

Ok Birim Tailings Storage Facility Project

Environmental and Social Impact Assessment

Chapter 10

Environmental impact assessment



10. ENVIRONMENTAL IMPACT ASSESSMENT

This chapter summarises the predicted environmental impacts associated with the proposed Ok Birim Tailings Storage Facility (TSF) Project (the project) on the existing physical and biological environments described in Chapter 8. It assesses how proposed activities during the construction, operations, and decommissioning and closure phases of the project may affect existing environmental values, and identifies the proposed measures to avoid, minimise or manage potential impacts. The chapter is structured as follows:

- Section 10.1- Methods for the environmental impact assessment (EIA).
- Section 10.2- Soils, landform and stability.
- Section 10.3- Groundwater.
- Section 10.4 - Physical riverine environment.
- Section 10.5- Aquatic biodiversity and ecology.
- Section 10.6- Terrestrial biodiversity and ecology.
- Section 10.7 - Air quality.
- Section 10.8 - Greenhouse gas (GHG) emissions.
- Section 10.9 - Noise and vibration.

Chapter 11 presents the socio-economic impact assessment, Chapter 12 presents cumulative impacts and Chapter 13 provides the assessment of natural hazards, climate change and unplanned events, e.g., low likelihood but high consequence events.

10.1 METHODS FOR ENVIRONMENTAL IMPACT ASSESSMENT

The approach followed for the EIA is consistent with the DEC (2004) EIA Guidelines and follows good international industry practice including the International Finance Corporation (IFC) Performance Standard (PS) (2012) and Equator Principles (EP4) (Equator Principles Association 2020a), which require projects to identify, predict and evaluate potential environmental and social risks and impacts, apply the mitigation hierarchy, and determine residual impacts after mitigation is applied. It is consistent with other ESIA for mining developments conducted in Papua New Guinea (PNG) and internationally, and aligns with the requirement IFC PS1 for systematic evaluation of:

- Direct impacts caused by project activities (e.g., vegetation clearance leading to habitat loss).
- Indirect impacts related to project activities but not directly caused by them; often occurs because of a direct impact (e.g., increased sediment loads in watercourses downstream of disturbed areas).
- Residual impacts after the implementation of proposed avoidance, minimisation, restoration, offset and compensation measures in line with the mitigation hierarchy.

The following impact assessment methods were used in the EIA depending on the nature of the environmental aspect:

- Significance assessment method, which applies where a qualitative or semi-qualitative assessment is appropriate. This method identifies credible impacts likely to occur, evaluates the sensitivity of affected environmental values, predicts the magnitude of change and determines the significance of residual impacts post mitigation.
- Compliance assessment method, which applies where PNG regulatory requirements and/or international standards exist, such as for surface water quality, air quality and noise. This involves modelling or predicting if project activities may exceed certain limits for which adverse impacts may occur.

- Benchmarking assessment method, which applies as a standard method for GHG emissions assessment by estimating and comparing project emissions with PNG's national emissions inventory to determine the project's potential relative contribution.

Further details on each method are provided in this section.

10.1.1 Significance assessment

The significance assessment determines residual impacts of the project following the implementation of proposed design, avoidance and management measures. This method also enables the most sensitive values to receive higher level of protection and prioritise where further mitigation may be required for significant impacts. This helps inform the development of environmental and social management and monitoring commitments for the project.

The process involves three key steps:

1. Identify and define environmental values potentially affected by the project and their sensitivity in accordance with the general criteria for sensitivity of environmental values outlined in Table 10.1.
2. Determine the magnitude of predicted impact after the implementation of proposed measures in accordance with the general criteria for magnitude of impact presented in Table 10.2.
3. Combine the assigned sensitivity and magnitude ratings using the significance assessment matrix shown in Table 10.3 to determine the significance of residual impact.

The last step assumes effective implementation of all proposed avoidance, management and mitigation measures set out in this chapter. Measures relevant to construction phase are included in the Construction Environmental and Social Management Plan (CESMP, Attachment 2) for the project.

Further details on each step are provided in the following subsections.

10.1.1.1 Defining environmental values and their sensitivity

Only environmental values that may be directly or indirectly affected by the project have been included in the impact assessment. Sensitivity is defined as the susceptibility of an environmental value to change, including its capacity to adapt or recover from changes caused by the project. Sensitivity is generally inherent to the value and tends to remain fixed, although it may change over time in certain cases.

Sensitivity is typically assessed in terms of the extent to which the value can adapt or recover from change, its replacement potential, as well as its intrinsic worth (societal value), intactness, uniqueness, or rarity. Where appropriate, sensitivity was defined based on professional judgement by technical specialists undertaking the assessments, taking into account:

- Formal status, such as protected site (e.g., wetland of international importance) or value (e.g., International Union for Conservation of Nature (IUCN)-listed species).
- Vulnerability to material damage or loss.
- Iconic or symbolic importance to cultural value systems.
- Importance to society and community.

Table 10.1 sets out the general criteria used to classify sensitivity of environmental value.

Table 10.1 General sensitivity criteria for environmental values

Sensitivity	Contributing factor	Definition
Very high	Formal status, value or importance to society and community	A critical asset, internationally and nationally recognised site or value. Iconic or symbolic importance to national cultural value systems.
	Vulnerability	Endemic or rare value with distribution restricted to the project area. No capacity to adapt to change. Site or value is intact (undisturbed) prior to project development.
High	Formal status, value or importance to society and community	A nationally recognised site or value. Iconic or symbolic importance to the broader area's cultural value systems (e.g., Ok Tedi and Fly River systems).
	Vulnerability	Abundance and distribution of site or value limited to the broader area (e.g., Ok Tedi and Fly River systems). Limited capacity to adapt to change. Site or value is in good condition prior to project development.
Medium	Formal status, value or importance to society and community	A regionally or provincially recognised site or value.
	Vulnerability	Abundance and distribution of site or value limited to region or province. Some capacity to change. Site or value is in moderate to good condition prior to project development.
Low	Formal status, value or importance to society and community	Some local value or recognition.
	Vulnerability	Widespread site or value with some representative examples found. Some resilience to change. Site or value is in poor to moderate condition prior to project development.
Not sensitive	Formal status, value or importance to society and community	Limited to no local value or recognition.
	Vulnerability	Abundant, widespread, numerous representative examples present. Easily adaptable to change. Site or value is in very poor condition prior to project development.

After defining environmental values and their sensitivity levels, technical specialists identified the key project activities or mechanisms of change attributable to the project that may affect these values, in terms of their nature and extent.

10.1.1.2 Magnitude of impact

The magnitude of impact typically refers to the scale, extent and duration of change relative to existing conditions. It considers:

- **Severity.** The degree of change from existing conditions resulting from the impact, including the intensity and whether it is positive or negative.
- **Geographical extent.** Whether the effects are confined to the site, local surrounds, broader area or region, and beyond (national/international effects).
- **Duration.** The timescale of the impact (if it is temporary, short-term or long-term) and its reversibility (whether an impact can recover within a specified timeframe).

Table 10.2 sets out the general criteria applied for defining the magnitude of impact. Ratings are determined through consideration of these criteria and professional judgement. Where necessary, technical specialists refined some magnitude ratings for particular aspects.

Table 10.2 General criteria for magnitude of impact

Magnitude	Contributing factor	Definition
Very high	Severity	Effects are likely to be very large (severe) with little or no recovery. Changes irreversible.
	Geographic extent	Effects are widespread and extend beyond the project area, potentially reaching national or transnational extents.
	Temporal extent	Effects are long-term or permanent, extending beyond the life of the project.
High	Severity	Effects are readily detectable but not severe with some recovery expected.
	Geographic extent	Effects are widespread across the project area, including downstream.
	Temporal extent	Effects are medium to long-term extending up to 10 years.
Moderate	Severity	Effects are readily detectable with recovery towards pre-impact conditions expected.
	Geographic extent	Effects extend beyond the area of disturbance but generally limited to the local surrounds (e.g., within 1 to 2 km of project activities).
	Temporal extent	Effects are medium term extending up to five years.
Low	Severity	Effects are likely to have limited effect on existing conditions with recovery expected.
	Geographic extent	Localised effect restricted to the proposed development area of the project.
	Temporal extent	Effects are short-term extending up to one year.
Very low	Severity	Effects are unlikely to affect existing conditions with full recovery expected.
	Geographic extent	Localised effect restricted to the disturbance area.
	Temporal extent	Once-off effect or occurs for less than one month.

10.1.1.3 Determining impact significance

The significance assessment for predicted residual impacts is determined based on the sensitivity of affected values and magnitude of the residual impact using the significance assessment matrix presented in Table 10.3, assuming effective implementation of proposed measures. The residual impact significance can be categorised as very low, low, moderate, high or major.

The impact assessment focusses on residual impacts rated moderate or higher. Low or very low impacts are only discussed where they are of particular interest or concern to communities or regulators. All other low or very low residual impacts are not specifically addressed in detail.

Table 10.3 Significance assessment matrix

Magnitude of impact	Sensitivity of value/aspect				
	Not sensitive	Low	Medium	High	Very high
Very high	Moderate	High	Major	Major	Major
High	Low	Moderate	High	Major	Major
Moderate	Low	Low	Moderate	High	High
Low	Low	Low	Low	Moderate	Moderate
Very low	Very low	Low	Low	Low	Moderate

10.1.2 Compliance assessment

The compliance assessment method was applied where a quantitative assessment was required, such as for surface water quality, air quality, noise and vibration. This method compares predicted conditions from modelling or other predictive technique against applicable statutory limits or international guidelines to identify potential exceedances and adverse effects to be managed or mitigated. Where PNG statutory limits or guidelines do not exist, relevant international standards were adopted.

Specific criteria adopted for the project are provided in the physical riverine environment (Section 10.4), air quality (Section 10.7) and noise and vibration (Section 10.9) assessments.

10.1.3 Benchmarking assessment

The benchmarking assessment for GHG emissions in Section 10.8 involved estimating the project's Scope 1 emissions and comparing the total with PNG's national emissions inventory to determine the project's potential relative contribution.

10.2 SOILS, LANDFORM AND STABILITY

This section describes the potential impacts to soils, landform and stability as a result of the project, and draws on information described in Chapter 8, Appendix K and activities described in Chapter 6. This information has been used to develop landform units to form the basis of the assessment and the sensitivity of each landform unit.

The landform units describe the transition of the terrain within the project area from steep-sided valleys and rugged mountains near the existing mine, transitioning towards more gently undulating land. Further from the TSF towards the Ok Tedi the landforms transition to low-lying floodplains.

10.2.1 Approach to impact assessment

The impact assessment method adopted for soils and landform aligns with the approach outlined in Section 10.1. This assessment involves the following steps to evaluate the project's impacts on identified soil and landform values:

- Define soil and landform values and evaluate their sensitivity to change.
- Identify project activities with the potential to impact soil and landform values.
- Identify management measures to avoid and/or reduce impacts to soil and landform values resulting from project activities.
- Predict the magnitude of the potential change to soil and landform values assuming successful implementation of management measures.
- Assess the residual impact significance based on the sensitivity of soil and landform values and magnitude of predicted impacts.

10.2.1.1 Identification of soils and landform values

The environmental values relevant to landform and soils to be protected are landform stability and soil capacity. Landform stability relates to the rate of soil erosion and the likelihood of failure (e.g., landslips). The more stable the landform, the lower the rate of erosion and less likely landslips are to occur. This also considers the slope, function, and aesthetics of the terrain to support vegetation, manage rainfall runoff and infiltration to groundwater.

Soil capacity relates to the physical and chemical characteristics to support biological growth (either natural vegetation or agriculture). The types of soil present are influenced by the underlying geology, elevation and slope as well as local climate. Degraded or unstable soils have a reduced capacity to support vegetation growth and provide habitat. This instability increases susceptibility to erosion, resulting in elevated sediment transport into waterways, which in turn degrades water quality and can negatively impact aquatic environments. Sections 10.4 and 10.5 assess impacts of the project on the physical riverine environment and aquatic ecology values, respectively.

Table 10.4 defines the sensitivity levels of soil and landform values and Table 10.5 presents the sensitivity rating for soil and landform values in each land facet group (as defined in Section 8.2).

Table 10.4 Definitions for the sensitivity of soil and landform environmental values

Sensitivity	Definition
Very high	Well-developed fertile soils with high organic matter. Soils are not contaminated. Soil type or landform is poorly represented in its distribution within project disturbance area. Soils are fragile and will not recover, landforms are fragile and will be difficult to stabilise and reform. Unique landform feature. Highly unstable and erodible landforms in steep to undulating terrain.
High	Moderately well-developed soils with moderate organic matter and nutrients. Soil is not very erodible and is not contaminated by previous land use. Soil type and/or landform is limited in its distribution within project disturbance area. Soils are not very robust, and recovery will be slow; landforms are not very robust and will stabilise and recover over time. Highly unstable and erodible landforms in steep to undulating terrain.
Medium	Developed soils with some organic matter and nutrients. Soil type and/or landform is less widely distributed and represented within project disturbance area. Soils are moderately robust and will recover over time; landforms are not very robust and will stabilise and recover over time. Potentially unstable landform in undulating terrain.
Low	Poorly developed soils with low organic matter and nutrients. Soil and/or landform potentially contaminated from previous land use. Soil type and/or landform is represented in its distribution within project disturbance area. Soil type is relatively robust and will recover from disturbance; landforms quite resilient and will stabilise and reform. Highly stable landform in flat or gently undulating terrain that has little susceptibility to erosion.
Not sensitive	Very poorly developed soils with negligible organic matter and nutrients. Soils and/or landform contaminated from previous land use. Includes fill or waste rock material in landforms from previous mining activities. Soil type and/or landform is widely distributed and represented within project disturbance area. Soils are robust and will quickly recover from disturbance; landforms quite resilient and will quickly stabilise and reform. Highly stable landform in flat or gently undulating terrain that is not susceptible to erosion.

Table 10.5 Sensitivity of identified landforms and soil environmental values

Environmental value	Land facet groups/landform unit*	Associated landform/soil characteristics	Sensitivity
TSF development area			
Physical integrity and stability of landforms	Ridgelines	Ridgelines exhibit clay dominated soils with limited resilience and capacity to accommodate change.	High
	Tributaries (perennial and seasonal)	Greater granular (sand and gravel) material, indicating greater resilience than the ridgeline facet group.	Medium
	Braidplains and floodplains	Greater granular (sand and gravel) material, indicating some resilience.	Low
	Marshland	Similar to perennial and seasonal tributaries facet groups, with little granular material.	Medium
Soil capacity (quantity and quality)	Ridgelines	Ridgelines exhibit clay dominated soils with limited resilience and capacity to accommodate change.	High
	Tributaries (perennial and seasonal)	Greater granular (sand and gravel) material, indicating greater resilience than the ridgeline facet group.	Medium
	Braidplains and floodplains	Greater granular (sand and gravel) material, indicating some resilience.	Low
	Marshland	Similar to perennial and seasonal tributaries facet groups, with little granular material.	Medium
Infrastructure development corridor			
Physical integrity and stability of landforms	Alluvial plains and swamps	Dissected relict alluvial, colluvial mudflow and fans and intricately dissected relict alluvial plains: low closely spaced ridges and narrow swampy valleys. These landforms typically have moderate erodibility soils.	Low
	Ridgelines	Polygonal karst: plateaux or broad ridges on limestone covered with numerous rugged hills. Homoclinal ridges and cuestas: inclined asymmetrical structurally controlled ridges.	High
	Floodplains	Meander floodplains: unstable alluvial floodplain.	Medium
	Mountainous and hilly terrain	Mountains and hills with weak or no structural control. Hilly terrain with weak or no structural control.	Medium
Soil capacity (quantity and quality)	Alluvial plains and swamps	Predominantly alluvial soils (paleudults, tropaquepts and dystropepts) that exhibit moderate erodibility and poor drainage.	Medium
	Ridgelines	Soils (predominantly dystropepts and lesser amounts of rendoll, tropaquept and humitropept soils) with variable depth and erodibility.	Medium
	Floodplains	Predominantly fluvaquent soils. Typically have moderate erodibility.	Low
	Mountainous and hilly terrain	Predominantly dystropept soils with lesser amounts of troporthents. Typically have moderate erodibility.	Medium

10.2.2 Potential impacts

This section describes potential impacts that may affect landform and soil environmental values as a result of project activities.

Construction and operation of the project will involve the excavation and movement of large volumes of material within the project's disturbance footprint. Project-related activities that may result in impacts to the soil and landform values are:

- Physical disturbance of soils and landforms caused by land clearance and bulk earthworks, such as for the construction of the TSF development area (TSF impoundment footprint, hydro-cyclone house, laydown area and associated ancillary infrastructure) and infrastructure corridor development area (proposed access roads, bridge and water crossings, tailings pipeline and supporting facilities outside the TSF development area).
- Erosion, compaction, land contamination from seepage and accidental spills or leaks, and exposure of acid sulfate soils (ASS) and/or potential acid sulfate soils (PASS). This may result in changes to soil physico-chemical properties.

Construction of the TSF and placement of tailings will result in changes to the landform. The visual assessment (Chapter 11) provides visual representations of the final landform and how it blends into the surrounding natural landscape. The final landform at closure of the project will include a TSF approximately 36 m high. Details with respect to the final landform are provided in Attachment 3.

If not appropriately managed, physical disturbance can expose soils, increasing susceptibility to erosion and compaction, which can reduce soil capacity to support vegetation growth. Physical disturbance can destabilise landforms, which can lead to erosion and slope failure. Physical disturbance impacts are expected to be greatest when ground disturbance is at its peak during the construction and decommissioning phases of the project.

Chemical impacts, which may occur due to seepage, soil contamination or exposure of ASS and/or PASS, can degrade soil quality and compromise soil function, limiting its ability to sustain vegetation. ASS/PASS impacts are expected to be greatest during construction as they are associated with ground disturbance, while seepage impacts will be greatest once the TSF is operational. Seepage impacts may persist into and beyond closure.

10.2.2.1 Summary of potential impacts according to project phases

Table 10.6 presents a summary of potential impacts and associated stressors on identified soil and landform values resulting from project activities across the different phases. Key impacts are further discussed in subsequent subsections.

Table 10.6 Potential impacts on identified soils and landform values according to project phases

Potential impact	Key source/project activity	Phase*			Comment/rationale
		C	O	D	
Changes to landform	Development of the TSF, pipeline and access roads	X	X	X	Landform changes resulting from construction and presence of TSF, pipelines, and access roads may alter surface water runoff patterns, increase erosion potential, and limit future land use options.
Reduced landform stability	Earthworks and ground disturbance, sidelaying	X	X	X	Landform instability is most likely to occur during construction due to extensive soil disturbance. However, stability risks may persist during operations and extend into closure if slopes, embankments, or spoil areas are not adequately stabilised.

Potential impact	Key source/project activity	Phase*			Comment/rationale
		C	O	D	
Degradation of soil capacity (including loss of soil) due to erosion	Land disturbance, earthworks, soil management	X	X		Ground disturbance may lead to landslips and displacement of soil, resulting in direct loss of soil resources, burial of topsoil, breakdown of soil structure, and alteration of the landform. This reduces soil availability for rehabilitation. Topsoil may be lost through erosion or poor handling and storage during and after construction of landforms (e.g., TSF). This reduces the capacity of the land to support vegetation, ecosystems, and post-project land uses.
	Management of soil stockpiles	X	X		Soil structure may be degraded due to poor stockpile management, rehandling, including compaction, mixing of soil horizons, erosion, and incorrect replacement of soil layers. These factors can adversely affect soil function and rehabilitation outcomes.
Degradation of soil capacity due to compaction	Heavy machinery traffic and repeated loading from construction equipment	X			Repeated trafficking by heavy machinery during construction can compact soils, reducing porosity, permeability, and overall soil capacity to support plant growth and infiltration.
Degradation of soil capacity due to soil contamination	Accidental spills and leaks, and inappropriate storage of fuels, chemicals, and hazardous materials.	X	X	X	Soil contamination may occur during all project phases due to spills, leaks, or improper storage and handling of hydrocarbons and hazardous materials used for equipment operation and on-site power generation.
	Seepage from the TSF		X	X	Would commence during operations once the TSF is operational and tailings are placed. Contaminated seepage may contaminate nearby soils.
	Management of disturbed and excavated soils	X	X		Contamination may occur through inadvertent mixing of contaminated and uncontaminated soils, or through the use of contaminated water (e.g., for dust suppression), reducing soil quality and its suitability for rehabilitation.
	Ground disturbance causing exposure of ASS and/or PASS	X			Exposure of ASS or PASS could generate acidic water that can leach into the soil, negatively impacting the capacity of the soil to support vegetation growth. Vegetation is less likely to become established in areas affected by acid leaching.

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.2.2.2 Landform alteration

Landform changes include alterations to the natural shape and features of the terrain through excavation, filling, and construction activities, which may modify surface water flow, increase erosion potential, and influence future land use. This section discusses potential impacts to landforms due to project activities.

Landform changes

The project will permanently change the landform in the Ok Yep catchment, through establishment of the 36-m-high TSF. Details on the final landform are provided in the conceptual TSF closure plan. This represents an irreversible/permanent major change to the existing landscape character and local drainage.

Landform stability

Areas in the upper catchment around the Ok Tedi Mine are prone to instability, with extensive evidence of landslips (see Section 8.2). Less mountainous areas, including much of the infrastructure corridor and TSF development area are more stable; however, existing instability may be exacerbated by project-related physical disturbance, for example, vegetation removal, changes to surface water drainage, excavation of slopes for access track construction, and sidecasting of material during earthworks. Sidecast spoil and vegetation may be susceptible to erosion or lead to instability if not appropriately managed.

Construction of the TSF will change surface water drainage patterns in the TSF development area, which may result in increased erosion of areas previously unaffected by drainage. Localised areas of steepness, such as ridgelines may be more susceptible to instability. These steep areas will also require excavation or cut and fill in some areas when constructing new access roads.

Disturbed areas in both the TSF development area and infrastructure development corridor will be susceptible to erosion. The extent of landform erosion is likely to be localised, but may persist if not revegetated, given the high rainfall in the region and potential changes to surface water drainage patterns, particularly within in the TSF development area.

During operations, limited land disturbance and vegetation clearance is required and impacted landforms will have the opportunity to stabilise.

10.2.2.3 Degradation of soil capacity

The degradation of soil capacity includes the physical loss of soil through erosion, and changes to the physical and chemical properties of the soil. This section discusses potential impacts to soil capacity due to project activities.

Erosion and direct soil loss

Soils may be lost due to land disturbance, earthworks and soil management, particularly in areas of high rainfall and steep slopes. Soil types that are naturally shallow and exposed to weathering and eroding processes (i.e., wind and rain), are susceptible to erosion as a result of ground-disturbing work. Over time, erosion can lead to a permanent loss of substrate for vegetative growth, particularly in steeper areas.

The key project activities with the potential to increase erosion are clearing vegetation and bulk earthworks. The TSF also has the potential to be a source of erosion due to the creation of large areas of exposed soil, embankments and altered drainage pathways within the high-rainfall environment. Rainfall and concentrated runoff may erode exposed surfaces, embankment faces and drainage channels, resulting in soil loss and the mobilisation of sediment.

Erosion and landslips may contribute to the degradation of soil structure through the burial of fertile topsoil and plant propagules, breaking up soil aggregates, and exposing more dispersive subsoils. Further, construction of the TSF will change surface water drainage patterns in the TSF development area, which may result in increased erosion of areas previously unaffected by drainage (see Section 10.4.4.1 for further details). Localised areas of soil erosion may occur in the floodplains and alluvial plain areas. However, soils in these areas are typically less dispersive, which will limit the extent of erosion.

Landform stability and soil capacity can be impacted by the modification of soils due to poor management of soil stockpiles. The exposure and subsequent use of subsurface soils incompatible with local vegetation has the potential to reduce successful revegetation during the rehabilitation phase.

Soil compaction

Compaction of soils in temporary workspaces may occur due to heavy machinery traffic and repeated loading from construction equipment. The construction of project infrastructure may lead to soil compaction throughout areas traversed by vehicles and laydown areas. The physical properties of the soil will change when compacted, making it difficult for naturally occurring vegetation to successfully re-establish during the rehabilitation phase of the project. The geographic extent of soil compaction is restricted to within the project area, with the areas of highest risk associated with areas surrounding the TSF required to facilitate construction, including temporary access roads and laydown areas. As permanent access roads and the TSF are permanent features, the existing soil and landform values will be lost, therefore soil compaction will no longer be relevant to these features.

Soil contamination

There is a potential for the release of chemicals, including liquid hydrocarbons and other hazardous materials to occur throughout the life of the project. This would negatively impact the soils capacity to support vegetation growth, depending on the type and extent of the release. Soil contamination may occur as a result of accidental spills and leaks, and inappropriate storage of fuels, chemicals, and hazardous materials. Uncontaminated soil may also become contaminated by poor management of disturbed and excavated contaminated soils.

Acid sulfate soils

Potential ASS may generate acidity and metal leachate if sulfide-bearing materials are exposed to oxygen during project activities, such as ground disturbance and earthworks. Oxidation of these materials can produce acidic runoff and mobilise dissolved metals into surrounding soils. Potential impacts may include degradation of soil quality, reduced vegetation growth, and consequent impacts on surface water and groundwater quality (see Section 10.3 and 10.4), which may adversely affect aquatic ecosystems (see Section 10.5) if not appropriately managed.

10.2.3 Avoidance, management and mitigation measures

OTML will implement avoidance, mitigation and management measures to address the potential impacts on soils and soil capacity. These measures will reflect current good practice at similar mines operating in similar environments. Areas of disturbance which are no longer required for operations will be rehabilitated progressively, but most will only become available for rehabilitation at the end of the project life. Learnings from rehabilitation at Bige will also be applied, where possible.

Table 10.7 presents an overview of the proposed management measures that will be adopted to limit the predicted impacts of the project on soils and landform environmental values during construction, operations and closure.

Table 10.7 Proposed soils and land management measures

Measure ID	Key measures	Phase*		
		C	O	D
Landform stability				
MM001	Design the TSF as a stable, water-shedding and erosion-resistant landform that comprises benched embankment slopes to safely convey PMF flows away from rehabilitated surfaces to the receiving environment via appropriately sized closure spillways and channels.	X		
MM002	Evaluate suitability of local borrow fill and gravel, and limit extraction from watercourses to the Ok Tedi to minimise impacts on other watercourses.	X	X	
MM003	Avoid sidecasting to the extent practicable, particularly in steep terrain. Where sidecasting cannot be avoided, conduct a site-specific risk assessment to evaluate potential downslope erosion and sediment transport impacts, including on downstream communities (if any) and identify appropriate controls.	X	X	
MM004	Adopt the following principles to manage erosion and sediment transport for construction of benches and batters: <ul style="list-style-type: none">Construct embankment slopes in a manner that facilitates controlled runoff and promotes drainage based on experience at Ok TediGrade benches to shed water and reduce the risk of erosion or batter slumping.Retain vegetation at crest of cut batters and at toe of fill batters where practicable to minimise erosion.Establish vegetation (e.g., shrubs/grasses/legumes) as soon as possible on benches. Consider using hydroseeding or direct planting where suitable.Install dykes and swales at top of batters (where practicable) and divert runoff to slope drains and into stabilised areas.Stabilise batters, such as by using brush layers or geotextile/fibrous matting, where required.Construct slope drainage such as cut-off trenches or horizontal drains at crest of batters/slopes, and install adequate drainage at the toe to maintain slope stability.	X	X	
Erosion and direct soil loss				
MM005	Implement appropriate erosion and sediment controls and structures prior to disturbance works commencing. Key controls may include retaining riparian vegetation buffer zones, rip-rap aprons, sediment control ponds and sediment fences.	X	X	X
MM006	Install and maintain sediment control measures where required such as drainage diversion into surrounding vegetation, rip-rap aprons, sediment control ponds and sediment fences.	X	X	
MM007	Clear accumulated material from behind sediment fences and barriers, cut-off drains and diversion drains associated with temporary erosion control berms. Dispose of sediment into the TSF	X	X	
MM008	Install sedimentation ponds downstream of key project infrastructure prior to construction to capture sediment-laden water and reduce sedimentation downstream	X	X	
MM009	Clear accumulated material from sediment ponds where required (to maintain minimum capacity required to allow sediment ponds to function properly and limit the potential for a large rain event to result in significant release of coarse sediment downstream). Dispose of sediment into the TSF	X	X	
MM010	Install and maintain sediment basins downstream of main drainage systems in the TSF to capture outflowing sediment.	X	X	
MM011	Design and construct sediment ponds to accommodate a 1 in 50 annual exceedance probability event	X		
MM012	Design and construct surface water management structures, such as structures including drains to convey contact drains and non-contact drains clean and dirty	X		

Measure ID	Key measures	Phase*		
		C	O	D
	water, for 1 in 20 year annual exceedance probability. Design other surface water structures, such as berm drainage, to 1 in 50 annual exceedance probability.			
MM013	Where practicable, locate valley-bottom access alignments to retain a buffer of natural vegetation between access ways and watercourses	X		
MM014	Implement the following measures to manage erosion and sediment transport during construction of access roads, bridges and water crossings: <ul style="list-style-type: none"> • Install temporary erosion and sediment controls during construction and permanent drainage structures such as road ditches and culverts. • Design and construct bridges and minor crossings with adequate protection to resist scour, erosion and failure due to flooding. • Refine alignments of project roads to follow natural ridges and hill slopes to minimise cut/fill and avoid crossing watercourses, ORWBs and wetlands to the extent possible. • Restrict watercourse crossings to designated crossing points where riparian vegetation clearing widths will be limited. Maintain riparian vegetation buffer zones elsewhere. 	X		
Management of topsoil and spoil				
MM015	Prioritise use of spoil (excess excavated material), where suitable, as borrow fill for project activities.	X	X	
MM016	Stockpile and reuse topsoil where practicable for use in progressive rehabilitation activities.	X	X	
MM017	Locate and stockpile all topsoil and spoil in approved designated locations away from watercourses, waterbodies or low-lying flood prone areas	X	X	
Soil compaction				
MM018	Restrict or limit vehicles to dedicated access tracks and roads	X	X	
MM019	Rehabilitate soil compacted during construction and operation to the agreed final landform, including cultivation (deep ripping to aerate compacted soils and application of soils ameliorants) prior to planting of vegetation.	X	X	X
MM020	Rehabilitate soil compacted during construction and operation (other than those with infrastructure to remain after closure), including ripping, spreading with topsoil and revegetating with native species to reduce the effects of compaction.	X	X	X
Accidental spills, leaks and contamination				
MM021	Clean up contaminated soils as soon as possible after the contamination event occurs or contamination is identified. This may include excavation of soils, decontamination, or neutralisation methods or dispose of in accordance with relevant legislation and the OTML General Waste Management Plan (OTML-IMS-PLA-3.06).	X	X	X
MM022	Manage incidents throughout all stages of the project in accordance with OTML's incident reporting standard, including recording details on the location, extent and nature of spills or site contamination. This will be used to monitor existing contamination and will be reassessed at closure to determine appropriate decontamination and remediation actions.	X	X	X
MM023	Conduct routine inspections and maintenance of all potential sources of contamination, including fuel and chemical storage facilities, heavy machinery, transport fleet, diesel generators, bund, and pipes, completed during all stage of the project for early detection and control of leaks and spills.	X	X	X
MM024	Store, handle and transport hazardous substances in accordance with the PNG Environmental Code of Practice for Vehicle/Machinery Workshops and Petroleum Storage/Resale/Usage Sites, and Australian Standards AS1940:2017 relevant to bunding.	X	X	
MM025	Install and maintain efficient oil and grease traps or sumps at refuelling facilities, workshops, fuel storage depots, and containment areas			

Measure ID	Key measures	Phase*		
		C	O	D
MM026	Minimise generation of hazardous waste as far as practicable. Dispose of hazardous waste, including waste oils and chemicals, spent packaging materials and containers in accordance with current OTML practices			
Acid sulfate soils				
MM027	<p>Conduct acid sulfate soils surveys within areas known or predicted to occur to determine the extent of ASS treatment that may be required and determine whether the development of a specific management plan is required. The plan may include the following management controls:</p> <ul style="list-style-type: none"> Mixing of high and very high ASS or PASS materials with a neutralising agent such as fine-ground lime that inhibits oxidation to increase pH. Short term stockpiling ASS material in a bunded area with an acid-resistant liner. 	X		

* C = Construction; O = Operations; and D = Decommissioning and closure.

Further measures to minimise erosion are described in Section 10.3.3 and details will be included in the CESMP summarised in Chapter 14 and presented in Attachment 2. Hazardous materials management is discussed in Chapter 13.

10.2.4 Residual impact assessment

This section describes the predicted residual impacts of the project on landform stability and soil capacity following successful implementation of the proposed management measures during each project phase. This section focusses on key impacts with a residual significance of moderate or greater.

10.2.4.1 Construction

Residual impacts arising from construction of the project are discussed in this section.

Landform changes

TSF development area

Construction of the TSF will permanently alter the existing landform within the Ok Yep catchment through the establishment of an approximately 36-m-high TSF, with associated drainage, embankments and ancillary infrastructure. This represents a major and irreversible modification of the existing landform, resulting in the permanent loss and reconfiguration of natural ridgelines, tributaries and marshland environments within the TSF footprint. The TSF will also alter local surface water drainage patterns.

While these impacts cannot be fully mitigated due to the permanent nature and scale of the TSF, project design has sought to minimise disturbance by largely confining the TSF footprint to a single catchment and avoiding direct interaction with the relatively undisturbed Ok Birim catchment. Rehabilitation and closure measures will also be implemented progressively to promote long-term stability of the TSF landform and reduce erosion risk.

Considering the high sensitivity of the ridgeline land facet group, and moderate magnitude of impact due to the permanent alteration of terrain and drainage features, the residual impact significance to the ridgelines land facet group is high.

Considering the **high** sensitivity of the tributaries (perennial and seasonal) and marshlands land facet groups, and **moderate** magnitude of impacts, due to the localised but permanent modification of landform characteristics and drainage patterns within these environments, the residual impacts to perennial and seasonal tributaries and marshland land facet groups are assessed as **moderate**.

Infrastructure development corridor

Landform changes associated with the infrastructure development corridor will primarily result from cut-and-fill earthworks, grading, trenching and construction of roads, bridge crossings and pipeline infrastructure. These activities will locally alter slope profiles and modify drainage pathways, particularly within steep ridgeline and hilly terrain areas. Although these changes will be permanent in some locations, impacts are expected to remain spatially confined to the infrastructure corridor footprint and are generally smaller in scale than those associated with the TSF.

With implementation of erosion and drainage controls, the magnitude of residual impacts is **low** across all landform units assuming sidecasting is appropriately managed in accordance with the site-specific risk mitigation measures developed prior to construction. Accordingly, residual impacts to the high sensitivity ridgeline landform unit are assessed as **moderate** significance, while impacts to alluvial plains, floodplains and mountainous or hilly terrain are assessed as **low** significance.

Landform stability

TSF development area

Landform stability within the TSF development area will be affected by vegetation clearing, excavation, cut-and-fill earthworks, drainage diversion and construction of the TSF embankments and associated infrastructure. Construction activities, notably work involving ground disturbance and vegetation clearance, will destabilise exposed soils and increase susceptibility to erosion, gully formation and localised landslip formation. The potential for localised erosion and shallow slope instability will be increased during periods of high rainfall. Vegetation clearing and earthworks on ridgelines and drainage lines will increase runoff velocities and sediment mobilisation into adjacent tributaries and low-lying areas.

Changes to surface water drainage associated with the TSF, diversion channels and embankments will also concentrate flows into previously undisturbed areas, increasing erosion and localised instability. Impacts are expected to be greatest prior to stabilisation and rehabilitation of disturbed areas.

Borrow extraction from the Ok Tedi for TSF construction materials will further contribute to localised bank instability and erosion within extraction areas along the floodplain and braidplains adjacent to the Ok Tedi. The extraction represents changes to the landform, sediment in the Ok Tedi is predominantly mine-derived, and extraction is largely reclamation of this mine-derived material. The system is highly impacted, dynamic and subject to ongoing erosion, deposition and channel migration processes. This means the system will be able to recover over time, particularly with implementation of appropriate management measures, including avoidance of sensitive or unstable areas to minimise erosion and potential instability.

Disturbed areas are expected to progressively stabilise following construction and the implementation of rehabilitation measures. Ongoing impacts will persist associated with exposed embankments, drainage channels, sediment management structures and maintenance activities. Long-term landform stability will depend on effective TSF design, erosion and sediment controls, drainage management, progressive rehabilitation and monitoring. With implementation of the proposed management measures, residual impacts on landform stability within the TSF development area are expected to range from low to moderate significance. Considering the **high** sensitivity of the ridgelines land facet group, and **moderate** magnitude of impacts, the residual impacts on the physical integrity and stability of landforms and soils within the ridgeline land facet group is **moderate**.

Infrastructure development corridor

Landform stability within the infrastructure development corridor will be affected by vegetation clearing, trenching, cut-and-fill earthworks, road and bridge construction and installation of the pipeline. The corridor traverses a range of terrain types, including alluvial plains, floodplains, ridgelines, mountainous and hilly terrain, some of which contain steep slopes, shallow soils and erosion-prone landforms.

The tailings pipeline will be buried in trenches for approximately 80% of its length, and 20% aboveground on concrete footings or pipe supports for specific locations such as river and ravine crossings. The rate of pipeline trenching will depend on the nature of the soils and terrain traversed but typically ranges from 50 m/day in steep terrain to 150 m/day in undulating, high water table areas. Buried sections will require right-of-way clearing and grading, including removing vegetation, topsoil, grading, and preparing for access. Where hard rock is encountered, drilling and blasting may be required. Trenching involves excavating to design depth/width using excavators and dewatering using damming and pumping methods with properly directed drainage outlets to manage unstable soils and water. Trenching will have a typical cross-section of 1.0 m wide by 1.6 m deep in 50 m lengths, incorporating drain-off points to allow for drainage during rainfall events.

Construction of roads, pipeline trenches and watercourse crossings will destabilise slopes and alter local drainage pathways, particularly in steep ridgeline and hilly terrain areas. Vegetation clearing and excavation on steep slopes will increase susceptibility to erosion, shallow landslips and sediment mobilisation during high rainfall events. Trenching activities and grading will also disturb naturally stable soils and increase the risk of localised instability where drainage is poorly managed or disturbed surfaces remain exposed for extended periods. In steep terrain, sidecasting of excavated spoil and vegetation adjacent to the construction corridor will further increase erosion and instability risks where unconsolidated material is placed on steep slopes or near drainage lines. Sidecast material may be susceptible to downslope movement, erosion and mobilisation during rainfall events, potentially resulting in localised slope instability and drainage blockage if not appropriately managed. OTML will minimise sidecasting, instead preferentially using excavated material for other construction activities. In accordance with MM003, OTML will conduct a risk assessment prior to works in steep terrain where sidecasting is proposed to evaluate potential downslope impacts and identify appropriate controls. These controls may include limiting the volume and extent of sidecast material, locating sidecast areas away from drainage lines and watercourses, benching or contouring slopes to improve stability, installing erosion and sediment control measures, progressively stabilising exposed material through revegetation, and undertaking routine inspection and maintenance following significant rainfall events. Additional controls such as retaining structures, drainage controls or relocating excavated material to designated spoil disposal areas may be implemented in areas particularly susceptible to instability to minimise the risk of downslope movement and off-site sediment transport.

Disturbed areas are expected to progressively stabilise following construction and the implementation of rehabilitation measures. Impacts will reduce substantially, although erosion may persist along unsealed roads, drainage structures and maintenance access areas. Potential instability associated with development of the infrastructure will persist as long as the infrastructure is present. Long-term stability of disturbed landforms within the corridor requires effective drainage design, erosion and sediment management, stabilisation of cut-and-fill batters, progressive rehabilitation and maintenance of infrastructure. With implementation of the proposed management measures, residual impacts on landform stability within the infrastructure corridor are expected to be localised and ranging from **low** to **moderate** depending on the landform unit. Management measures including minimisation of sidecasting, stabilisation of spoil material, management of excavated material, and progressive rehabilitation will be implemented to reduce erosion and instability impacts associated with construction activities.

Considering the **high** sensitivity of the ridgelines landform unit, and **low** magnitude of impacts, the residual impacts on the physical integrity and stability of landforms and soils within the ridgelines landform unit is **moderate**, assuming sidecasting is appropriately managed in accordance with the site-specific risk mitigation measures developed prior to construction.

Soil capacity

TSF development area

Soil capacity within the TSF development area may be affected by vegetation clearing, earthworks, drainage modification, erosion, compaction and potential contamination. The project area contains highly weathered and erosion-prone soils that support lowland rainforest, swamp woodland and riparian vegetation communities. Disturbance of these soils may reduce their physical and chemical capacity to support vegetation growth, maintain soil structure and sustain ecological functions.

Construction activities, including clearing, excavation, grading and embankment construction, will result in direct loss and disturbance of topsoil and underlying soil profiles within the TSF footprint and associated infrastructure areas. Removal of vegetation and exposure of soils may increase susceptibility to erosion, leading to loss of fertile topsoil, breakdown of soil structure and mobilisation of fine sediments during heavy rainfall events. Changes to drainage patterns associated with the TSF and diversion channels may further increase soil saturation or erosion in some areas, potentially affecting soil stability and rehabilitation potential.

Compaction of soils may occur in areas subject to repeated heavy vehicle movements, laydown areas, access roads and construction platforms. Soil compaction may reduce infiltration, permeability and root penetration, limiting the capacity of soils to support revegetation and increasing runoff and erosion potential. Poor management of topsoil stripping, stockpiling and replacement may further reduce soil fertility, biological function and rehabilitation potential, particularly under the high rainfall conditions characteristic of the project area. In addition, accidental spills or leaks of fuels, chemicals and hazardous materials may alter soil chemistry and reduce soil suitability for rehabilitation if not effectively managed.

Impacts on soil capacity are expected to reduce as disturbed areas progressively stabilise and rehabilitation measures are implemented. However, some permanent loss of soil function will occur within the TSF development area.

The ridgeline land facet group within the TSF development area is the most susceptible to impacts on soil capacity associated with compaction, contamination and poor soil management due to the presence of shallow, clay-dominated and highly weathered soils with limited resilience to disturbance. These areas are particularly vulnerable to degradation of soil structure and erosion following vegetation clearing, earthworks and repeated heavy machinery movements. Marshland and tributary land facet groups are also susceptible due to poorly drained soils, proximity to drainage lines and the potential for sediment and contaminant transport through surface water systems.

Long-term impacts on soil capacity will depend on successful management of erosion, drainage, contamination risks and rehabilitation activities. Implementation of management measures to appropriately manage erosion, hazardous materials, and topsoil for rehabilitation, will limit chemical alterations to soil and degradation of soil capacity and reduce the severity and duration of the impact. With implementation of the proposed mitigation measures, residual impacts on soil capacity within the TSF development area are expected to range from low to moderate.

