstream.
- Most of the sediment that is not captured by the sedimentation ponds or raw water dam (downstream of the process plant terrace) is likely to be deposited on the Lower Watut River floodplains.
- Modelled sediment impacts are likely to be relatively localised and implementation of management measures (such as sediment ponds and silt fences, rock-lined catch drains, drop structures and clean water diversions) are likely to result in a reduction to these sediment load predictions.

Exposures to contaminants in soils and sediments in waterways by people may occur during gardening or other water related activities such as fishing. On the basis that the potential release of sediments during construction activities that will disturb soils or sediments will be managed via implementation of the Project Environmental Management Plan (Attachment 3), in addition to the processes outlined to settle and capture suspended solids during operations (see Chapter 6, Project Description), exposures to villages downstream of mining activities are likely to be acute (i.e., short term). Potential exposures relating to Project activities were therefore assumed to be minimal however baseline exposures were addressed via a Tier 1 (T1) screening assessment of the available soil and sediment data to determine whether exposures to contaminants warranted further quantitative assessment.

19.3.2.4. Mine Closure

Chapter 6, Project Description, Chapter 14, Physical and Biological Environment Impact Assessment and Chapter 15, Freshwater Environment Impact Assessment, present the results of post-closure groundwater and surface water quality modelling (based on the assessment made by Piteau presented in Appendix X, Assessment of Closure Conditions and Water Management Options for the Wafi-Golpu Block Cave and Subsidence Zone), and the assessment of residual impacts to the terrestrial and freshwater environment.

Generation of poor quality groundwater within the subsidence zone lake represents a potential source of long-term impact to groundwater discharge features, particularly the groundwater springs on the eastern slopes of Mt Golpu and baseflow to Buvu Creek, Nambonga Creek and Wafi River. The likely timeframe for contaminated groundwater reaching Nambonga Creek and Wafi River has not been estimated, but could reasonably be expected to persist for 50 years following mine closure.

The potential direct and indirect impacts to human health are likely to be significant where poor quality groundwater discharges to springs or waterways. The volume of contaminated water that people might be exposed to is dependent on whether re-activated springs and groundwater-fed surface water features return to pre-mining flows. People who currently use the springs as their preferred potable water supply are to be relocated prior to mine construction. Attachment 2, Conceptual Closure and Rehabilitation Plan, proposes closure objectives for the management of water quality and human access to the subsidence zone after mine closure. The residual impacts of treated seepage and/or subsidence zone lake overtopping discharges to the Wafi River system are expected to be low based on the assumption that WGJV proposes to treat this water to meet water quality criteria prior to discharge to the environment and until such time that closure objectives are met.

19.3.2.5. Deep Sea Tailings Placement

The assessment of potential human health risks associated with DSTP considered the bioavailability of metals in the Project tailings discharge to the Huon Gulf, and the biological pathways by which metals could be accumulated in fish that people consume based on the findings presented in Appendix N, Assessment of Metal Bioaccumulation and Biomagnification from DSTP in the Huon Gulf. A review of studies undertaken at other mining projects that use DSTP to manage tailings was also undertaken to assess the potential for adverse health impacts to local communities (Appendix W, Human Health Risk Assessment). As discussed in Chapter 5, Stakeholder Engagement, the Wagang and Labu communities raised concern regarding the potential for DSTP to pollute the Huon Gulf and impact their communities.

19.3.2.5.1. DSTP Health Evaluation

Numerous rivers, notably the Markham and Busu rivers near the outfall site, contribute about 50 million tonnes per annum (Mtpa) of sediment to the Huon Gulf, augmented by ten other rivers along the north shore of the Huon Gulf which contribute another 10Mtpa (Appendix J, Density Current, Plume Dispersion and Hydrodynamic Modelling). The introduction of some 16.5Mtpa of tailings via DSTP will mix with the currently estimated natural background riverine suspended sediment load of approximately 60Mtpa. The receiving area for the sediments has low diversity and low abundance in terms of edible fish species.

As described in Chapter 6, Project Description, the tailings will be transported from the Mine Area to the Outfall Area via pipeline and enter a mix/de-aeration tank, where it will be mixed with seawater supplied by seawater intake pipelines. From the mix/de-aeration tank, tailings will be discharged via two DSTP outfall pipelines, at a depth of approximately 200m.