Considering the **high** sensitivity of the ridgelines landform unit, and **low** magnitude of impacts, the residual impacts on the soil capacity within the ridgelines landform unit is **moderate** significance. Impacts on all other land facet groups are **low** significance.

Infrastructure development corridor

Soil capacity within the infrastructure development corridor may be affected by vegetation clearing, trenching, earthworks, road construction, compaction and contamination associated with construction of the pipeline and access roads. The corridor traverses a range of soil and landform types, including alluvial plains, floodplains, ridgelines and hilly terrain, with varying levels of erodibility, drainage and rehabilitation potential.

Construction activities may result in direct disturbance and loss of topsoil, mixing of soil horizons and exposure of dispersive or poorly structured subsoils. In steep or erosion-prone areas, disturbance of shallow soils may increase erosion and reduce the capacity of soils to support revegetation. Trenching and grading activities may also alter natural drainage patterns and increase runoff, contributing to localised soil loss and sediment transport during rainfall events.

Repeated movement of heavy machinery and vehicles along access tracks, laydown areas and construction zones may compact soils and reduce permeability, infiltration and root growth potential. This is an issue for temporary tracks that will be rehabilitated. Some areas along the corridor may also contain dispersive soils or potentially ASS/PASS, which may require specific management to prevent soil degradation, acidification or contamination following disturbance. Testing will confirm this.

Accidental spills and leaks of fuels, hydrocarbons and hazardous materials may contaminate soils and reduce their suitability for rehabilitation if not appropriately managed. Ongoing use of unsealed roads may contribute to localised soil disturbance, erosion and compaction.

Net acidity (excluding acid neutralising capacity (ANC)) results indicated that PASS may be present in soils along the alignment. However, where ANC testing was undertaken, results showed that there was sufficient excess neutralising capacity for disturbed soils to self-neutralise, indicating PASS is unlikely. ANC testing was not undertaken on all samples, and there is some uncertainty in the ability of some of the locations to self-neutralise. The results of the field ASS testing generally indicated that there was a low potential for significant acid generation across the proposed alignment. In accordance with MM027, further testing of soils will determine the presence and required management of PASS. Appropriate soil management and monitoring measures will be implemented during construction to minimise the potential for acidification or impacts associated with disturbance of these soils.

Within the infrastructure development corridor, ridgelines and mountainous or hilly terrain are the most susceptible landform units to impacts on soil capacity due to steep slopes, shallow and moderately erodible soils, and the need for cut-and-fill earthworks, trenching and repeated vehicle access during construction. Disturbance of these areas may increase soil compaction, erosion potential and rehabilitation difficulty, particularly where topsoil management is poor or disturbed surfaces remain exposed. Alluvial plains and swamp areas are also susceptible to soil compaction and contamination because of their soft, poorly drained soils and high moisture content, which may be readily disturbed by heavy machinery and construction activities. Effective topsoil management, vehicle controls and contamination prevention measures will therefore be important to maintain soil function and support successful rehabilitation across the corridor.

With implementation of the proposed management measures, including erosion controls, topsoil management, rehabilitation and contamination controls, residual impacts on soil capacity within the infrastructure corridor are expected to be localised and of low magnitude. Considering the sensitivity of the landform units and **low** magnitude of impacts, the residual impacts on the soil capacity within all landform units is **low** significance.

Residual impact assessment summary - construction

Table 10.8 presents the residual impact assessment during the construction phase.

Table 10.8 Residual impact assessment – construction

Impact description	Land facet groups/landform unit	Sensitivity	Residual impact assessment	
			Magnitude	Significance
TSF development area				
Changes to landform	Ridgelines	High	Moderate	High
	Tributaries (perennial and seasonal)	Medium	Moderate	Moderate
	Braidplains and floodplains	Low	Moderate	Low
	Marshland	Medium	Moderate	Moderate
Reduced physical integrity and stability of landforms and soils	Ridgelines	High	Low	Moderate
	Tributaries (perennial and seasonal)	Medium	Low	Low
	Braidplains and floodplains	Low	Moderate	Low
	Marshland	Medium	Low	Low
Reduced soil capacity (quantity and quality)	Ridgelines	High	Low	Moderate
	Tributaries (perennial and seasonal)	Medium	Low	Low
	Braidplains and floodplains	Low	Low	Low
	Marshland	Medium	Low	Low
Infrastructure development corridor				
Changes to landform due to development of the TSF	Alluvial plains and swamps	Low	Low	Low
	Ridgelines	High	Low	Moderate
	Floodplains	Medium	Low	Low
	Mountainous and hilly terrain	Medium	Low	Low
Reduced physical integrity and stability of landforms and soils	Alluvial plains and swamps	Low	Low	Low
	Ridgelines	High	Low	Moderate
	Floodplains	Medium	Low	Low
	Mountainous and hilly terrain	Medium	Low	Low
Reduced soil capacity (quantity and quality)	Alluvial plains and swamps	Medium	Low	Low
	Ridgelines	Medium	Low	Low
	Floodplains	Low	Low	Low
	Mountainous and hilly terrain	Medium	Low	Low

10.2.4.2 Operations

Residual impacts arising from operation of the project are discussed in this section.

Landform stability

During operations, impacts on landform stability within the TSF development area are primarily associated with the long-term presence and operation of the TSF embankments, drainage diversion infrastructure, ongoing maintenance activities, and continued extraction of material from the Ok Tedi.

Localised erosion of the TSF embankment surfaces and drainage channels, and minor gullyng associated with concentrated runoff, will occur. Borrow areas along the Ok Tedi that continue to be used during operations may also remain susceptible to localised erosion and bank instability until recovery occurs through natural sediment transport and floodplain processes. Following implementation of the engineered TSF design, drainage controls, erosion and sediment management measures, progressive rehabilitation and routine

maintenance programs, the extent of erosion and instability is expected to be minimised. Residual impacts are expected to be confined to isolated areas of disturbance and maintenance activities, with the overall stability and integrity of the TSF landform maintained over the operational life of the facility.

These impacts will primarily affect the braidplains and floodplains land facet groups. Considering the **low** sensitivity of the braidplains and floodplains land facet groups and **moderate** magnitude of impacts, the residual impacts on the physical integrity and stability of landforms and soils within these landform units are assessed as **low** significance.

No impacts on landform stability along the infrastructure corridor are expected during operations.

Soil capacity

TSF development area

During operations, impacts on soil capacity within the TSF development area are primarily associated with soil contamination from accidental spill or leaks and potential TSF seepage, and long-term management of disturbed soils surrounding permanent infrastructure.

Preliminary results from TSF seepage modelling indicate that predicted toe seepage water quality under conservative assumptions is expected to have a pH neutral to slightly alkaline (pH ~7–8) with elevated solute concentrations, including total dissolved solids (TDS) of approximately 3,200 mg/L, sulfate concentrations of around 2,200 mg/L, copper concentrations up to 70 µg/L, and arsenic concentrations up to 10 µg/L. The groundwater model predictions indicate that the spatial extent of the predicted seepage is limited and generally confined to within approximately 300 to 500 m of the TSF, with low concentrations of more mobile parameters such as sulfate extending to about 1 km. Section 10.3 discusses impacts of seepage on groundwater quality further.

Potential seepage from the TSF and accidental spills or leaks of fuels, hydrocarbons and hazardous materials may alter soil chemistry and reduce the ability of soils to support vegetation growth and ecological function if not effectively managed.

A range of management measures will be implemented to minimise impacts associated with soil contamination during operations. These measures include appropriate storage and containment of fuels and hazardous materials, spill prevention and response procedures, routine inspection and maintenance of infrastructure, and implementation of containment systems designed to prevent uncontrolled releases to the surrounding environment. In addition, the TSF and associated seepage management systems will be designed and installed to manage seepage collection, recovery and controlled discharge. Chapter 6 provides further information on TSF design.

As a result, contamination impacts to soils are expected to be localised to operational areas and immediately adjacent disturbed land. Potential impacts associated with seepage and contaminant migration are discussed further in the groundwater impact assessment in Section 10.3.

With implementation of the proposed management measures, residual impacts on soil capacity during operations are expected to remain localised and generally of **low to moderate** significance. Considering the **high** sensitivity of the ridgelines land facet groups and **low** magnitude of impacts, the residual impacts on soil capacity within the ridgelines landform unit is **moderate** significance. Residual impacts on all other landform units are assessed as **low** significance.

Infrastructure development corridor

During operations, impacts on soil capacity within the infrastructure development corridor are primarily associated with continued use and maintenance of access roads, pipeline infrastructure and associated operational areas. Repeated vehicle movements along temporary unsealed roads and maintenance access tracks will result in ongoing localised soil compaction that needs to be rehabilitated, particularly within poorly

drained alluvial plains and swamp areas. There is also potential for localised soil contamination from accidental spills or leaks of fuels, lubricants and hazardous materials during maintenance activities. Impacts along the infrastructure development corridor are **low** significance for all landform units.

Residual impact assessment summary - operations

Table 10.9 presents the residual impact assessment during the operations phase.

Table 10.9 Residual impact assessment – operations

Impact description	Land facet groups/landform unit	Sensitivity	Residual impact assessment	
			Magnitude	Significance
TSF development area				
Reduced physical integrity and stability of landforms and soils	Braidplains and floodplains	Low	Moderate	Low
Reduced soil capacity (quantity and quality)	Ridgelines	High	Low	Moderate
	Tributaries (perennial and seasonal)	Medium	Moderate	Medium
	Braidplains and floodplains	Low	Low	Low
	Marshland	Medium	Low	Low
Infrastructure development corridor				
Reduced soil capacity (quantity and quality)	Alluvial plains and swamps	Medium	Low	Low
	Ridgelines	Medium	Low	Low
	Floodplains	Low	Low	Low
	Mountainous and hilly terrain	Medium	Low	Low

10.2.4.3 Decommissioning and closure

Once mining operations have ceased, decommissioning will commence and will involve the removal of infrastructure, facilities, equipment and services, unless otherwise agreed with regulators and communities. Therefore, impacts associated with the construction and operations phase will also be applicable during closure, due to the removal of infrastructure and exposure of soils, although the impact is expected to be less severe and localised as progressive rehabilitation will be implemented throughout operations and the disturbed areas at the end of operations will be rehabilitated nominally within two years.

Ongoing impacts that commenced during the construction or operations phase, such as those relating to seepage from the TSF, may persist following closure.

10.3 GROUNDWATER

This section describes the potential impacts to groundwater as a result of the project, and draws on information described in Chapter 8, Appendix D and activities described in Chapter 6. This information has been used to identify groundwater values to form the basis of the assessment.

10.3.1 Approach to impact assessment

The following approach was adopted to assess the significance of impacts to the groundwater environment:

- Identify the groundwater values and the sensitivity of groundwater values to change/disturbance.
- Identify potential impacts.
- Identify management and mitigation measures for potentially significant impacts.
- Assess the magnitude of impacts, and the significance of residual impacts to groundwater values, following the application of management and mitigation measures.

The first part of this assessment identifies and describes the potential impacts that could arise from the project based on the nature of the proposed activities, impact pathways, and the characteristics of the receiving environment. This represents a preliminary assessment of impacts and is undertaken prior to consideration of any modelling results. The purpose of this is to identify the range of plausible impacts that may occur and to establish the key issues requiring further evaluation. The residual impact assessment is informed by groundwater modelling completed by KCB (Appendix D). This modelling comprised a three-dimensional numerical ground flow and transport model to assesses groundwater flow paths and seepage at the TSF site. Predicted concentrations of sulfate, TDS, copper and arsenic were modelled and assessed against the PNG water quality criteria for aquatic life protection, the Australian Drinking Water Guideline (NHMRC 2022) and the WHO drinking water guideline (WHO 2022). The modelling analyses are used to quantify and refine the understanding of these potential impacts and, along with proposed mitigation measures, inform the assessment of residual impacts.

10.3.1.1 Groundwater values

Groundwater is assessed for its suitability to support key beneficial uses in the study area, which include:

- Consumptive and productive uses: including drinking water, domestic use and agriculture.
- Groundwater dependent ecosystems: including springs, seeps, baseflow contribution to watercourses and terrestrial vegetation accessing shallow groundwater.
- Cultural and spiritual purposes: including aesthetic, historical, scientific, social or other significance to the present and future generations.

These beneficial uses can be adversely impacted by project activities through changes to either quantity or quality of groundwater. Therefore, the groundwater values are:

- Groundwater quantity: groundwater levels and the security of supply for identified receptors, including community dug wells, groundwater-supported surface water features (e.g., baseflow to rivers, springs) and groundwater-dependent ecosystems.
- Groundwater quality: the chemical status of groundwater relative to its suitability for existing beneficial uses, including drinking water, domestic and agricultural use, and its capacity to support terrestrial and aquatic ecosystems.

Sensitivity describes how susceptible the groundwater system is to changes in quantity or quality, its capacity to adapt to the types of changes that could arise from project activities, and the intrinsic importance of the resource to groundwater users. Table 10.10 presents the groundwater value sensitivity, based on the sensitivity criteria outlined in Table 10.11 and the understanding of the existing environment established in Chapter 8.

Table 10.10 Definitions for sensitivity of groundwater values

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

Table 10.11 Sensitivity of groundwater values

Groundwater value	Sensitivity	Justification
Groundwater quantity	Medium	Shallow local aquifers contribute to surface water flow and supply dug wells; both of which are the primary sources of drinking water in the communities near the TSF and support domestic and productive uses. The groundwater system is susceptible to changes in groundwater quantity as a result of changes in flow behaviour. High natural recharge in the area means that natural dilution processes are continuous, so the groundwater system may experience localised changes and recovers quickly.
Groundwater quality	Medium	Shallow local aquifers contribute to surface water flow and supply dug wells; both of which are the primary sources of drinking water in the communities near the TSF and support domestic and productive uses. The groundwater system is susceptible to changes in quality but is expected to be able to recover from changes to groundwater quality. High natural recharge in the area means that natural dilution processes are continuous, so the groundwater system may experience localised changes and recover quickly.

10.3.1.2 Key assumptions and limitations

Groundwater modelling was limited to the TSF development area because this component of the project represents the primary long-term source of groundwater interaction and potential seepage impacts. In contrast, potential groundwater impacts associated with the infrastructure development corridor are not expected to result in substantial long-term alteration of regional groundwater systems or persistent seepage sources that would warrant detailed groundwater modelling.

Groundwater modelling results should be considered indicative of likely groundwater behaviour and impact pathways rather than precise predictions of future groundwater conditions.

10.3.2 Potential impacts

This section describes potential impacts that may affect groundwater values as a result of project activities.

Construction and operation of the project will involve earthworks, excavation, trenching, drainage modification, operation of the TSF and usage, storage and handling of fuels, chemicals and hazardous materials within the project area. These activities could alter groundwater flow behaviour, recharge processes and groundwater quality within underlying aquifers and hydraulically connected surface water systems.

Project-related activities that could lead to impacts to groundwater values include:

- Development and operation of the TSF resulting in changes to groundwater levels and flow behaviour, increased hydraulic loading (causing mounding) and potential seepage to underlying groundwater systems.
- Excavation and earthworks for TSF embankments, starter dams, roads and infrastructure corridor works, which may alter groundwater flow paths, intercept shallow groundwater systems and reduce groundwater storage.
- Trenching and pipeline installation along the infrastructure corridor, intercepting shallow groundwater flow and altering groundwater discharge to surface water features.
- Land clearance and vegetation removal, resulting in altered infiltration rates, surface runoff patterns and groundwater recharge.
- Accidental spills and leaks of fuels, chemicals and hazardous materials, and seepage from the TSF, which may reduce groundwater quality.
- Ground disturbance and excavation activities, leading to mobilisation of existing contaminants or naturally occurring metals into groundwater systems.

Changes to groundwater quantity may occur through alteration of recharge, groundwater levels and flow directions, groundwater storage, and baseflow contributions to local watercourses. These changes could affect groundwater systems used by local communities and groundwater dependent ecosystems, including springs and surface water features connected to aquifers.

Groundwater quality impacts may occur through seepage from the TSF, infiltration of contact water, accidental spills or leaks, or mobilisation of contaminants during earthworks and excavation. Potential groundwater quality changes include increased salinity, sulfate and dissolved metal concentrations within shallow groundwater systems surrounding the TSF and disturbed operational areas.

Table 10.12 presents a summary of potential impacts on identified groundwater values resulting from project activities across the different phases. These impacts could result in the reduction or loss of the beneficial uses of groundwater such as their capacity to support aquatic ecosystems or drinking water and agricultural supply. The potential impacts are considered further in the following sections where they relate to either impacts to groundwater quantity or quality.

Table 10.12 Potential impacts to groundwater values according to project phases

Potential impact	Key source/project activity	Phase*			Comment/rationale
		C	O	D	
Changes to surface expression of groundwater and increased baseflow to drainage lines due to altered groundwater levels and flow [†]	Changes to the natural surface topography (such as through earthworks and construction of TSF) during TSF development and following TSF closure		X		May include loss of springs due to siting May include increased groundwater levels (mounding), and changes to surface expressions and baseflow to drainage lines in areas where elevated groundwater levels are indicated.
Altered groundwater flow paths, behaviour or availability	Excavation, earthworks, trenching and pipeline installation	X			Trenches and backfilling can intercept baseflow to surface water features. Cut/fill and changed subsurface geometry can alter baseflow paths and reduce groundwater storage.
	Land clearance and loss of vegetation	X			Reduced infiltration and alteration to the runoff routing can reduce local recharge to shallow groundwater levels.
Reduced quality of groundwater due to increased salinity and metal concentrations [†]	Seepage or leakage from stored water, tailings pore water or decant water at the TSF		X	X	TSF seepage is expected to increase salinity, sulfates and potentially contain heavy metals. Seepage will commence during operation following placement of tailings in the TSF and will continue post-closure
Reduced quality of groundwater due to introduction or mobilisation of contaminants	Accidental spills and leaks of chemicals and hazardous materials	X	X	X	Surface spills can infiltrate to groundwater causing contamination. There are a number of project activities that require the use of hazardous liquid chemicals, additives and hydrocarbon fuel.
	Mobilisation of contaminants during excavation and earthworks	X	X	X	Ground disturbance can increase turbidity and release metals or other contaminants to infiltrating water.

* C = Construction; O = Operations; and D = Decommissioning and closure.

[†] Informed by Appendix D.

10.3.2.1 Groundwater quantity

Changes to groundwater quantity may occur through alteration of groundwater levels, recharge, flow behaviour, storage and discharge to surface water systems. These changes could affect shallow groundwater systems that contribute to local wells, springs, seeps, baseflow to creeks and groundwater dependent ecosystems. This section discusses potential impacts to groundwater quantity resulting from project activities.

Changes to groundwater levels, flow paths, discharge, baseflow or surface expressions

Construction and operation of the TSF may alter groundwater levels and groundwater flow directions within shallow aquifers surrounding the TSF. Storage of tailings and decant water within the TSF will increase hydraulic loading on underlying groundwater systems, potentially causing mounding and altering natural groundwater flow behaviour. Changes to groundwater levels may alter the location and extent of groundwater discharge to surface water systems, including springs, seeps and drainage lines.

Groundwater flow paths could be altered through construction of TSF embankments, diversion structures, roads, pipeline trenches and associated earthworks. Excavation and trenching activities may intercept shallow groundwater systems and alter groundwater discharge pathways or baseflow contributions to local creeks and drainage features. Changes to groundwater flow behaviour can result in increased or decreased groundwater discharge to some surface water features.

Changes to groundwater levels may result in localised surface expressions of groundwater, including seepage breakout areas, saturated ground conditions or changes to spring and seep locations. Altered groundwater discharge and baseflow conditions could affect groundwater dependent ecosystems and shallow groundwater users.

Altered groundwater recharge and infiltration

Groundwater recharge may be altered through vegetation clearing, construction of roads, hardstand areas and other project infrastructure that modify natural infiltration and runoff processes notwithstanding the project area receives 6,000 mm or more of rainfall per year. Compaction of disturbed surfaces and installation of impermeable surfaces could reduce infiltration and groundwater recharge in some areas, while concentration of runoff from disturbed areas may locally increase recharge.

10.3.2.2 Groundwater quality

Groundwater quality impacts may occur through seepage from the TSF, accidental spills and leaks of hazardous materials, infiltration of contact water and mobilisation of contaminants during excavation and earthworks. Potential groundwater quality changes include increased salinity, sulfate and dissolved metal concentrations within shallow groundwater systems. This section discusses potential impacts to groundwater quality resulting from project activities.

TSF seepage

Seepage from the TSF has the potential to alter groundwater quality within shallow groundwater systems surrounding the TSF footprint. Tailings pore water, decant water and seepage from stored tailings may contain elevated concentrations of dissolved salts, sulfate and metals which could migrate through the underlying groundwater system.

Groundwater seepage may migrate towards surrounding drainage systems through shallow weathered materials, fractured rock zones or structural pathways. This is of particular concern near Kungembit where potential structural features are present (see Figure 8.16). Seepage may discharge to local creeks, drainage lines, seepage areas or shallow groundwater systems hydraulically connected to surface water features.

Changes to groundwater quality have the potential to alter the quality of groundwater contributing to springs, seeps and baseflow.

Leaks and spills of fuels, chemicals and hazardous materials

There is potential for accidental spills and leaks of fuels, hydrocarbons and hazardous materials to occur throughout the life of the project. These contaminants may infiltrate into shallow groundwater systems and reduce groundwater quality depending on the type, location and extent of the release. Potential contamination sources include fuel and hazardous material storage, refuelling, vehicle maintenance areas associated with construction and operation of the TSF and infrastructure corridor.

Contaminants that migrate through shallow groundwater systems can potentially affect groundwater users, groundwater-dependent ecosystems or connected surface water features

Mobilisation of contaminants during excavation and earthworks

Ground disturbance associated with excavation, trenching and earthworks may mobilise naturally occurring metals, sediments or existing contaminants, resulting in them infiltrating shallow groundwater. Disturbance of shallow soils and weathered rock may increase turbidity and release contaminants to groundwater systems, particularly during periods of heavy rainfall or where disturbed areas remain exposed for extended periods.

Infiltration of contact water from disturbed areas

Contact water generated from areas of disturbance, such as roads, laydown areas, stockpiles and other infrastructure areas, may infiltrate into shallow groundwater systems if not effectively managed. Infiltration of sediment-laden or contaminated runoff can locally alter groundwater quality, particularly in low-lying or poorly drained areas.

10.3.3 Avoidance, management and mitigation measures

Table 10.13 lists specific groundwater measures proposed to be implemented by OTML to manage potential impacts during each phase of the project. Proposed groundwater monitoring programs are detailed in Chapter 14.

Table 10.13 Proposed groundwater management measures

Measure ID	Key measures	Phase*		
		C	O	D
Contamination, accidental spills and leaks				
MM021	Clean up contaminated soils as soon as possible after the contamination event occurs or contamination is identified. This may include excavation of soils, decontamination, or neutralisation methods or dispose of in accordance with relevant legislation and the OTML General Waste Management Plan (OTML-IMS-PLA-3.06).	X	X	X
MM080	Implement an automated alarm and warning system to alert the control rooms if there is a leak or abnormal conditions in the tailings pipeline pumping system. Immediately shut down the pipeline pumping system should this occur.		X	
MM024	Store, handle and transport hazardous substances in accordance with the PNG Environmental Code of Practice for Vehicle/Machinery Workshops and Petroleum Storage/Resale/Usage Sites, and Australian Standards AS1940:2017 relevant to bunding.	X	X	X
MM028	Conduct a contaminated soil and groundwater investigation (such as validation sampling) to determine what further assessment or remediation may be required to prevent ongoing impacts to groundwater as part of closure and rehabilitation planning		X	X

Measure ID	Key measures	Phase*		
		C	O	D
MM029	Design and construct engineering controls (such as bunding and impermeable barriers) where practicable to minimise the risk of groundwater and surface water contamination from infrastructure	X		
MM030	Divert clean water around disturbed areas using suitable designs and construction materials to minimise the volume of contact water.	X		
MM031	Prohibit disposal of domestic and industrial waste into streams or sinkholes.	X	X	X
MM032	Make an alternative, equally suitable source of drinking water available to communities in the event that drinking water sources used by local villages become contaminated by the project.	X	X	
Seepage				
MM033	Design and construct the TSF in a location that reduces the potential for impact on sensitive receptors, e.g., village drinking sources.	X		
MM034	Design and construct effective interception and drainage of groundwater expression as part of the surface water diversion proposed along the north-eastern embankment of the TSF.	X		
Groundwater flow and levels				
MM035	Confirm water quality and level impacts are as predicted as part of the ongoing groundwater monitoring program. Implement additional management measures if required to address unexpected impacts.	X	X	X

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.3.4 Residual impact assessment

The assessment of residual impacts to groundwater has been conducted by examining the magnitude of an impact occurring assuming the effective implementation of the proposed management measures summarised in Section 10.3.3 and an overall appreciation of the project description. The residual impact assessment also considers the degree of impact that may already exist in the project area as a result of existing mining activities and land use. These assessments have been based on site observations and surface water assessments, with inferences made for the groundwater resources within the catchment.

10.3.4.1 Construction

Residual impacts arising from construction of the project are discussed in this section.

Groundwater quantity

TSF development area

Construction of the TSF and associated infrastructure, including embankments, roads and drainage structures, will alter local topography, surface water drainage patterns and shallow groundwater flow behaviour within the Ok Yep catchment. Excavation, earthworks, land clearance and vegetation removal may modify groundwater recharge and infiltration processes, while permanent infrastructure and compacted surfaces may reduce infiltration in some areas, potentially changing the distribution and rate of groundwater recharge to shallow aquifers.

Reduced infiltration may occur beneath permanent infrastructure and construction areas, while excavation and drainage diversion may alter flow and recharge behaviour. These changes are expected to be localised to disturbed areas and shallow groundwater systems. Given the high rainfall and recharge rates in the region, the groundwater system is expected to quickly adapt and recover from these changes.

Considering the **medium** sensitivity of groundwater quantity and **moderate** magnitude of impact, the residual significance of altered groundwater recharge rates due to construction of TSF infrastructure, roads, impermeable hard standing or blocking recharge pathways is **moderate**.

Infrastructure development corridor

Construction of the infrastructure corridor, including roads, trenching, excavations and pipeline installation, may alter local groundwater recharge and shallow groundwater flow pathways. Trenching and excavation activities may intercept shallow groundwater systems, temporarily alter subsurface drainage conditions and affect groundwater discharge to nearby drainage lines or low-lying areas.

Vegetation clearing, soil compaction and construction of access roads and hardstand areas may also reduce infiltration and modify local recharge processes. These impacts are expected to be localised, generally limited to the active construction footprint and shallow groundwater systems adjacent to disturbed areas. The groundwater system is expected to quickly adapt and recover from these changes.

Considering the **medium** sensitivity of groundwater quantity and **moderate** magnitude of impact, the residual significance of altered groundwater recharge rates due to construction of the pipeline and road along the infrastructure development corridor is **moderate**.

Groundwater quality

Potential groundwater quality impacts during construction are primarily associated with accidental spills and leaks of fuels, hydrocarbons and hazardous materials, mobilisation of sediments, existing contamination or naturally occurring contaminants during excavation and earthworks, and infiltration of contaminated contact water from disturbed areas, laydown areas and construction facilities.

Impacts are expected to be localised and primarily limited to shallow groundwater systems within or immediately adjacent to active construction areas. The project area is characterised by very high rainfall in excess of 6,000 mm per year, which may assist recovery by diluting contaminants and allowing recovery of the system. Potential sources of contamination can generally be managed with measures to minimise spills and leaks and implementing drainage systems.

Considering the **medium** sensitivity of groundwater quality and **moderate** magnitude of impact, as the groundwater system is expected to recover quickly, the residual significance of this impact across both the TSF development area and infrastructure development corridor is **moderate**.

Residual impact assessment summary – construction

Table 10.14 presents a summary of the residual impact assessment for the construction period.

Table 10.14 Residual impact assessment for construction

Impact description	Value	Sensitivity	Residual impact assessment	
			Magnitude	Significance
TSF development area				
Altered groundwater flow paths and recharge rates due to construction of TSF infrastructure, roads, impermeable hard standing or blocking recharge pathways	Groundwater quantity	Medium	Moderate	Moderate
Reduction in groundwater quality due to leaks or spills of chemicals, infiltration of contaminated contact water, and mobilisation of existing contaminants during construction	Groundwater quality	Medium	Moderate	Moderate

Impact description	Value	Sensitivity	Residual impact assessment	
			Magnitude	Significance
Infrastructure development corridor				
Altered groundwater flow paths and recharge rates due to construction of roads, trenching, excavations, impermeable hard standing or blocking recharge pathways	Groundwater quantity	Medium	Moderate	Moderate
Reduction in groundwater quality due to leaks or spills of chemicals, infiltration of contaminated contact water, and mobilisation of existing contaminants during construction	Groundwater quality	Medium	Moderate	Moderate

10.3.4.2 Operations

Residual groundwater impacts are subject to uncertainty associated with hydrogeological variability, preferential flow pathways and long-term seepage behaviour. Ongoing monitoring and adaptive management are required to verify model predictions, confirm seepage behaviour, and assess the effectiveness of management measures. Residual impacts arising from operation of the project are discussed in this section.

Groundwater quantity

TSF development area

Seepage and hydraulic loading associated with stored tailings and decant water will alter local groundwater flow conditions. Operation of the TSF will increase underlying groundwater levels, resulting in development of a groundwater mound and radial seepage into surrounding groundwater systems, predominantly within shallow zones. Radial groundwater flow is predominantly directed towards the south and southeast along valleys towards the Ok Yep and Ok Tedi systems, and locally towards the northwest in the direction of Kungembit.

Groundwater mounding beneath the TSF is predicted to result in groundwater levels up to approximately 30 m higher than surrounding groundwater levels in the aquifers surrounding the TSF; however, the extent of influence is generally limited to within 800 m of the toe of the TSF embankment. Beyond this, groundwater levels are not expected to materially change. Groundwater seepage is expected to constitute a relatively small proportion of the overall TSF water balance, but it will migrate into shallow groundwater systems surrounding the TSF. The groundwater model predicts TSF seepage rates during peak operations between ~3,500 m³/day from the inner TSF and up to 20,000 m³/day associated with the embankment seepage. The TSF is designed with seepage interception and drainage systems to collect seepage discharged from the embankments.

Figure 10.1 and Figure 10.2 show predicted water levels at key representative locations across the TSF development area compared to existing modelled groundwater levels at the end of operations and following closure, respectively. Predicted groundwater levels at observation points indicate that groundwater levels surrounding the TSF are expected to increase following commissioning and operation of the TSF, with seasonal fluctuations continuing in response to rainfall recharge conditions. Predicted seepage and elevated groundwater levels may result in localised surface expression and saturation of low-lying areas surrounding the TSF footprint where groundwater discharges to surface if not appropriately managed.

Figure 10.3 shows areas predicted to be at risk of surface expression, including areas on the eastern side of Cell 1 and the southern side of Cell 2. Surface expression of seepage is not predicted to occur in proximity to villages. Seepage and elevated groundwater levels may also increase groundwater discharge and baseflow contributions to nearby drainage lines and streams surrounding the TSF footprint.

Groundwater modelling indicates that groundwater levels are expected to remain elevated following closure and continue to be influenced by the presence of the TSF. Groundwater level fluctuations are predicted to

remain relatively stable over time and continue to respond seasonally to rainfall variation, with no significant long-term changes in groundwater flow gradients expected.

Considering the **medium** sensitivity of groundwater quantity and the **moderate** magnitude of impacts associated with altered groundwater levels and surface expression, the residual significance of altered surface expression due to altered groundwater levels and flow is **moderate**.

Increased groundwater discharge and baseflow contributions to nearby drainage lines may also occur in areas where groundwater levels are elevated surrounding the TSF. These changes may alter local hydrological conditions and potentially affect adjacent terrestrial and aquatic ecosystems in low-lying areas surrounding the TSF footprint. Considering the **medium** sensitivity of groundwater quantity and the **moderate** magnitude and localised nature of impacts, the residual significance of increased baseflow to nearby drainage lines is **moderate**.

Infrastructure development corridor

Operational impacts on groundwater quantity within the infrastructure development corridor are expected to be limited. Localised alteration of infiltration and shallow groundwater recharge may occur beneath roads, drainage structures and compacted operational areas; however, no substantial long-term alteration to regional groundwater flow systems is anticipated. Considering the **medium** sensitivity of groundwater quality and **very low** magnitude of impact the residual significance of this impact is **low**.

Groundwater quality

TSF seepage

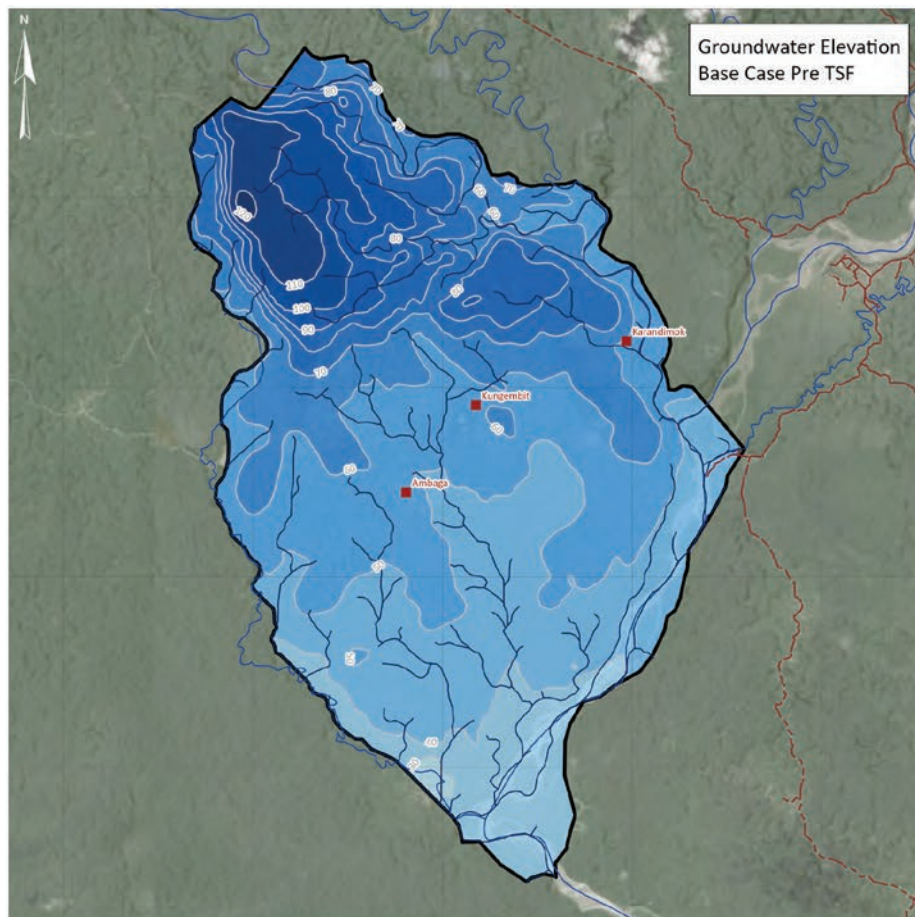
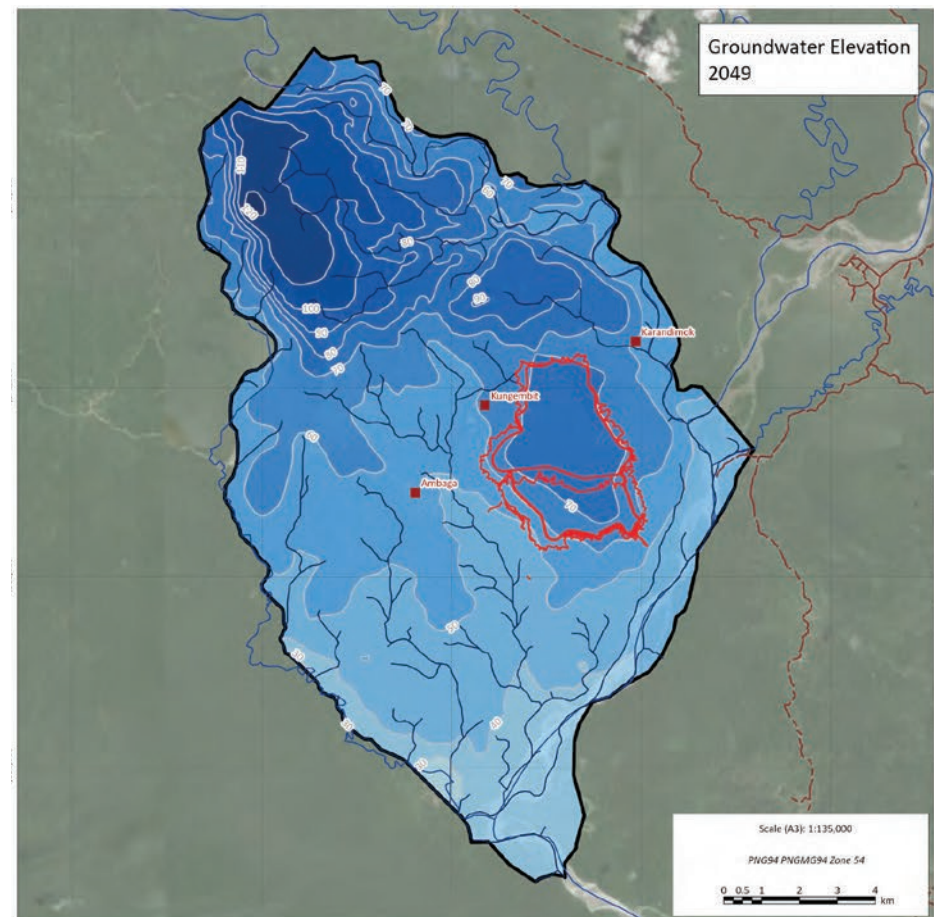
Operation of the TSF will generate seepage containing elevated salinity, sulfate and dissolved metals relative to existing groundwater conditions. Predicted seepage water quality is expected to be slightly neutral to slightly alkaline, with a pH between approximately 7 and 8, with TDS of approximately 3,200 mg/L, sulfate concentrations of approximately 2,200 mg/L, copper concentrations of approximately 70 µg/L, and arsenic concentrations of approximately 10 µg/L. Groundwater modelling assessed sulfate and TDS as parameters of interest for salinity, while dissolved arsenic and copper were assessed as parameters of interest representative of dissolved metals.

Migration of seepage contaminants is influenced by groundwater flow conditions, geological variability and preferential flow pathways, including valleys and possible structural features. Seepage is expected to migrate primarily through groundwater flow, with concentrations decreasing over distance due to dilution and dispersion associated with the high rainfall and recharge conditions at the site. Fine tailings are expected to generate relatively low seepage because of their low hydraulic conductivity, while the coarser embankment materials are predicted to contribute more seepage due to their higher hydraulic conductivity.

Elevated salinity, sulfate and dissolved metal concentrations in groundwater and groundwater-fed surface water systems may affect local groundwater and surface water resources used for domestic, agricultural and livestock purposes in areas immediately surrounding the TSF. Increased concentrations may also affect shallow groundwater-dependent terrestrial and aquatic ecosystems surrounding the TSF footprint through changes in groundwater and baseflow quality.

Seepage from the TSF is expected to continue through operations and post-closure (see Figure 10.3)

Groundwater modelling indicates that elevated sulfate, salinity and dissolved metal concentrations may persist in shallow groundwater and groundwater-fed surface water systems in the vicinity of the TSF after closure.



Notes

1. Background Imagery: Earthstar Geographics, Esri, NASA, NGA, USGS
2. Model Data provided by KCB Australia.
3. Topographical Data sourced from Mine Resource Authority, PNG Government 2025.