In Study Area 4, the Outfall Area will be located 1,600m to the east of Wagang village. Other villages in the Coastal Area, including those in Study Area 3, are also known to catch and/or consume seafood from the Huon Gulf. The deep-slope study of pelagic fish within the DSTP study area (Chapter 11, Offshore Marine Environment Characterisation) and fish sold at local markets in Study Area 4 (Appendix P, Deep-slope and Pelagic Fish

Characterisation) was undertaken to determine the types of fish consumed by locals, where the fish are caught and the baseline concentration ranges of metals in fish tissue.

Metals concentrations in muscle and liver of the bony fish and sharks examined in the deep-slope pelagic characterisation study (Appendix P, Deep-slope and Pelagic Fish Characterisation) exceeded the adopted health screening criteria for arsenic, copper, mercury, selenium and zinc.

Species observed at the Department of Civil Aviation (known locally as DCA) Point fish market were reportedly captured within the upper 100m, and in coastal areas south of Lae, typically outside the influence of noticeable sediment plumes from the Markham River. The discussions with local people in Study Area 4 and with fishermen at the Department of Civil Aviation Point fish market indicates local people do not eat the types of fish, particularly sharks, known to inhabit the DSTP study area as most of their catch is obtained in the shallow coastal waters of the Huon Gulf.

As presented in Section 19.3.1.1.5 and the deep-slope pelagic study (Appendix P, Deep-slope and Pelagic Fish Characterisation), data from the Huon Gulf indicates that the health screening criteria for arsenic and mercury may be exceeded in fish that people already consume in the Huon Gulf, i.e., in the absence of a DSTP discharge. Other metals examined such as copper, nickel, zinc and manganese occur at low concentrations in fish tissue and infrequently exceed food safety guidelines.

This information suggests that adopted health screening criteria may already be exceeded in fish for arsenic and mercury due to sources such as discharges from major rivers in the region (e.g., Markham River) and existing human sources of metals including sewage, industrial discharges, shipping activities and historic artisanal mining. The Tier 1 (T1) screening assessment of metal contaminants in fish tissue and the quantitative Tier 2 (T2) evaluation concluded baseline levels of mercury in fish may present an elevated health risk to receptors in the Coastal Area.

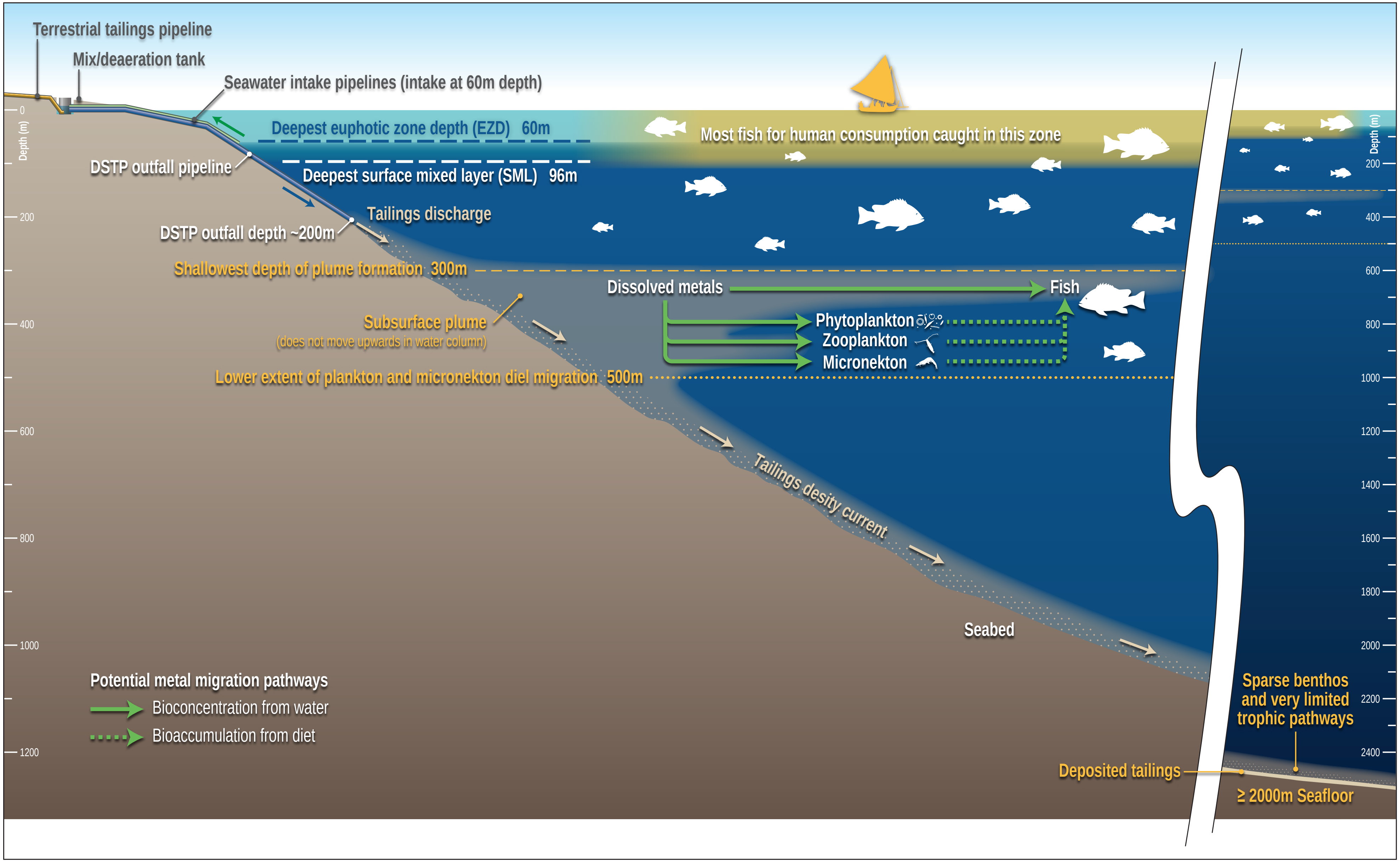
19.3.2.5.2. Conceptual Site Model and Exposure Pathways