SOURCE
Appendix D

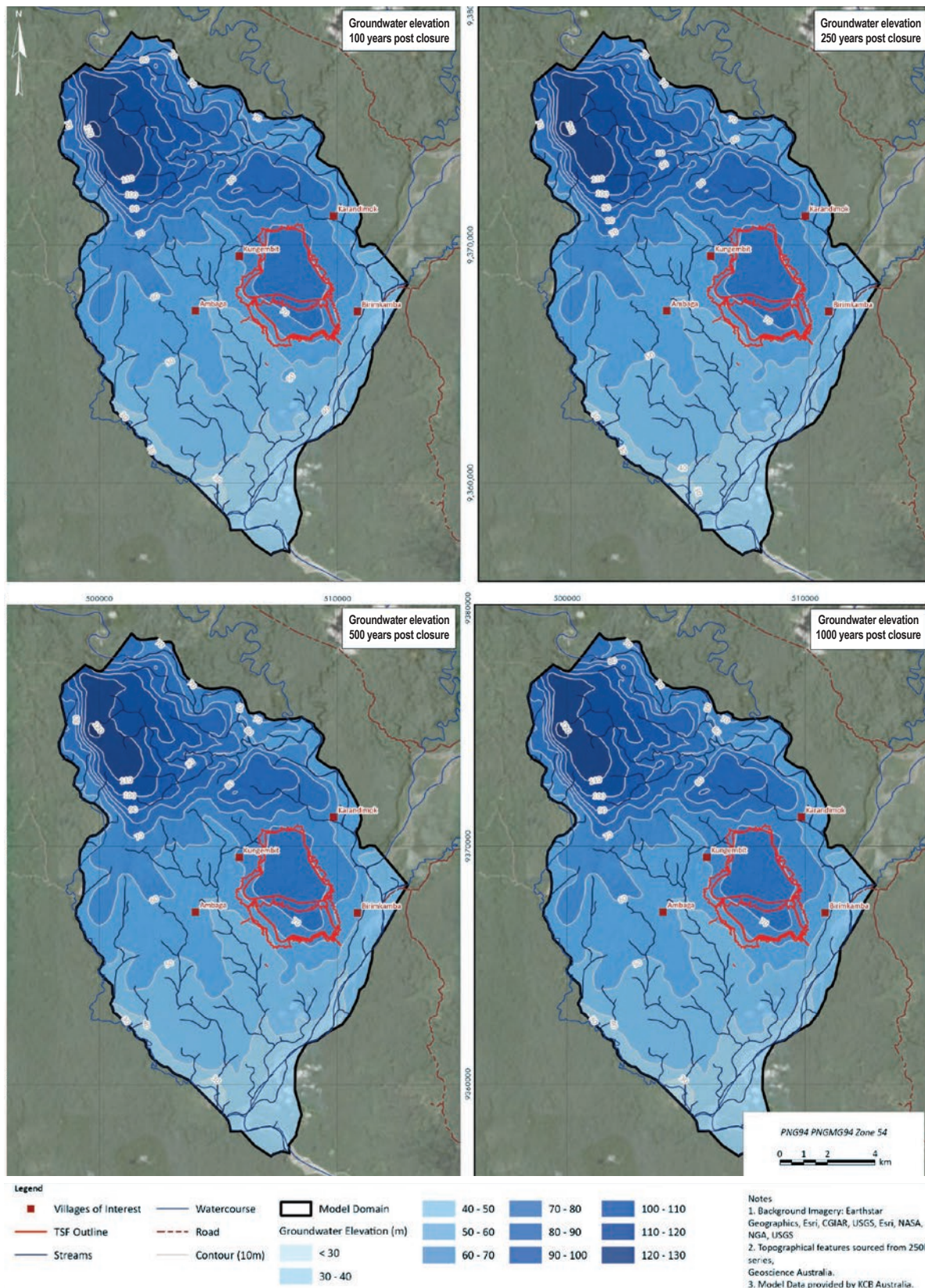


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FIGURE 10.1
Groundwater elevation contour map:
pre-TSF and at end of operations (2049)



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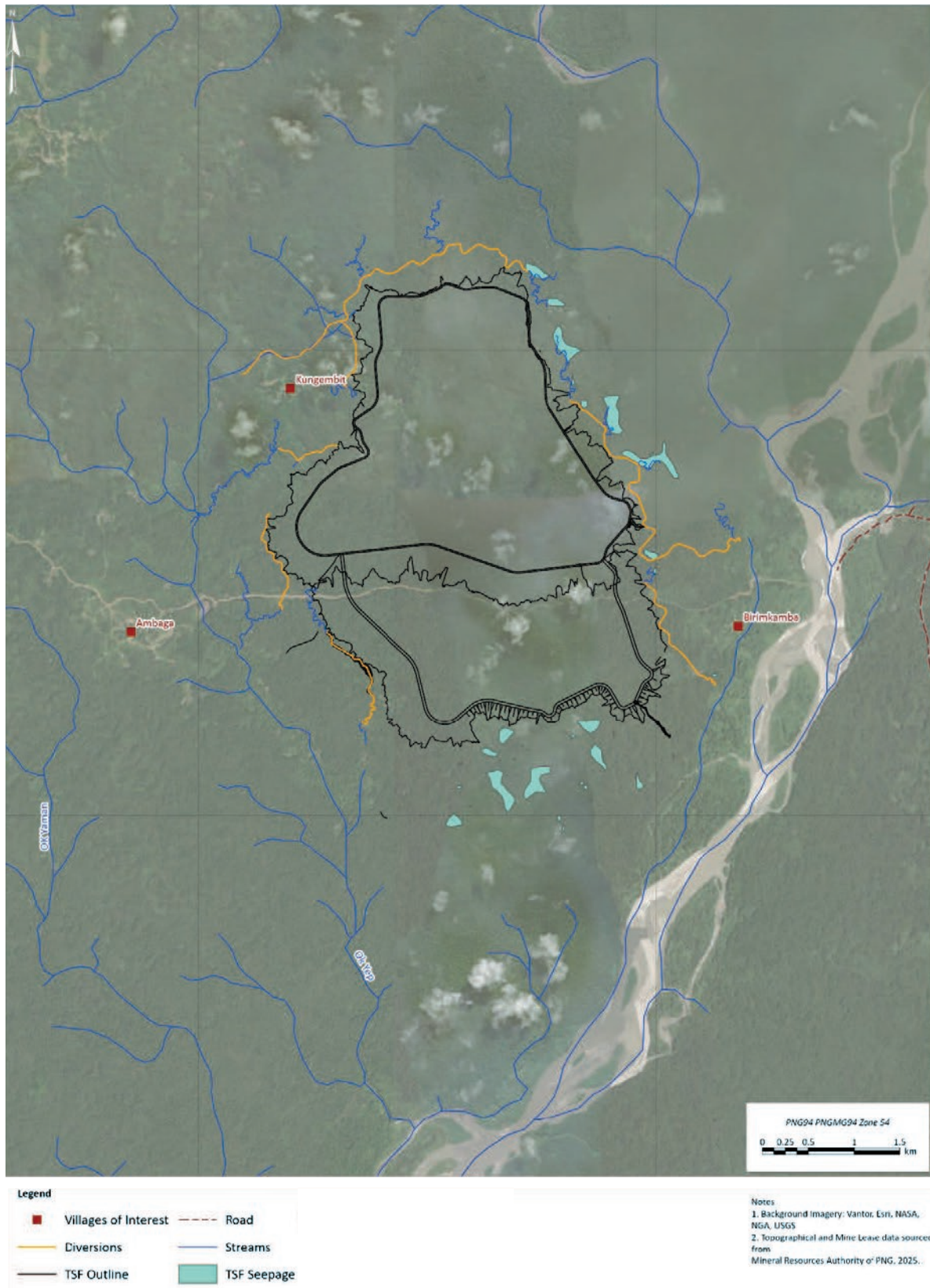
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FIGURE 10.2
Predicted groundwater elevation post-closure



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FIGURE 10.3
Predicted surface expressions of seepage



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Sulfate and TDS

Groundwater quality modelling indicates that elevated sulfate concentrations during TSF operations are expected to remain largely confined to areas immediately surrounding the TSF and decrease rapidly with distance. Groundwater observation points associated with nearby villages are not predicted to experience measurable increases in sulfate concentrations during operations (Figure 10.4). Overall, modelling indicates that contaminant migration during operations is limited in extent and is not expected to affect village groundwater receptors.

Following closure, modelling indicates that elevated sulfate and TDS concentrations are expected to remain largely confined to groundwater systems surrounding the TSF, with migration extending predominantly along downgradient valley pathways to the south towards the Ok Yep and Ok Tedi systems (Figure 10.5 and Figure 10.6).

TDS concentrations are predicted to decrease with distance from the TSF due to dilution and groundwater mixing. Predicted TDS increases at village observation points are low to negligible and are well below the WHO drinking water guideline value of 1,000 mg/L.

Although sulfate concentrations greater than 250 mg/L are predicted to extend up to approximately 1 km from the TSF in some areas, predicted sulfate increases at village observation points remain low to negligible. Elevated sulfate concentrations are predicted at monitoring locations situated closer to the TSF. The highest concentrations are predicted at monitoring location KCB2025-BH1006S/D, located approximately 300 m south of Cell 2, where concentrations of approximately 1,000 to 2,000 mg/L are predicted. Additional localised increases are predicted at KCB2025-BH1002S/D east of Cell 2 and at the deeper monitoring bore KCB2025-BH1003D west of Cell 1 near Kungembit, where concentrations of approximately 300 to 600 mg/L are predicted. Predicted sulfate concentrations in the adjacent shallow bore KCB2025-BH1003S remain comparatively low.

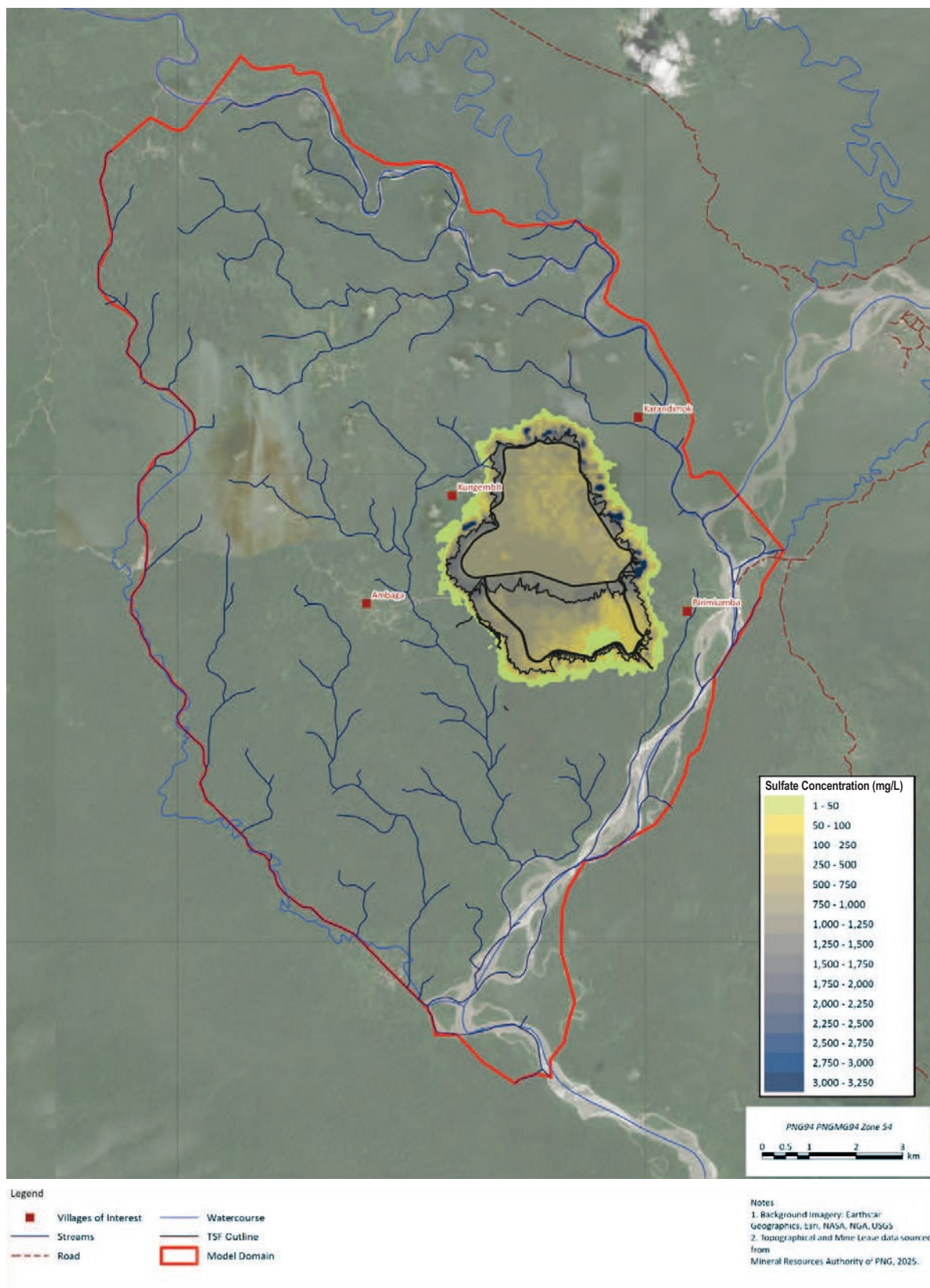
In areas where groundwater quality is affected, increased groundwater discharge and baseflow contributions may also influence sulfate concentrations in nearby streams and drainage lines connected to the groundwater system.

Dissolved metals

Following closure, modelling indicates that copper and arsenic migration above background concentrations is expected to remain limited to groundwater systems immediately surrounding the TSF, with only minor migration along downgradient valley pathways to the south and southeast (Figure 10.7 and Figure 10.8).

Predicted copper concentration increases at village observation points remain very low, with maximum increases of less than approximately 0.2 µg/L. Copper concentrations are not predicted to exceed the Australian drinking water guideline or the PNG *Environment Act 2000* aquatic life guideline of 100 µg/L at any village observation point or groundwater monitoring location. Predicted concentrations also remain below international irrigation guideline values of 100 µg/L associated with potential plant toxicity. The highest predicted copper concentrations occur at monitoring location KCB2025-BH1006S/D, located approximately 300 m south of Cell 2, where concentrations of approximately 25 to 50 µg/L are predicted.

Predicted arsenic concentration increases at village observation points remain very low, with maximum increases of less than approximately 0.5 µg/L. Arsenic concentrations are not predicted to exceed the Australian drinking water guideline of 10 µg/L or the *Environment Act 2000* aquatic life guideline of 50 µg/L at any village observation point or groundwater monitoring location.



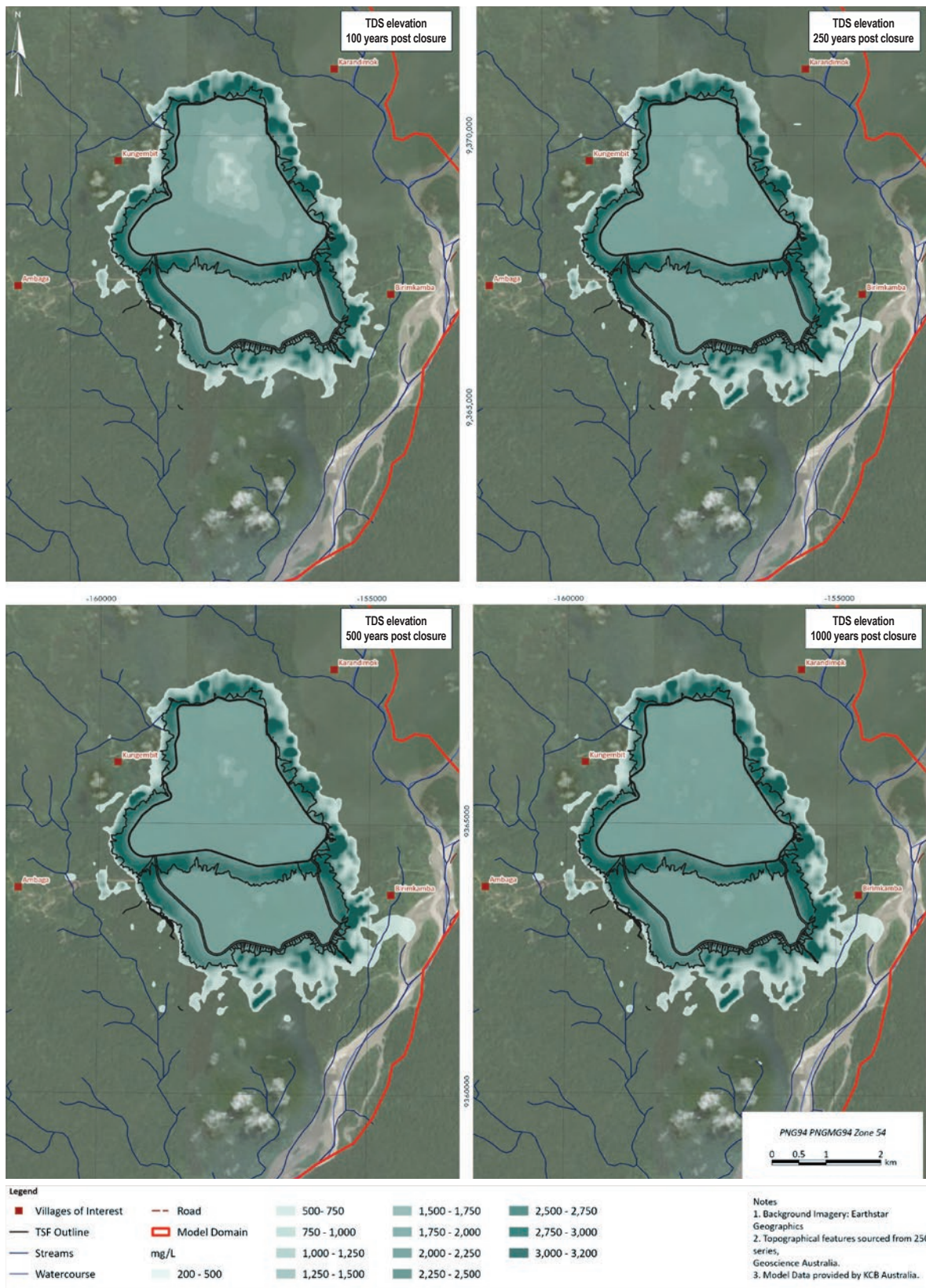
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FIGURE 10.4
**Sulfate concentrations in groundwater
at the end of operations (2049)**





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FIGURE 10.6
Total dissolved solids post-closure



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Summary

Considering the **medium** sensitivity of groundwater quality and the **moderate** magnitude of impacts associated with increased salinity and metal concentrations affecting groundwater and groundwater-fed surface water systems near the TSF, the residual significance of these impacts is **moderate**.

Considering the **medium** sensitivity of groundwater quality and the **moderate** magnitude of impacts associated with increased salinity and metal concentrations in groundwater affecting agricultural, livestock, and domestic uses (near TSF; Kungembit), the residual significance of impact is **moderate**.

Considering the **medium** sensitivity of groundwater quality and the **moderate** magnitude of impacts associated with increased salinity and metal concentrations in surface water baseflow affecting agricultural, livestock, and domestic uses at Kungembit, the residual significance of impact is **moderate**.

Other contamination

Additional groundwater quality impacts during operations may occur through accidental spills and leaks of fuels, hydrocarbons and hazardous materials, infiltration of contaminated contact water from roads and disturbed operational areas, and mobilisation of contaminants associated with earthworks and disturbed ground surfaces.

Generation of acidic leachate associated with disturbance of potential ASS may occur locally where such materials are exposed during construction and remain inadequately managed during operations. These impacts may result in localised degradation of shallow groundwater quality adjacent to roads, crossings and operational infrastructure.

Potential impacts are expected to be localised and primarily affect shallow groundwater systems immediately adjacent to operational infrastructure and disturbed areas. High rainfall, recharge and groundwater throughflow rates are expected to dilute contaminants, limiting the extent of the impact.

Considering the **medium** sensitivity of groundwater quality and the **moderate** magnitude and localised nature of impacts, the residual significance of groundwater quality impacts associated with spills, leaks and infiltration of contact water within the TSF development area an infrastructure development corridor is **moderate**.

Residual impact assessment summary - operations

Table 10.15 presents a summary of the residual impact assessment for the operations phase.

Table 10.15 Residual impact assessment for operations

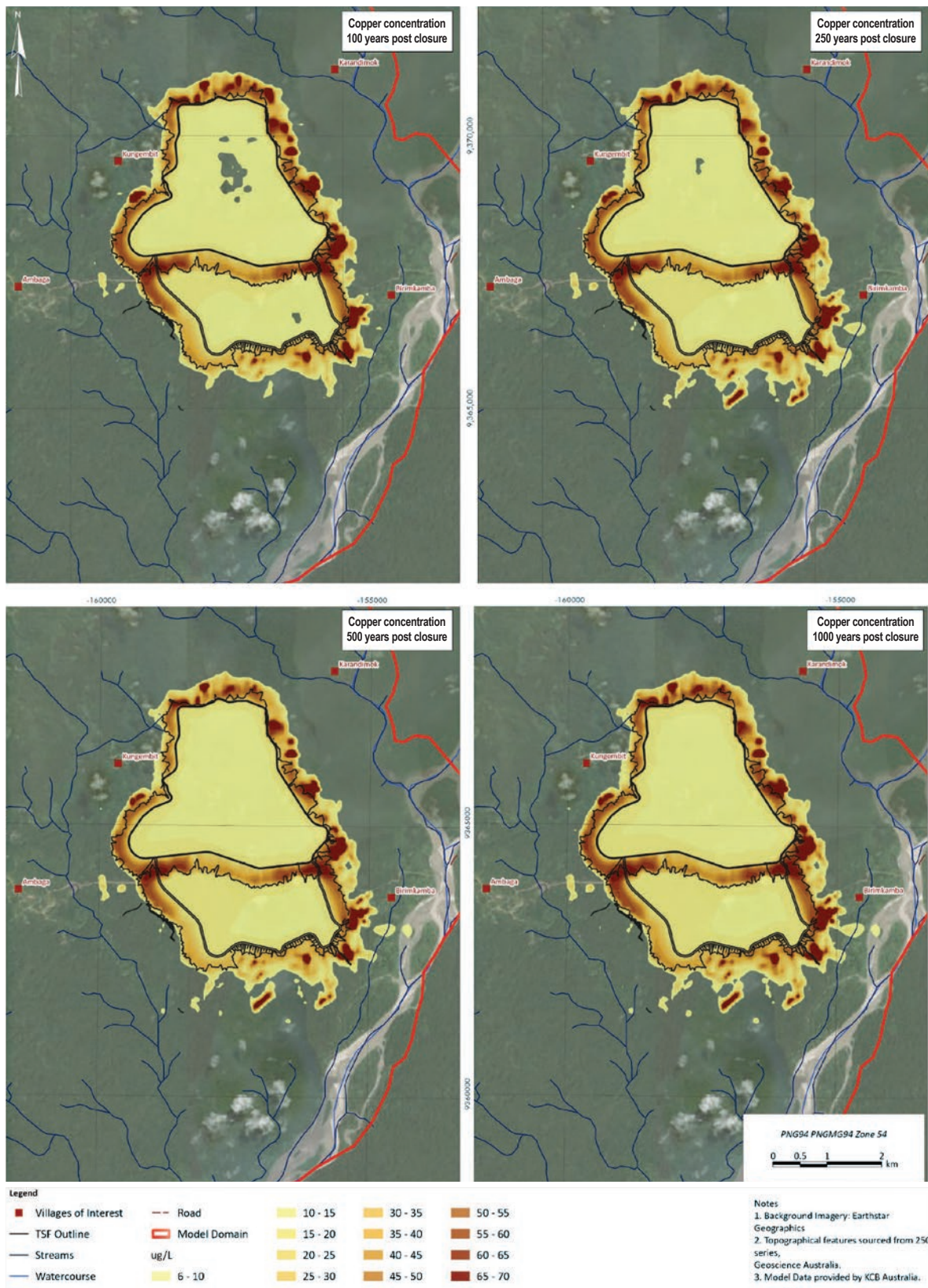
Impact description	Value	Sensitivity	Residual impact assessment	
			Magnitude	Significance
TSF development area				
Altered surface expression due to altered groundwater levels and flow	Groundwater quantity	Medium	Moderate	Moderate
Increased baseflow to drainage lines in areas groundwater levels are elevated due to earthworks or landscape changes *	Groundwater quantity	Medium	Moderate	Moderate
Increased salinity and metal concentrations in groundwater due to TSF seepage*	Groundwater quality	Medium	Low Moderate	Moderate
Reduction in groundwater quality due to leaks or spills, infiltration of contact water from TSF, roads and other areas of disturbance, or mobilisation of existing groundwater contamination	Groundwater quality	Medium	Moderate	Moderate

Impact description	Value	Sensitivity	Residual impact assessment	
			Magnitude	Significance
Infrastructure development area				
Altered groundwater flow and recharge behaviour due to permanent infrastructure	Groundwater quantity	Medium	Very low	Low
Reduction in groundwater quality due to leaks or spills, infiltration of contact water from roads and other areas of disturbance, or mobilisation of existing groundwater contamination	Groundwater quality	Medium	Moderate	Moderate

* Informed by Appendix D

10.3.4.3 Decommissioning and closure

Residual impacts associated with TSF seepage assessed as part of the operations period may persist into the closure period and are assessed in Section 10.3.4.2. A conceptual closure plan is presented in Attachment 3. New impacts during the decommissioning and closure period are expected to be similar to those experienced during construction.



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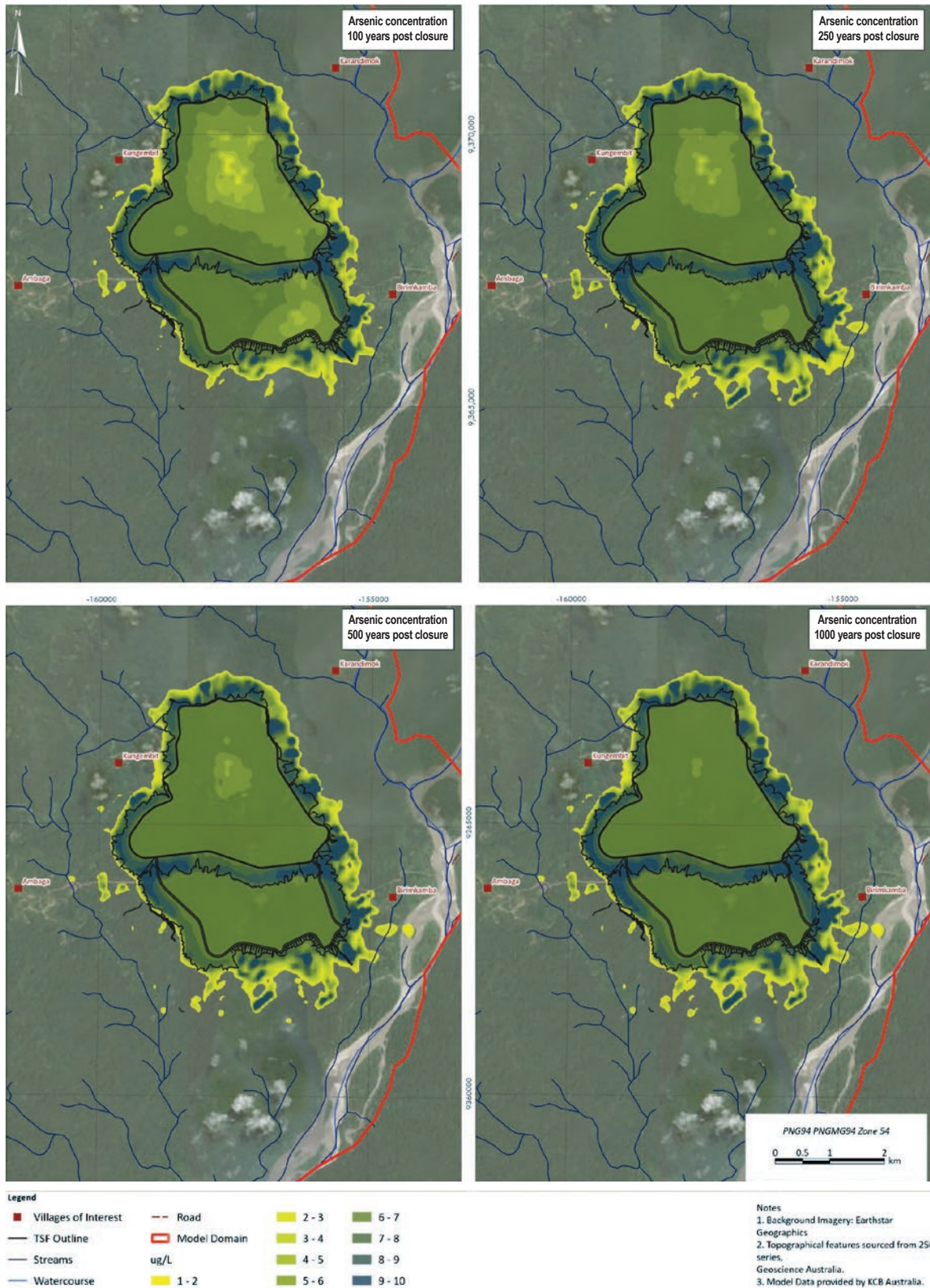
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FIGURE 10.7
Copper concentrations post-closure



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FIGURE 10.8
Arsenic concentrations post-closure



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10.4 PHYSICAL RIVERINE ENVIRONMENT

This section assesses the potential impacts of the project on the physical aspects of the riverine environment described in Chapter 8, including drainage and hydrology, sediment transport and surface water quality. It outlines the proposed mitigation and management measures and presents an assessment of residual impacts following implementation of those measures. This information informs the aquatic ecology impact assessment in Section 10.5.

10.4.1 Approach to impact assessment

The physical riverine impact assessment for the receiving environment associated with the project comprised:

- Define the spatial and temporal scopes of the assessment based on the proposed project activities.
- Identify potential stressors associated with project activities, where stressors are defined as physico-chemical pressures on the receiving riverine environment, including consideration of the nature, concentration or load (where relevant) and mode of action for the stressors.
- Identify the beneficial values of the riverine environment for management and protection.
- Assess potential impact and improvement pathways on identified physical beneficial values.
- Undertake numerical modelling to predict changes in hydrology, sediment transport and surface water quality resulting from project activities. Specifically, future conditions were evaluated using predictive sediment transport, particulate geochemistry and surface water quality models developed by OTML over the last 20 to 25 years. Modelling results were then used to inform the residual significance and/or compliance assessment.
- Develop management and mitigation measures to reduce impacts to identified beneficial values.
- Evaluate residual impacts and improvements on the receiving environment following implementation of proposed measures.

The assessment is informed by a hydrology, sediment transport and riverine particulate geochemistry modelling and assessment study completed by Dr Geoffrey Pickup (Appendix B), a surface water quality modelling and assessment study undertaken by EGi (Appendix C), and a TSF site conceptual water balance prepared by KCB (2026e).

Overarching assumptions and limitations for the impact assessment are:

- The impact assessment has been undertaken assuming existing conditions are baseline, including historical and ongoing impacts associated with the Ok Tedi Mine and other activities (e.g., artisanal and small-scale mining).
- It considers potential impacts arising from normal operating conditions. Chapter 13 addresses unplanned events such as those involving a natural disaster, significant spill of a hazardous chemical, failure of the TSF or rupture of the tailings pipeline.
- Sediment transport modelling (Appendix B) did not consider river extraction of suitable borrow fill and gravel from the Ok Tedi proposed to construct the TSF embankment of approximately 4 Mm³ to 5 Mm³; this has been addressed qualitatively given the inability of models to satisfactorily address this activity.
- Surface water quality modelling (Appendix C) conservatively assumed no implementation of management and mitigation measures.

10.4.1.1 Spatial and temporal scope

Section 8.3 describes the major rivers and their tributaries within the study area. The spatial extent of this assessment is defined by the project's area of influence on the receiving riverine environment, which is categorised as follows:

- Upstream project area:
 - Mine area creeks (Ok Mani, Harvey Creek, Sulphide Creek, which are tributaries of the Ok Tedi).
 - Upper and Upper Middle Ok Tedi.
- TSF development area:
 - Ok Yep and its tributaries.
- TSF area:
 - Middle Ok Tedi.
- Downstream project area:
 - Lower Ok Tedi, including associated floodplains and off-river water bodies (ORWBs).
 - Fly River (Upper and Middle reaches), including associated floodplains and ORWBs.
- Infrastructure development corridor:
 - Ok Hwie, Ok Ma, Ok Taub, Ok Birim and their tributaries.

The assessment does not extend into the South Fly River below the confluence of the Middle Fly and the Strickland River at Everill Junction given that at this distance, project-related effects are not expected to be detectable, and any outputs would be subject to a high degree of uncertainty.

The temporal extent of the assessment includes the construction phase, operational phase (approximately 20 years), and decommissioning, closure and post-closure phases.

10.4.1.2 Identification of surface water beneficial values

A key step in assessing anticipated project impacts is the identification of beneficial values of the receiving environment that require management and protection. A beneficial value is defined in the *Ok Tedi Environment Management Act 2019* (OTEMA) as:

'beneficial value means a quality or characteristic of the environment or any element or segment of the environment, which –

(a) is conducive to ecological health, public benefit, welfare, safety, health or aesthetic enjoyment and which requires protection from environmental harm; or

(b) is declared in Regulation, an Ok Tedi Technical Standard or the Ok Tedi Permit to be a beneficial value'

Beneficial values reflect the interaction of the physical and biological environment, local communities and other relevant stakeholders. Consistent with the environment values identified in the existing Environment Permit EP-L3(636), the recognised beneficial values of the Ok Tedi and Fly River systems upstream, within and downstream of the project area which form the basis for assessing sensitivity and potential impacts can be summarised as follows:

- Aquatic ecosystem protection and health values, including the ecology of the river and floodplain system downstream of the mining operation as assessed in Section 10.5, including the following key aspects:
 - Surface water quality for aquatic ecosystem protection.
 - Fish diversity, biomass and abundance in the Ok Tedi and Fly River main channels.
 - Aquatic fauna diversity and abundance in selected Middle Fly floodplain ORWBs.

- Social values assessed in Chapter 11 related to the following key aspects:
 - Water quality is to a drinkable standard downstream of the mining operation following settlement of the total suspended solids.
 - Water-based resources of the Ok Tedi and Fly Rivers downstream of the mining operation are available to meet normal community requirements, including for drinking, domestic purposes (e.g., washing, cooking) and agricultural use (e.g., crops, sago making).
 - Fish and other aquatic resources of the Ok Tedi and Fly River receiving environment are safe to eat, including fish edibility (fish, decapod crustaceans (prawns and crabs)) and water-associated fauna (e.g., turtles, crocodiles), aquatic plants and water-associated indigenous plants.
 - River navigability for the main river channels of the Lower Ok Tedi and Fly River for village craft and commercial shipping.

These values and associated aspects may be adversely impacted by project activities through changes (both negative and positive) relative to existing conditions, including historical and ongoing mining activities. The assessment below focusses on physical changes, impacts and opportunities for improvement to the riverine environment that may then affect aquatic ecological and social values. Aquatic ecological aspects are assessed in Section 10.5 and social values are addressed in Chapter 11 and have not been considered here.

Key physical riverine aspects where predicted changes are expected to occur include:

- Drainage and hydrology, including associated channel and floodplain morphology.
- Sediment transport and associated surface water quality.

The general approach for the physical riverine impact assessment follows the process outlined in Section 10.1 with further details on sensitivity and magnitude relevant to surface water impacts described below.

10.4.1.3 Sensitivity and magnitude criteria

Sensitivity was determined based on how the identified physical riverine values or aspects are susceptible to changes, the capacity to adapt to the types of changes that may arise from project activities, and the intrinsic importance of these aspects to associated biological (such as aquatic biodiversity and ecology) and social riverine aspects (such as associated water-based resources).

The sensitivity of key physical riverine aspects varies across the project area and is presented in Table 10.16 based on the relevant criteria outlined in Table 10.1 and appreciation of existing conditions characterised in Chapter 8.

Table 10.16 Sensitivity rating of physical riverine environment aspects

Zone	Sensitivity	Reasoning
Upstream project area	Low	Physical riverine aspects in the upstream project area are generally in poor condition due to existing mining-related disturbance and sedimentation, remain strongly influenced by long-term mine-derived sediment inputs and have limited local value, but have some capacity to recover from or adapt to further change.
Infrastructure development corridor	High	Physical riverine aspects within the infrastructure corridor area are generally in good condition, with some capacity to recover from or adapt to change. The area includes relatively undisturbed watercourses that may support endemic or locally restricted aquatic biota, which may have high ecological value and associated sensitivity to disturbance.
TSF development area	High	Physical riverine aspects within the TSF development area are generally in good condition, with some capacity to recover from or adapt to change. The area includes relatively undisturbed watercourses and drainage lines that support endemic or locally restricted aquatic biota, which have high ecological value and associated sensitivity to disturbance.

Zone	Sensitivity	Reasoning
TSF area – Middle Ok Tedi	Low	Physical riverine aspects in the Middle Ok Tedi area are generally in poor condition due to existing mining-related disturbance and sedimentation, remain strongly influenced by long-term mine-derived sediment inputs and have limited local value, but have some capacity to recover from or adapt to further change.
Downstream project area (including floodplains and ORWBs)	Low	Physical riverine aspects in the downstream project area including the Lower Ok Tedi and Fly River floodplains as well as ORWBs are generally in poor condition due to existing mining-related disturbance and sedimentation, remain strongly influenced by long-term mine-derived sediment inputs and have limited local value, but have some capacity to recover from or adapt to further change.

Table 10.17 provides the specific criteria used for assigning magnitude in relation to physical riverine impacts or improvements. Magnitude was determined based on the most significant change and associated response in terms of physical and water quality effects.

Table 10.17 Specific criteria for magnitude of physical riverine impact or improvement

Magnitude	Impact definition	Improvement definition
Very high	Characterised by widespread and major (severe) deterioration in physical riverine aspects relative to existing conditions, such as major changes to sediment regime (e.g., large increases or decreases in sediment loads), increases in suspended sediments, turbidity, extensive sedimentation; and/or decline in surface water quality (e.g., elevated total suspended solids (TSS), turbidity, metals or nutrients), flows or channel morphology. These changes may lead to severe degradation of specific watercourses or ORWBs. Effects typically extend over large reaches or multiple watercourses beyond the project area and/or persist over the life of the project or longer, with little or no recovery.	Characterised by widespread and major improvement in physical riverine aspects relative to existing conditions, such as major reductions in sediment loads, suspended sediments, turbidity, sedimentation; and/or significant improvement in surface water quality (e.g., reduced turbidity, sediment-associated contaminants) flows or channel morphology. These changes may lead to major improvements of specific watercourses or ORWBs. Effects typically extend over large reaches or multiple watercourses beyond the project area and/or sustained over the life of the project or longer.
High	Characterised by large but not severe deterioration in physical riverine aspects relative to existing conditions, such as large increases in suspended sediment and sedimentation, reductions in surface water flows, and/or deterioration to surface water quality or channel morphology. These changes may lead to severe degradation of specific watercourses or ORWBs. Typically occurs across multiple reaches across the project area and/or medium to long term (up to 10 years), with some recovery expected.	Characterised by substantial improvement in physical riverine aspects relative to existing conditions, such as largely reduced suspended sediment and sedimentation, improved surface water quality for aquatic ecosystem protection, and/or improved channel and floodplain stability and function. Typically occurs across multiple reaches across the project area and/or medium to long term (up to 10 years).
Moderate	Characterised by detectable but not severe deterioration in physical riverine aspects relative to existing conditions, such as moderate increases in sediment loads, suspended sediments, turbidity, sedimentation; and/or decline in surface water quality, flows or channel morphology. Typically confined to localised reaches or sub-catchments (within 1 to 2 km of project activities) and/or medium term (up to five years), with slow recovery towards pre-impact conditions expected.	Characterised by detectable but not large improvement in physical riverine aspects relative to existing conditions, such as moderate reductions in sediment loads, suspended sediments, turbidity, sedimentation; and/or improved surface water quality, flows or channel morphology. Typically confined to localised reaches or sub-catchments (within 1 to 2 km of project activities) and/or medium term (up to five years).

Magnitude	Impact definition	Improvement definition
Low	Characterised by detectable but minor or highly localised deterioration in physical riverine aspects relative to existing conditions, such as small or short-term increases in sediment loads, suspended sediments, turbidity, localised sedimentation; and/or minor/localised declines in surface water quality, flows or channel morphology. Effects are typically highly localised (restricted to the development area) and/or short-term (up to one year), with rapid recovery expected.	Characterised by minor or highly localised improvements in physical riverine aspects relative to existing conditions, such as slightly reduced sediment loads, suspended sediments, turbidity, localised sedimentation; and/or minor/localised improvements in surface water quality, flows or channel morphology. Effects are typically highly localised (restricted to the development area) and/or short-term (up to one year).
Very low	Characterised by no detectable project-related adverse or beneficial changes, with physical riverine aspects consistent with existing conditions. The condition of specific watercourses or ORWBs will remain generally unchanged.	

Table 10.18 and Table 10.19 provide the relevant significance assessment matrix used for determining residual physical riverine impacts or improvements, respectively. Significance was determined based on the most significant change in physical riverine aspects. The - and + symbols have been used in subsequent residual impact summary tables to signify negative and positive residual impacts, respectively.

Table 10.18 Significance matrix of residual physical riverine impacts

Magnitude	Sensitivity of aspect				
	Not sensitive	Low	Medium	High	Very high
Very high -	Moderate -	Moderate -	Major -	Major -	Major -
High -	Minor -	Moderate -	Moderate -	Major -	Major -
Moderate -	Minor -	Minor -	Moderate -	Moderate -	Moderate -
Low -	Minor -	Minor -	Minor -	Moderate -	Moderate -
Very low -	Negligible	Negligible	Minor -	Minor -	Moderate -

Table 10.19 Significance matrix of residual physical riverine improvements

Magnitude	Sensitivity of aspect				
	Not sensitive	Low	Medium	High	Very high
Very low +	Negligible	Negligible	Minor +	Minor +	Moderate +
Low +	Minor +	Minor +	Minor +	Moderate +	Moderate +
Moderate +	Minor +	Minor +	Moderate +	Moderate +	Moderate +
High +	Minor +	Moderate +	Moderate +	Major +	Major +
Very high +	Moderate +	Moderate +	Major +	Major +	Major +

10.4.1.4 Adopted project guidelines and compliance assessment criteria

Table 10.20 summarises the relevant national and international standards and guidelines for assessing surface water quality impacts associated with the project. These set out the statutory limits or international guidelines to identify potential exceedances and adverse effects to be managed or mitigated for key surface water parameters to indicate where an environmental impact may occur.

Table 10.20 Relevant surface water quality guidelines

Aspect	Title	Author/Year of publication
Ambient water quality	<i>PNG Environment (Water Quality Criteria) Regulations</i> , Schedule 1, 2002, as applicable under the OTEMA	State of PNG 2002
	<i>Guidelines for protection of freshwater aquatic life. Environmental Code of Practice for the Mining Industry</i> (PNG ECP)	Office of Environment and Conservation 2000
	<i>Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters</i> . Australian and New Zealand Environment and Conservation Council, Agricultural and Resource Management Council of Australia and New Zealand. October 2000	ANZECC/ARMCANZ 2000; which is now superseded by ANZG 2018
	<i>Australian and New Zealand Guidelines for Fresh and Marine Water Quality</i>	ANZG 2018
Drinking water quality	<i>PNG Public Health (Drinking Water) Regulation</i> , Schedule 1, 1984. The standards for raw water drinking water quality in this regulation are legally enforceable.	State of PNG 1984
	<i>Water quality criteria for raw drinking water</i> . Environmental Code of Practice for the Mining Industry.	OEC 2000
	World Health Organisation (WHO) <i>Guidelines for Drinking Water Quality</i> , 4 th edition.	WHO 2022

In accordance with Environment Permit L3(636), the specific assessment criteria adopted for the project are:

- Ambient water quality standards: PNG Schedule 1 of the *Environment (Water Quality Criteria) Regulations 2002* and ANZG (2018) guidelines, which replaces the superseded ANZECC/ARMCANZ (2000) guidelines (95% ecosystem protection).
- Drinking water standards: PNG Schedule 1 of the *Public Health (Drinking Water) Regulation 1984*.
- Predicted TSF discharge water quality has been assessed against these standards as well as existing background levels, where appropriate.

In addition to PNG legislative requirements, OTML is generally aligning the project with the IFC PS and Equator Principles. In the absence of specific PNG guidelines for general point source discharges and effluent, the IFC *General Environmental, Health and Safety (EHS) Guidelines for Mining* have been considered, in particular the effluent criteria for site runoff from facilities and treated effluents to surface waters.

10.4.1.5 Methods for technical studies

The establishment of project infrastructure including the TSF and infrastructure corridor as well as release of excess water from the TSF to the Ok Tedi during operations will have implications for hydrology, sediment transport and water quality across the project area. Details of the study methods and inputs are summarised below and further described in the respective technical studies (Appendix B, Appendix C and KCB 2026).

TSF water balance

KCB developed an initial water balance specifically for the TSF to assess projected water volumes and screen geochemical conditions associated with TSF discharges over the life of the project. The water balance model accounts for the flow of water through the TSF system including primary inflows of decant water contained in the final tailings slurry, rainfall and beach runoff entering the TSF impoundment. The water balance modelling allowed determination of project-related changes to flows and volumes of water in the Ok Tedi downstream of the TSF over the project life. Chapter 6 provides further details on the TSF water balance.