The bioaccumulation and/or biomagnification of metals via the food chain may form a complete exposure pathway for metals in fish tissues that people consume. A generalised depiction of the potential exposure pathways and interactions relevant for potential human health risks associated with DSTP at the Outfall Area is shown in Figure 19.3.

Given the fishing habits of local fishermen and the home ranges of deep sea fish, the deep sea benthic species are unlikely to be a source of metals in fish species that people consume.

Published journal papers (Brewer et al., 2012; Neff, 2002) of metal bioaccumulation and biomagnification in biota report mostly low bioaccumulation and limited or no biomagnification of most of the metals of concern in the Huon Gulf (Appendix N, Assessment of Metal Bioaccumulation and Biomagnification from DSTP in the Huon Gulf).

Tissue data from different trophic levels within the Huon Gulf indicates that, with the possible exception of manganese, arsenic and mercury, metals evaluated in recent Huon Gulf studies (Appendix P, Deep-slope and Pelagic Fish Characterisation, and Appendix Q, Zooplankton and Micronekton Characterisation) do not biomagnify in fish that people consume. The available information indicates that for many of the metals examined (copper, zinc, manganese and nickel), tissue concentrations appear highest in zooplankton and micronekton in the Huon Gulf.



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Project: 754-ENAUABTF100520DD
File Name: 0520DD_10_F19.03_GRA

WAFI-GOLPU JOINT VENTURE
Wafi-Golpu Project

Conceptual site model of DSTP and potential exposure pathways for biota

Figure No: 19.3

19.3.2.5.3. Predicted Metal Concentrations in Locally Consumed Fish

The Assessment of Metal Bioaccumulation and Biomagnification from DSTP in the Huon Gulf, Papua New Guinea (Appendix N, Assessment of Metal Bioaccumulation and Biomagnification from DSTP in the Huon Gulf) used predicted environmental metal concentrations derived from site-specific three-dimensional modelling and trophic pathway analysis to incorporate both bioconcentration and bioaccumulation of metal in each trophic level (zooplankton, micronekton and fish). The evaluation adopted species-specific ingestion rates and standard bioconcentration and bioaccumulation factors for each metal and it was conservatively assumed that each trophic level and fish species was exposed to bioavailable metals continuously.

The study found that the transfer of metals from benthic sediments and/or benthic organisms into fish consumed by people is an incomplete trophic pathway. As a result, this pathway poses no risk to human health.