Results of the TSF water balance modelling have been taken into account for the hydrology, sediment transport, and water quality assessments, where appropriate.

Hydrology and sediment transport modelling and assessment

The assessment of riverine impacts associated with the proposed TSF considers both existing sediment transport processes within the Ok Tedi and Fly River systems and the incremental changes expected from the project. Because sediment already present in the river systems will continue to move downstream irrespective of whether a TSF is constructed, the assessment distinguishes between background river processes and project-related changes so that modelling results represent the additional effects associated with the TSF development.

The hydrology and sediment transport study by Dr Geoffrey Pickup provided in Appendix B involved:

- Characterisation of the current river systems, including the main river channel, floodplains and ORWBs, as well as exchanges between the river channel and floodplain. This involved a description of the river system, its current state and the ongoing range of river system change processes (see Section 8.3). ORWBs such as oxbow lakes are of particular biological importance as they may provide the only surface waterbodies outside the main river channel during periodic droughts that affect the region and support critical aquatic habitats for biodiversity conservation.
- Evaluation of historical and ongoing sediment inputs. These include tailings and waste rock discharged from the mine since operations began in 1984, with projected inputs through to the planned mine closure in 2050, and additional sediment sources such as erosion from erodible waste rock dumps, landslides in the Upper Ok Tedi catchment and abrasion of gravel during downstream transport. The analysis incorporated updated mine plans and considered potential reductions in sediment inputs associated with the construction of engineered waste rock dumps (EWRDs).
- Consideration of existing OTML sediment control strategies, particularly the dredging and stockpiling operations at Bige approximately 100 km downstream of the mine and 25 km south of the TSF site. Since 1998, dredging has removed deposited sediments to reduce flood risk and channel aggradation. The assessment evaluated how sediment supply and dredging requirements may change if the TSF reduces sand-sized sediment inputs to the river systems.
- Analysis of the geomorphic response of the river system. In the upper system, including mine area creeks and the Middle Ok Tedi, significant aggradation has occurred as a result of mine-derived sediment. In the lower system, including the Lower Ok Tedi and the Fly River floodplains, sediment deposition has contributed to channel aggradation, levee formation and floodplain inundation. Connectivity between river channels and ORWBs was also assessed.
- Assessment of future conditions using predictive sediment transport modelling, which simulated several scenarios including continued riverine tailings disposal from the mine, TSF implementation, operation with one or two EWRDs, and a 'recovery baseline' scenario assuming no further mine waste inputs after 2025 to determine natural system evolution as comparison.
- Consideration of local geomorphic changes associated with TSF construction, including drainage diversions and modifications to local hydrological pathways.

In areas where quantitative modelling was not feasible or data availability was limited, qualitative assessment based on long-term monitoring data and expert interpretation was used to evaluate likely geomorphic trends.

This assessment used the following models specifically developed for the Ok Tedi and Fly River systems and used by OTML over the last 20 to 25 years:

- **Sediment transport modelling:** Predictive sediment transport models (including the OKTUGS model based on the TUGS unified gravel–sand transport equation and the HEC-6 sediment transport model) were used to simulate erosion, transport, deposition and downstream sediment loads under different mine waste disposal scenarios.
- **Hydrology modelling:** Regional hydrological models and flow datasets were used to generate river discharge inputs and simulate flow conditions at key locations across the Ok Tedi and Fly River systems to support sediment transport modelling.

Both sediment transport models were reviewed by external expert panels, the lower river sediment transport model (HEC-6) in 2004 and 2013, and the newer upper river model (OKTUGS) in 2013. Both were accepted subject to limited available technology and input data availability and quality.

Table 10.21 presents the modelled scenarios used for this assessment. Plans B and C represent scenarios with a TSF which form the basis of this ESIA. Modelling results are predicated on continued dredging to 2050.

Table 10.21 Upper river sediment transport modelled scenarios

Plan	Continued dredging to 2050	TSF	EWRD1 (currently under construction)	EWRD2 (proposed from 2030 onwards, subject to approvals)	EWRD Loss*
A – No TSF and EWRD1 constructed	Yes	No	Yes	No	Not applicable
B – With TSF and EWRD1 constructed	Yes	Yes	Yes	No	5%
C – With TSF and two EWRDs constructed	Yes	Yes	Yes	Yes	5%
D – No TSF, two EWRDs constructed	Yes	No	Yes	Yes	5%
E – recovery baseline scenario	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

* EWRD loss refers to the rate at which material placed in a constructed dump is lost to the river system by erosion, slope failure etc. It is calculated as rate x input for each year plus rate x total dump contents in the previous year. The rate may vary over time and is higher in early years of dump construction.

Key limitations and assumptions associated with modelling the Ok Tedi and Fly River, which are complex and dynamic river systems, included:

- Predictions were based on the current approved mine plan up to 2050 and projected waste rock and tailings production to the end of mine life. Changes to mine production rates and mine life extensions, waste rock management strategies or operational practices may alter sediment inputs to the river systems and therefore influence model outcomes.
- The sediment transport models represent simplified numerical representations of the complex Ok Tedi and Fly River systems and may not fully capture all geomorphic processes such as channel migration, floodplain sediment exchange and ORWB dynamics.
- Uncertainty around the potential influence of climate change on rainfall and river flows across the region. Analysis of long-term climate monitoring records indicated no clear increase in rainfall trends at the upper Ok Tedi weather station since 1984, although some increases were observed in downstream lowland

areas from around 2000. No notable changes in the frequency of extreme weather events have been observed in the water level records of the Ok Tedi and the Fly River over this time. Further, potential climate-related trends may be difficult to detect due to the strong influence of river morphology changes associated with mine-derived sediment deposition and the limited number of extreme events recorded. Accordingly, model predictions should be considered indicative projections of future system behaviour only and are not reliable beyond 20 to 30 years due to uncertainty in inputs and system behaviour.

Riverine particulate geochemistry modelling and assessment

Dr Geoffrey Pickup's study (Appendix B) for the ESIA also assessed potential changes in riverine particulate geochemistry associated with mine-derived sediment transported in the Ok Tedi and Fly River systems. Surface water quality conditions in the river systems and potential TSF-related impacts were assessed separately in the surface water quality modelling and assessment conducted by EGi (Appendix C).

Particulate geochemistry modelling was undertaken using two related geochemical models (referred to as OkBalARD), based on the previous OKARD model developed for OTML by EGi in 2003. These models were used to predict downstream changes in sediment chemistry under different mine waste disposal scenarios. The modelling included:

- Sulfur and ANC modelling, which evaluates the balance between sulfide mineral inputs and neutralising materials in sediments to predict potential acid generation risks in the upper river system, including the mine area creeks and the Middle Ok Tedi.
- Particulate copper concentration modelling, to predict the downstream distribution and dilution of copper associated with mine-derived sediments.

Model inputs included long-term historical monitoring data (from 2001 onwards) and quarterly values of the mass, sulfur content, copper concentration and ANC values of waste rock and tailings derived from historical records and current or future mine plan for projected mine waste disposal scenarios. Additional inputs were obtained from the sediment transport modelling, including estimates of sediment deposition rates and changes in storage from the OKTUGS sediment model. Model predictions were calibrated and validated against long-term monitoring datasets.

To assess downstream impacts, predicted particulate geochemistry was compared with levee and floodplain sampling data collected by OTML annually along the Lower Ok Tedi and Middle Fly River. Dilution effects from tributary inflows, particularly from the Upper Fly River, were incorporated to estimate downstream concentration trends. Potential changes in the lower river geochemistry including from the effect of constructing and operating a TSF were modelled using simple dilution coefficients applied on the model outputs for Bige and comparing with observed levee surface geochemistry data.

Where quantitative modelling was limited by data or other constraints, qualitative interpretation based on monitoring records and system understanding was used to assess likely trends in sediment geochemistry and floodplain deposition.

Surface water quality modelling and assessment

EGi conducted water quality modelling to assess the potential for the TSF to impact water quality along the Ok Tedi and Fly River (Appendix C). The assessment included review of available OTML monitoring data collected for riverine sediments and water quality along the Ok Tedi and Fly River from 2004 to present, and the development of a hydrogeochemical model, OkChem-TSF, to predict the chemistry of water discharge from the TSF as well as potential changes the discharge may have on river water quality.

The model developed for the project is based on work carried out by EGi and Dr Geoffrey Pickup in 2011-2012 for OTML to assist with evaluating the likely impact of mine life extension on the geochemistry of mine-derived sediments depositing within the Ok Tedi and Fly River catchments; and the potential impact on river water chemistry during operations and post-closure due to acid and elements released from the

sediments and contained in drainage from the mine pit. The model was specifically adapted to consider existing water quality at Ningerum as the starting source for river water chemistry, calculate inputs to the river from areas of exposed riverine deposited sediment (i.e., sand bars and levee banks) based on the physical characteristics of exposed riverine sediment for various segments of the Ok Tedi and Fly River system, and allow for adsorption/desorption reactions between copper and other metals with suspended sediment.

Seepage rates and contaminant load from the groundwater model (see Section 10.3) are included as part of the input to the surface water quality model.

Modelling was undertaken to assess two points in time for the project: Stage 1 when Cell 1 is completed; and Stage 2 when Cell 2 is completed. The two stages adopted for the modelling included:

- Tailings associated with the TSF beach and exposed riverine sediments were assumed to be non-acid forming (NAF) and have ANC/maximum potential acidity (MPA) ratios with no risk of acid generation, and runoff/leachates from these materials will be alkaline. This is consistent with results of geochemical characterisation testwork of the coarse- and fine-grained tailings streams produced from hydro-cycloning (Appendix A), which indicated that static tests classify both the fine- and coarse-grained tailings as strongly NAF, determined by negative net acid producing potential (NAPP) and neutral net acid generating pH (NAGpH).
- Four months of kinetic testing indicated that, on average:
 - TSF tailings oxidation rates are likely to be relatively low, and leachate pH for all samples under both free draining and saturated conditions remained neutral, consistent with the NAF classification of these materials.
 - The NAF tailings to be placed in the TSF, as well as riverine sediments, will still have a significant sulfide content, in the range 0.5 to 1 %S. This sulfide may be susceptible to oxidation in situations where the tailings/sediment are exposed to atmospheric conditions and there is capacity for ingress of oxygen into the pore space of the tailings/sediment.
 - Concentrations of metal(loid)s in leachates were generally very low, except for manganese which is likely associated with calcite; and leachate copper concentrations are similar for saturated and free draining columns in contrast to apparent dissimilar sulfide oxidation rates. This suggests that copper is not readily mobilised from these tailings, even under the oxidising conditions of the free draining columns with an associated low risk of metalliferous, neutral or acid leachate.
 - Leachate chemistry was dominated by calcium and sulfate, consistent with ongoing sulfide oxidation and concomitant calcite dissolution and acid neutralisation, albeit at a much-reduced rate in saturated columns.
 - Overall, the testwork results indicate a low risk of AMD leachate from the TSF tailings. This assumes OTML's current mitigation strategy of removing pyrite materials at the tailings processing plant (TPP) along with the addition of limestone to the crusher at the beginning of processing is continued throughout the life of mine to significantly minimise the risk of sulfuric acid generation and reduce AMD issues in the riverine system.
- TSF beach areas above the water table and embankments were assumed to be unsaturated. This is a conservative assumption as it means most of the pore space of the near surface deposited tailings is air-filled and hence available for ingress of atmospheric oxygen. Much higher moisture contents will likely persist, especially close to active tailings deposition, which will markedly limit the potential for sulfide oxidation to occur.
- The oxidation depth for the tailings beach was constrained to 1 m, which implies the tailings below 1 m remain permanently saturated (i.e., not influenced by surface drying). The depth of oxidation was determined by Constant Intrinsic Oxidation Reaction methodology (subject to any imposed depth-to-water table constraints), and the mass of tailings within this zone is used to estimate loadings of sulfate and metals released from the beach area.

- For riverine sediments, the exposed areas, moisture contents, and depths-to-water table were based on data previously used in OkBalARD modelling for the 2011-2012 mine life extension study.
- Four river system flow scenarios were modelled representing El Niño, Low flow, Median flow and High flow conditions. Flow has implications for the area of exposure of riverine sediments but in the current version of OkChem-TSF the composition and discharge of water from the TSF are assumed to be independent of climatic conditions.
- Model calibration was undertaken considering a range of values from monitoring of the Ok Tedi at Ningerum assuming existing conditions.

10.4.2 Potential impacts and improvements

This section provides an overview of the key potential impacts and improvements on the physical riverine environment associated with project activities. Chapter 13 Natural hazards, climate change and unplanned events separately assesses potential impacts and risks associated with unplanned events, including significant hazardous substance spills, tailings pipeline and/or TSF failure, as well as potential climate change risks to the project.

Table 10.22 summarises the potential impact pathways and stressors affecting relevant riverine values and aspects within affected catchments according to key project activities and phases. Key potential impacts are further described taking into consideration the types of changes that may occur as a result of project activities relative to existing conditions (including those influenced by mining activities) in subsequent sections.

Table 10.23 summarises the potential improvement pathways and associated physical processes anticipated, particularly in the Ok Tedi and Fly River main channels. Section 10.4.4 describes the magnitude and significance of residual impacts and improvements following implementation of proposed management and mitigation measures.

Table 10.22 Potential impacts to the physical riverine environment according to project phases

Potential impact	Key source/project activity	Phase*			Impact pathway
		C	O	D	
Altered drainage and hydrology	Diversion and modification of drainage lines and watercourses; in-stream works (e.g., for crossings, culverts); formation of hardstand or compacted surfaces and project roads	X	X	X	Diversion or modification of local drainage and watercourses, including in-stream works (e.g., crossings and culverts) and construction of compacted surfaces and roads, may alter local drainage patterns and flow paths. These changes may result in localised increases or decreases in surface water flows, changes in flow duration, and increased potential for erosion, turbidity and sediment transport. Increased surface runoff and peak flows may further cause erosion, scouring and sedimentation in receiving watercourses and floodplain/ORWBs. Impacts may be temporary during construction or persist where diversions or changes in local drainage are maintained during operations and post-closure.
Erosion and sediment transport from exposed surfaces and unsealed roads	Creation of disturbed surfaces, project-related traffic and vehicle/machinery movements on unsealed roads and exposed surfaces	X	X	X	Runoff from exposed surfaces and unsealed roads may contribute to localised increases in sediment transport into nearby watercourses. Impacts are generally localised and manageable through drainage controls and road maintenance.

Potential impact	Key source/project activity	Phase*			Impact pathway
		C	O	D	
Changes in sediment input and transport (total suspended solids (TSS), turbidity, sediment loads, metals)	Land clearing, earthworks and construction of project infrastructure (e.g., TSF, pipeline, roads, bridges) In-stream works (e.g., for installation of water crossings, culverts) Local riverine extraction and stockpiling of borrow fill and gravel for TSF and infrastructure corridor infrastructure	X	X	X	Vegetation removal, land clearing, earthworks and disturbed areas during all phases and in-stream works may increase erosion potential and sediment transport, particularly during high rainfall events. This may lead to increased suspended sediment concentrations, turbidity, sediment deposition and transport of particulate-associated contaminants within the receiving environment. Effects are generally greatest during construction although likely short-term and localised, and reduce during operations with stabilisation and mitigation.
Surface water contamination from leaks and spills of hydrocarbons or chemicals	Transportation, storage, use and disposal of hydrocarbons and hazardous substances; operation of vehicles and machinery	X	X	X	Accidental spills or leaks may result in localised contamination of surrounding surface waters. Possible during all phases due to the transport, storage and handling of hydrocarbons and other hazardous substances to operate heavy machinery and transport fleet as well as use of diesel generators for on-site power generation.
Wastewater and effluent (nutrients, pathogens, TSS and turbidity, metals and hydrocarbons)	Accommodation camps and site facilities (e.g., kitchen and ablutions, workshops, vehicle maintenance and washdown areas, waste storage facilities) generating wastewater/effluent/leachate/raw sewage	X	X	X	Discharges from accommodation camps and other site facilities may contaminate surface water with nutrients, pathogens and other contaminants if not adequately managed, potentially affecting downstream water quality.
Changes in surface water during TSF operations	Planned TSF operational discharges Riverine extraction and stockpiling of borrow fill and gravel from the Ok Tedi		X		Planned TSF discharges and riverine extraction of borrow materials may alter downstream flow characteristics and change the levels of suspended solids and associated water quality parameters in the receiving environment. The extent of change will depend on the anticipated TSF discharge volumes, timing and effluent quality relative to existing conditions.
Long-term surface water changes during closure and post-closure	TSF closure and post-closure seepage and/or discharges			X	Residual seepage or discharges from the TSF following closure may result in long-term changes to local hydrology (i.e., altered flows) and surface water quality (e.g., dissolved metals and metalloids; sulfate; altered pH).

* C = Construction; O = Operations; and D = Decommissioning and closure.

Table 10.23 Potential improvements to the physical riverine environment according to project phases

Potential improvement	Key source/project activity	Phase*			Improvement pathway
		C	O	D	
Long-term reduced downstream sediment inputs and associated sediment deposition in the mine-affected river system.	Operation of the TSF and land-based storage of final tailings in the TSF.		X	X	Reduction in final tailings entering the Ok Tedi and Fly River system by up to ~90% will significantly decrease mine-derived sediment inputs in the river system. Associated downstream improvements including in river and floodplain morphology, sedimentation and aquatic habitat conditions are expected to occur progressively over the long term and continue post-closure.
Long-term reduced rates of downstream riverbed aggradation and geomorphic change in mine-affected river system.	Land-based storage of final tailings in the TSF in combination with the continued dredging program.		X	X	Reduced coarse sediment inputs in downstream river channels may decrease ongoing riverbed aggradation and associated changes to river and floodplain morphology. These downstream improvements are expected to occur gradually over the long term, with positive changes largely occurring incrementally at a geomorphological scale post-closure.
Long-term improvement in downstream riverine particulate geochemical conditions associated with reduced mine-derived sediment inputs in the mine-affected river system.	Land-based storage of final tailings in the TSF.		X	X	Reduced discharge of potentially reactive tailings material to the river system due to the TSF may result in lower downstream particulate metal and sulfur loadings over the long term.
Long-term reduction in floodplain inundation frequency and extent of mine-derived floodplain sediment deposition in the mine-affected river system.	Operation of the TSF and land-based storage of final tailings in the TSF in combination with the continued dredging program.		X	X	Reduced mine-derived sediment inputs in the river system may lead to lower sediment deposition within river channels and reduce overbank flooding and the movement of mine-derived sediment onto floodplains and ORWBs. These downstream improvements are expected to occur gradually over the long term, with positive changes largely occurring incrementally at a geomorphological scale post-closure.
Long-term reduced rates of levee growth and associated floodplain sediment accumulation in the mine-affected river system.	Operation of the TSF and land-based storage of final tailings in the TSF.		X	X	Reduced mine-derived sediment inputs in downstream floodplain systems may result in reduced overbank sediment deposition and slow the rate of ongoing levee growth and floodplain sediment build-up. These downstream improvements are expected to occur gradually over the long term, with positive changes largely occurring incrementally at a geomorphological scale post-closure.
Decreased TSS levels in main channels and ORWBs with associated reduction in biological stress.	Operation of the TSF and land-based storage of final tailings in the TSF.		X	X	Currently there is no mitigation method to capture the fine (silt) particles in tailings. The silt causes elevated TSS and turbidity and is a primary stressor on downstream aquatic ecosystems. The TSF will capture a substantial proportion of the fine silt fraction of tailings, and will result in lower TSS and turbidity levels and likely reduced biological stress in downstream aquatic systems.

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.4.2.1 Drainage and hydrology

Alterations to drainage and hydrology may arise from project construction and operation, including proposed surface water management structures, TSF and ancillary infrastructure (pipeline, access roads, bridges and water crossings), as well as riverine extraction activities for borrow fill and gravel. These activities may modify drainage and surface water flows within the project area and lead to:

- Altered flows to existing watercourses, drainage lines and aquatic habitats from altered drainage.
- Changes in local hydrological regimes in affected catchments, ranging from minor to high changes in flow patterns, volumes and durations.

The TSF, surface water diversions, access roads and crossings also have the potential to create physical barriers that may restrict flow or connectivity, potentially influencing movement pathways for aquatic fauna and affecting connectivity between channels, floodplains and ORWBs.

10.4.2.2 Sediment input and transport

Project activities involving land disturbance, earthworks and riverine extraction of borrow fill and gravel during construction and operation may increase erosion potential and sediment loads in runoff reporting to watercourses downstream of the project, particularly during and after heavy rainfall. Additional potential effects may include:

- Changes in delivery of suspended sediments, particularly coarse-grained sediment input ('bed load') to rivers and watercourses leading to localised increases in sediment deposition, channel aggradation or modification of channel form.
- Bank overtopping and localised flooding in low-lying areas adjacent to rivers and watercourses due to combined effects of increased channel sedimentation and high intensity rainfall.
- Loss or degradation of aquatic habitats and biota in affected reaches of watercourses.

These changes are typically most pronounced during construction and tend to reduce over time as disturbed areas are stabilised.

However, the project also has the potential to provide some long-term beneficial improvements to physical riverine conditions for sediment input and transport, which are primary stressors in the Ok Tedi and Fly River systems. The diversion of final tailings to a TSF will capture both the sand and silt component of tailings. Operation of the TSF is expected to reduce final tailings entering the river system by approximately 90%, thereby significantly decreasing mine-derived sediment inputs to the downstream river system. Additional potential secondary beneficial effects associated with these reductions include:

- Reduced downstream sediment transport and associated sediment deposition within river channels and floodplain systems.
- Reduced rates of riverbed aggradation and associated geomorphic change in downstream river reaches.
- Improved downstream riverine particulate geochemical conditions.
- Reduced floodplain inundation frequency and extent of mine-derived sediment deposition onto floodplains and ORWBs.
- Reduced rates of levee growth and floodplain sediment accumulation over time.
- Reduced turbidity and TSS levels in main river channels and associated floodplain/ORWBs beneficial to downstream aquatic ecosystems.

These downstream improvements are expected to occur gradually over the long term, with positive changes largely occurring incrementally at a geomorphological scale post-closure.

10.4.2.3 Surface water quality

Surface water quality impacts are primarily associated with changes in sediment inputs and the introduction of contaminants as outlined below.

Total suspended solids and turbidity

The historical and ongoing riverine discharge of tailings and waste rock and associated sediment loading continues to be the most significant long-term environmental impact for OTML.

Increased sediment mobilisation from project activities, particularly ground disturbance and in-stream works around the TSF and along the infrastructure corridor, may further elevate TSS concentrations and turbidity which adversely affect surface water quality in receiving surface waters for aquatic ecosystems protection and downstream water users (such as communities relying on affected watercourses for drinking, fishing, domestic and agricultural uses, and navigation).

Conversely, operation of the TSF is expected to provide a long-term improvement in surface water quality through reductions in TSS and turbidity within downstream river channels and ORWBs. Currently, there is no mitigation method that captures the fine silt fraction of tailings, which contributes to elevated TSS and turbidity and is a primary stressor on downstream aquatic ecosystems. By capturing a substantial proportion of this fine (silt) material from the tailings, the TSF is expected to reduce fine-sediment related biological stress, resulting in gradual improvements to aquatic habitat condition and ecosystem health over time.

Contaminants (metals, hydrocarbons, nutrients and pathogens)

Downstream water quality impacts may arise from the following potential sources of water quality contamination associated with project activities:

- Sediment-associated metals mobilised in surface waters from project activities.
- Acid and metalliferous drainage (AMD) leaching if deposits of historical mine-derived sediments (e.g., tailings and waste rock) in the Ok Tedi system or within surrounding PASS are exposed by project activities.
- TSF discharge water.
- Hydrocarbons and chemicals from spills or leaks in machinery or during transport or storage.
- Nutrients (such as nitrogen and phosphorus) and pathogens (such as faecal coliforms) from inadequately managed or treated wastewater (e.g., raw sewage) or solid waste.

These stressors may result in localised or downstream changes in surface water quality, depending on the scale and duration of exposure.

Deposition of mine-derived sediment

Mine-derived sediments within the Ok Tedi and Fly River systems contain elevated concentrations of metals, particularly copper, associated with mining and historical riverine disposal of tailings and waste rock. These sediments are transported and deposited within the river system (i.e., sand bars and levees), where they act as ongoing sources of contaminants (i.e., dissolved and bioavailable copper and other metals) in the system.

Metals may also be leached directly from disturbed soils within the project area and transported downstream in runoff during rainfall events, particularly where potentially acid forming materials are exposed and unmanaged. Furthermore, bioavailable metals may accumulate within aquatic food chains within the receiving environment.

However, there will be reduced discharge of potentially reactive tailings material to the river system due to establishing a TSF which may also lead to improved downstream riverine particulate geochemical conditions, such as lower downstream particulate metal and sulfur loadings.

10.4.3 Avoidance, management and mitigation measures

Table 10.24 lists measures to manage potential impacts on the physical riverine environment during construction, operation and decommissioning and closure phases of the project.

Consistent with current OTML practices, key control strategies that will continue to be applied for the project to manage environmental impacts associated with riverine mine waste disposal include:

- The dredging program in the Ok Tedi at Bige will continue to extract mine-derived sand-sized sediment from the river. Dredging recovers approximately 85% of the sand component of the tailings and waste rock for land deposition on the east and west banks of the river and reworked into stable, engineered stockpiles that are progressively revegetated. The rate of future dredging will be limited by available sand supply to the dredge slot, with the volume of this reduced because of the TSF. This is because tailings sand currently directly discharged to the river system at Ok Kumiup and extracted at Bige will be permanently stored on land at the TSF meaning less sand in the river system for the dredge to remove.
- Additional limestone will continue to be added to waste rock. Since 2006, additional limestone has been added to waste rock (when required) to control acid formation in waste rock which also prevents ARD across all size fractions downstream, especially in the upper Ok Tedi reach. The existing Environmental Permit requires OTML to add sufficient limestone to the combined failing waste rock dumps so as to achieve a NAPP equal to or more negative the $-150 \text{ kg H}_2\text{SO}_4/\text{t}$ on an annual basis. All modelling assumes that this continues for the mine life.
- Ground limestone will continue to be added to the mill feed to maintain adequate ANC to final tailings to be stored in the TSF. Since 2011, OTML has added neutralising capacity (limestone) to the tailings mill feed to counteract acid formation associated with tailings discharge. The bulk of milled limestone is deposited in the dredge slot at Bige dredge which improves the geochemical quality of the dredge sand and cover materials to support stockpile rehabilitation. The existing Environmental Permit requires OTML to add sufficient limestone to the mill feed to ensure that the final tailings satisfy a NAPP of $-30 \text{ kg H}_2\text{SO}_4/\text{t}$ on a quarterly basis. All modelling assumes that this continues for the mine life.
- Sulfur (generally in the form of pyrite) in the mill tailings will continue to be extracted as pyrite concentrate and deposited sub-aqueously at Bige, consistent with international best practice, to minimise exposure to oxygen and limit the potential for oxidation and acid generation. Since 2008, this key control strategy has been implemented to further reduce the potential for acid formation. Along with the addition of limestone, removal of PCon renders the tailings NAF. The existing Environmental Permit requires OTML to ensure that final tailings have a sulfur concentration $< 1.0\%$ on a quarterly basis. All modelling assumes that this continues for the mine life.
- As a separate mitigation project, OTML is constructing an EWRD to the north of the mine pit and has plans for a second EWRD to the south of the pit if the initial EWRD is successful; both of which will reduce environmental impact associated with riverine mine waste disposal. A small portion of waste rock mined at Mt Fubilan will continue to be disposed by existing erodible dumps.

These existing measures are expected to continue to significantly reduce ongoing mine-associated impacts within the Ok Tedi and Fly River system and maintain the final tailings proposed for disposal in the TSF as NAF.

OTML's existing surface water monitoring program is outlined in Section 8.3 and the proposed surface water monitoring program for the project is presented in Chapter 14.

Table 10.24 Proposed management measures for the physical riverine environment

Measure ID	Key measures	Phase*		
		C	O	D
Hydrology and surface water management				
MM036	Integrate key design measures to avoid, minimise and mitigate hydrology and surface water impacts to the receiving riverine environment, including: <ul style="list-style-type: none">• Confine the TSF and associated infrastructure within the Ok Tedi catchment to minimise introducing new impacts to other catchments such as the Ok Birim, which remains unaffected by mining activities.• Locate the TSF and key infrastructure above the high banks of the Ok Birim and Ok Tedi to minimise potential flood interaction.• Design infrastructure to minimise disruption of natural surface water flow paths.• Maintain hydraulic connectivity along access road infrastructure, such as via culverts and drains where required.• Design and construct bridges, culverts and crossings to allow for high flow events following heavy rainfall, and to mimic natural flow characteristics where possible during and after construction.• Where feasible, consider using trenchless methods such as horizontal directional drilling (HDD) for installation of the tailings pipeline at major, large, deep or fast flowing watercourses, including the Ok Tedi crossing near Tabubil.	X	X	X
MM037	Separate ‘clean’ water (unaffected by project activities) from ‘dirty’ water that contains elevated TSS requiring settling in sedimentation ponds, before either being reused or released into the receiving environment (if suitable).	X	X	X
MM038	Incorporate as required rip-rap, gabions and check dams to reduce velocity flow of water in constructed drainage channels	X	X	X
MM039	Use energy dissipaters or erosion control structures on drains, discharge outlets and steep slopes where appropriate.	X	X	X
MM040	Establish surface water diversions and channels as needed to divert existing streams and clean surface water flows away from the TSF and ground-disturbance activities during all phases of the project.	X	X	X
MM041	Design TSF and emergency spillways to accommodate the probable maximum flood (PMF) of 1:100,000 AEP storm event with minimum 3 m operational freeboard.	X		
MM042	Provide surface water management structures and controls as per the Surface Water Management Plan to be implemented, including all surface water diversions designed to accommodate at minimum the greater of a 2-hour and 24-hour 1:100 AEP flood event; erosion protection designed to protect from damage or flooding for the 1:100 AEP peak streamflow; side slopes no steeper than 2H:1V overall	X	X	
MM043	Undertake routine maintenance of surface water management infrastructure and controls to prevent sediment build-up and maintain drainage effectiveness.	X	X	X
MM044	Operate the TSF as a flow-through system with excess decant water reporting to the Ok Tedi to enable planned and emergency release of excess TSF decant water as needed.		X	
MM045	Re-use to the extent practicable decant water from the TSF as process water via dedicated pumping and piping distribution infrastructure.		X	
MM046	Prioritise use of suitable clean water temporarily stored in sedimentation ponds for construction water, dust suppression, vehicle washdown and progressive rehabilitation works (if deemed adequate).	X	X	X
MM047	Recover and direct all water used for tailings pipeline and hydro-cyclone house flush water systems to the TSF for reuse in the hydro-cyclone house system.		X	
MM048	Maintain an up-to-date TSF water balance using live monitoring data to enable early detection of critical excesses or shortages in operational water supply		X	
MM049	Restore disturbed primary drainage paths if they are not required for the life of the project, where practicable.	X	X	X

Measure ID	Key measures	Phase*		
		C	O	D
MM001	Design the TSF as a stable, water-shedding and erosion-resistant landform that comprises benched embankment slopes to safely convey PMF flows away from rehabilitated surfaces to the receiving environment via appropriately sized closure spillways and channels.			X
MM050	Periodically review and update the TSF water balance, design resilience and flood contingency requirements using monitoring data, observed climate trends and relevant climate projections, and implement adaptive management measures where required.	X	X	X
Erosion and sediment transport management				
MM003	Avoid sidestepping to the extent practicable, particularly in steep terrain. Where sidestepping cannot be avoided, conduct a site-specific risk assessment to evaluate potential downslope erosion and sediment transport impacts, including on downstream communities (if any) and identify appropriate controls.	X	X	
MM051	In areas that will be rehabilitated, use land-clearing techniques that preserve the rootstock of removed vegetation in the ground, where practicable.	X	X	X
MM053	Preserve riparian vegetation to the greatest extent practicable, avoid disturbance of terrain alongside watercourses and create a buffer of natural vegetation between watercourses and project areas where practicable. Trim, rather than remove riparian trees where practicable.	X		
MM054	Restore and rehabilitate disturbed areas no longer required for use as early as possible and progressively throughout project construction	X	X	
MM055	Minimise vegetation clearance and ground disturbance as far as practicable, including locating project infrastructure, including vehicle parks, laydown areas, storage sites, fuel storage, non-mining waste dumps in cleared areas, in secondary and/or degraded forest areas.	X	X	X
MM056	Mark the extent of vegetation to be cleared on all technical drawings and clearly mark approved clearing limits in the field prior to works. Do not clear beyond design limits.	X	X	
MM005	Implement appropriate erosion and sediment controls and structures prior to disturbance works commencing. Key controls may include retaining riparian vegetation buffer zones, rip-rap aprons, sediment control ponds and sediment fences.	X	X	X
MM013	Where practicable, locate valley-bottom access alignments to retain a buffer of natural vegetation between access ways and watercourses	X		
MM057	Construct temporary construction sediment ponds downstream of major sediment sources (such as disturbed areas and stockpiles) to settle suspended solids prior to discharge into the receiving environment.	X	X	X
MM004	Adopt the following principles to manage erosion and sediment transport for construction of benches and batters: Construct embankment slopes in a manner that facilitates controlled runoff and promotes drainage based on experience at Ok Tedi <ul style="list-style-type: none"> • Grade benches to shed water and reduce the risk of erosion or batter slumping. • Retain vegetation at crest of cut batters and at toe of fill batters where practicable to minimise erosion. • Establish vegetation (e.g., shrubs/grasses/legumes) as soon as possible on benches. Consider using hydroseeding or direct planting where suitable. • Install dykes and swales at top of batters (where practicable) and divert runoff to slope drains and into stabilised areas. • Stabilise batters, such as by using brush layers or geotextile/fibrous matting, where required. • Construct slope drainage such as cut-off trenches or horizontal drains at crest of batters/slopes, and install adequate drainage at the toe to maintain slope stability. 	X	X	X

Measure ID	Key measures	Phase*		
		C	O	D
MM014	Implement the following measures to manage erosion and sediment transport during construction of access roads, bridges and water crossings: <ul style="list-style-type: none"> • Install temporary erosion and sediment controls during construction and permanent drainage structures such as road ditches and culverts. • Design and construct bridges and minor crossings with adequate protection to resist scour, erosion and failure due to flooding. • Refine alignments of project roads to follow natural ridges and hill slopes to minimise cut/fill and avoid crossing watercourses, ORWBs and wetlands to the extent possible. • Restrict watercourse crossings to designated crossing points where riparian vegetation clearing widths will be limited. Maintain riparian vegetation buffer zones elsewhere. 	X	X	
MM002	Evaluate suitability of local borrow fill and gravel, and limit extraction from watercourses to the Ok Tedi to minimise impacts on other watercourses.	X	X	
MM008	Install sedimentation ponds downstream of key project infrastructure prior to construction to capture sediment-laden water and reduce sedimentation downstream	X	X	
Water quality management				
MM058	Where potentially acid forming materials are encountered such as within road and infrastructure cuts and during riverine extraction of borrow fill/gravel, conduct a risk-based assessment to determine appropriate controls to manage potential geochemical risks such as addition of limestone and treatment of potentially contaminated runoff and leachate prior to discharge to the receiving environment. Implement these controls during construction	X	X	X
MM024	Store, handle and transport hazardous substances in accordance with the PNG Environmental Code of Practice for Vehicle/Machinery Workshops and Petroleum Storage/Resale/Usage Sites, and Australian Standards AS1940:2017 relevant to bunding.	X	X	
MM059	Manage sewage in an appropriate manner to prevent environmental contamination.	X	X	X
MM031	Prohibit disposal of domestic and industrial waste into streams or sinkholes.	X	X	X
MM060	Dispose of domestic and industrial waste, including wastewater and raw sewage, in accordance with OTML's currently approved waste management practices.,	X	X	X
MM061	Capture and treat all project wastewater where necessary prior to discharge, to meet the receiving environment water quality criteria (Environment (Water Quality Criteria) Regulation 2002)	X	X	X
MM062	Design planned discharge of excess TSF water to report to the Ok Tedi without requiring treatment except for sediment settling.	X		
MM063	Regularly inspect and maintain all water management and wastewater treatment facilities for adequacy.	X	X	X
MM064	Implement relevant groundwater management measures to manage risk of potentially contaminated TSF seepage water entering surface water discharged to the receiving environment.		X	

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.4.4 Residual impact assessment

Residual impacts to the physical riverine environment were assessed following implementation of the avoidance, management and mitigation measures listed in Section 10.4.3. The residual impact assessment considered predicted changes to drainage and hydrology, sediment transport and associated surface water quality for the construction, operations, decommissioning and post-closure phases.

10.4.4.1 Construction

Key residual impacts and improvements during the construction phase across the physical riverine environment are summarised in this section.

Upstream project area (mine area creeks, Upper and Upper Middle Ok Tedi)

Drainage and hydrology

Major changes to existing flow regimes within the upstream project area are not expected due to construction of the project as the TSF and associated major disturbance areas are located downstream of the Upper Ok Tedi catchment. Flows in the mine area creeks, Upper Ok Tedi and Upper Middle Ok Tedi are expected to remain broadly consistent with existing conditions during this phase.

Sediment transport

Significant impacts from current OTML operations on the riverine environment are primarily associated with historical and ongoing riverine disposal of tailings and waste rock into the upper tributaries of the Ok Tedi as well as erosion and sediment transport from disturbed surfaces, failing waste rock dumps and unsealed roads. These represent major sources of suspended sediment loads entering the Ok Tedi system.

During the construction phase, riverine disposal of tailings and waste rock from existing operations will continue in accordance with the currently approved operating regime. Consequently, sediment transport processes within the mine area creeks and Upper Middle Ok Tedi will continue to be dominated by existing mining-related sediment inputs.

Residual impacts to drainage and hydrology, sediment transport and associated surface water quality within the upstream project area during construction are predicted to be **negligible**.

TSF development area (Ok Yep and its tributaries)

The TSF development area is expected to experience the greatest residual physical riverine impacts during construction due to extensive land disturbance, earthworks, materials stockpiling and handling, and site preparation required for the establishment of surface water diversion drains and sediment control structures, TSF starter embankments, hydro-cyclone house, tailings pipeline, initial access roads, and ancillary infrastructure.

Considering the high sensitivity of the Ok Yep catchment, residual construction impacts to local drainage and hydrology, sediment transport and associated water quality within the TSF development area have been assessed as **major** adverse based on the below key impacts.

Drainage and hydrology

The TSF has been confined as far as practicable within the Ok Yep catchment, in a small lowland area on the western side of the Ok Tedi, reporting to the mine-affected river. This minimises effects on adjacent catchments, particularly the relatively less disturbed Ok Birim. It also has been designed to follow natural catchment boundaries where possible to limit changes to local drainage and cut/fill requirements. Likewise, project road alignments have been designed to follow natural ridgelines away from floodplains to minimise flood interactions and minimise cut/fill works.

However, the TSF development will permanently modify local drainage patterns within the eastern branch of the Ok Yep catchment through the establishment of diversion structures, embankments and altered surface runoff pathways. Surface water diversions will redirect clean water flows around the TSF footprint while project affected water containing elevated TSS will be collected and directed to sedimentation ponds for treatment via settlement prior to discharge to the receiving environment of the Ok Yep and Ok Tedi systems. There is no planned outflow or discharge into the relatively undisturbed Ok Birim.

In addition, the TSF and permanent surface water diversions within the Ok Yep catchment will create localised barriers to surface water connectivity, with associated impacts on local aquatic habitat and biota. However, project roads are not expected to impede drainage or form significant barriers to flow, as culverts and drainage structures will be installed to maintain cross-drainage, particularly during heavy rainfall.

Surface water extraction during the construction phase is expected to be limited (if needed, up to 3.3 ML/year), temporary and spread across multiple locations. Given the relatively small extraction volumes proposed for each site and the availability of water within the local catchments given the very high average annual rainfall in excess of 6,000 mm, residual impacts on downstream flows are expected to be **negligible**, localised and temporary.

Overall, these activities will result in **major** localised changes to drainage and hydrology within the eastern branch of the Ok Yep catchment which in turn will affect local surface water connectivity.

Sediment transport

Within the TSF development area, the hydrology and sediment transport study (Appendix B) indicated that local lowland watercourses carry low sediment loads and occupy shallow, well-vegetated valleys. Construction activities such as land clearing, topsoil stripping and earthworks required for the TSF and associated infrastructure will generate erosion and suspended sediments which will likely produce a localised pulse of sediment load to the Ok Yep, particularly prior to completion of the ring dyke impoundment. This may lead to stream bed aggradation in the Ok Yep, with some subsequent flushing expected post-construction; however, some deposited sediment may persist due to the reduced post-construction catchment area and streamflow. Ongoing sediment inputs to the lower Ok Yep may also occur from the constructed flow diversion channels that border the ring dyke and other disturbed areas, particularly if sediment build-up leads to blockages. These impacts are expected to be most pronounced during land clearance, site preparation and earthworks but then reduce progressively following stabilisation and rehabilitation of disturbed surfaces. Such impacts are anticipated to be localised and short term and managed through appropriate design of drainage channels and routine maintenance to prevent sediment build-up and maintain drainage effectiveness.

In addition, the local impact of the TSF on the geomorphology of the river system will be mostly confined to the eastern branch of the Ok Yep. Within the Ok Yep catchment, there may be elevated sediment yield and deposition along the watercourse during the construction period. Post construction, some of the deposits may be eroded but sediment yield from the catchment is likely to remain higher than under pre-construction conditions (hydrology and sediment transport study in Appendix B).

The impact on sediment load is likely to be greatest during the construction phase. Most of the sediment will result from water erosion of disturbed areas during heavy rainfalls, while wind erosion will provide some additional input during drier periods. Localised and temporary sedimentation impacts (i.e., elevated TSS concentrations, turbidity and sediment deposition) from runoff and disturbed areas are expected within the Ok Yep catchment during construction but will be managed via proposed surface water management and sediment control infrastructure.

The establishment of surface water diversions may lead to certain adjacent drainage lines and watercourses to become blocked to some degree via sedimentation, raising water levels and resulting in localised vegetation dieback upstream if unmanaged.

Riverine extraction of borrow fill and gravel

Up to 5 Mm³ of borrow fill sand and gravel may be extracted from the Ok Tedi bed near the TSF to support construction of the starter embankments, roads, surface water management structures and infrastructure pads as well as ongoing operational requirements such as road maintenance. This activity will temporarily change the channel bed and bank profile leading to altered hydrological conditions, increase turbidity and TSS concentrations, and affect aquatic habitat. However, relative to the volume of sediment already stored and transported within the Ok Tedi system, the volume of riverine material proposed for extraction is small and is not expected to materially influence sediment transport processes, river morphology or hydrology at a

catchment scale. Consequently, any effects are expected to be localised, temporary and confined to the extraction areas.