The predicted dissolved metal concentrations in the subsurface DSTP plume and the representative fish species that people consume from the Huon Gulf are presented in Table 19.9. The observed concentration range of metals in fish and the adopted human health screening criteria (refer to Section 19.3.1.1.5 and Appendix W, Human Health Risk Assessment) are also shown. An area use factor was applied to indicate the home range of the fish; in this instance, it was conservatively estimated the fish of interest inhabited subsurface plume waters 10% of the time, as they prefer shallow waters.

Data collected thus far from the Huon Gulf suggest that arsenic and mercury may be bioaccumulated at higher concentrations in fish and that current conditions in the Huon Gulf, without DSTP, suggest that fish consumed by people in Huon Gulf may already exceed food safety guidelines (FSANZ, 2016) for arsenic as well as mercury and that the use of DSTP will not make a discernible contribution to fish tissue metal concentrations beyond existing baseline levels, when considering the area use factor adjusted figures.

The maximum predicted concentrations (adjusted for area use) of arsenic, mercury, nickel and copper in the edible fish obtained in the Huon Gulf were within the range of concentrations measured in the Market Basket Survey (Bentley, 2011) and the Lae market survey (Appendix P, Deep-slope and Pelagic Fish Characterisation). The zinc concentrations reported in fish tissue were higher in the Market Basket survey, Lae market survey and deep-slope marine survey when compared to the predicted concentrations in fish (adjusted for area use) associated with the DSTP. Manganese is predicted to increase above the background range of <0.1 to 0.12mg/kg to 0.241mg/kg. This is due to the relatively high bioaccumulation factor at lower trophic levels measured in the samples. While the concentration of manganese is predicted to be double the observed background range, the predicted concentration is relatively low compared to amounts of manganese required in the human diet. The recommended adequate intake of manganese for adults 19 years and older is established as 2.3mg and 1.8mg per day for males and females, respectively (NAS, 2004). Adequate intakes range from 1.2 to 1.6mg per day for children aged 1 to 18 years old. The tolerable upper intake level (i.e., the maximum usual daily intake level at which no risk of adverse health effects is expected) is 11mg per day for adults 19 and older and 2 to 9mg per day for children aged 1 to 18. The USEPA determined an oral reference does of 0.14mg/kg per day, which is an estimated dose that is not associated with adverse health effects in the general population (EPA, 2015). For a 70kg person, this value is 9.8mg per day of manganese. To exceed this value from fish consumption alone, one would need to eat in the order of 40kg of fish per day with a manganese concentration of 0.241mg/kg.

Table 19.9: Predicted metal concentrations in DSTP subsurface plume and fish tissue in the Huon Gulf

Metal	Predicted DSTP Subsurface Plume Concentration(1) (mg/L)	Fish Tissue Metal Concentration (2) (mg/kg)		Maximum Predicted Concentration Considering Area Use Factor (3) (mg/kg)	Existing Concentrations in Edible Fish from Huon Gulf (mg/kg)	Screening Criteria – Human Health (mg/kg)
		Water Ingestion Only	Prey Ingestion Only			
Arsenic	0.0016	***3.00***	***4.55***	0.455	<0.4 – ***6.2***	2
Copper	0.011	***2.20***	***3.00***	0.3	0.11 – 0.5	2
Manganese	0.011	1.32	2.41	0.241	<0.1 – 0.12	Not established
Mercury(4)	0.0000001	***0.53***	***0.53***	0.053	0.03 – ***0.75***	0.5
Nickel	0.0014	0.07	0.087	0.0087	<0.06	Not established
Zinc	0.012	5.53	7.18	0.718	2.0 – 4.80	15

Values shown in bold and italicised indicate an exceedance of the adopted screening criteria

[1] These concentrations come from the elutriate tests at 1,000 dilutions as described in Section 2.2 of Appendix N, Assessment of Metal Bioaccumulation and Biomagnification from DSTP in the Huon Gulf. A conservative approach was taken whereby, for each metal the highest concentration for two tailings samples, Tailings 1 and Tailings 2, measured at 1;1,000 dilution was adopted as the metal concentration in the subsurface tailings plume. The dilution of 1,000 presented in Appendix N, Assessment of Metal Bioaccumulation and Biomagnification from DSTP in the Huon Gulf, is within about 1.2km from the outfall and less than 100m radius from where the tailings plume shears off from the density current.

[2] Wet weight. Also of note is that the total predicted fish metal concentrations are likely to overestimate actual fish tissue concentrations because the total tissue concentration assumes that fish will accumulate 100% of the metal from micronekton and 100% of the metal from water ingestion in the plume. Clearly, the fish tissue concentrations observed will be the result of some (unknown) combination of diet and water ingestion.

[3] Area use factor considers the fish home range. It was assumed most of the fish species consumed by people obtained from the Huon Gulf are likely to spend < 10% of their time at depths exposed to tailings plumes (i.e., below 300m) as their preferred habitat is in shallower depths of <200m. The area use factor of 0.1 was adopted.

[4] Mercury was not analysed in the CSIRO elutriate tests (Appendix L, Tailings Ecotoxicology and Geochemistry), but this metal is expected to be below detection limits in the undiluted tailings liquor (i.e., below 0.1µg/L) (Watt, pers comm. 2018) and this concentration was assumed in the assessment.

Mercury reported in fish tissue is assumed to be present as a result of natural or anthropogenic sources. On the basis that tailings studies undertaken for this Project indicate mercury concentrations in tailings liquor were below the ANZECC/ARMCANZ marine guidelines for 95% species protection level (ANZECC/ARMCANZ, 2000), any predicted bioaccumulation of mercury is not considered to be as a result of the proposed DSTP.

The predicted bioaccumulation results derived from these analyses are supported by other studies of metal bioaccumulation in fish in PNG and other tropical Asia-Pacific locations, and from metal bioaccumulation information from the published literature. Consistent with the findings of this assessment, these studies have found no bioaccumulation and biomagnification of metals concentrations beyond background due to DSTP.

19.3.2.5.4. Evaluation of Potential Human Health Risks Associated with DSTP

The potential human health risks associated with the proposed DSTP have been evaluated based on the following multiple lines of evidence:

- Quantitative evaluation of the potential bioaccumulation and biomagnification of metals in the fish locals in Study Area 3 and Study Area 4 consume that are caught in Huon Gulf
- A review of other DSTP projects to determine the long-term outcomes of similar projects to human health

- Comparison with the quantitative Tier 2 (T2) baseline health risk evaluation of baseline conditions for villagers in Study Area 3 and Study Area 4

The evaluation found that while mercury levels in fish consumed by villages in Study Area 3 and Study Area 4 currently exceeded the tolerable daily intakes, the predicted levels of mercury in these fish were not expected to change based on the bioaccumulation study. The results of trophic pathway modelling indicate that there is limited biomagnification of most metals in upper trophic level fish, and fish tissue metal concentrations that are currently below food safety guidelines are likely to remain so with DSTP in the Huon Gulf. Therefore, DSTP is not predicted to pose an additional human health risk to the Study Area 3 and Study Area 4 communities.

19.4. Design Controls and Management Measures

This section presents an overview of the management measures WGJV proposes to implement to address potential releases of contaminants to the environment.

The principal proposed management measures to limit or reduce the quantities of fugitive sediment delivered to the natural drainage during construction and operations relate to Project design controls presented in Chapter 6, Project Description, including but not limited to, the following:

- Capture and treat mine wastewater where necessary prior to discharge to meet environment permit conditions
- Treat sewage in accordance with environment permit conditions
- Properly maintain all water and wastewater treatment facilities
- Actively manage potentially acid forming (PAF) materials and control runoff and leachate from areas containing PAF material including:
    - Selective placement of PAF and non-acid forming (NAF) material in the waste rock dump in accordance with the waste rock dump design
    - In situ treatment or reprocessing stockpiled material through the process plant
    - Diversion of clean surface water around the site
    - Capture and treat contaminated runoff and leachate prior to discharge to meet environment permit conditions.
    - Treatment of contaminated water from seepage and/or crater lake overtopping discharges to the Wafi River System to meet water quality criteria prior to discharge to the environment and until such time that closure objectives are met.

Further supporting the design controls, proposed management measures presented in the Project Environmental Management Plan (Attachment 3) and Conceptual Closure and Rehabilitation Plan (Attachment 2) would mitigate the potential for release of contaminants to the environment that could otherwise result in risks to human health.

Ongoing regular monitoring of human health aspects and fish tissue sampling and analysis is planned throughout the life of the mine.

19.5. References

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