Potential benefits may also occur where riverine extraction removes accumulated coarse sediment from aggraded sections of the Ok Tedi, potentially contributing to localised reduction in bed levels or sediment availability. However, these benefits are difficult to quantify and are expected to be limited and localised compared with the broader sediment transport changes predicted during TSF operations.

Middle Ok Tedi and downstream project area (Lower Ok Tedi, Fly River)

During construction, the project's residual impact on hydrology of the Middle Ok Tedi and further downstream are expected to be **negligible**.

Construction activities are not expected to result in measurable changes to drainage and hydrology, sediment transport or associated surface water quality in the Lower Ok Tedi, Fly River floodplains or associated ORWBs. Downstream sediment-related effects from construction runoff are expected to be rapidly diluted in the larger river system and remain localised and temporary, particularly in the context of existing sediment loads in the system. Thus, residual impacts to the downstream project area during construction will be **negligible**.

Infrastructure development corridor

The infrastructure corridor traverses several major watercourses including the Ok Tedi, Ok Taub and Ok Birim and key tributaries such as the Ok Ma and its upper creeks and Ok Hwie, which form part of the Upper Middle Ok Tedi catchment. Except for the Ok Tedi, these watercourses have largely not been influenced by mining activities and are in relatively good condition. Furthermore, none of these watercourses subsequently flow across the international border with Indonesia. While the Ok Birim does cross the international border, this occurs upstream of the proposed infrastructure corridor crossing.

Construction of the pipeline access road, tailings pipeline, bridges, culverts and water crossings will disturb soils, modify local drainage and surface water flows as well as increase erosion and sediment transport downstream. These impacts are expected to be greatest where works occur near watercourses, on steep terrain, and at bridge or crossing locations; the effects will be greatest in high value watercourses which are in relatively undisturbed conditions such as the Ok Birim and Ok Taub; whereas such effects will be marginal in mine-affected watercourses such as the Ok Tedi.

Borrow fill and gravel extraction from local watercourses along the infrastructure corridor will also be required for construction of the pipeline access road, tailings pipeline construction and associated facilities but at reduced volumes compared to that required for the TSF development.

Additionally, construction of new road, pipeline and ancillary infrastructure will generate increased fugitive sediment loads, transported in surface runoff from exposed soils and vehicle/machinery movements. This will result in short-term localised increases in TSS concentrations, turbidity and sedimentation downstream of active work areas. The new road Section between the Ok Tedi crossing and TSF site is expected to generate more fugitive sediment, particularly in steeper, mountainous terrain where rainfall is higher, cut/fill slopes take longer to stabilise, and larger volumes of borrow material, topsoil and spoil will need to be stockpiled. Sidecasting will be avoided to the extent practicable, particularly in steep terrain. Where sidecasting cannot be avoided, a site-specific risk assessment will be undertaken and appropriate management and mitigation measures implemented prior to commencement of works. The existing road section to be upgraded between Ok Tedi Mine and Tabubil is expected to generate less fugitive sediment as construction works will mainly be limited to pipeline installation.

Localised accumulations of coarse sediment will occur in the drainage lines downstream of the construction areas and where sidecasting along roads occur (if applicable), although the extent of the accumulation will be

dependent on the terrain and the effectiveness of sediment control measures implemented. Where accumulation occurs, it is likely to be visible and adversely affect the receiving environment.

Soil erosion and scouring of disturbed surfaces and stockpiled material at the approaches to, and banks of, creeks and rivers at road crossings is predicted to cause temporary sedimentation of aquatic habitats immediately downstream of the crossing sites. However, successive torrential flows are expected to resuspend temporarily settled coarse-grained deposits and transport these further downstream. This pattern of sedimentation of coarse-grained sediments and subsequent re-suspension and transport downstream is expected to continue until erodible soils have been stabilised and revegetated either naturally or by progressive rehabilitation of disturbed areas for the project.

Additionally, local surface water contamination may occur in areas where soil contamination, ASS/PASSs, and highly erodible soils are present (refer to Section 10.2 for details).

Coarse sediment will temporarily accumulate in drainage lines and watercourses immediately downstream of disturbed areas, particularly where exposed soils, stockpiles or cut/fill slopes are not yet stabilised. These effects are expected to reduce progressively over a post-construction period of between 18 months and two years to pre-disturbance levels, provided adequate road maintenance, erosion and sediment controls and progressive rehabilitation of disturbed surfaces are implemented and maintained. Such controls are expected to reduce the residual impact.

However, because several affected watercourses have **high** sensitivity, residual construction impacts in the infrastructure corridor are assessed as **moderate** adverse for drainage and hydrology, sediment transport and surface water quality.

Residual impact assessment summary

Table 10.25 provides a summary of the residual impact assessment for the construction phase. The primary residual impacts during this phase are predicted within the TSF development area and infrastructure corridor, where direct disturbance to drainage lines, watercourses, and extensive land clearing and earthworks will occur and lead to residual impacts of moderate to **major** adverse significance. Residual impacts in the upstream and downstream areas are expected to be mostly **negligible** during this phase, as most construction activities and major disturbance areas will occur elsewhere.

Table 10.25 Residual impact assessment - construction phase

Zone	Key aspect	Sensitivity	Residual impact (-)	
			Magnitude	Significance
Upstream project area	Drainage and hydrology	Low	Very low -	Negligible
	Sediment transport and associated water quality	Low	Very low -	Negligible
Infrastructure corridor	Drainage and hydrology	High	Moderate -	Moderate -
	Sediment transport and associated water quality	High	Moderate -	Moderate -
TSF development area	Drainage and hydrology	High	Very high -	Major -
	Sediment transport and associated water quality	High	Very high -	Major -
TSF area – Middle Ok Tedi	Drainage and hydrology	Low	Low -	Minor -
	Sediment transport and associated water quality	Low	Moderate -	Minor -
Downstream project area (including associated floodplains and ORWBs)	Drainage and hydrology	Low	Very low -	Negligible
	Sediment transport and associated water quality	Low	Very low -	Negligible

10.4.4.2 Operations

Hydrology, sediment transport, river morphology and riverine particulate geochemistry modelling (Appendix B) was undertaken to assess the long-term effects of the proposed TSF on the Ok Tedi and Fly River systems relative to existing conditions. The modelling considered both historical and ongoing mine-derived sediment already stored within the river system, and the predicted reduction in future tailings inputs associated with diversion of approximately 90% of total final tailings from the Ok Tedi Mine to the TSF; with up to 10% potentially requiring direct discharge to the Ok Tedi as per current approved practice if/when the tailings pipeline is offline for maintenance.

Modelled surface water impacts of a TSF on the Ok Tedi and Fly River system

Modelling was conducted to assess the long-term effects of the proposed TSF on the Ok Tedi and Fly River systems relative to existing conditions, considering both existing sediment transport and geochemistry processes within the river systems and the incremental changes expected from diversion of tailings to the TSF.

Key sediment inputs and outputs considered in the assessment included (Appendix B):

- The Lower Ok Tedi and Middle Fly floodplains have developed over millennia as the river has meandered across its containing valley. As such, the floodplains are zones of long-term sediment storage and loss of material from the sediment load of the river. Sediment is added to the floodplain both by channel migration and as overbank floods deposit material on the floodplain surface. As such, the floodplain becomes an area of long-term sediment storage. Sediment is only released by floodplain destruction as the river channel migrates laterally which, on the Lower Ok Tedi and Middle Fly, is a very slow process occurring over many centuries. The study estimated a long-term average sediment loss rate of about 5 Mt/year.
- Historical waste rock inputs entering the river system with peaks of up to 80 Mt/year and recent averages of around 55 Mt/year mostly via the Southern Dumps, and recent inputs via the Northern Dumps averaging around 30 Mt/year.
- Future reductions of inputs to the river system are anticipated through the implementation of EWRDs and projected reduction in mine waste rock production from 2030 onwards. The modelled scenarios included the operation of one or two EWRDs after 2030 onwards.
- Tailings production has declined historically from an average of ~26 Mt/year to average 17 Mt/year since 2013.
- Landslides are common in the mountain areas of the Ok Tedi drainage basin and are a major, though intermittent, source of sediment delivery to the river system. Major natural and mine-triggered slides include the Vancouver Avalanche which delivered an estimated 115 Mt between 1989 and 1991 and the Harvey Creek landslides which added 19 to 28 Mt/year to the river system between 1991 and 1996.
- The major outputs or sediment losses from the river system are dredged material and long-term storage in designated depositional areas on floodplains at Bige, and discharge of sediment to the Lower Fly and the Fly Delta. The latter was not specifically considered in the study but is estimated at about 15 Mt/year when averaged over the overall mine life.
- Since 1998, dredging at Bige in the Lower Ok Tedi has removed about 17 Mt/year of sand from the river. This has halted or reversed pre-dredging bed level rise on the Lower Ok Tedi and on the Upper and central Middle Fly but there continues to be very slow bed level rise further downstream as progression of material already in the river system occurs.
- Dredging does not capture the silt component of the tailings or waste rock inputs.
- Diversion to a TSF will capture both the sand and silt component of tailings but not those of waste rock inputs. Waste rock has a large component of siltstone and limestone, both of which abrade to mostly silt.

- Previous studies on benthic geochemistry and total suspended sediment in the South Fly indicate that approximately 85% of delivered sediment comes from the Strickland River. Consequently, it is unlikely that the impact of a TSF would be discernible in the South Fly and even less in the Fly Delta where marine sourced sediment inputs may exceed those of the South Fly tenfold.

Key results from the modelling and impact assessment are summarised below.

Sediment transport

Table 10.26 compares modelled cumulative deposition by river reach from 1990 to 2060 for the scenario with TSF (Plan C) and without TSF (Plan D). Modelling assumes continued dredging operations at Bige until 2050. Under the TSF scenario (Plan C), dredging at 17 Mt/year up to 2030 was assumed followed by a lesser rate thereafter dictated by sand availability. The modelled deposition for without TSF (Plan D) is shown in brackets where differences occur. Modelled results indicate (see Figure 8.12 and Figure 8.14 for locations):

- Initially, heavy sediment accumulation occurs in the upper part of the Ok Tedi between logi Village and D'Albertis Junction. This deposition is subsequently reduced by dredging. The Lower Ok Tedi holds material for longer and deposition persists in some reaches to at least 2060. There is a pattern of long-term sediment accumulation and retention over most of the Middle Fly which, once sediment is in place shows little tendency to clear except in the uppermost section.
- Comparatively, modelled deposition patterns for both with and without TSF scenarios are identical up to 2030, after which the without TSF scenario (Plan D) continues to show greater downstream deposition and floodplain accumulation. There is little change downstream beyond Wygerin and deposition continues to increase right up to 2060 but at a slower rate from 2045.
- Sediment transport modelling predicts significant long-term reductions in sand and silt delivery to the Lower Ok Tedi and Middle Fly River with the TSF.

Table 10.26 Modelled cumulative deposition by reach from 1990 to 2060 for the scenario with TSF (Plan C) and without TSF (Plan D, shown in brackets)

Year	Lower Middle Ok Tedi	Lower Ok Tedi	Upper Middle Fly		Middle Fly	
	Bige-Ieran	Ieran-D'Albertis	D'Albertis-Wygerin	Wygerin-Mabaduem	Mabaduam-Manda	Manda-Obo
1990	4.9	6.8	10.3	6.6	4.1	9.6
1995	18.3	31.4	42.2	14.3	13.3	18.8
2000	18.3	42.9	79.9	32.3	27.8	31.6
2005	11.1	40.8	83.8	50.7	39.7	54.2
2010	9.1	38.5	92.9	59.4	59.2	58.0
2015	0.4	32.0	91.2	63.5	71.5	69.9
2020	-4.3	23.7	82.6	67.3	81.7	80.7
2025	-6.9	17.2	72.1	66.1	88.1	97.6
2030	-10.1	13.0	70.5	63.0	95.5	106.9
2035	-13.4 (-6.5)	9.0 (17.7)	63.4 (71.7)	60.3 (63.6)	93.0 (97.5)	124.1 (129.4)
2040	-15.4 (-8.4)	5.2 (17.4)	56.0 (67.7)	58.3 (63.7)	92.7 (97.3)	132.8 (142.1)
2045	-16.9 (-9.9)	2.1 (17.1)	48.1 (63.4)	53.8 (61.7)	91.8 (97.3)	141.2 (149.3)
2050	-19.0 (-8.3)	-2.0 (20.6)	45.4 (68.4)	51.6 (61.6)	91.2 (100.4)	143.7 (150.8)
2055	-12.6 (-7.9)	-2.7 (18.5)	41.6 (71.9)	49.9 (60.7)	88.3 (98.9)	147.8 (159.9)
2060	-8.6 (-6.0)	11.3 (25.9)	37.1 (68.2)	47.6 (62.9)	86.6 (97.1)	152.4 (159.8)

Source: Appendix B

Water level changes

Modelled water level changes indicate that the effect of a TSF is greatest between the Lower Middle Ok Tedi and Lower Ok Tedi towards the Upper and Middle Fly, with decreases in water level of up to 1.5 m but this is not sufficient to offset the historical increases in water levels caused by decades of riverine mine waste disposal. However, it does represent an environmental improvement relative to existing conditions and in combination with dredging at Bige produces a small but meaningful improvement downstream as far as Wygerin. Further downstream, any changes are small. By 2060, water levels are still predicted to remain above pre-mining conditions due to the large volume of historical sediment already stored within the river system over all the Lower Ok Tedi and most of the Middle Fly.

River and floodplain response

Satellite imagery and field observations have shown that flood pulsing from the floodplain has now been reduced due to riverbed aggradation, consistently raised water levels, and since the 1997/98 El Niño event, an elevated river levee bank acting as a hydraulic dam retains water on the floodplain. This altered hydrologic regime has also resulted in extensive areas of vegetation dieback covering over 2,000 km² of the Ok Tedi and Fly River floodplains. This also has impacts on vegetation and fish biodiversity (OTML 2024f).

Further observed trends for river and floodplain response over the project area are (Appendix B):

- Upper project area: In the mine area creeks and Middle Ok Tedi, ongoing deposition and rising water level continue to occur.
- TSF and downstream project area: In the Lower Ok Tedi and Middle Fly, there has been increased floodplain inundation, continuing levee buildup, and some in-filling of water bodies held in oxbow lakes on the floodplain. In the early years of mine operation when tailings sulfur content was high, localised acid mine drainage breakout zones occurred in downstream reaches of the Middle Fly notably on levees and levee backslopes.
- Floodplain inundation appears to be close to the maximum spatial extent and is limited by the higher ground that makes up valley edges. There may, however, still be some expansion into upper sections of tributaries.

These observations reflect existing conditions and ongoing geomorphological responses to historical and current mine-derived sediment inputs within the Ok Tedi and Fly River systems. While the TSF is not expected to completely halt or reverse these processes due to the large volume of sediment already stored within the river system and floodplains, it is predicted to gradually slow their rate over the long term and accelerate ultimate recovery of the system, particularly within the Lower Ok Tedi and Upper Middle Fly.

Riverine particulate geochemistry

Reactive sulfide minerals in mine-derived sediments, especially tailings, are potentially acid forming. While this is controllable by treatment of the tailings and the addition of limestone to ore and waste rock, these measures were only implemented from 2010 and 2011 respectively. In the past, this has led to localised oxidation of reactive sulfide minerals and release of acidity and dissolved metals and poor water quality under certain climatic conditions, especially during El Niño events.

In response to these observed effects and to reduce the risk of acid generation, OTML has progressively implemented a range of management measures over the past 27 years that have substantially improved the geochemistry of the mine waste and river system, such as improved metal recovery and removal at the TPP of iron sulfides (pyrite) from the tailings before discharging and milling of limestone. OTML (2024d) reported no observed evidence of adverse acid rock drainage (ARD)-related changes to existing water chemistry along the river channel downstream of the mine, and that a general improvement trend in the acid base geochemistry of deposited sediments within various reaches of the system continues to be observed.

Tailings and waste rock from the Ok Tedi Mine contain elevated levels of several potentially toxic metals, particularly copper. A portion of this copper dissolves in Ok Tedi water, leading to an increase in copper

concentration that exceeds the ANZECC/ARMCANZ (2000) threshold values for aquatic ecosystem protection. Additionally, tailings and waste rock are rich in pyrite, which can undergo oxidation to form sulfuric acid. If this process occurs, the resulting increase in acidity can elevate dissolved metal concentrations, especially copper, causing significant negative impacts on the aquatic environment. The concentration of sulfur in discharged tailings is critical to the downriver water and sediment quality and ecosystem health, with this potential risk now largely mitigated by OTML via key controls such as the addition of limestone and removal of PCon.

The riverine particulate geochemistry modelling and assessment indicated that (Appendix B):

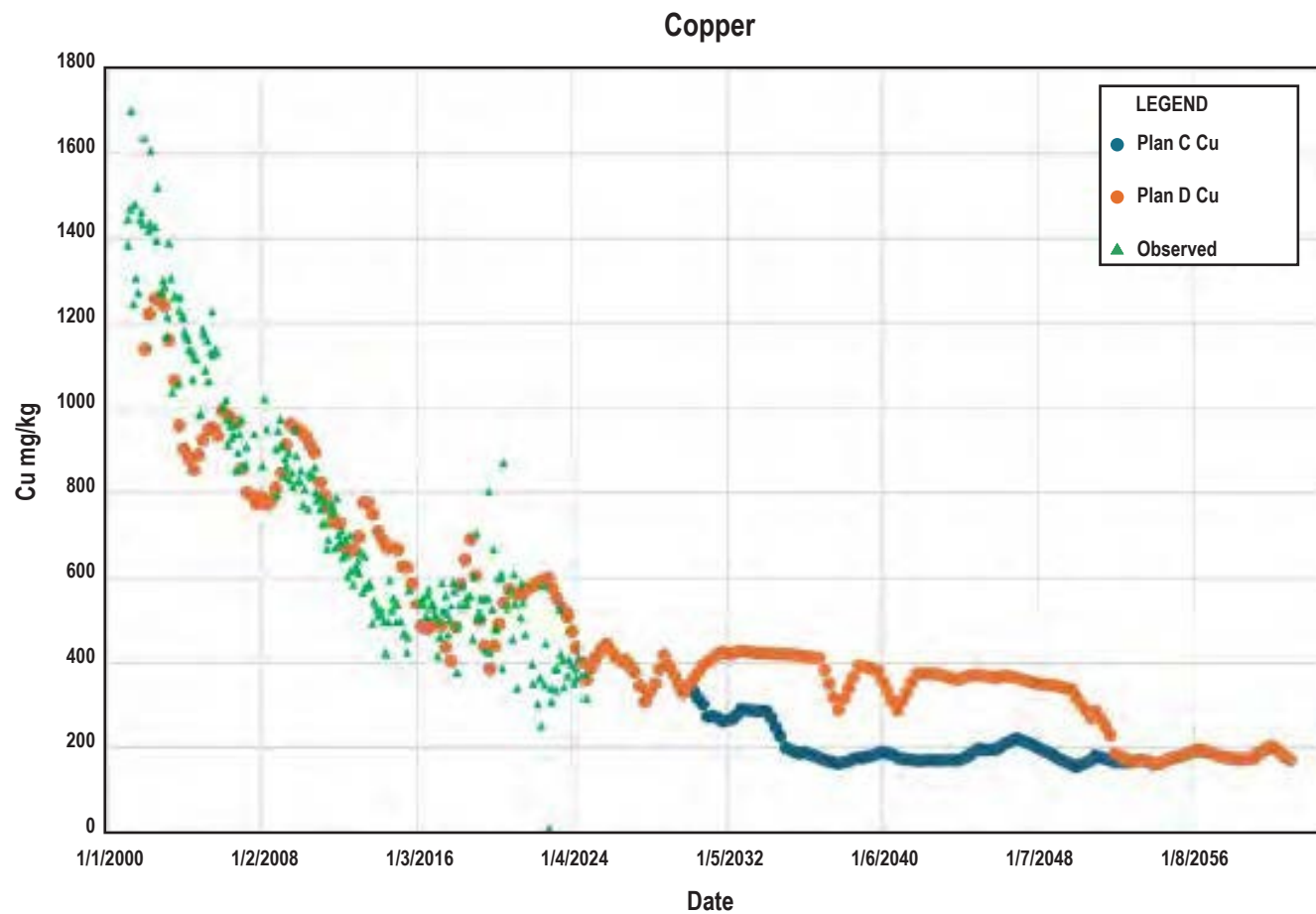
- Particulate metals dominate the geochemical pollution of the Fly River system with over 99% of copper released into the river in particulate form, while less than 1% is present in dissolved form. This means that sediment storage, remobilisation, and floodplain deposition are key pathways through which geochemistry shapes downstream ecosystems.
- Sulfide-bearing mine waste tailings and some components of waste rock may be rich in sulfur and heavy metals. Some studies indicate that sulfide tailings with sulfur concentrations above 1% have the potential to generate ARD and this level of concentration was the norm up to 2010. Sulfur concentrations in tailings are now slightly below 1% and are projected to remain there for the remainder of mine life since the tailings pyrite processing plant provides an engineered control of tailings sulfur concentration. Addition of ground limestone to tailings further reduces the likelihood of ARD.
- ANC (largely derived from limestone) reduces the possibility of acid generation with ANC:MPA ratios of 2 or more being regarded as indicating minimal acid generation risk. Ratios of 1 to 2 are regarded as showing some level of risk. Geochemistry model predictions for future sediment outflows from the Middle to the Lower Ok Tedi indicate that without a TSF, the ratios will lie between 2 and 3. With a TSF, the ratios lie between 5 and 6. ANC:MPA ratios from depositional bars in the Middle Ok Tedi which contain only limited amounts of deposited tailings can be much higher, indicating minimal ARD risk.
- Copper content of tailings is now about one third to one quarter of values in the early 2000s. This reduction is due to decreased head grades in ore combined with increased copper recoveries in the processing plant. Sulfur values have decreased by more than 60% due to the operation of the tailings processing plant that removes PCon for long-term subaqueous disposal at Bige.
- The highest concentrations of deposited particulate copper in the floodplain reaches of the river system occur on main channel and tie channel levees close to it. Monitoring of levees in the Lower Ok Tedi and Middle Fly shows progressive reduction of copper and sulfur concentrations over time and increasing ANC. ANC declines downstream due to dilution by Upper Fly inputs but downstream ANC:MPA ratios measured from levee sediment samples would be classified as NAF and unlikely to be a source of acidic drainage for the remainder of mine life.
- The persistence of mine-derived sediment, especially sulfur-bearing tailings in oxbows and floodplain waterbodies may extend these risks by creating long-term repositories of once reactive material. Little is known of this material. However, this material is mostly submerged or buried suggesting that it is low risk.
- With a TSF, particulate copper discharge to the Lower Ok Tedi will decrease by about 50% compared with no TSF with values decreasing from an average of 371 mg/kg for the 2030-2050 period to 196 mg/kg. These differences will persist on the levees downstream throughout Lower Ok Tedi and Middle Fly with only limited dilution by input from the Upper Fly (Figure 10.9 and Figure 10.10).
- With a TSF, the decrease in sulfur concentrations in sediment discharge (as measured in Bige dredge material) is about 28% for the 2030-2050 period, from 1.29% to 0.93%. Concentrations on the Lower Ok Tedi levees are about 60% of these values with the differences initially persisting downstream on the levees but becoming more diluted by Upper Fly inputs and in the Lower Middle Fly.

- With a TSF, ANC (as measured in Bige dredge material) increases from 101 kg H₂SO₄/t to 140 kg H₂SO₄/t, a 39% increase. There is minimal dilution on the Lower Ok Tedi levees, slightly more below the junction with the Upper Fly with a further decrease in the central Middle Fly and beyond.
- With a TSF, the ANC:MPA ratio (as measured in Bige dredge material) almost doubles from 2.58 to 5.11 with the differences also persisting downstream on the levees suggesting little ARD risk compared with the early 2000s.
- It is concluded that the TSF provides a significant improvement to lower river system particulate geochemistry.

Future predictions

Key future predictions from the hydrology and sediment transport study (Appendix B) for a TSF operating from 2030 and capturing 90% of tailings, plus dredging at Bige continuing throughout mine life, are:

- Without a TSF, there will be continued sedimentation, water level rise, and further floodplain impacts. However, at present, dredging is removing enough sand to limit bed level rise, especially in upper floodplain reaches.
- With a TSF, there is predicted to be:
 - Significant reductions in sand and silt delivered to the Lower Ok Tedi and Middle Fly. Diversion of tailings to a TSF will cut tailings inputs to the river system by approximately 85 to 95%, resulting in an estimated 40% reduction in the sand:silt ratio of the river sediment load and generally finer sediment load downstream.
 - A potential two-thirds reduction in sand delivery for dredging at Bige.
 - Increased riverbed erosion on the lower Ok Tedi and at the upper end of the Middle Fly but little change further downstream, and possible continued deposition on the Lower Middle Fly but at a very slow rate.
 - Reductions in water levels on the Lower Ok Tedi but at a decreasing rate further downstream with minimal change beyond Mabaduam (approximately 100 km south (direct distance) of the proposed TSF site) and into the Middle and Lower Middle Fly.
 - Possible reduction in floodplain inundation frequency and delivery of mine-derived sediment to floodplains and ORWBs, which refers to oxbow lakes, cut-off meanders and blocked valley lakes located along the floodplain.
 - Levee growth as a slower process than changes on the riverbed and likely to slowly continue but at a reduced rate, especially in the upper floodplain reaches.
- Both with and without a TSF:
 - Floodplain isolation from the main river is likely to continue.
 - Most sediment delivered to the floodplain will remain in long term storage due to limited lateral channel migration and erosion.
- A Recovery Baseline run (a model run with no further disposal of waste rock or tailings after 2025) provided insight into long-term natural reworking of stored sediments. It showed a reduction in sand and silt in the sediment load to a base level over a period of 5 to 10 years but little change beyond that over the next 25 to 30 years (the limits of modelling) suggesting further decades of elevated sediment transport. The base level is about twice the estimated pre-mine sediment transport rate.



SOURCE
Appendix B



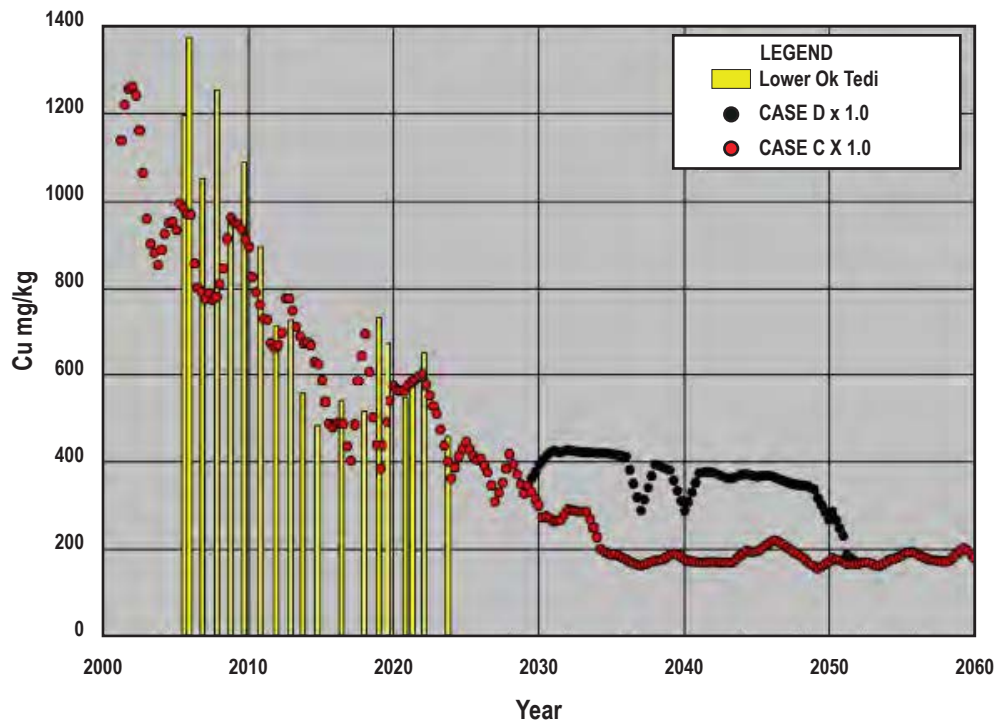
OK TEDI MINING LIMITED
OK BIRIM TAILINGS STORAGE FACILITY PROJECT



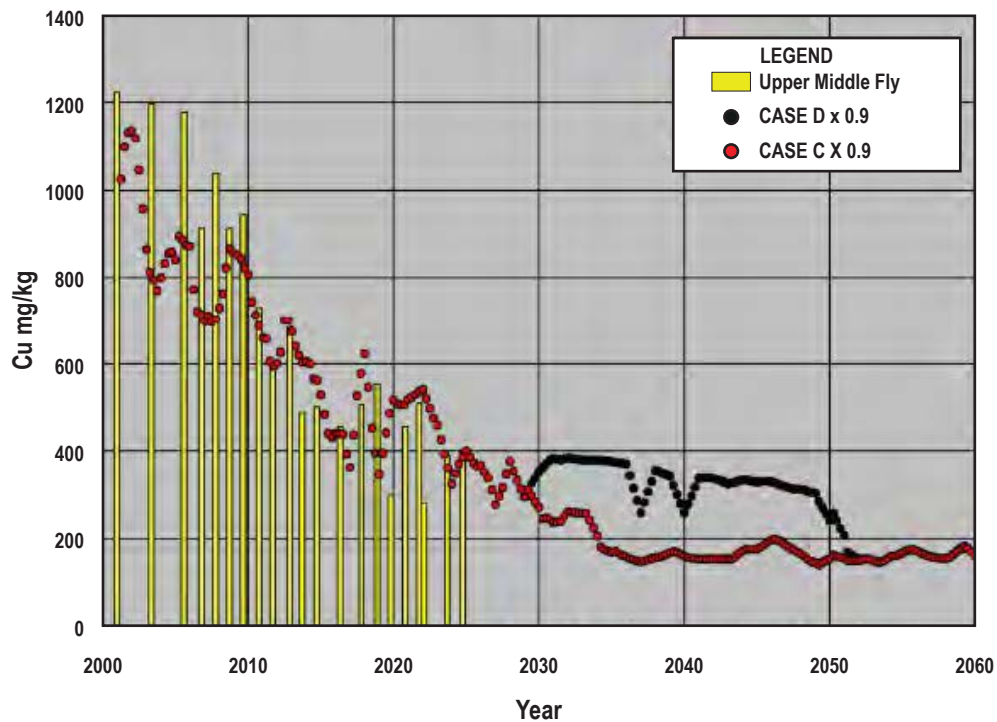
FIGURE 10.9
Observed and predicted particulate copper concentrations for sediment delivered to the floodplain reaches of the upper river system

DATE: 22.06.26 PROJECT: 754-MELN374244 FILE: 374244C_R08_F10.09_GRA

Lower Ok Tedi - copper



Upper Middle Fly - copper



SOURCE
Appendix B



OK TEDI MINING LIMITED
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FIGURE 10.10
Observed and predicted particulate copper concentrations in Lower Ok Tedi levee sediments and in Upper Middle Fly levee sediments



DATE: 22.06.26 PROJECT: 754-MELEN374244 FILE: 374244C_R08_F10.10_GRA

Summary of predicted environmental improvements associated with a TSF

Based on the findings presented in Appendix B, the TSF is predicted to result in substantial long-term improvements to the mine-affected physical riverine environment by significantly reducing mine-derived tailings inputs to the Ok Tedi and Fly River systems. Key physical riverine processes where the TSF is predicted to positively influence river system behaviour include:

- **Changes in Ok Tedi water levels:** Historical riverine tailings and waste rock disposal has altered downstream flow dynamics and the natural functioning of the river systems. The TSF is predicted to contribute to gradual reductions in water levels in the Lower Ok Tedi, with progressively smaller changes further downstream and minimal change beyond Mabaduam and into the Middle and Lower Middle Fly.
- **Sediment loading and transport:** Sediment loads strongly influence river morphology, bank stability and downstream aquatic habitat processes. The TSF is expected to substantially reduce downstream delivery of tailings-derived sand and silt, leading to long-term reductions in suspended sediment loads and downstream sediment accumulation.
- **Sediment deposition in river channels, floodplains and ORWBs:** Reduced sediment loads are predicted to decrease riverbed aggradation, floodplain sediment deposition and the frequency and extent of overbank flooding in some reaches. However, historical sediment already stored within the river system and floodplains will continue to influence sedimentation processes for decades. By capturing a substantial proportion of the fine (silt) material from the tailings, which is a primary source of elevated turbidity and biological stress in downstream aquatic ecosystems, the TSF is expected to reduce turbidity and TSS levels in main river channels and associated floodplain/ORWBs.
- **Floodplain and levee processes:** Historical aggradation in the Lower Ok Tedi and Middle Fly has increased the frequency and duration of floodplain inundation and contributed to tie-channel blockage and levee growth. While levee growth is expected to continue, the rate of aggradation and floodplain sediment accumulation is predicted to reduce progressively over the long term with the TSF.
- **Riverine particulate geochemistry:** Historical riverine disposal of sulfide-bearing tailings and waste rock has resulted in elevated concentrations of particulate copper and sulfur within sediments of the Ok Tedi and Fly River systems. Although significant improvements have occurred through removal of PCon and the addition of limestone to the mill feed, mine-derived sediments remain an ongoing source of particulate-associated contaminants. The TSF is predicted to provide substantial long-term improvement to downstream riverine particulate geochemistry through a significant reduction in particulate copper and sulfur discharged to the river system, and a significant increase in ANC and a corresponding substantially lower long-term acid generation risk.

Where appropriate, these findings have been incorporated into the residual impact assessment.

Upstream project area (mine area creeks, Upper and Upper Middle Ok Tedi)

Drainage and hydrology

No major changes are proposed to the existing mine water supply associated with the TPP for the slurry tailings transfer via pipeline to the TSF. Process water supply for the TPP will continue to be sourced from Tinaroo Dam and the existing mill area. Additional process water requirements, such as for flushing the tailings pipeline, is estimated at approximately 25 ML including 10% contingency, which represents approximately 10% of the available raw water storage capacity at Ok Tedi Mine. Given this relatively small demand compared with existing storage capacity and the high rainfall across the project area, impacts on existing flow regimes, hydrological conditions and water supply availability are expected to be **negligible**.

Sediment transport

During operations, diversion of approximately 90% of final tailings from current riverine disposal to the TSF is expected to substantially reduce tailings-derived sediment inputs into the Ok Kumiup Valley and downstream sections of the Ok Mani and Middle Ok Tedi. However, the TSF will have minimal effect on Ok Mani deposition.

The hydrology and sediment transport assessment in Appendix B indicates that:

- The behaviour of the mine area creeks will continue to be largely governed by coarse waste rock inputs from failing waste rock dumps and downstream transfer of previously deposited coarse material to the Middle Ok Tedi. The EWRD/s, if successfully constructed and operated, will substantially reduce new inputs to the system but will have minor effects on existing riverbed deposits and the downstream transfer of material.
- The main body of material in the Ok Mani/Harvey Creek system will peak in 2030 to 2035 and will then slowly reduce as it is discharged to the Middle Ok Tedi.
- The Sulphide Creek system will continue to discharge most delivered material quickly and will only store limited amounts.
- The Middle Ok Tedi will continue to accumulate deposited material to 2060 and beyond.
- At present, most tailings pass through the mine area creeks and the Middle Ok Tedi as wash load and there will be limited deposition and storage except in the interstices of existing gravel deposits. However, there may be some sand build-up in the reach immediately upstream of the dredge site at Bige.
- A TSF will divert most tailings from the mine site to the TSF but stored material in existing riverbed deposits will continue to be delivered to the lower Section of the Middle Ok Tedi where there will be limited deposition at present. Otherwise, no significant effect on the upper river system deposition is expected.
- Direct discharge of about 10% of tailings into the river during planned offline periods for the tailings pipeline and hydro-cyclone house is predicted to have very little effect on upper river system sediment load as it will only make up about 7% of total sediment discharge and will be mostly transported downstream as wash load.
- A TSF will make a substantial difference to the suspended sediment load of the Middle Ok Tedi and the particle size distribution of material discharged to the Lower Ok Tedi from 2030. That effect will continue up to mine closure in 2050 and for a few years beyond that.
- The substantial reduction in sand discharge to Bige and possible dredging may create issues for supply of stockpile cover material.
- Having an operational TSF will change the sand:silt ratio of the sediment load discharged to the Lower Ok Tedi after 2030 from about 0.8 to 0.45. Dredging of the remaining sand reaching Bige under the scenario with the TSF (Plan C) will reduce the ratio even further. This suggests some transition of the floodplain reaches of the river from a sand bed type towards a silt dominated system. However, there is sufficient sand already in the system for the river to continue to behave mostly as a sand bed system for a considerable time.

While geomorphic behaviour within the upper river system will continue to be strongly influenced by historical mine-derived sediment stores and ongoing waste rock inputs from existing erodible dumps, the reduction in direct tailings discharge is expected to improve suspended sediment loads and particulate geochemical conditions over time relative to existing conditions. In particular, reductions in sulfur-bearing tailings inputs and associated particulate copper concentrations are expected to improve downstream sediment geochemistry and reduce long-term acid generation risk.

The upper river system is nevertheless expected to continue to experience elevated sediment transport and deposition for decades due to previously deposited material. As such, large-scale improvements to river morphology or hydrology within the upper system are not expected during the operational life of the project.

Residual impacts within the upstream project area during operations are therefore assessed as **minor to moderate** improvement for sediment transport and associated surface water quality.

TSF development area (Ok Yep and its tributaries)

Drainage and hydrology

The TSF operations will permanently alter local drainage patterns and hydrology within the eastern Section of the Ok Yep catchment through the establishment of embankments, ring-dyke impoundments, diversions and drains, sedimentation ponds and TSF controlled discharge systems.

Figure 10.11 shows the anticipated extent of project affected watercourses and sub-catchment associated with the TSF development. The TSF footprint covers much of the east branch of the Ok Yep catchment, which is a small catchment 66.6 km² in size that drains south and joins the Ok Tedi about 4 km south of the TSF.

The TSF will permanently cut off some of the upper tributaries of Ok Yep in the north and east and redirects flow back into the western arm of the Ok Yep further south. The overall effect of these diversions and the TSF discharges to the Ok Tedi is likely to reduce flows in the lower Ok Yep. The TSF emergency spillway and discharge system are planned to be on the east side of the TSF and report to small drainage lines flowing into the Ok Tedi. Project affected water will collect excess water from the TSF pond, impoundment, embankment runoff and associated seepage collection systems.

Groundwater modelling (see Section 10.3) indicates that localised impacts may occur in areas immediately downgradient of the TSF, particularly along small valleys and drainage pathways where preferential flow could concentrate seepage and lead to localised discharge to surface water systems. However, these impacts are predicted to be spatially constrained and strongly attenuated by natural processes.

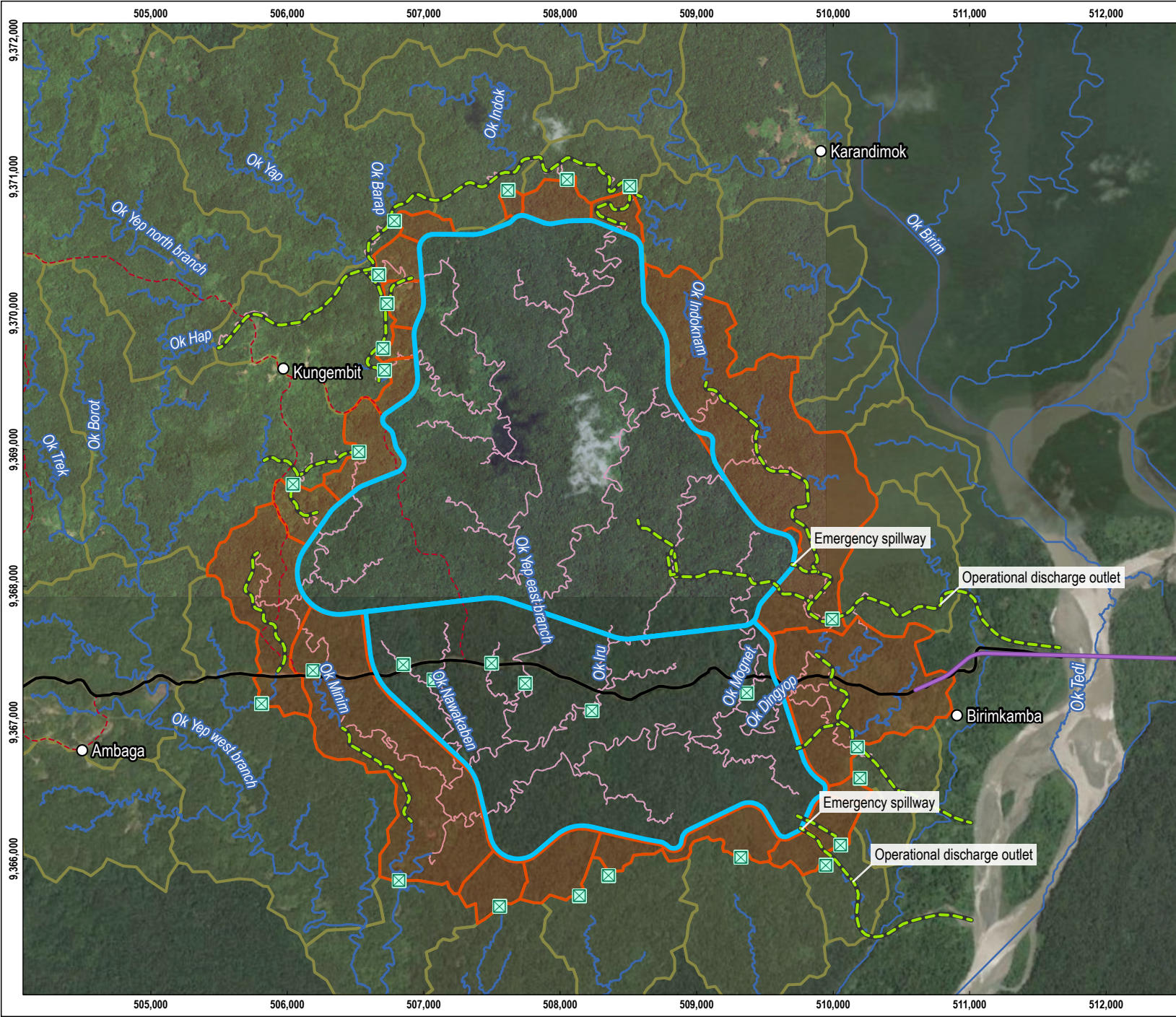
Residual impacts to local drainage and hydrology are predicted within the TSF development area are therefore assessed to be **major** adverse due to permanent modification of local catchments, altered drainage pathways and reduced surface water connectivity.

Sediment transport

During operations, localised sedimentation and elevated suspended solids may continue within the Ok Yep catchment and immediately downstream of TSF discharge locations. However, these impacts are predicted to reduce substantially compared with the construction phase following progressive stabilisation and rehabilitation of disturbed areas and settling in sedimentation ponds.

As described in Appendix A, based on predicted TSF discharge surface water quality results, no specific water treatment of excess TSF decant water is proposed prior to discharge to the receiving environment other than settlement of suspended solids within the TSF pond and downstream sedimentation ponds. Geochemical and surface water quality modelling indicated that the TSF discharge water is expected to be generally NAF and of relatively low geochemical risk, although sulfate and copper concentrations are predicted to be elevated relative to existing background conditions in the Ok Tedi. Surface water quality impacts associated with planned TSF discharges are predicted to be localised immediately downstream of the discharge locations. Modelling indicates that sulfate concentrations may increase locally, while dissolved copper concentrations are predicted to remain broadly consistent with existing background conditions due to rapid dilution and adsorption to suspended sediments.

Operational residual impacts within the TSF development area are therefore assessed as **moderate** adverse for sediment transport and associated water quality.



LEGEND

- Community
- Road
- - - Track
- Natural watercourse
- Project affected watercourse
- Project affected catchment
- Natural catchment

Proposed layout

- Sediment pond
- Diversion drain
- TSF footprint

ITCS road project (separately approved)

- Alice Pit bridge
- Road

SOURCE

Villages from Tetra Tech Coffey.
Surface water plan from KCB.
Proposed infrastructure from KCB and OTML.
Roads from OSM. Imagery from ESRI and Google Earth.



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FIGURE 10.11

Project affected watercourses and sub-catchment associated with the TSF



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Middle Ok Tedi and downstream project area (Lower Ok Tedi, Fly River)

This section describes predicted surface water impacts within the Middle Ok Tedi and downstream project area, during operations.

Drainage and hydrology

During operations, the TSF has been designed to safely pass designated flood events and operate as a flow-through system that enables planned discharge to the Ok Tedi. Under extreme rainfall conditions, the system is designed to return stored water to normal operating volumes within approximately five days, inclusive of operational inputs from the hydro-cyclone house. The modelled water balance indicates that the TSF design (i.e., pond and discharge capacities via siphon system) will have sufficient capacity to accommodate expected inflows under current climate conditions, including extremes and potential future climate change effects.

Approximately 265,000 ML of water is expected to be delivered in the final tailings slurry over the life of the project, equivalent to about 36.3 ML/day over 20 years assuming continuous operations. Around 38 ML/day of TSF decant water will be re-used as process water at the hydro-cyclone house. Due to the volume of process water within the tailings slurry combined with high rainfall and runoff, the TSF is expected to maintain a positive water balance requiring continuous discharge via a siphon pump system throughout the year. Excess TSF decant water will be discharged to the Ok Tedi continuously at an average flow rate of approximately 2 kL/s, equivalent to 172.8 ML/day, following settlement of suspended solids within the TSF pond and downstream sedimentation ponds. The TSF's discharge flows are expected to be negligible relative to background flows in the Ok Tedi and not expected to materially affect the river's hydrology or surface water flow regime.

The siphon system and emergency spillways will discharge into the same natural drainage lines flowing east towards the Ok Tedi; during Cell 1 operation approximately 1.2 km downstream of the Ok Birim confluence, and during Cell 2 operation from the southeast corner of the TSF. Project affected water reporting to the western side of the TSF will be directed to sedimentation ponds for settling prior to discharge into the eastern branch of the Ok Yep, which then flows into the Ok Tedi over 5 km further downstream. The locations of sedimentation ponds will be adapted throughout the life of the project to intercept and manage on-site project affected water and excess TSF decant water prior to discharge into the receiving environment.

Groundwater seepage is expected to constitute a relatively small component of overall TSF water balance. Section 10.3 provides further details on associated groundwater impacts.

Overall, the most significant drainage and hydrology effects associated with operation of the TSF are predicted to occur at a regional scale through long-term changes to sediment loading and associated river and floodplain processes in the downstream Ok Tedi and Fly River systems. Reduced mine-derived sediment inputs are predicted to result in gradual long-term hydrological and geomorphological improvements relative to existing conditions, including reduced riverbed aggradation, slower levee growth and lower rates of floodplain sediment accumulation, particularly within the Lower Ok Tedi and Upper Middle Fly. Over time, these geomorphological changes are also expected to contribute to gradual reductions in water levels and overbank flooding frequency in some downstream reaches.

While the magnitude of these predicted improvements is **high to very high**, the overall residual significance is limited by the **low** sensitivity of the mine-affected receiving environment. On this basis, residual impacts on drainage and hydrology are assessed as **minor** improvement for the Middle Ok Tedi and **moderate** improvement for the downstream project area, particularly within the Lower Ok Tedi and Upper Middle Fly.

Sediment transport

Sediment loads in excess TSF decant water and other project effluent will be reduced through settlement of suspended solids within the TSF decant pond and downstream sedimentation ponds prior to discharge to the receiving environment and ultimately the Ok Tedi.

The TSF discharge water is predicted to contain elevated TSS concentrations during operations. However, sediment-related impacts to the Ok Tedi beyond the immediate discharge area are predicted to be negligible due to rapid dilution from river flows and because existing background TSS levels are generally well above the adopted ambient water quality criteria (refer to Section 10.4.5).

The Lower Ok Tedi and Middle Fly are predicted to experience the greatest long-term environmental improvements associated with operation of the TSF. By substantially reducing downstream delivery of tailings-derived sand and silt, the TSF is predicted to reduce suspended sediment loads, slow rates of riverbed aggradation and levee growth, lower rates of floodplain sediment accumulation over time, and reduce turbidity and TSS levels in main river channels and associated floodplain/ORWBs likely to be beneficial to downstream aquatic ecosystems.

The modelling indicates approximately a two-thirds reduction in sand delivery to the Bige dredge reach and substantial improvement in downstream riverine particulate geochemistry, including lower particulate copper and sulfur concentrations and increased ANC within downstream sediments. These changes are predicted to progressively improve downstream river and floodplain conditions relative to existing mine-affected conditions.

The most pronounced geomorphic improvements are expected within the Lower Ok Tedi and Upper Middle Fly. Further downstream, improvements are expected to occur more gradually due to the persistence and continued downstream transport of historical sediment already stored within the river system and floodplains. These improvements are expected to occur progressively over the long term and incrementally at a geomorphological scale, including post-closure.

Although the magnitude of these predicted improvements is **very high**, the overall residual significance is assessed as **moderate** improvement within the Middle Ok Tedi and downstream project area due to the **low** sensitivity of the receiving environment, which remains degraded and heavily mine-affected.

Infrastructure development corridor

During operations, residual impacts within the infrastructure corridor will primarily relate to ongoing use and maintenance of unsealed roads, bridges and crossings, which will continue to generate highly localised erosion, sediment transport and sediment-laden runoff during rainfall events but at a much lesser scale than during the construction phase.

Residual impacts are expected to remain largely confined to immediately adjacent drainage lines and receiving watercourses and are predicted to progressively reduce over time through implementation of adequate drainage, erosion and sediment control measures, road maintenance and progressive rehabilitation.

Given surface water impacts within the infrastructure corridor area are anticipated to be highly localised and greatly reduce within two years following construction, residual impacts during the operational phase associated with drainage and hydrology, sediment transport and surface water quality are assessed as **moderate** adverse.

Residual impact assessment summary

Table 10.27 provides a summary of the residual impact assessment for the operational phase. The most significant adverse residual impacts are predicted within the TSF development area, where permanent changes to drainage pathways, altered surface water connectivity, controlled TSF discharges, and ongoing erosion and sediment transport from roads and infrastructure will occur, resulting in adverse residual impacts of **moderate** to **major** significance.

Conversely, operation of the TSF is predicted to provide substantial long-term improvements to the mine-affected Ok Tedi and Fly River systems through major reductions in downstream mine-derived sediment loading relative to existing conditions. The greatest beneficial residual effects are predicted within the Middle Ok Tedi, Lower Ok Tedi and Upper and Middle Fly reaches, where reduced sediment loads are expected to

gradually improve drainage and hydrology, sediment transport processes and riverine particulate geochemistry over the long term.

The upstream project area is also expected to experience beneficial residual effects of **negligible to moderate** significance as the TSF is expected to substantially reduce tailings-derived sediment inputs into the Ok Kumiup Valley by up to 90%.

Table 10.27 Residual impact assessment - operational phase

Zone	Key aspect	Sensitivity	Residual impact (-) /improvement (+)	
			Magnitude	Significance
Upstream project area	Drainage and hydrology	Low	Negligible	Negligible
	Sediment transport and associated surface water quality	Low	Very high +	Moderate +
Infrastructure corridor	Drainage and hydrology	High	Moderate -	Moderate -
	Sediment transport and associated surface water quality	High	Moderate -	Moderate -
TSF development area	Drainage and hydrology	High	Very high -	Major -
	Sediment transport and associated surface water quality	High	Low -	Moderate -
TSF area – Middle Ok Tedi	Drainage and hydrology	Low	Moderate +	Minor +
	Sediment transport and associated surface water quality	Low	Very high +	Moderate +
Downstream project area (including associated floodplains and ORWBs)	Drainage and hydrology	Low	Very high +	Moderate +
	Sediment transport and associated surface water quality	Low	Very high +	Moderate +

10.4.4.3 Decommissioning and closure

During closure and post-closure, the TSF will be transitioned to a stable, water-shedding landform with passive drainage via closure spillways and permanent drainage infrastructure. Where practicable, flows will be passively discharged to the same receiving drainage lines and sedimentation ponds as during operations, which flows to the Ok Tedi. Based on current modelling, no further post-closure treatment of TSF discharge water is expected to be required.

Residual closure phase impacts include temporary increases in erosion, sediment transport and turbidity associated with earthworks and rehabilitation activities entering the receiving surface water environment. However, these impacts are expected to reduce progressively following stabilisation and revegetation of disturbed areas.

Long-term residual impacts during and after closure relate primarily to permanently altered drainage pathways and ongoing surface water discharges from the rehabilitated TSF landform.

Post-closure improvements within the downstream river systems are expected to continue gradually over time due to the long-term reduction in mine-derived tailings inputs and associated secondary beneficial effects, particularly in the Lower Ok Tedi and Upper and Middle Fly River. These improvements include lower rates of riverbed aggradation, reduced floodplain inundation frequency and extent, improved geochemical stability of the river system as well as in fish habitat condition. Post-mine closure sediment concentrations in the river systems will slowly fall but will remain well above pre-mine levels for decades to centuries.

Given the temporary and localised nature of decommissioning and closure related disturbance, together with the long-term beneficial reduction in mine-derived sediment loading to the downstream river systems, residual

impacts during the decommissioning and closure phase associated with drainage and hydrology, sediment transport and surface water quality are assessed overall as minor improvement.

10.4.5 Water quality compliance assessment

This section summarises the predicted surface water quality impacts associated with the project compared to adopted water quality guidelines and existing background levels. Predicted surface water quality parameters are based on the results of EGi's geochemical and surface water quality modelling of TSF discharges in Appendix C. The assessment uses the compliance method; there is no corresponding residual impact assessment (see Section 10.1).

10.4.5.1 TSF discharge quality

Predicted TSF discharge quality modelling undertaken by EGi for the TSF operations (Appendix C) indicates TSF discharges are expected to contain elevated sulfate and copper concentrations compared to selected upstream Ok Tedi water quality sites. Discharge loads are predicted to increase as each TSF cell is completed. However, these discharges will only have a minor and localised effect on surface water quality in the Ok Tedi immediately downstream of the discharge point, irrespective of flow conditions. Water quality in the Ok Tedi has been impacted for decades by riverine tailings and waste rock disposal; the minor, localised effect needs to be considered in the context of the removal of direct discharge of tailings into the Ok Kumiup.

When Cell 1 is completed, annual sulfur generation rates are estimated to be approximately 27 t/ha for the tailings beach and 195 t/ha for the embankment, resulting in a combined sulfate release of approximately 1,240 g/s. Sulfate contributions from decant water runoff contained in the final tailings slurry are expected to be minor relative to releases from the beach and embankments. This discharge is modelled to increase sulfate concentrations in the Ok Tedi by approximately 3 to 14 mg/L, depending on river flow, corresponding to an increase of approximately 37 mg/L upstream to ~43 mg/L downstream under median flow conditions. Sulfate concentrations are expected to decrease further downstream as the Ok Tedi is diluted by other watercourses; however, sulfate concentrations in the Ok Tedi at Atkamba can increase significantly (up to around 60 mg/L) under low flow and El Niño conditions due to sulfate release of exposed mine-derived sediments in the Middle and Lower Ok Tedi.

Copper release at completion of Cell 1 is estimated at 0.08 g/s, which would theoretically raise copper concentrations in the river by about 0.3 µg/L relative to the upstream concentration of 6 µg/L at Ningerum. However, more than half of the dissolved copper is expected to adsorb onto suspended solids, reducing the predicted incremental increase in dissolved copper to approximately 0.1 µg/L, resulting in negligible changes in copper concentrations in the Ok Tedi.

At completion of Cell 2, where the greatest changes are expected, sulfates are likely to increase by approximately 9 mg/L under median flow (i.e., from 37 mg/L upstream of TSF discharge to 46 mg/L downstream), and copper is predicted to have an incremental increase in dissolved copper of only 0.2 µg/L, as most of the added copper (around 60%) adsorbs to suspended solids. This is relatively minor in comparison to the dissolved copper concentration of 6 µg/L upstream of the discharge point. pH is not expected to change.

Overall, while minor increases in sulfate concentrations may occur depending on flow conditions, modelling indicates negligible to no change is predicted for dissolved copper concentration within the Ok Tedi. With copper, the main factor appears to be adsorption/desorption from mine-derived sediment fines being transported by the river rather than loadings of copper associated with TSF discharge or leachates from exposed sand bars or levees. With the TSF discharges, dissolved copper concentrations in the Ok Tedi are predicted to remain largely unchanged and remain approximately at 6 µg/L, with predicted copper concentrations generally trending lower with distance further downstream, consistent with dilution.

Given that existing background dissolved and total concentrations of several monitored parameters in the Ok Tedi already frequently exceed adopted ambient water quality criteria, particularly for ANZG (2018) ambient guidelines/ANZECC/ARMCANZ 2000 criteria (for 95% ecosystem protection), existing background concentrations have been adopted to provide a representative baseline against which predicted TSF discharge water quality can be compared.

Figure 10.12 shows the selected upstream and downstream monitoring locations on the Ok Tedi and Ok Yep used for comparison:

- Monitoring Point 1: OTML monitoring site in the Ok Tedi at Ningerum, approximately 7 km upstream of TSF (upstream site).
- Monitoring Point 2: OTML monitoring site in the Ok Tedi at Bige, approximately 30 km downstream of TSF (downstream site).
- Monitoring Point 3: Upstream Ok Yep tributary southwest of Kungim (upstream site).
- Monitoring Point 4: Downstream eastern branch of the Ok Yep where project affected water in the western catchment is planned to be received (downstream site).

The TSF discharge includes tailings slurry decant water, runoff/leachate from the tailing beach, and runoff/leachate from the embankment. The results show that most total concentrations of key parameters in TSF discharge water are predicted to meet the adopted water quality criteria except for sulfate, copper, potassium and zinc. However, concentrations of these parameters generally remain within the range of existing background variability, with the exception of sulfate and to a lesser extent potassium. For the existing OTML monitoring sites, background variability was represented by the historical average minimum and maximum concentrations recorded between 2020 and 2025.

Table 10.28 compares predicted TSF discharge water quality with existing upstream and downstream background levels in the Ok Tedi and Ok Yep (shown in Figure 10.12). The TSF discharge includes tailings slurry decant water, runoff/leachate from the tailing beach, and runoff/leachate from the embankment. The results show that most total concentrations of key parameters in TSF discharge water are predicted to meet the adopted water quality criteria except for sulfate, copper, potassium and zinc. However, concentrations of these parameters generally remain within the range of existing background variability, with the exception of sulfate and to a lesser extent potassium. For the existing OTML monitoring sites, background variability was represented by the historical average minimum and maximum concentrations recorded between 2020 and 2025.

Table 10.28 Background and predicted key water quality parameters upstream and downstream of the TSF

Key Parameter	pH	TSS	TDS	SO ₄	Ca	K	Mg	Al	Cd	Cu	Fe	Mn	Zn
Adopted surface water quality guidelines and criteria*													
PNG Schedule 1, drinking raw water standards	5-9.2	n/a	1,500	400 mg/L	n/a	n/a	n/a	n/a	0.01 mg/L	n/a	1 [#] mg/L	0.5 [#] mg/L	15 [#] mg/L
PNG Schedule 1, ambient water quality standards	<i>No alteration to natural pH</i>	n/a	n/a	400 mg/L	n/a	5.0 mg/L	n/a	n/a	0.01 mg/L	1 mg/L	1 mg/L	0.5 mg/L	5 mg/L
IFC EHS Mining (2007) effluent guidelines	6-9	50 mg/L	n/a	n/a	n/a	n/a	n/a	n/a	0.05 mg/L	0.3 mg/L	2 mg/L	n/a	0.5 mg/L
ANZG (2018) ambient guidelines	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.038 mg/L	0.0002 [†] mg/L	0.0014 mg/L	0.28 mg/L	1.9 [§] mg/L	0.008 ^{‡§} mg/L
Background surface water quality parameters upstream and downstream of the TSF*													
MP1: Upstream Ok Tedi monitoring point (Ningerum) (mg/L)	7.9 - 8.3 (8.1)	236 – 5,900 (2,128.0)	n/a	0.0 - 77.0 (38.6)	18.0 - 55.0 (37.3)	0.1 - 2.0 (1.5)	0.0 - 4.0 (2.3)	0.0 – 0.1 (0.036)	0.0 - 0.00024 (0.00004)	0.004 – 0.014 (0.0074)	0.0 – 0.039 (0.011)	0.003 – 0.14 (0.050)	0.0 – 0.0058 (0.001)
MP2 - Downstream Ok Tedi monitoring point (Bige) (mg/L)	6.8 - 8.6 (8.08)	22 – 11,723 (1,355.06)	n/a	0.5 - 391.1 (45.46)	6.4 - 150.0 (28.75)	0.1 - 2.0 (0.89)	0.1 - 9.0 (1.83)	0.0 – 0.090 (0.038)	0.0 – 0.0017 (0.0003)	0.0 – 0.027 (0.008)	0.0005 – 0.080 (0.022)	0.0001 – 0.084 (0.016)	0.0003 – 0.014 (0.001)
MP3: Upstream Ok Yep monitoring point (south of Kungim) (mg/L)	6.2	1.9	n/a	<1	2	<1	1	<0.01	<0.001	0.003	0.041	0.015	<0.003
MP4: Downstream Ok Yep surface water diversions, monitoring point (mg/L)	5.1	7.1	n/a	409	<0.2	<0.1	<0.1	0.089	<0.0006	0.006	0.09	0.018	0.001
Predicted TSF discharge quality													
Predicted TSF discharge water after Cell 1 completion [†] (mg/L)	6.3	n/a	1,318	925	343	22	11	0.001	0.0002	0.049	0.05	0.11	0.014

Source: Appendix C.

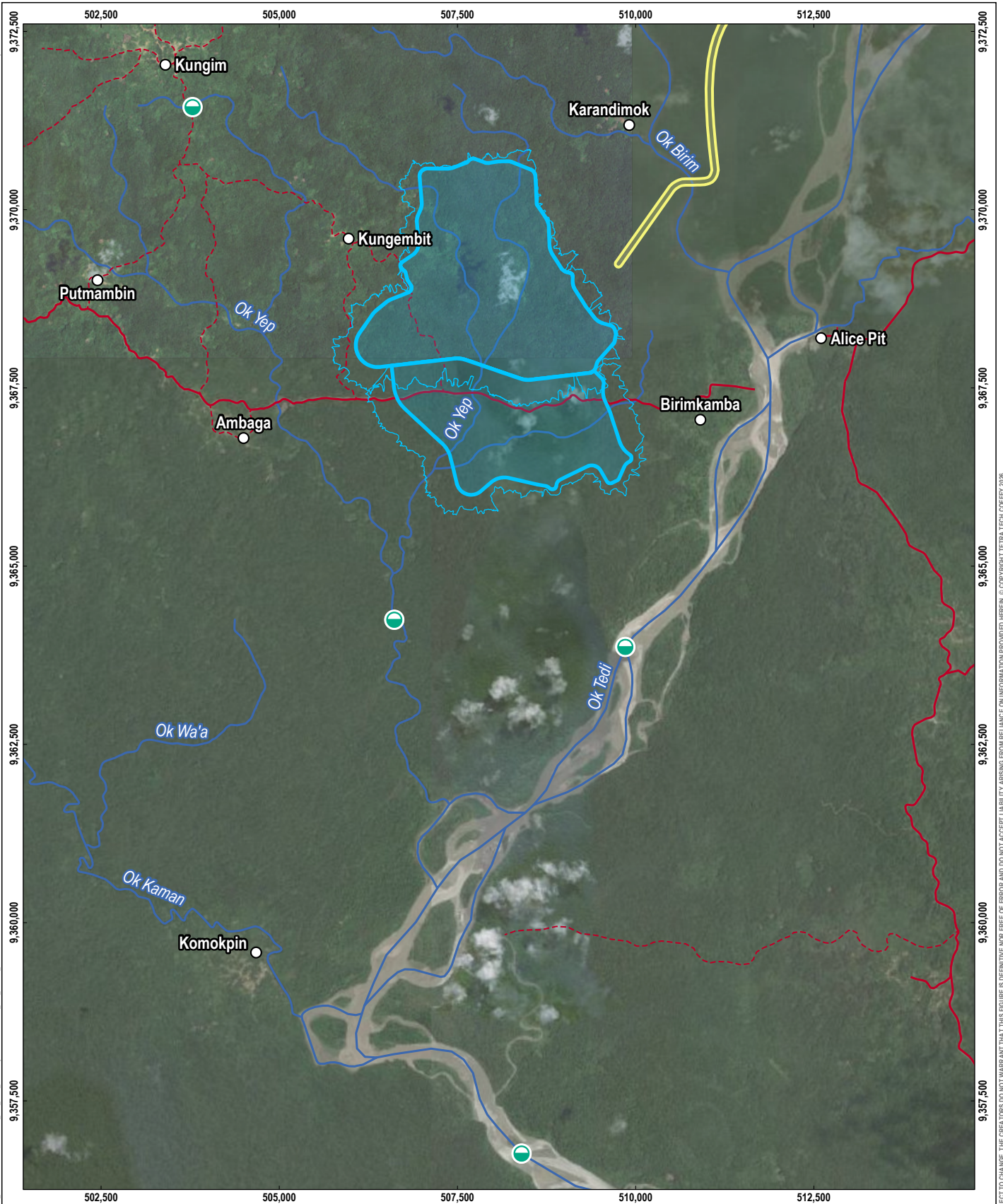
* Italics represent the adopted criteria value for the project. Values in bold indicate an exceedance of project adopted criteria. Values in brackets are averages. n/a = not available.

† Predicted chemistry of TSF discharge water after Cell 1 completion, noting that TSF discharge quality at end of Stage 2 is assumed to be broadly similar.

‡ Values should be adjusted for site specific hardness.

§ Figure may not protect key test species from chronic toxicity (this refers to experimental chronic figures or geometric mean for species).

Aesthetically-based value.



LEGEND

- Proposed surface water monitoring location
- Community
- Road
- Track
- Watercourse
- Proposed TSF footprint
- Proposed infrastructure corridor



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SOURCE
Proposed sampling and villages from Tetra Tech Coffey.
Proposed infrastructure from KCB and OTML.
Topographic features from OSM.
DEM from SRTM. Imagery from ESRI and Google Earth.

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FIGURE 10.12

Location of surface water quality monitoring and sampling points for the project



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10.4.5.2 Consideration of mixing zone and monitoring points

In PNG, a mixing zone is the legally-prescribed body of water into which project wastewater or effluent is discharged and where the prescribed water quality criteria are not required to be met. The downstream extent of the mixing zone is typically the first location downstream of the proposed discharge point where local people use the river and is generally adopted as the compliance point under an environment permit.

Modelling of TSF discharge to predict water quality impacts to the Ok Tedi indicate that mixing of TSF discharge with Ok Tedi flows results in no significant addition of metals or the promotion of metal precipitates, and the project effluent water quality will not require further water treatment after settling to reduce suspended solids. On this basis, a mixing zone is not proposed for the project given the rapid and significant dilution of TSF discharge water with Ok Tedi flows immediately downstream during normal operating conditions.

Figure 10.12 identifies proposed surface water quality monitoring points for the TSF involving site-specific trigger values, located as follows:

- Ok Birim:
 - Upstream of the proposed Ok Birim bridge crossing (upstream reference site).
 - Downstream of the proposed Ok Birim bridge crossing before the junction with Ok Tedi, to monitor potential water quality effects associated with the bridge construction, operation and unanticipated TSF-related discharges (downstream impact site).
- Ok Yep and its tributaries:
 - Monitoring Point 3: Upstream Ok Yep tributary southwest of Kungim (upstream reference site).
 - Monitoring Point 4: Downstream eastern branch of the Ok Yep to monitor potential water quality effects associated with runoff from the TSF embankment and permanent surface water diversions from the western Ok Yep catchment (downstream impact site).
- Ok Tedi:
 - Approximately 5 km downstream of the TSF discharge points to monitor associated water quality influence and dilution within the receiving environment (downstream impact site).
 - Immediately upstream of Ok Tedi's confluence with Ok Kaman at Komokpin to determine combined influence of TSF discharge and impacted Ok Yep flows (downstream impact site).

OTML's existing monitoring site upstream of Bige, approximately 35 km downstream of the TSF (as a downstream TSF impact site prior to Bige influences).

These locations are proposed as monitoring points for TSF-related discharges to confirm that water quality is within levels predicted above; triggers will determine the need for further investigation and/or intervention if levels exceed those predicted.

PNG ambient and drinking water criteria may not always provide adequate protection for aquatic ecosystems or human health based on current state of knowledge of toxicant exposure to biota and people. The ANZG (2018) ambient guideline values for 95% aquatic ecosystem protection and site-specific criteria will provide trigger values for further action (which may include further site-specific investigations and/or additional management measures), where background concentrations also exceed adopted guideline values. The 90th percentile background concentration is proposed to be adopted as the site-specific trigger value with surface water quality at selected downstream impact monitoring points expected to remain within 10% range of existing background levels. Further investigations will be triggered if this is not the case.

10.4.6 Watercourse residual impact and improvement zones

The project is predicted to result in both adverse and beneficial residual effects on the physical riverine environment. and summarise the magnitude and significance of residual impacts and improvements during the construction and operational phases.

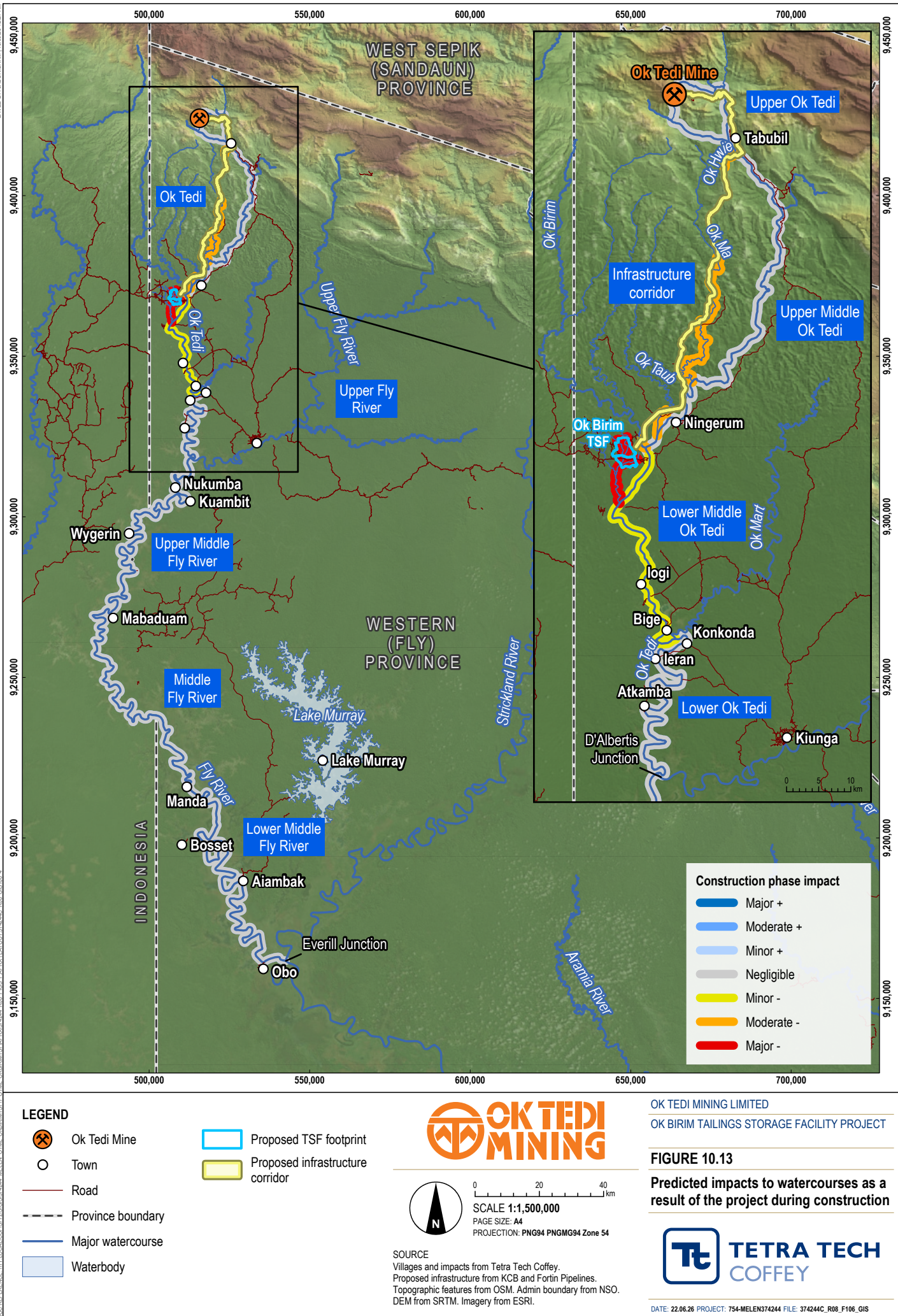
Based on these outcomes, Figure 10.13 and Figure 10.14 illustrate the predicted spatial extent and severity of residual watercourse impacts and beneficial improvements associated with the project during construction and operations. These represent the overall predicted changes relative to existing conditions following implementation of proposed management and mitigation measures. They are classified as negligible, minor, moderate or major severity impact or improvement, as defined in Table 10.29.

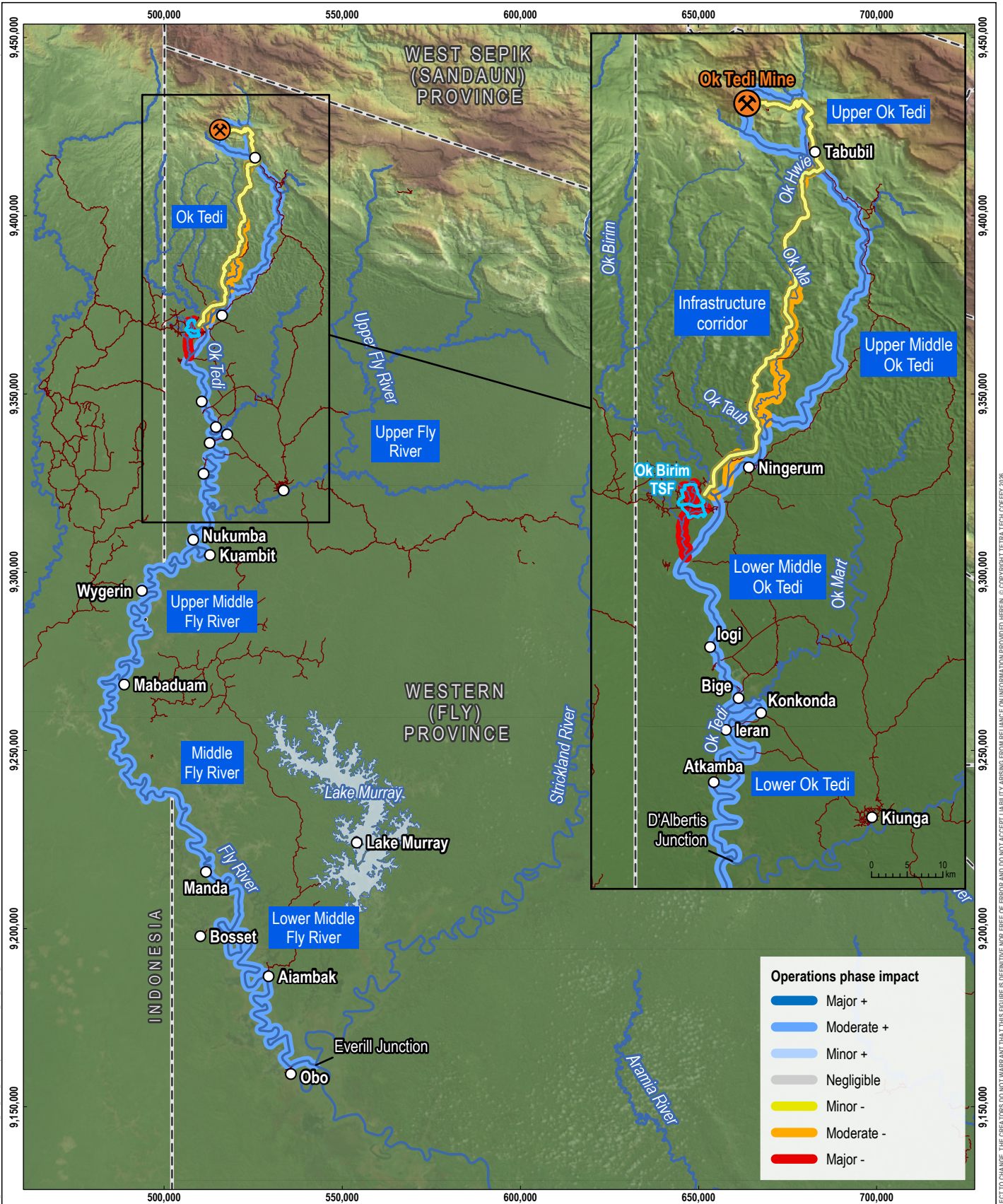
Figure 10.13 displays the predicted residual watercourse impact zones during construction (2027 to end of 2029). During this phase, the greatest residual adverse impacts are expected within the TSF development area and infrastructure corridor, primarily associated with permanent drainage modification, altered surface water connectivity, and increased erosion and sediment transport from land disturbance and infrastructure development. Negligible project-related impacts are predicted within the upstream and downstream project area.

Figure 10.14 displays the predicted residual watercourse impact and improvement zones during operations (2030 to 2050). During this phase, moderate to major adverse residual impacts are predicted within the TSF development area and moderate adverse impacts within the infrastructure corridor due to permanent drainage modification, altered surface water connectivity, ongoing localised erosion and sediment transport including from project affected water. However, this contrasts with the long-term beneficial improvements predicted with minor to major improvements expected in the upstream project area, Middle Ok Tedi and downstream project area due to substantial reductions in mine-derived sediment inputs resulting from diversion of tailings to the TSF. These improvements are expected to occur progressively over the long term, including post-closure, and include reduced sediment loading, slower riverbed aggradation and levee growth, lower floodplain sediment accumulation, improved riverine particulate geochemistry relative to existing conditions, and reduced turbidity and TSS levels in main river channels and associated floodplain/ORWBs beneficial to downstream aquatic ecosystems. While the magnitude of these predicted improvements is **high to very high**, their overall residual significance is limited by the **low** sensitivity of the receiving riverine environment, which remains degraded and heavily mine-affected.

Table 10.29 Significance definitions for residual watercourse impacts and improvements

Category	Impact definition	Improvement definition
Major	Characterised by widespread, severe and persistent deterioration in physical riverine aspects relative to existing conditions such as major increases in suspended sediment and sedimentation, reductions in surface water flows, and/or deterioration to surface water quality or channel morphology.	Characterised by widespread, major improvement in physical riverine aspects relative to existing conditions, such as significantly reduced suspended sediment and sedimentation, improved surface water quality for aquatic ecosystem protection, and/or improved channel and floodplain stability and function.
Moderate	Characterised by detectable but not severe deterioration in physical riverine aspects relative to existing conditions, such as moderate increases in turbidity, sedimentation, reduced surface water quality and/or flows.	Characterised by detectable but not large improvement in physical riverine aspects relative to existing conditions, such as moderate reductions in suspended sediment and turbidity, improved surface water quality, and/or in morphology condition.
Minor	Characterised by detectable but small adverse changes in physical riverine aspects relative to existing conditions, such as slightly elevated turbidity, localised sedimentation, small/localised declines in surface water quality and/or flows.	Characterised by slight improvements in physical riverine aspects relative to existing conditions, such as slightly reduced turbidity, sedimentation and/or other stressors affecting surface water quality.
Negligible	Characterised by physical and biological riverine aspects will remain consistent with existing conditions, with no detectable project-related adverse or beneficial changes.	





LEGEND

- Ok Tedi Mine
- Town
- Road
- Province boundary
- Major watercourse
- Waterbody
- Proposed TSF footprint
- Proposed infrastructure corridor



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SOURCE
Villages and impacts from Tetra Tech Coffey.
Proposed infrastructure from KCB and Fortin Pipelines.
Topographic features from OSM. Admin boundary from NSO.
DEM from SRTM. Imagery from ESRI.

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FIGURE 10.14

Predicted impacts and improvements to watercourses as a result of the project during operations



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10.5 AQUATIC BIODIVERSITY AND ECOLOGY

This section describes the potential impacts to aquatic biodiversity and ecology as a result of the project, and draws on information described in Chapter 8 and activities described in Chapter 6. This section primarily draws on the assessment provided in Appendix F and the results of Section 10.3 and Section 10.4.

10.5.1 Approach to impact assessment

The impact assessment method adopted for aquatic biodiversity and ecology generally aligns with the approach outlined in Section 10.1. This assessment involves the following steps to evaluate the project's impacts on identified aquatic biodiversity and ecology values:

- Define aquatic biodiversity and ecology values and evaluate their sensitivity to change.
- Identify project activities with the potential to impact aquatic biodiversity and ecology values.
- Develop management measures to avoid and/or reduce impacts to aquatic biodiversity and ecology values resulting from project activities.
- Predict the magnitude of the potential change to aquatic biodiversity and ecology values assuming successful implementation of management measures.
- Assess the residual impact significance based on the sensitivity of aquatic biodiversity and ecology values and magnitude of predicted impacts.

Potential impacts to aquatic biodiversity values may arise from a range of direct and indirect project-related sources that often interact and occur cumulatively. As impacts on aquatic biodiversity and ecology values are typically complex and interrelated, the assessment considered impacts holistically to determine the overall magnitude of impacts on aquatic ecology values. Direct impacts relate to physical habitat disturbance and fragmentation caused by project activities, while indirect impacts arise through secondary pathways.

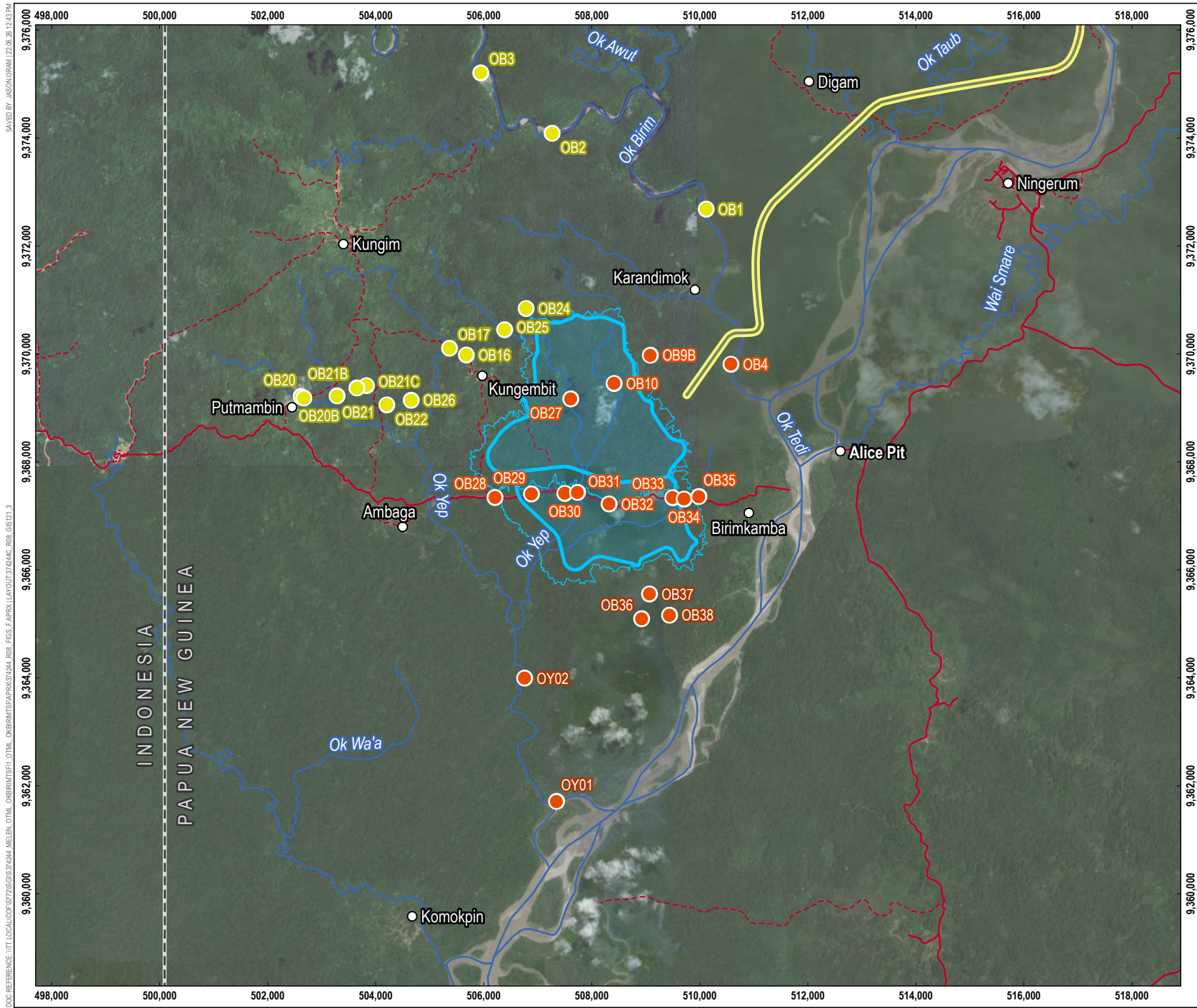
10.5.1.1 Identification of aquatic biodiversity and ecological values

Aquatic ecology values of that may be impacted by the project are:

- Aquatic ecosystem quality
- Aquatic fauna health.

Aquatic ecosystem health reflects the physical and chemical characteristics of watercourses, including water quality and sediment dynamics that sustain ecological function. The sites across the study area apart from the Ok Tedi are characterised by low-disturbed tributaries and a healthy ecosystem, comprising low natural sediment loads, stable channel conditions, and water chemistry within background values that support natural and biological processes. Figure 10.15 and Figure 10.16 show the reference sites and potentially exposed sites assessed in the aquatic ecology study (Appendix F) that informs this section.

Aquatic fauna health relates to the diversity, abundance, distribution, including the ability of aquatic fauna (e.g., fish, macroinvertebrates, crayfish) to persist under natural and disturbed conditions. The changes in ecosystem health can cause physiological stress to sensitive species, particularly the species of high conservation value and those having restricted distribution within the project development area. The aquatic fauna considered in this assessment include all aquatic fauna that are present, including restricted-range and threatened fish species, which are species listed as Critically Endangered, Endangered, and Vulnerable on the IUCN Red List; it also conservatively includes species listed as Near Threatened, Data Deficient and Least Concern on the IUCN Red List, as well as Protected under the *PNG Fauna (Protection and Control) Act 1966*.



LEGEND

- Community
- Road
- - - Track
- Watercourse
- - - International border
- Proposed TSF footprint
- ▭ Proposed infrastructure corridor

Aquatic survey site

- Potentially exposed
- Reference

SOURCE
Aquatic survey sites from SLR.
Villages from Tetra Tech Coffey.
Proposed layouts from KCB and OTML (indicative only).
Topographic features from OSM.
DEM from OTML (captured 2012). Imagery from ESRI.



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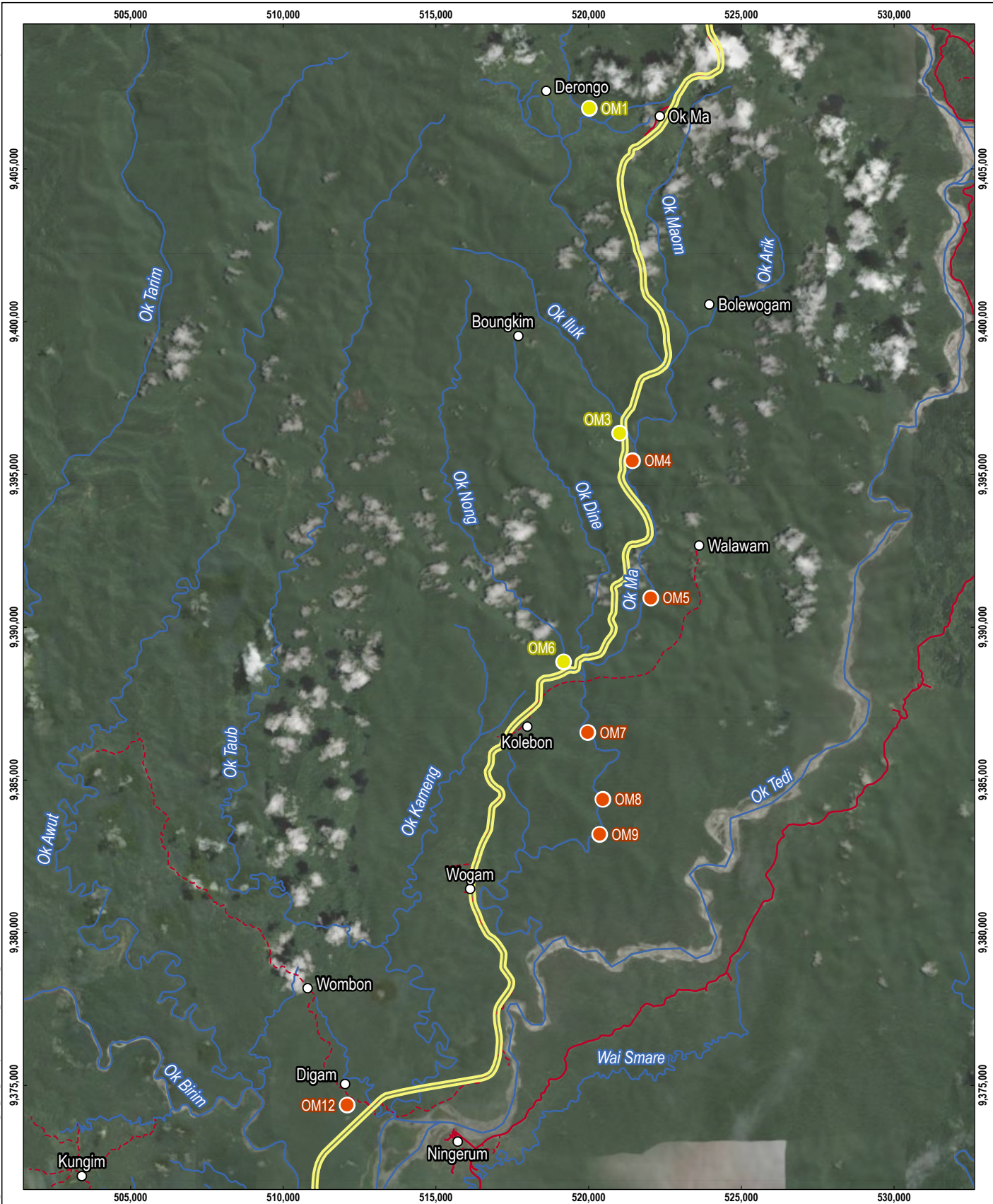
FIGURE 10.15

Aquatic ecology survey sites in the TSF development area: potentially exposed and reference sites



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LEGEND

- Community
- Road
- - - Track
- Watercourse

Proposed infrastructure corridor

Aquatic survey site

- Potentially exposed
- Reference



0 2.5 5 km
SCALE 1:175,000
PAGE SIZE: A4
PROJECTION: PNG94 PNGMG94 Zone 54

SOURCE
Aquatic survey sites from SLR. Villages from Tetra Tech Coffey.
Proposed layouts from KCB and OTML (indicative only).
Topographic features from OSM.
DEM from OTML (captured 2012). Imagery from ESRI.

OK TEDI MINING LIMITED

OK BIRIM TAILINGS STORAGE FACILITY PROJECT

FIGURE 10.16

Aquatic ecology survey sites along the infrastructure development corridor: potentially exposed and reference sites



TETRA TECH
COFFEY

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The sensitivity of these values varies spatially across the project area. Table 10.30 defines the sensitivity of each value and Table 10.31 presents the sensitivity rating for each value in key locations.

Table 10.30 Definition for the sensitivity of aquatic ecosystem health and aquatic fauna health

Sensitivity	Definition
Very high	<p>Critical habitat (IFC PS6) supporting Critically Endangered/Endangered species and restricted-range or endemic aquatic fauna</p> <p>Aquatic ecosystems with unique ecological function (e.g., refuge systems) essential for regional recolonisation and long-term ecosystem recovery</p> <p>Irreplaceable habitats (e.g., headwater tributaries) with negligible recovery potential if lost</p> <p>Aquatic ecosystems and fauna highly sensitive to disturbance due to specialised environmental conditions (e.g., low conductivity, stable physicochemical regimes, specific habitat dependencies)</p> <p>High dependence for ecosystem services (water supply, subsistence fisheries, cultural values) combined with high ecological value</p>
High	<p>Habitats supporting high aquatic biodiversity and fauna health, including threatened or locally restricted species, but with some redundancy across the landscape</p> <p>Systems functioning as important refugia or ecological corridors for aquatic fauna</p> <p>High sensitivity of ecosystem processes (water quality, sediment regime, hydrology) to disturbance</p> <p>Moderate recovery potential, but likely long-term impacts if significantly disturbed</p>
Medium	<p>Natural aquatic systems with moderate ecosystem and fauna health, supporting common native assemblages</p> <p>Some resilience to disturbance; however, impacts may result in measurable but not irreversible ecological change</p> <p>Recovery possible over time, although not immediate and dependent on disturbance intensity</p>
Low	<p>Modified or simplified aquatic systems with reduced ecosystem and fauna health</p> <p>Limited presence of sensitive or threatened species</p> <p>Relatively tolerant to disturbance, with recovery likely in the short to medium term</p>
Not sensitive	<p>Highly disturbed, artificial, or degraded environments with minimal aquatic ecosystem or fauna health value</p> <p>No known occurrence of sensitive species or important ecological functions</p> <p>High resilience to change, with negligible ecological consequence from further disturbance</p>

Table 10.31 Sensitivity of aquatic ecology values

Value/Location	Associated ecological characteristics	Sensitivity
Aquatic ecosystem health		
TSF development area		
Ok Yep and Ok Birim headwater and tributary creek system	<p>Supports restricted and threatened species. Relatively intact systems supporting native fauna that is sensitive to disturbance and changes to water quality</p> <p>Favourable condition for typical freshwater fauna persisting well in low conductivity environment, and highly sensitive to small physicochemical changes</p> <p>The Ok Yep downstream environment near the confluence with the Ok Tedi is already exposed to elevated sediment and metal concentrations from existing mining activities. Partial modification to habitat and reducing ecological health</p>	Very high
Infrastructure development corridor		
Ok Birim main channel	High fish diversity and key refuge system for regional recolonisation, and considered important ecological function. Major intact tributary of the Ok Tedi	High

Value/Location	Associated ecological characteristics	Sensitivity
Ok Ma main channel and tributaries	Supports diverse aquatic fauna including sensitive species and exposed to sediment and contamination risks. Relatively intact systems that support native fauna. Sensitive to disturbance and sediment inputs. Smaller tributaries may have naturally low buffering capacity and low conductivity, while larger tributaries may be alkaline with coarser substrates and greater hydraulic resilience	High
Downstream watercourses		
Lower Ok Tedi and Middle Fly River	Downstream system that has been substantially affected by historical riverine tailings disposal, resulting in elevated sediment loads, riverbed aggradation, increased turbidity and altered aquatic habitat conditions.	Moderate
Aquatic fauna health, including restricted-range and threatened fish species		
Ok Yep and Ok Birim headwater and tributary creek system	Supports several threatened and restricted-range fish species, including the Critically Endangered Paska's blue-eye (<i>Pseudomugil paskai</i>), Endangered Fly River rainbowfish (<i>Melanotaenia sexlineata</i>), Endangered Swamp Gudgeon (<i>Oxyeleotris stagnicola</i>) and the restricted-range Kiunga blue-eye (<i>Kiunga leucozona</i>). These species have high vulnerability to habitat loss and water quality change.	Very high
Ok Birim main channel	Supports high fish diversity and functions as an important refuge for species that have declined elsewhere in the Ok Tedi system.	High
Ok Ma main channel and tributaries	Supports the Critically Endangered Ok Tedi rainbowfish (<i>Melanotaenia oktediensis</i>) and the Near Threatened Robert's goby (<i>Glossogobius robertsi</i>).	High
Lower Ok Tedi and Middle Fly River	Supports limited fish assemblages that are under stress from existing mine impacts along the Ok Tedi system. These fish have limited capacity to recover from further stresses.	High

10.5.2 Potential impacts

The development of the project will have impacts extending into watercourses across the TSF development area, infrastructure corridor, and downstream. Impacts have the potential to occur across the construction, operation, and decommissioning/closure phases.

This section describes the potential impacts of the project on identified aquatic biodiversity and ecological values. The potential impacts identified include:

- Permanent loss of aquatic fauna habitat
- Direct mortality/displacement of aquatic fauna
- Reduced ecosystem health due to reduced surface water quality
- Reduced ecosystem health due to increased TSS and sedimentation
- Reduced aquatic ecosystem connectivity due to disruption of hydrological connectivity and flow regime
- Reduced aquatic fauna health due to reduced surface water quality and increased TSS concentrations and sedimentation.

In addition to potential negative impacts, there is the potential for beneficial improvement to aquatic ecosystems downstream of the Ok Tedi Mine in the long-term due to the use of the TSF instead of ongoing riverine tailings discharge.

Table 10.32 presents a summary of potential impacts and associated stressors on identified aquatic biodiversity and ecological values resulting from project activities across the different phases. Key impacts are further discussed in subsequent subsections.

Table 10.32 Potential impacts to aquatic biodiversity and ecological values according to project phases

Potential impact	Key source/project activity	Phase*			Comment/rationale
		C	O	D	
Permanent loss of aquatic fauna habitat	Vegetation clearing, TSF footprint development, creek diversion	X	X	X	Clearing of spring-fed creeks and small watercourses results in irreversible loss of habitat and critical biodiversity values.
Direct mortality/displacement of aquatic fauna	Vegetation clearing, in-stream works, sediment impacts	X			Disturbance and habitat removal at construction can directly kill or displace aquatic fauna, including restricted species.
Reduced ecosystem condition and fauna health due to reduced surface water quality	Accidental spills or leaks of hydrocarbons or hazardous materials from fuel storage, machinery operation, transport activities	X	X	X	Risk of spills during all phases may lead to contamination and toxicity impacts on aquatic habitats.
	Contaminated runoff from new roads	X	X		Potentially contaminated contact water generated from areas of disturbance, such as roads, laydown areas, stockpiles and other infrastructure areas, may enter surface water systems.
	TSF seepage or discharge		X	X	Elevated dissolved metals (Cu, Zn, Pb, Cd, As) and electrical conductivity may exceed toxicity thresholds affecting aquatic life. This alteration may be permanent.
Reduced ecosystem condition and fauna health due to increased TSS and sedimentation	Increased TSS and sedimentation due to land clearing, earthworks, road and pipeline construction	X	X	X	Increased sediment loads lead to turbidity, streambed aggradation and smothering of benthic habitat. Changes in water quality and habitat condition reduce ecological conditions and affect sensitive species.
Reduced aquatic ecosystem connectivity due to disruption of hydrological connectivity and flow regime	Earthworks, drainage modification, TSF embankment construction	X	X	X	Alteration of natural flow regimes and connectivity affects aquatic ecosystem processes and species movement.

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.5.2.1 Permanent loss of aquatic fauna habitat

The construction of the TSF may result in the loss of spring-fed creeks and headwaters of the Ok Yep. The TSF footprint includes critical habitat encompassing restricted species including *Pseudomugil paskai*, *Melanotaenia oktediensis*, and *Kiunga leucozona*.

10.5.2.2 Direct mortality/displacement of aquatic fauna

In addition to the loss of aquatic habitats within the TSF footprint, construction of the TSF may result in direct mortality or displacement of aquatic fauna within the TSF footprint. Species such as *Melanotaenia sexlineata* and *Pseudomugil paskai* are known to exist within the project footprint. Fauna that is not lost may be displaced due to construction activities, migrating into nearby tributaries over the short to medium term.

10.5.2.3 Reduced ecosystem condition and fauna health due to reduced surface water quality

Accidental spills from hydrocarbons or hazardous materials

While not predicted, there is credible potential for accidental spills of hydrocarbons or other hazardous materials during the construction phase, with risks potentially extending into the operational and closure phases of the project. The spills may arise from sources including fuel storage facilities and machinery operations if not appropriately managed.

The likelihood of accidental spills is considered low; however, the consequences could be significant should an event occur. Depending on the volume and extent of the spill, hydrocarbon releases could result in water quality deterioration, toxicity to aquatic biota, habitat degradation, and long-term ecological impacts, particularly in sensitive and low-conductivity tributary systems.

TSF seepage and discharge

Operation of the TSF has the potential to affect aquatic ecosystem condition and aquatic fauna health through seepage to groundwater systems and subsequent discharge to connected surface water environments. Groundwater and water quality modelling indicates that seepage from the TSF may contain elevated concentrations of dissolved salts, sulfate and metals derived from stored tailings and decant water. These constituents may migrate through shallow groundwater systems and discharge to nearby drainage lines, streams and seepage areas surrounding the TSF footprint.

Elevated concentrations of dissolved metals and increased salinity have the potential to affect aquatic fauna through direct toxicity, physiological stress and reduced suitability of aquatic habitats. Low-conductivity stream systems and small tributaries surrounding the TSF are considered particularly sensitive because aquatic communities are adapted to naturally low ionic concentrations and stable physicochemical conditions. Relatively small changes in water chemistry may therefore affect sensitive fish and aquatic invertebrate species.

Seepage-related changes to water quality may also alter aquatic ecosystem processes through changes in primary productivity, nutrient cycling and community composition. Prolonged exposure to elevated dissolved metals and sulfate concentrations may result in shifts in aquatic assemblages, with sensitive species being replaced by more tolerant taxa. Restricted-range and threatened fish species associated with small tributary systems and spring-fed habitats may be particularly vulnerable where seepage influences receiving waters. Elevated suspended sediment concentrations, dissolved metals or changes to water chemistry may reduce aquatic habitat quality and affect aquatic fauna health in receiving waters.

Contaminated runoff

The potential use of mineralised road-base materials derived from the Ok Tedi system may also contribute to the mobilisation of metals at stream crossings. In addition, low pH conditions in certain tributaries (e.g., Ok Ma) may further enhance metal solubility and toxicity. Prolonged exposure to elevated metal concentrations and associated toxicity may degrade water quality and result in chronic stress on aquatic organisms, potentially affecting the survival, growth, and recovery of fish and other sensitive species over the long term.

10.5.2.4 Reduced ecosystem condition and fauna health due to increased TSS and sedimentation

Construction activities associated with the TSF, access roads, river crossings and infrastructure corridor may result in increased TSS concentrations and mobilise fine sediments into receiving waterways. Sediment runoff from vegetation clearing, earthworks, excavation and construction activities may be transported downstream, contributing to increased turbidity, channel aggradation and deposition of fine sediments within stream channels and aquatic habitats.

Elevated TSS and sedimentation have the potential to degrade aquatic ecosystem condition by altering physical habitat structure and ecological processes. Increased sediment deposition may result in bed aggradation, the infilling of bed substrates, smother benthic habitats, reduce habitat availability for macroinvertebrates and spawning fish, and decrease the suitability of refuge habitats for sensitive aquatic fauna.

10.5.2.5 Reduced aquatic ecosystem connectivity due to disruption of hydrological connectivity and flow regime

The TSF and associated infrastructure have the potential to alter hydrological connectivity within portions of the project area, particularly in small headwater tributaries and spring-fed creek systems located within the TSF footprint. These watercourses currently maintain natural hydrological flow regimes and ecological connectivity and may be disturbed during construction through river diversion, channel modification, temporary isolation of stream reaches, and installation of crossings.

Disruption of hydrological connectivity may affect fish passage, access to dry-season refuge habitats, and movement between intermittent and perennial stream systems, particularly within smaller tributaries. Reduced connectivity may therefore affect the ability of aquatic fauna to move between habitats, access refuge areas during periods of environmental stress, and recolonise disturbed habitats following natural or human-induced disturbance.

Changes to flow regimes may also alter the frequency, duration and extent of hydraulic connectivity between tributaries and main channels, potentially affecting spawning, feeding and recruitment processes for some aquatic species. Smaller tributaries and low-conductivity stream systems are likely to be particularly sensitive to these changes due to their dependence on relatively stable hydrological conditions and connectivity with adjacent aquatic habitats.

10.5.2.6 Improvements

Diversion of tailings from direct riverine discharge to the TSF may result in substantial long-term benefits to aquatic ecosystems within the Ok Tedi and Fly River system. The project will reduce tailings-derived sediment inputs to the river system, resulting in lower suspended sediment concentrations, reduced sand and silt loading, and decreased riverbed aggradation within the Lower Ok Tedi and Middle Fly River. These changes may improve channel stability, water clarity and aquatic habitat quality, reducing physical disturbance of benthic habitats and improving conditions for fish and macroinvertebrate communities.

10.5.3 Avoidance, management and mitigation measures

OTML has sought to minimise impacts on the Ok Birim catchment, by locating the TSF entirely within the Ok Yep catchment, as the Ok Birim catchment is currently not impacted by mining activities. Table 10.33 lists specific aquatic biodiversity measures proposed to be implemented by OTML to manage potential impacts during construction, operation and decommissioning and closure phases of the project. Learnings from rehabilitation at Bige will also be applied, where possible.

Table 10.33 Proposed aquatic biodiversity management measures

No.	Key measures	Phase*		
		C	O	D
Permanent loss of aquatic fauna habitat				
MM065	Optimise project layout and construction footprint to minimise vegetation clearing, and minimise disturbance to significant aquatic habitats, including sensitive creek lines	X	X	
MM066	Manage construction activities, including storage and stockpiling, within the defined development footprint to minimise the spatial extent and intensity of vegetation clearing	X		
MM067	Protect adjacent catchments as refugia by limiting the number of catchments impacted by the project.	X	X	X
MM068	Support recovery of aquatic habitats through protection of refugia and appropriate management of impacted areas	X	X	X
MM069	Minimise impacts to critical habitat in accordance with IFC PS6	X	X	X
Direct mortality, displacement or disturbance of aquatic fauna				
MM070	Restrict disturbance footprint/duration	X	X	
MM071	Pre-clearance fauna salvage and relocation where feasible and/or minimise impacts to IUCN-listed species/habitats	X		
MM072	Maintain refuge habitats at nearby tributaries not impacted by project activities	X	X	X
MM073	Maintain records of all contacts with or injuries to fauna including nature and severity of injury.	X	X	X
MM074	Shield external lights and direct lights onto work areas, wherever practicable to reduce light directed toward fauna habitat	X	X	X
Disruption to hydrological connectivity and flow regime				
MM075	Maintain flow regimes and downstream connectivity along the infrastructure development corridor to support aquatic ecosystem function and/or design crossings to maintain fish passage	X	X	X
MM076	Restore watercourses (e.g., creeks, drainage lines, channels) that are disturbed during construction back to their original or stable functional condition where the impact is limited to the construction phase (i.e., not impacted during operations)	X		X
MM077	Conduct inspection to confirm aquatic connectivity of disturbed watercourses; remove barriers to flow regimes including fauna movement where required.	X	X	X
MM078	Design bridges and road culverts to allow for high flow events following heavy rainfall, and to mimic natural flow characteristics where possible.	X	X	
MM079	Design and construct mine infrastructure to minimise deviation of natural surface water flow paths.	X		
Accidental spills and leaks				
MM022	Manage incidents throughout all stages of the project in accordance with OTML's incident reporting standard, including recording details on the location, extent and nature of spills or site contamination. This will be used to monitor existing contamination and will be reassessed at closure to determine appropriate decontamination and remediation actions.	X	X	X
MM023	Conduct routine inspections and maintenance of all potential sources of contamination, including fuel and chemical storage facilities, heavy machinery, transport fleet, diesel generators, bund, and pipes, completed during all stage of the project for early detection and control of leaks and spills.	X	X	X
MM080	Implement an automated alarm and warning system to alert the control rooms if there is a leak or abnormal conditions in the tailings pipeline pumping system. Immediately shut down the pipeline pumping system should this occur.		X	

No.	Key measures	Phase*		
		C	O	D
MM024	Store, handle and transport hazardous substances in accordance with the PNG Environmental Code of Practice for Vehicle/Machinery Workshops and Petroleum Storage/Resale/Usage Sites, and Australian Standards AS1940:2017 relevant to bunding.	X	X	
TSS and sedimentation downstream				
MM004	Adopt the following principles to manage erosion and sediment transport for construction of benches and batters: <ul style="list-style-type: none"> Construct embankment slopes in a manner that facilitates controlled runoff and promotes drainage based on experience at Ok Tedi Grade benches to shed water and reduce the risk of erosion or batter slumping. Retain vegetation at crest of cut batters and at toe of fill batters where practicable to minimise erosion. Establish vegetation (e.g., shrubs/grasses/legumes) as soon as possible on benches. Consider using hydroseeding or direct planting where suitable. Install dykes and swales at top of batters (where practicable) and divert runoff to slope drains and into stabilised areas. Stabilise batters, such as by using brush layers or geotextile/fibrous matting, where required. Construct slope drainage such as cut-off trenches or horizontal drains at crest of batters/slopes, and install adequate drainage at the toe to maintain slope stability. 	X	X	
MM006	Install and maintain sediment control measures where required such as drainage diversion into surrounding vegetation, rip-rap aprons, sediment control ponds and sediment fences.	X	X	
MM007	Clear accumulated material from behind sediment fences and barriers, cut-off drains and diversion drains associated with temporary erosion control berms. Dispose of sediment into the TSF	X	X	
MM008	Install sedimentation ponds downstream of key project infrastructure prior to construction to capture sediment-laden water and reduce sedimentation downstream	X	X	
MM009	Clear accumulated material from sediment ponds where required (to maintain minimum capacity required to allow sediment ponds to function properly and limit the potential for a large rain event to result in significant release of coarse sediment downstream). Dispose of sediment into the TSF	X	X	
MM053	Preserve riparian vegetation to the greatest extent practicable, avoid disturbance of terrain alongside watercourses and create a buffer of natural vegetation between watercourses and project areas where practicable. Trim, rather than remove riparian trees where practicable.	X	X	X
MM081	Minimise the creation and extent of new access corridors in undisturbed catchments.	X	X	
Waste management				
MM031	Prohibit disposal of domestic and industrial waste into streams or sinkholes.	X	X	X
MM083	Develop and implement a Weed, Pest and Quarantine Management Plan (to include pest and weed quarantine procedures (including for inbound foreign freight, and imported bulk materials), a weeds management plan procedure to limit the introduction of invasive weed species, periodic habitat monitoring to detect new alien incursions, and protocols for reporting sightings of serious infestations) to protect the biodiversity of the site.	X	X	X
MM084	Wash down vehicles, plant and equipment before arrival at site.	X	X	
MM085	Induct contractors and employees in the identification of invasive exotic species.	X	X	X
MM086	Where appropriate, establish permanent chemical wash down point(s) to prevent weeds and pathogens being transported to work sites.	X	X	X

No.	Key measures	Phase*		
		C	O	D
Permanent alteration to water quality (metals)				
MM087	Implement effective TSF seepage and sediment management.	X	X	X
MM088	Implement continued removal and subaqueous storage of PCon at Bige to minimise acid and metal generation risks.	X	X	X
MM089	Conduct routine inspection and monitoring of dissolved metals in water and aquatic biota and implement adaptive management to address exceedances to maintain conditions that minimise metal mobilisation and ecological risk.	X	X	X

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.5.4 Residual impact assessment

This section describes the predicted residual impacts of the project on aquatic biodiversity and ecology values following successful implementation of the proposed management measures in Section 10.5.3. It also considers the outputs of the physical riverine environment impact assessment in Section 10.4. Ecosystem and aquatic fauna health are highly sensitive to system changes. The discussion of residual impacts is focussed on ecosystems in key locations, and restricted range and threatened fish species. Impacts on other species will generally be driven by the impacts on ecosystems.

10.5.4.1 Construction

Residual impacts arising from construction of the project are discussed in this section.

Ok Yep and Ok Birim headwater and tributary creek system

Construction of the TSF within the Ok Yep headwaters will result in the direct removal of spring-fed creeklines, small watercourses and associated aquatic habitats. These creeklines support high-value and restricted-distribution aquatic species, and their removal constitutes an irreversible local impact. The affected habitats occur within the Ok Yep sub-catchment, which is identified as critical habitat based on species of conservation concern recorded within the TSF development area.

Construction of the TSF will degrade ecosystem condition and fauna health in the Ok Yep and associated tributaries through degraded surface water quality. Increased TSS and sedimentation will also contribute to degradation of the Ok Yep and associated tributary creeklines. Surface water runoff from disturbed areas will transport elevated sediment loads into adjacent creeklines and drainage channels, resulting in elevated TSS, streambed aggradation, and smothering of benthic habitats. These impacts are expected to degrade water quality and disrupt ecological functioning, with the greatest sediment load effects occurring during construction. Reduced habitat quality for sensitive aquatic biota will occur through deposition of fine sediment across creek substrates and associated loss of benthic habitat condition.

Impacts are also expected to arise from disruption of hydrological connectivity and changes to the local flow regime. Aquatic fauna in the smaller creeklines and springs have limited connectivity, and that fauna within the two larger tributaries of the Ok Yep (e.g., at sample sites OB27 and OB10 on Figure 10.15) would likely become isolated in the upper reaches where the TSF cuts off connectivity. Upstream reaches may dry out due to changes in hydrology within the catchment, and that bypass channels, although redirecting flow back to the Ok Yep, are unlikely to be habitable by native fauna sensitive to the predicted water-quality changes. Aquatic ecosystems in the Ok Yep and associated tributaries will therefore be impacted by fragmentation of the headwater and tributary creek system, reduced refuge access, and a loss of ecological connectivity across the affected creek network.

Overall, residual impacts on the Ok Yep and associated tributary creeklines will be concentrated in the spring-fed headwaters, smaller creeklines and tributary habitats within the TSF footprint and immediate receiving environment. These impacts arise from the combined effects of direct habitat removal, sediment mobilisation, water quality degradation and altered hydrology.

The Ok Yep backwater deposition zone at the junction with the Ok Tedi is expected to experience impacts due to increased sediment input and reduced water quality from the erosion and water quality impacts upstream. Increased sediment from the Ok Yep is unlikely to be detectable in Ok Tedi. Site OY01, located upstream of the confluence of the Ok Yep with the Ok Tedi (see Figure 10.15), already shows localised increased sediment concentrations likely due to the backwater effect of sediments being deposited during high flow events within the Ok Tedi. This indicates that the lower Ok Yep backwater environment is already susceptible to and impacted by sediment accumulation and altered substrate condition. While additional sediment delivery and elevated TSS from disturbed areas are expected to increase deposition within this zone, with potential for further bed aggradation, reduction in habitat quality, and smothering of benthic substrates, the aquatic ecosystems present are already degraded.

These impacts will occur downstream of the TSF within the Ok Yep and extend into Ok Yep backwater deposition area. The implementation of erosion and sediment controls, protection of refuge habitats, and measures to maintain hydrological function where practicable will reduce downstream sediment inputs and limit the spatial extent of habitat degradation beyond the immediate TSF area. Sediment control measures, progressive stabilisation of disturbed areas, and management of runoff from construction activities are expected to reduce sediment delivery to downstream environments, limiting the extent of additional degradation within the already disturbed backwater deposition zone.

Considering the **very high** sensitivity of the Ok Yep headwaters and associated tributaries and **very high** magnitude of impact in the TSF footprint and **high** magnitude adjacent to the TSF footprint, the residual significance on aquatic ecosystems in these systems due to project construction is **major** within the TSF footprint and adjacent areas.

Ok Birim main channel

Construction of the infrastructure corridor will cause localised short-term degradation of ecosystem condition and fauna health in the Ok Birim main channel through localised contamination pathways associated with crossings, runoff and accidental releases, particularly at the Ok Birim watercourse crossing. The Ok Birim main channel is an important refuge system, so even localised deterioration in water quality has the potential to affect refuge function and the condition of aquatic fauna, particularly where contaminants or disturbed runoff reach the channel at or near the bridge crossing. The project is not expected to materially reduce connectivity between the major refuge systems of the Ok Birim and Ok Tedi. The TSF has been deliberately located outside the Ok Birim catchment to avoid direct impacts to this system, and infrastructure crossings of the Ok Birim are intended to maintain natural flow processes and fish passage. Consequently, any connectivity impacts are expected to be localised and associated primarily with temporary construction disturbance rather than permanent barriers to aquatic fauna movement.

Increased TSS and sedimentation may also produce residual impacts in the Ok Birim main channel in the vicinity of bridge construction. Vegetation clearing, earthworks and crossing construction will increase sediment mobilisation, with elevated TSS and sediment runoff able to degrade aquatic habitat, fill interstices and reduce the quality of benthic substrate. In the Ok Birim main channel, this is most relevant to local refuge habitat and spawning areas, where even short-term sediment deposition may reduce habitat suitability for sensitive fauna and reduce the quality of the channel as a refuge and recolonisation resource. The effect of this will reduce over time and be barely detectable during operations. The upper parts of the Ok Birim catchment are naturally affected by landslides and slope failures associated with steep terrain and high rainfall. These events result in sediment entering the Ok Birim, causing short-term increases in TSS and turbidity. As a result, aquatic habitats in the Ok Birim are already exposed to occasional natural sediment

fluxes. Localised sediment inputs associated with construction activities will occur within this existing natural disturbance regime.

The use of erosion and sediment controls, appropriately designed watercourse crossings, and management of construction runoff and contaminants will reduce the duration and extent of water quality and habitat disturbance, confining impacts largely to areas immediately adjacent to crossing locations. With effect implementation of management measures, impacts will be short-term, with localised impacts associated with sediment mobilisation as a result of vegetation clearing and earthworks associated with access roads, bridge construction and pipeline installation.

Considering the **high** sensitivity of the Ok Birim main channel and **very low** magnitude of impact, the residual significance on aquatic ecosystems in this area due to project construction is **low**.

Ok Ma main channel and tributaries

The Ok Ma main channel and tributaries are expected to experience impacts from reduced surface water quality due to runoff, contaminants and disturbance along the infrastructure corridor. Because this system has high ecological integrity and supports aquatic fauna adapted to very clear waters, even relatively small changes in water quality are likely to reduce ecosystem condition and fauna health across the main channel and tributary network. The project is not expected to materially reduce connectivity between the Ok Ma and the Ok Tedi. Infrastructure crossings in the Ok Ma catchment will be designed to maintain natural flow processes and fish passage. Similar to the Ok Birim, any connectivity impacts are expected to be localised and associated primarily with temporary construction disturbance rather than permanent barriers to aquatic fauna movement.

Increased TSS and sedimentation are expected to affect the Ok Ma main channel and tributaries through runoff from disturbed areas, resulting in bed aggradation, sediment deposition and infilling of substrate interstices that provide important benthic habitat and fish spawning areas. These effects are of particular concern in the Ok Ma catchment, which functions as a high-integrity aquatic refuge supporting species sensitive to water-quality change, including species of conservation significance. Sedimentation will reduce habitat quality and diminish the refuge value of tributaries immediately downstream of construction activities through increased turbidity, altered streambed conditions and reduced habitat complexity. Like the Ok Birim, the upper Ok Ma catchment is characterised by steeper terrain and high rainfall and is naturally subject to landslides and slope failures. These events can introduce sediment into streams and cause temporary increases in TSS and turbidity. Consequently, aquatic habitats in the Ok Ma are naturally exposed to periodic sediment fluxes, although the catchment remains a high-quality refuge system that is sensitive to sustained increases in sedimentation and water quality change.

Construction activities will reduce aquatic ecosystem connectivity where watercourse crossings and altered drainage patterns disrupt natural movement pathways between tributaries and the main channel. In a system that provides refuge habitat and supports species with restricted distributions, reduced connectivity may limit movement between habitats, restrict access to refuge and breeding areas, and adversely affect the persistence of sensitive aquatic fauna populations. Appendix F notes that the extent of impacts depends on factors such as crossing design, construction methods, erosion and sediment controls, and construction material sourcing, with the vulnerability of the system resulting in potentially high consequences even under conservative disturbance scenarios. Application of erosion and sediment management measures, retention of riparian vegetation where practicable, and crossing designs that maintain natural flow processes and aquatic connectivity will reduce sediment-related impacts and help maintain the ecological function of the catchment. Assuming effective implementation of management measures, impacts are expected to be relatively localised. Impacts associated with runoff from the road are **low** magnitude, while impacts associated with increased TSS from clearance and ground disturbance is **moderate** magnitude.

Considering the **high** sensitivity of the Ok Ma and tributaries and **low to moderate** magnitude of impact, the residual significance on aquatic ecosystems in this area due to project construction is **moderate to high**.

Summary of residual impacts – construction

Table 10.34 presents the residual impact assessment on aquatic ecosystems and fauna during construction.

Table 10.34 Residual impact assessment – construction

Value/location	Impacts	Sensitivity	Magnitude	Significance
Ok Yep and associated tributaries (directly within the TSF footprint)	Permanent loss of spring-fed creeks and small tributaries within TSF footprint.	Very high	Very high	Major
Ok Yep and Ok Birim headwater and tributary creek system (adjacent to the TSF footprint)	Loss of aquatic habitat and aquatic fauna communities. Increased sediment mobilisation from clearing and earthworks. Elevated TSS and turbidity. Streambed aggradation and smothering of benthic habitat. Altered hydrology and potential drying/isolation of upstream habitats. Loss of connectivity between tributaries and downstream systems.	Very high	High	Major
Ok Birim main channel	Localised sediment runoff from road, bridge and pipeline crossing construction. Temporary increases in turbidity and suspended solids. Potential nutrient and hydrocarbon contamination from construction activities.	High	Very low	Low
Ok Ma main channel and tributaries	Extensive sediment runoff from corridor clearing, road construction and earthworks. Elevated TSS, turbidity and sediment deposition. Increased EC and nutrient runoff. Potential mobilisation of metals if road-base material sourced from Ok Tedi sediments. Degradation of tributary habitats and spawning/interstitial habitats. High risk to aquatic refuge habitats.	High	Low to Moderate	Moderate to High
Lower Ok Tedi and Middle Fly River	Not predicted	Moderate	N/A	N/A

10.5.4.2 Operations

Residual impacts arising from operation of the project are discussed in this section.

Ok Yep and Ok Birim headwater and tributary creek system

There will be no planned TSF surface discharges into the Ok Yep or its tributaries, with TSF surface discharge via spillways in the southeastern corners of cells 1 and 2 essentially reporting directly to the Ok Tedi. Operation of the TSF will, however, degrade ecosystem condition and fauna health in the Ok Yep and associated headwater and tributary creek systems through ongoing seepage-related changes to surface water quality.

In the context of the Ok Yep catchment, which is characterised by extremely low conductivity waters and aquatic communities adapted to highly dilute conditions, elevated TDS and sulfate have the potential to cause osmotic stress and alter the suitability of habitat for sensitive species. Continued sedimentation and elevated TSS associated with TSF embankment runoff and diversion channels and potentially sulfate and TDS associated with TSF embankment runoff, are also expected to contribute to long-term degradation of aquatic habitat quality within the receiving creek system.

The combined effects of aggradation, elevated TSS, habitat smothering and degraded water quality will reduce habitat suitability for sensitive aquatic fauna and contribute to ongoing ecological stress in downstream reaches. Prior to the application of management measures, impacts are considered high due to the persistence and duration of the predicted changes. With implementation of seepage controls, sediment management measures and water quality management systems, impacts are expected to be reduced, although some long-term alteration of habitat and ecological condition is still anticipated.

In addition to water quality changes, persistent sediment delivery is expected to continue during operations, although at much lower levels than during the construction phase. Ongoing sediment deposition may reduce habitat quality through infilling of stream substrates and continued alteration of natural channel conditions. Collectively, these changes may result in the permanent loss or severe reduction of sensitive aquatic fauna populations downstream of the TSF, particularly species adapted to clear, low-conductivity headwater environments. Appendix E indicates that impacts are potentially very high prior to the application of management measures due to the sensitivity of the receiving environment and the magnitude and duration of the predicted changes. Seepage management systems, water quality monitoring, adaptive management, and ongoing sediment control are expected to reduce the magnitude and extent of water quality changes, although some long-term alteration of aquatic habitat conditions is still predicted within affected receiving waters. With implementation of management measures, impacts are expected to be reduced to moderate, reflecting a persistent but managed decline in ecosystem condition and fauna health within the affected portions of the Ok Yep and associated tributary systems.

The Ok Yep backwater deposition area is expected to experience ongoing changes to sediment and water quality conditions during operation of the TSF. Sediment delivered from TSF embankment runoff, seepage pathways and diversion channels is predicted to result in continued deposition and localised streambed aggradation within low-energy reaches of the system. Elevated TSS may contribute to habitat smothering, reducing the availability and quality of benthic habitats and altering channel substrate characteristics. In addition to sediment-related impacts, seepage from the TSF is predicted to increase concentrations of dissolved metals, sulfate and TDS relative to existing conditions. Water quality modelling indicates that some parameters exceed aquatic ecosystem protection guideline values, resulting in adverse conditions for aquatic fauna adapted to the naturally dilute waters of the Ok Yep catchment.

Considering the very **high** sensitivity of the Ok Yep and Ok Birim headwater and tributary creek system and **high** magnitude of impact, the residual significance on aquatic ecosystems in this area due to project operation is **major**.

Ok Birim main channel

The TSF has been specifically configured to avoid direct interaction with the Ok Birim, and no direct discharge from the TSF to the Ok Birim catchment is proposed. Consequently, operational impacts to the Ok Birim main channel are limited primarily to those associated with the infrastructure crossings. Potential effects include minor increases in sediment runoff from road crossings and associated infrastructure, resulting in small increases in TSS during rainfall events. Impacts are expected to be confined to areas immediately downstream of the infrastructure crossing and are not predicted to affect the broader Ok Birim catchment.

The Ok Birim is recognised as an important aquatic refuge system supporting species that have declined elsewhere in the Ok Tedi catchment, making protection of its water quality and habitat values a key project

consideration. Appendix F notes impacts will be high to major prior to the application of management measures. Drainage controls, road maintenance, sediment management measures and infrastructure designs that minimise disturbance to natural flow paths are expected to limit operational impacts to localised areas surrounding infrastructure crossings. With the application of management measures impacts are expected to be localised, short-term and low magnitude. As a result, residual effects on water quality, sediment regimes and aquatic habitat within the Ok Birim main channel are predicted to be limited to the immediate vicinity of infrastructure crossings.

Considering the **high** sensitivity of the Ok Birim main channel and **low** magnitude of impact, the residual significance on aquatic ecosystems in this area due to project operation is **moderate**.

Ok Ma main channel and tributaries

Operation of the access road and associated infrastructure within the infrastructure development corridor has the potential to affect water quality and aquatic habitat values through increased runoff from unsealed road surfaces and watercourse crossings. Surface runoff from compacted road surfaces and disturbed areas may result in elevated TSS and increased sediment delivery to tributaries and the Ok Ma main channel. Over time, this may reduce water clarity and contribute to the gradual degradation of streambed habitats through sediment deposition, particularly in smaller tributaries with limited dilution capacity.

Appendix F states that in the absence of effective erosion and sediment controls, impacts associated with increased TSS and sediment runoff could be high. With implementation of management measures, impacts are predicted to be localised and low magnitude, reflecting the limited spatial extent of sediment-related effects and the capacity for water quality and habitat conditions to be maintained through appropriate design, erosion control, drainage management and rehabilitation measures. Continued implementation of erosion and sediment controls, rehabilitation of disturbed areas, and maintenance of watercourse crossings will minimise sediment delivery to waterways and reduce ongoing pressure on aquatic habitats and refuge areas.

Appendix F states impacts on aquatic fauna in the Ok Ma infrastructure corridor watercourses will be high magnitude; however, this rating considers the effects of a major pipeline rupture. Pipeline ruptures are addressed in Chapter 13 as this chapter deals with unplanned events such as this.

Considering the **high** sensitivity of the Ok Ma and tributaries and **low** magnitude of impact, the residual significance on aquatic ecosystems in this area due to project operation is **moderate**.

Lower Ok Tedi and Middle Fly River

Diverting tailings from direct riverine discharge to land-based storage is expected to deliver a system-wide positive outcome for the Ok Tedi and Fly River systems. Largely eliminating riverine tailings disposal and implementing the TSF will significantly reduce tailings-derived sediment inputs, resulting in reduced sand and silt loading, lower bed aggradation in the Lower Ok Tedi and Middle Fly, improved channel stability, improved water clarity, and reduced smothering and physical disturbance of benthic habitats. These changes are expected to improve habitat conditions for fish and macroinvertebrates and support the long-term recovery of the river system. Considering the **positive** magnitude of impact on the Lower Ok Tedi and Middle Fly River, the significance of impacts in these systems is **positive**.

Summary of residual impacts - operations

Table 10.35 presents the residual impact assessment on aquatic ecosystems and fauna during operations

Table 10.35 Residual impact assessment – operations

Location/value	Impacts	Sensitivity	Magnitude	Significance
Ok Yep and Ok Birim headwater and tributary creek system	Ongoing seepage-related water quality changes. Elevated dissolved copper and zinc concentrations predicted in receiving waters. Elevated sulfate and TDS relative to baseline conditions. Osmotic stress to fauna adapted to extremely low-conductivity waters. Continued sedimentation and elevated TSS from TSF embankment runoff and diversion channels. Long-term degradation of aquatic habitat quality. Permanent loss or severe reduction of sensitive aquatic fauna populations downstream of the TSF.	Very high	High	Major
Ok Birim main channel	No direct discharge from the TSF to the Ok Birim catchment. Minor increases in sediment runoff from road crossings and associated infrastructure. Potential minor increases in TSS during rainfall events. Impacts predicted to be localised.	High	Low	Moderate
Ok Ma main channel and tributaries	Increased runoff from unsealed access roads and watercourse crossings. Elevated TSS and sediment delivery to tributaries and the Ok Ma channel. Reduced water clarity and gradual degradation of streambed habitats. Ongoing pressure on aquatic refuge habitats through sedimentation and water quality change.	High	Low*	Moderate
Lower Ok Tedi and Middle Fly River	Approximately 85–95% reduction in tailings-derived sediment inputs. Reduced sand and silt loading. Reduced bed aggradation in Lower Ok Tedi and Middle Fly. Improved channel stability. Reduced TSS and turbidity. Improved water clarity and aquatic habitat quality. Reduced particulate copper transport. Improved geochemical stability. Enhanced recovery of fish populations and aquatic productivity. Long-term ecological improvement of the Ok Tedi–Fly River system.	Moderate	Positive	Positive

* Appendix F states impacts on aquatic fauna in the Ok Ma infrastructure corridor watercourses will be high magnitude; however, this rating considers the effects of a major pipeline rupture. Pipeline ruptures are addressed in Chapter 13 and unplanned events such as this do not influence the significance of a residual impact.

10.5.4.3 Aquatic fauna health

The impacts on aquatic ecosystems are expected to affect restricted-range and threatened fish species. The Ok Yep, Ok Birim and Ok Ma catchments qualify as critical habitat under IFC PS6. Other restricted or potentially restricted species occur at exposed and reference sites along the corridor. The Ok Birim also supports fish species of conservation concern, including species that use the main channel as a refuge from impacts in the Ok Tedi and are sensitive to changes in water quality and sedimentation. Protection of refuge

habitats, minimisation of disturbance to critical aquatic environments, maintenance of aquatic connectivity where practicable, fauna salvage and relocation where feasible, and ongoing water quality management and monitoring will reduce pressures on sensitive species, although significant residual impacts remain where habitat loss and long-term changes to water quality cannot be fully avoided.

Species such as Kiunga blue-eye, Paska's blue eye, and the restricted Fly River rainbowfish are highly sensitive to elevated TSS and siltation, while operational water-quality changes may exceed levels known to be acutely toxic to resident biota. Direct habitat loss, sediment smothering, degraded water quality and reduced connectivity will reduce the availability of refuge, feeding and breeding habitat, fragment local populations, and increase mortality or displacement risk for species with narrow habitat tolerances and restricted distributions. Construction and operation of the TSF will result in local population decline and loss of ecological function for restricted-range and threatened fish species within the affected creek environments.

The greatest impacts on restricted-range and threatened fish species are associated with construction and operation of the TSF and its effects on the Ok Yep catchment and associated tributary creek systems. Construction of the TSF will result in the permanent loss of spring-fed creeks, seepage zones and small tributaries that support several species of conservation concern, while sediment mobilisation will increase TSS and sediment deposition within downstream habitats. During operations, ongoing seepage-related water quality changes are predicted to elevate dissolved copper, zinc, sulfate and TDS above baseline conditions, with concentrations potentially exceeding levels known to adversely affect aquatic fauna. Species most at risk include the restricted-range Kiunga blue-eye, for which the assessment estimates that approximately 40% of known occurrences may be lost because of habitat removal and downstream water quality impacts. The Endangered Fly River rainbowfish is also vulnerable due to its association with shallow, low-conductivity spring-fed habitats, with approximately 17% of known occurrences within the Ok Yep sub-catchment potentially affected. The Critically Endangered Paska's blue-eye, which occupies highly specialised seep and spring habitats, may also be affected where suitable habitat occurs within the TSF footprint or downstream impact area. The Endangered swamp gudgeon may experience habitat loss and degradation within affected tributaries.

Considering the very high sensitivity of these species and the very high magnitude of impacts due to permanent loss of habitat, the residual significance of TSF-related impacts on aquatic fauna in the Ok Yep and Ok Birim headwater and tributary creek system is major during construction. Considering the very high sensitivity of these species and the very high magnitude of impacts due to water-quality change within portions of the Ok Yep adjacent to the TSF, the residual significance of impacts on aquatic fauna in Ok Yep and Ok Birim headwater and tributary creek system is **major** during operations.

Impacts associated with the infrastructure development corridor are concentrated within the Ok Ma catchment and arise primarily from vegetation clearing, earthworks, watercourse crossings, increased sediment runoff and associated changes to water quality and habitat condition. These impacts may affect species dependent on the Ok Ma as a refuge system, including the Critically Endangered Ok Tedi rainbowfish and the Near Threatened Robert's goby. Elevated TSS, sediment deposition, bed aggradation and reduced habitat quality may affect feeding, breeding and refuge habitats, while localised reductions in aquatic connectivity at watercourse crossings may further constrain movement between tributaries and the main channel. Impacts on aquatic fauna along the Ok Birim are more limited than along the Ok Ma, generally restricted to near watercourse crossings.

The Ok Birim and Ok Ma catchments are naturally dynamic systems that experience periodic increases in TSS and sediment transport associated with landslides, slope failures and high rainfall events in their upper catchments. Consequently, aquatic ecosystems and the fauna within are naturally exposed to natural sediment fluxes and habitat disturbance. Project-related sediment inputs will occur within this existing natural disturbance regime and are expected to be concentrated around watercourse crossings and disturbed areas rather than occurring across the broader catchments. Impacts on restricted-range and threatened fish species are generally related to the potential for localised degradation of refuge habitats, spawning areas and aquatic

connectivity in tributaries immediately downstream of infrastructure works, rather than short-term exposure to elevated sediment loads.

More broadly, both the Ok Birim and Ok Ma function as regionally important refugia for species that have declined in the Ok Tedi and Middle Fly and are expected to play an important role in future recolonisation of the Ok Tedi system following mine closure. Degradation of habitat quality within these refuge systems has implications beyond individual species and may reduce the resilience and recovery potential of fish communities at a broader catchment scale.

Considering the **high** sensitivity of aquatic fauna in the Ok Birim main channel and the **low** magnitude of impact, the residual significance on aquatic fauna in the Ok Birim main channel is **moderate** during construction and operations. Appendix F states impacts on aquatic fauna in the Ok Birim main channel will be **high** magnitude when considering the effects of a major pipeline rupture and **very low** magnitude considering minor pipeline ruptures.

Considering the **high** sensitivity of aquatic fauna in the Ok Ma main channel and tributaries and the **moderate** (construction) to **high** (operation) magnitude of impacts, the residual significance on aquatic fauna in the Ok Ma main channel and tributaries is **moderate**. Appendix F states impacts on aquatic fauna in the Ok Ma main channel and tributaries watercourses will be **high** magnitude; however, this rating considers the effects of a major pipeline rupture. Pipeline ruptures are addressed in Chapter 13. This chapter assumes the magnitude of impact will be lower when excluding a **major** pipeline rupture.

The **positive** impacts on aquatic ecosystem condition in the Lower Ok Tedi and Middle Fly River from largely eliminating riverine tailings disposal will have consequent benefits on aquatic fauna within these rivers. Considering the positive magnitude of impact on aquatic fauna within the Lower Ok Tedi and Middle Fly River, the significance of impacts on aquatic fauna in these systems is **positive**.

Table 10.36 presents the residual impact assessment on restricted-range and threatened fish species.

Table 10.36 Residual impact assessment – restricted-range and threatened fish species

Species	Sensitivity	Magnitude	Significance
Construction			
Ok Yep and Ok Birim headwater and tributary creek system	Very high	Very high	Major
Ok Birim main channel	High	Low	Moderate
Ok Ma main channel and tributaries	High	Moderate	High
Operations			
Ok Yep and Ok Birim headwater and tributary creek system	Very high	High	Major
Ok Birim main channel**	High	Very low	Low
Ok Ma main channel and tributaries*	High	High	High
Lower Ok Tedi and Middle Fly River	High	Positive	Positive

*Appendix F states impacts on aquatic fauna in the Ok Ma main channel and tributaries watercourses will be high magnitude; however, this rating considers the effects of a major pipeline rupture. Pipeline ruptures are addressed in Chapter 13. This chapter assumes the magnitude of impact will be lower when excluding a major pipeline rupture.

**Appendix F states impacts on aquatic fauna in the Ok Birim main channel will be high magnitude when considering the effects of a major pipeline rupture and very low magnitude considering minor pipeline ruptures

10.6 TERRESTRIAL BIODIVERSITY AND ECOLOGY

This section describes the potential impacts to terrestrial biodiversity and ecology as a result of the project, and draws on information described in Chapter 8 and activities described in Chapter 6. This section is based on the assessment by Francis Crome provided in Appendix G.

10.6.1 Approach to impact assessment

- The impact assessment method adopted for terrestrial biodiversity and ecology generally aligns with the approach outlined in Section 10.1. This assessment involves the following steps to evaluate the project's impacts on identified terrestrial biodiversity and ecology values:
- Define terrestrial biodiversity and ecology values and evaluate their sensitivity to change.
- Identify project activities with the potential to impact terrestrial biodiversity and ecology values.
- Identify management measures to avoid and/or reduce impacts to terrestrial biodiversity and ecology values resulting from project activities.
- Predict the magnitude of the potential change to terrestrial biodiversity and ecology values assuming successful implementation of management measures.
- Assess the residual impact significance based on the sensitivity of terrestrial biodiversity and ecology values and magnitude of predicted impacts. This varies slightly from the approach outlined in Section 10.1 to also include positive impacts (Table 10.37). Positive residual outcomes were assigned where long-term ecological recovery and habitat improvement are predicted to outweigh localised direct disturbance.

Table 10.37 Significance matrix

Magnitude of impact	Sensitivity of value				
	Not sensitive	Low	Medium	High	Very high
Very high	Moderate	High	Major	Major	Major
High	Low	Moderate	High	Major	Major
Moderate	Low	Low	Moderate	High	High
Low	Low	Low	Low	Moderate	Moderate
Very low	Very low	Low	Low	Low	Moderate
Positive	Positive	Positive	Positive	Positive	Positive

Potential impacts to terrestrial biodiversity values may arise from a range of direct and indirect project-related sources that often interact and occur cumulatively. As impacts on terrestrial biodiversity and ecology values are typically complex and interrelated, the assessment considered impacts holistically to determine the overall magnitude of impacts on flora, fauna and habitats.

Direct impacts relate to physical habitat disturbance and fragmentation caused by project activities, while indirect impacts arise through secondary pathways such as increased access or hunting pressure. Indirect impacts were assessed separately but considered additive to direct impacts, recognising that they are unlikely to occur independently.

10.6.1.1 Identification of terrestrial biodiversity and ecological values

Terrestrial biodiversity and ecological values that may be impacted by the project are habitats, species and key biodiversity areas (KBAs). Table 10.38 defines the sensitivity levels of each value and Table 10.39 presents the sensitivity rating for each value.

Table 10.38 Criteria for sensitivity of receptor

Sensitivity	Contributing factor	Definition
Very high	Formal status, value or importance to society and community	An IUCN Critically Endangered or Endangered Species. A critical asset, internationally and nationally recognised site or value. Iconic or symbolic importance to national cultural value systems.
	Vulnerability	Known local endemic or very rare with distribution restricted to the project area. Extent of occurrence (if known) <500 km ² . Habitat specialist and/or highly vulnerable to hunting or ecology unknown.
High	Formal status, value or importance to society and community	An IUCN Vulnerable Species. A species new to science. A nationally recognised site. Iconic or symbolic importance to the broader area's cultural value systems (e.g., Ok Tedi and Fly River systems).
	Vulnerability	Abundance and distribution of site or value limited to the broader area (e.g., Ok Tedi and Fly River systems). Extent of occurrence (if known) <10,000 km ² . Limited capacity to adapt to change.
Medium	Formal status, value or importance to society and community	An IUCN Near threatened species and/or classified as Protected under the PNG Fauna Act. A species with an extent of occurrence <50,000 km ² . A regionally or provincially recognised site or value.
	Vulnerability	A species with an extent of occurrence <50,000 km ² . Abundance and distribution of site or value limited to region or province. Some capacity to change.
Low	Formal status, value or importance to society and community	An IUCN Data Deficient species. Some local value or recognition.
	Vulnerability	Widespread site or value with some representative examples found. Some resilience to change.
Not sensitive	Formal status, value or importance to society and community	Limited to no local value or recognition.
	Vulnerability	Abundant, widespread, numerous representative examples present. Easily adaptable to change.

Table 10.39 Sensitivity ratings

Value		Sensitivity	Justification†
Habitat	Low altitude forest on uplands	Medium	High conservation value supporting biodiversity and ecosystem function but is common throughout PNG, with natural regeneration capacity.
	Caves	High	Provide habitat for cave-dependent fauna including bats and swiftlets. Vulnerable to disturbance.

Value			Sensitivity	Justification†
	Streams and riparian vegetation		Medium	Dynamic and able to recover from some change.
Species	IUCN Endangered tree species	<i>Calophyllum collinum</i> (Collin's calophyllum)*	Very high	EN
		<i>Cryptocarya albifrons</i>	Very high	EN
		<i>Cryptocarya brevipes</i>	Very high	EN
		<i>Cryptocarya fluminensis</i>	Very high	EN
		<i>Cryptocarya sulcata</i>	Very high	EN
		<i>Endiandra engleriana</i>	Very high	EN
		<i>Timonius argenteus</i>	Very high	EN
		<i>Palaquium morobense</i>	Very high	EN
	Flagship mammals	<i>Zaglossus bartoni</i> (eastern long-beaked echidna)	High	VU and P
		<i>Dendrolagus spadix</i> (lowlands tree-kangaroo)*	High	VU and P
		<i>Dendrolagus stellarum</i> (Seri's tree kangaroo)*	High	VU and P
		<i>Aproteles bulmerae</i> (Bulmer's fruit bat)*	Very high	CR and P
	Hunted species	<i>Echymipera orio</i> (orio echymipera)*	Medium	NE
		<i>Echymipera echinista</i> (Menzies' echymipera)*	Low	DD
		<i>Dorcopsis luctuosa</i> (gray forest wallaby)	High	VU
		<i>Dorcopsulus vanheurni</i> (small dorcopsis)	Medium	NT
		<i>Goura sclaterii</i> (Sclater's crowned pigeon)	Medium	NT
		<i>Harpyopsis novaeguineae</i> (Papuan eagle)	High	VU and P
		<i>Probosciger aterrimus</i> (palm cockatoo)	Medium	NT and P
		<i>Psitttrichas fulgidus</i> (Pesquet's parrot)	High	VU and P
		<i>Cicinnurus regius</i> (king bird-of-paradise)	Medium	LC and P
		<i>Paradisaea raggiana</i> (raggiana bird-of-paradise)	Medium	LC and P
		<i>Paradisaea apoda</i> (greater bird-of-paradise)*	Medium	LC and P
	Upland species	<i>Dasyurus albopunctatus</i> (New Guinea quoll)	Medium	NT
		<i>Kallistobatrachus majikthise</i>	Medium	LC
		<i>Teinobasis cuneata</i>	Medium	DD
		<i>Teinobasis flavolineata</i>	Medium	DD
		<i>Idiocnemis schorri</i>	Medium	DD
		<i>Nososticta oculata</i>	Medium	DD
	Species new to science	<i>Choerophryne</i> sp. 1 cf. <i>gracilirostris</i>	High	NE
		<i>Hylophorbus</i> sp. 1 (fast call)	High	NE
		<i>Teinobasis</i> sp. 1 (long, slender)	High	NE
		<i>Teinobasis</i> sp. 2 (yellow)	High	NE
		<i>Idiocnemis</i> sp. 1	High	NE
		<i>Nososticta</i> sp. 1	High	NE
		<i>Palaiargia</i> sp. 1	High	NE
		<i>Papuargia</i> sp. 1	High	NE
		<i>Begonia</i> sp. 1	High	NE

Value			Sensitivity	Justification†
KBAs		<i>Begonia</i> sp. 2	High	NE
		<i>Calophyllum</i> sp. 1 (kalo)	High	NE
		<i>Garcinia</i> sp. 1 (kandis)	High	NE
		<i>Dillenia</i> sp. 1	High	NE
		<i>Aglaia</i> sp. 1	High	NE
		<i>Dysoxylum</i> sp. 1	High	NE
		<i>Glochidion</i> sp. 1	High	NE
	Turtles	<i>Pelochelys bibroni</i> (Southern New Guinea giant softshell turtle)	High	VU
		<i>Carettochelys insculpta</i> (pig-nosed turtle)*	High	EN
		<i>Chelodina parkeri</i>	Medium	NT
		<i>Chelodina reimanni</i>	Medium	NT
	Other species		Not assessed	
	Star Mountains KBA	Not assessed (see Section 10.6.4)		

* Possible

† IUCN Listings: CR – Critically Endangered, E – Endangered, VU – Vulnerable, NT Near Threatened, DD – Data Deficient, LC – Least Concern, NE – Not Evaluated. PNG Fauna (Protection and Control) Act 1966: P – Protected

10.6.2 Potential impacts

This section describes potential direct and indirect impacts that may affect terrestrial biodiversity and ecology values as a result of project activities.

10.6.2.1 Summary of potential impacts according to project phases

Table 10.41 presents a summary of potential impacts and associated stressors on identified terrestrial biodiversity and ecological values resulting from project activities across the different phases. Key impacts are further discussed in subsequent subsections.

Table 10.40 Potential impacts to terrestrial biodiversity and ecological values according to project phases

Potential impact/stressor	Key source/project activity	Phase*			Comment/rationale
		C	O	D	
Loss and fragmentation of terrestrial habitat	Vegetation clearing for TSF, infrastructure corridor, access roads, laydown areas and ancillary infrastructure	X	X	X	Vegetation clearing will result in direct loss and fragmentation of habitat for flora and fauna, reducing habitat availability, foraging resources and ecological connectivity.
Edge and barrier effects	Clearing of vegetation along infrastructure corridor and around TSF	X	X	X	Forest edges created by clearing may alter microclimatic conditions and increase susceptibility to invasive species, desiccation and windthrow. Cleared corridors may also restrict movement of some fauna species and fragment habitat.

Potential impact/stressor	Key source/project activity	Phase*			Comment/rationale
		C	O	D	
Disturbance and damage to caves and cave fauna	Blasting, quarrying, increased access and disturbance near cave systems	X	X		Disturbance near cave systems may impact bat and swiftlet colonies through vibration, noise, physical damage and increased human access or hunting.
Damage to riverine and aquatic habitats	Removal of riparian vegetation, earthworks, watercourse crossings and sediment runoff	X	X	X	Disturbance to waterways and riparian areas may degrade aquatic and riverine habitats through vegetation loss, sedimentation and altered hydrology.
Erosion, sedimentation and altered hydrology	Earthworks, sidelaying, spoil disposal and disturbance of steep terrain	X	X	X	Erosion and sediment runoff may smother vegetation and aquatic habitats, alter local drainage patterns and degrade stream microhabitats through sediment deposition.
Contamination of terrestrial and aquatic habitats	Spills, leaks and release of fuels, hydrocarbons, chemicals, sewage and other wastes	X	X	X	Release of contaminants may affect biodiversity through direct toxicity and reduced survivability of flora and fauna, particularly sensitive amphibians and aquatic species.
Fauna interaction with the TSF	Open water, presence of tailings and ponded areas within the TSF		X	X	Fauna may interact with open water and wet tailings areas within the TSF, potentially resulting in localised mortality if animals become trapped or bogged.
Disturbance and mortality of fauna from human activity	Traffic, lighting, noise, dust, fumes, hunting, construction activities	X	X	X	Project activities may disturb fauna, reduce habitat use near active areas and result in fauna injury or mortality through vehicle strike, infrastructure collision or direct human interference.
Fauna entrapment in open trenches	Pipeline trenching and excavation activities	X			Open trenches may temporarily trap fauna moving through the construction corridor, potentially resulting in injury or mortality.

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.6.2.2 Direct impacts

Direct sources of impact from the physical disturbance, removal or modification of habitat by project activities include vegetation clearing, earthworks and construction of project infrastructure. These impacts may also result from the ongoing presence of infrastructure and associated changes to habitat availability and connectivity, such as barriers to fauna movement.

Clearing and forest loss

Vegetation clearing associated with the project will result in direct loss of habitat for flora and fauna, reducing local populations of plants and resident fauna and decreasing foraging habitat for species such as bats and frugivorous birds. Fauna displaced from cleared areas may have limited ability to successfully relocate into surrounding forest due to competition with existing territory holders and resource limitations, which may reduce survivability for some species.

Edge and barrier effects

Edge effects may occur where vegetation clearing exposes the forest edge to increased wind, heat, light and drying. This can cause degradation of the forest edge, which may cause it to recede, increase susceptibility to invasive species, and increase susceptibility to desiccation, fire and windthrow.

Barrier effects may occur where cleared corridors create open areas that fragment habitat and restrict movement of some fauna species, including forest interior and canopy-dependent fauna such as arboreal mammals and frogs. Infrastructure that follows existing roads or tracks reduces the extent of new fragmentation, and some species such as insectivorous bats and birds may benefit from the increased habitat diversity associated with linear clearings.

Damage and disturbance to caves

Caves may provide habitat for bat and swiftlet colonies. They may be impacted by disturbance from nearby project-related activities, including blasting, quarrying, physical damage and increased human access or hunting. Frequent disturbance to cave roosts and breeding colonies can result in mortality or abandonment of caves, particularly during breeding periods when young bats are unable to fly. The Lukwi caves, located approximately 1.3 km west of the infrastructure corridor, support known bat colonies.

Damage to riverine habitats

Riverine habitats may be damaged through removal of riparian vegetation and soil disturbance, as well as sedimentation from upstream disturbance and erosion. Frog and odonate species are found in riverine habitats and may be susceptible to these impacts.

Erosion, movement of spoil and changes to hydrology

Erosion, sidecasting and spoil disposal during construction of the infrastructure corridor may impact biodiversity through direct smothering of vegetation and habitats, particularly in steep terrain. Sediment runoff may also enter nearby streams and waterways, altering local hydrology and degrading aquatic habitats through increased sedimentation (see Section 10.4 and Section 10.5). Fine sediments can smother stream microhabitats by filling pools and interstitial spaces, with consequent impacts on riparian vegetation and amphibians.

Contamination of waterways and riverine forest from waste streams and materials handling

There is a potential for the release of waste and chemicals, including liquid hydrocarbons and other hazardous materials to occur throughout the life of the project. These substances may impact biodiversity through direct toxicity, reduced reproductive success and decreased survivability of flora and fauna. Sensitive amphibians and odonate species are particularly susceptible to contamination impacts. Wildlife may also be exposed through direct contact with or ingestion of contaminated materials.

Fauna interactions with the TSF

Fauna may be impacted if they interact with the TSF through exposure to tailings or becoming trapped within wet tailings or ponded water areas. Potentially affected fauna includes forest mammals and birds, as well as waterbirds attracted to open water within the facility. As the stored tailings have pyrite removed and cyanide is not used in ore processing, tailings are not expected to be toxic. Localised mortality of individuals may occur if they become bogged within the TSF.

Other human disturbance of fauna

Project activities may disturb fauna through direct human interference, including increased traffic, noise, lighting, dust, fumes and general construction activity. Disturbance may temporarily displace fauna from areas adjacent to construction sites, although many species are expected to return once activities cease, provided they are not subject to ongoing hunting or harassment. Traffic and infrastructure also present a risk of fauna injury or mortality through vehicle strike and collisions with powerlines.

Noise may particularly affect birds and bats, with elevated noise levels potentially reducing habitat use in areas close to active project activities. Dust generated from traffic and construction activities during extended dry periods may represent a minor nuisance to most fauna species.

Loss of fauna in the pipe trench

During pipeline construction, sections of open trench may create a temporary hazard to fauna, with animals potentially falling into excavated areas and becoming trapped or unable to escape. This may result in injury or mortality for fauna moving through the construction corridor.

10.6.2.3 Indirect impacts

Indirect impacts arise as a consequence of project activities but occur with some separation in time or space from the original activity. These impacts are typically linked through secondary cause-and-effect pathways. For example, increased access and in-migration associated with the project may lead to increased hunting pressure on wildlife populations.

Hunting and collecting of fauna and flora.

Hunting is a traditional activity in the project area, and the project may indirectly increase hunting pressure through increased access, workforce presence and in-migration. This may contribute to declines in wildlife populations, particularly larger mammals, birds and species that congregate in large numbers such as flying foxes.

Accidental introduction of exotic weeds, pests and diseases

The introduction and/or spread of invasive species has the potential to impact terrestrial biodiversity and ecology values through predation, competition, habitat degradation and disruption of ecological processes. Invasive species such as feral cats, invasive ants, rodents and weeds may adversely affect native fauna and ecosystems, with some species capable of causing significant ecological degradation once established.

While the project area is currently in relatively good ecological condition with few known invasive species, project logistics and road development may facilitate the introduction and spread of pests, weeds and diseases into previously undisturbed areas. While proposed roads provide pathways for the movement of people, vehicles, equipment and materials into previously isolated areas, existing access routes from Indonesia already provide potential pathways for invasive species to enter the Ok Yep catchment. In addition, construction of the infrastructure corridor access road may facilitate the spread of invasive species into previously intact and relatively undisturbed forest areas within the Ok Ma and Ok Taub catchments.

Accidental wildfires

Forest fires may occur as a result of deliberate burning, or accidental escapes of domestic or industrial fires, cooking fires, or fires set to burn rubbish or cleared vegetation. Although fire is relatively uncommon in wet tropical forests, prolonged dry conditions can increase fire risk, even in high-rainfall environments.

Uncontrolled fires have the potential to damage forest habitats, alter vegetation structure and ecological processes, and contribute to long-term degradation of biodiversity values.

Impacts from increased access to the area

Project-induced in-migration and increased access associated with the project may contribute to increased pressure on forest resources and biodiversity through greater hunting, resource extraction and vegetation clearing. While the TSF development area is already accessible, the project will improve access between Tabubil and the TSF development area and increase access to previously undisturbed forest areas traversed by the infrastructure corridor, particularly within the intact forest areas between Ok Ma and Kolebon. Increased population pressure and easier access to remote areas, including the Lukwi caves, may increase disturbance to sensitive habitats and fauna.

Reduction in wetlands in the floodplain

Reduced overbank flooding and improved drainage within the floodplain may result in a reduction of wetland habitats and associated waterbird habitat in some areas. These changes are expected to partially reflect restoration of more natural floodplain conditions, as presence of aquatic and swamp vegetation in some areas are a function of mining impacts. Areas of mining-induced historical dieback and altered hydrology have re-established as aquatic and swamp vegetation (wetland habitat) within parts of the floodplain.

Reduced dieback

The project is expected to significantly reduce sediment discharge into the Ok Tedi and Fly River systems, improving floodplain drainage and reducing vegetation stress. These changes are likely to support the gradual recovery of areas affected by mining-induced dieback and help stabilise regrowth of degraded forests. Over time, this is expected to enhance habitat condition and support the re-establishment and succession of biodiversity within the floodplain

10.6.3 Avoidance, management and mitigation measures

Table 10.42 lists specific terrestrial biodiversity measures proposed to be implemented by OTML to manage potential impacts during construction, operation and decommissioning and closure phases of the project.

Table 10.41 Proposed terrestrial biodiversity management measures

Measure ID	Management Measure	Phase*		
		C	O	D
Fauna injury or disturbance				
MM074	Shield external lights and direct lights onto work areas, wherever practicable to reduce light directed toward fauna habitat	X	X	X
MM090	Conduct a pre-clearance survey of infrastructure, including quarries, to determine presence of caves with bat colonies. Where colonies are located within 100 m of infrastructure, establish procedures to reduce disturbance, where practicable.	X	X	X
MM091	Implement cave management protocols for worker and contractor inductions, to prohibit unnecessary disturbance of bat colonies by project workers.	X	X	X
MM092	Limit or control where practicable, blasting within 150 m of known colonies of cave bats.	X	X	
MM093	Do not locate borrow/gravel pit areas within 150 m of caves with known bat species.	X		

Measure ID	Management Measure	Phase*		
		C	O	D
MM094	Prohibit hunting of wildlife and/or transport of wildlife or wildlife products by project workers, contractors or visitors who are not landowners. For employees who are also landowners, prohibitions should apply while working or staying on site in a work-related capacity.	X	X	X
MM095	Implement appropriate site inductions and training to educate staff regarding hunting and collecting regulations.	X	X	X
MM096	Prohibit project staff and contractors, including landowners, from possessing firearms and/or bows and arrows while engaged in project activities.	X	X	X
MM097	Implement speed limits via posted speed limit signs on project unsealed roads and tracks.	X	X	X
MM098	Develop a fauna rescue system in a Biodiversity Action Plan	X		
Vegetation clearance and management				
MM052	Conduct pre-construction surveys of areas proposed to be disturbed to identify sensitive species, including: <ul style="list-style-type: none"> • <i>Eurya ryojana</i> • <i>Cyrtostachys bakeri</i> • <i>Cryptocarya dipterocarpifolia</i> Avoid disturbing these species, as far as practicable. Where the species cannot be avoided, identify and implement site-specific management measures to minimise impacts and update management plans accordingly.	X		
MM053	Preserve riparian vegetation to the greatest extent practicable, avoid disturbance of terrain alongside watercourses and create a buffer of natural vegetation between watercourses and project areas where practicable. Trim, rather than remove riparian trees where practicable.	X	X	X
MM099	Stabilise cleared banks of streams with local materials, such as vegetation and rocks, to provide a suitable habitat for recolonisation	X		
MM056	Mark the extent of vegetation to be cleared on all technical drawings and clearly mark approved clearing limits in the field prior to works. Do not clear beyond design limits.	X	X	
MM055	Minimise vegetation clearance and ground disturbance as far as practicable, including locating project infrastructure, including vehicle parks, laydown areas, storage sites, fuel storage, non-mining waste dumps in cleared areas, in secondary and/or degraded forest areas.	X	X	
MM100	Where practicable and safe to do so, leave very large trees (>130 cm diameter at breast height (dbh)), fig trees (>100cm dbh) and other roosting sites for fauna at sites for temporary facilities such as vehicle parks, laydown areas, storage sites and bulk fuel storage areas.	X	X	
MM101	As far as practicable, locate borrow/gravel pits and quarries in cleared areas, secondary and/or degraded forest, and use suitable competent rock that is excavated at construction sites to limit the need for quarries.	X	X	
MM102	Prohibit project workers/contractors engaged in project activities from lighting and using fire except for specific work requirements controlled under a 'Hot Works' permit procedure and in designated smoking areas.	X	X	X
MM103	Avoid burning cleared vegetation, wherever practicable. Cleared vegetation should be left to rot rather than be burnt.	X	X	X
Reducing edge and barrier effects				
MM104	Allow forest edges to naturally regenerate or create conditions to facilitate natural regeneration.	X	X	
MM105	If safe and practicable, fell trees into planned footprints or into natural spaces in the surrounding habitat.	X	X	
MM106	Prevent machinery from injuring or scarring trees on the work site edges	X	X	

Measure ID	Management Measure	Phase*		
		C	O	D
MM107	Where feasible in the infrastructure corridor keep clearing to less than the designed 50 m.	X		
Disturbance to caves				
MM108	Prohibit limestone quarrying in the Lukwi cave area.	X	X	X
MM109	Prohibit entry of worker and contractors into caves.	X	X	X
Reducing degradation of streams and riparian vegetation				
MM110	Conduct fine-scale routing of access ways to place crossings in disturbed riparian vegetation as far as practicable and keep road alignment approaches to watercourses as close to right angles as practicable to limit disturbances to the banks of watercourses.	X	X	X
MM111	Place suitable erosion control devices between tracks, haul roads and streams.	X	X	X
MM013	Where practicable, locate valley-bottom access alignments to retain a buffer of natural vegetation between access ways and watercourses	X	X	X
MM112	Implement good industry-practice management of in-stream activities to limit the downstream extent of turbid water created by fords, trenching or bridge building as far as practicable.	X	X	
MM113	Maintain buffer zones between permanent surface water and project infrastructure to protect waters and riparian vegetation, except to carry out works associated with the construction of watercourse crossing or where facilities must be located within that buffer.	X	X	
MM114	Stabilise spoil stockpiles and areas of ground disturbance as soon as practicable after initial disturbance	X		
MM115	Prohibit the washing, servicing or refuelling of equipment, vehicles or machinery near or within watercourses.	X	X	
MM116	Wherever practicable, do not fell vegetation into waterways	X	X	X
MM117	Where watercourse crossings are to be revegetated use local species wherever practicable.	X	X	X
MM118	Reduce sediment loading by reducing side casting above watercourses.	X	X	X
Reduction of hunting and disturbance to fauna				
MM119	Prohibit procuring or consuming bush meat at any project site.	X	X	X
MM120	Prohibit keeping or temporary housing of pets or wild fauna at project facilities other than trained guard dogs under the control of a handler.	X	X	X
MM121	Prohibit keeping of cats at project facilities.	X	X	X
MM122	Prohibit mine personnel and those of its contractors bringing any plants or animals into the project development area.	X	X	X
Weeds, pests and diseases management				
MM123	<p>Determine the current status of all potentially serious invasive species, especially around existing infrastructure. Based on these results, update and implement the Weeds, Pests and Diseases Management Plan. Depending upon the results of the exotic species investigations, the plan may need updated to include the following measures:</p> <ul style="list-style-type: none"> • Prepare a priority weeds list, • Develop and implement pest and weed quarantine procedures including for inbound foreign freight, and imported bulk materials. • Develop and implement a weed management procedure to limit the introduction of invasive weed species. • Develop and implement protocols for reporting sightings of serious infestations. • Prohibit transportation of live plants or seeds to the project sites unless part of an approved rehabilitation and restoration plan. • Check that soil and weed seeds are cleaned from plant and machinery elsewhere in PNG before bringing to site. 	X	X	X

Measure ID	Management Measure	Phase*		
		C	O	D
	<ul style="list-style-type: none"> Develop and implement procedures to prohibit project workers/contractors from establishing any gardens, or introducing or transporting any plants, seeds or animals, including fish species, within the project area. Conduct pre-construction surveys of work sites for weeds and exotic fauna. Eradicate infestations of high priority weeds at worksites prior to commencement of construction. Prohibit use of exotic plants or seeds in the project sites. Inspect and treat imported equipment and materials as necessary. Develop disposal/destruction mechanisms for potentially contaminated material such as confiscated items. Conduct periodic habitat monitoring to detect new alien incursions. 			
MM124	Provide relevant contractors and OTML departments with materials to assist with the identification of weeds occurring within the project area.	X	X	X
MM125	Train and induct relevant personnel and contractors in procedures for weed control and eradication.	X	X	X
MM126	Locate wash-down facilities to ensure that run-off does not transfer weed seeds, spores or infected soils containing pathogens to adjacent non-weed infested areas, natural drainage lines or watercourses.	X	X	X
MM127	Conduct a pre-construction survey of access tracks, drill pad sites and fly camps to assess the presence of, and appropriately treat, any infestations of weeds prior to establishing a new work site.	X	X	
MM128	Establish and implement a Quarantine Program and focus on sites where equipment and supplies will be brought into the project area.	X	X	
MM129	Obtain approval from the OTML Environment Department before undertaking any vegetation clearing activities.	X	X	
MM130	Visually inspect all new vehicles, plant and equipment entering or leaving the project area to ensure they are free of soil and plant material.	X	X	X
MM131	Control and eradicate weeds in areas adjacent to the disturbed areas to reduce the potential seed load.	X	X	X
MM124	Provide relevant contractors and OTML departments with materials to assist with the identification of weeds occurring within the project area.	X	X	X
MM132	Check topsoil for weeds prior to transferring it from one area to another. Topsoil must not be transferred from known weed-infested areas to non-weed infested areas. Obtain approval from the OTML Environment Department prior to transferring any topsoil.	X	X	X
MM133	Minimise use of chemical herbicides and pesticides. If required, select herbicides and pesticides with consideration of WHO recommendations and train personnel in their use. Handle, store, apply and dispose of herbicides and pesticides appropriately.	X	X	X
MM031	Prohibit disposal of domestic and industrial waste into streams or sinkholes.	X	X	X
Rehabilitation and revegetation				
MM134	Undertake rehabilitation trials on TSF material to determine the design of cover and growth media requirements for revegetation.		X	X
MM135	As far as practicable avoid using grasses for revegetation/rehabilitation as they can carry fire into the surrounding forest.	X	X	X
MM136	Prioritise IUCN endangered and new to science species when planting to regenerate disturbed areas	X	X	X
MM137	Where practicable and appropriate, revegetate with local species, prioritising species of plants that provide nectar and fruit for fauna. They attract dispersers, which generate a seed rain that speeds up regeneration and reduces costs.	X	X	X

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.6.4 Residual impact assessment

This section describes the predicted residual impacts of the project on terrestrial biodiversity and ecology values following successful implementation of the proposed management measures.

Management measures described in Table 10.41 and preparation of a Biodiversity Action Plan are intended to reduce and manage broader direct and indirect impacts to terrestrial biodiversity and ecology values throughout the life of the project. These measures include controls on vegetation clearing and habitat disturbance, erosion and sediment management, quarantine and pest management measures, fauna management procedures for open trenches and the TSF, restrictions on hunting by project personnel, and management of noise, lighting and human disturbance. Additional measures relating to cave protection, rehabilitation and revegetation, monitoring of biodiversity recovery and fauna interactions, and ongoing community engagement are also proposed to minimise impacts associated with increased access, in-migration and indirect disturbance. While some broader regional impacts associated with increased access and population movement are not fully within the project's control, implementation of these management measures is expected to reduce the extent and severity of impacts on terrestrial biodiversity and ecology values.

Several values may benefit from reductions in floodplain dieback stress and long-term floodplain habitat recovery. Vegetation recovery, dieback reduction and habitat condition will need to be verified through monitoring. Additional biodiversity monitoring will include monitoring of rehabilitation and revegetation success, erosion and sedimentation impacts on streams and riparian habitats, spread of invasive species, fauna interactions with project infrastructure (including the TSF and open trenches), and monitoring of sensitive habitats and species if and where required under the Biodiversity Action Plan. Monitoring outcomes will be used to assess the effectiveness of management measures, improve understanding of long-term ecological responses, and inform adaptive management where required.

10.6.4.1 Habitats

Low Altitude Forest on Uplands

Construction of the TSF is predicted to result in an overall net positive biodiversity outcome by reducing the extent and severity of vegetation stress and dieback within the Ok Tedi and Fly River floodplains compared with continuation of riverine tailings disposal.

To allow direct comparison of habitat loss with potential floodplain recovery gains, a habitat hectare approach was applied using the formula, $\text{habitat hectare} = \text{area} \times \text{condition} \times \text{value}$. Condition scores and conservation values were used in the assessment. Vegetation structure is commonly used as an indicator of condition and expressed as a percentage of growth condition, while conservation values were assigned in accordance with PNG Forest Authority (2022).

In the absence of detailed vegetation condition data in PNG, a simplified condition scoring was assigned based on the forest type and disturbance level:

- Intact low altitude forest on uplands (low altitude forest on uplands) scores 1.0.
- Agricultural land (degraded low altitude forest on uplands) scores 0.5.
- Roads scores 0.0.

The assessment of habitat loss using the condition and value is outlined in Table 10.42.

Table 10.42 Habitat hectare losses

Habitat	Area (ha)	Condition	Value	Habitat hectare
Low altitude forest on uplands	1,563	1	1	1,563
Agricultural land (degraded low altitude forest on uplands)	318	0.5	1	159
Roads	132	0	0	0
Total				1,722

While predicting ecological benefit from reduced stress are uncertain, dieback recovery modelling was adopted to predict potential habitat and ecological gains under two scenarios:

- Pessimistic: Assumes a limited ecological and hydrological response to sediment reduction.
- Optimistic: Assumes a stronger and more widespread system response.

Each scenario is presented as a range defined by lower and upper bounds, representing the range of possible recovery outcomes associated with reduced sedimentation and riverine tailings disposal. The lower bound reflects the minimum expected level of recovery, while the upper bound represents the maximum expected recovery under the same scenario assumptions. The outcome, assuming gains are entirely within low altitude forest on uplands, is summarised in Table 10.43.

Table 10.43 Habitat hectare gains

Low altitude forest on uplands	Pessimistic		Optimistic	
	Lower	Upper	Upper	Lower
Area (ha)	3,700	4,500	7,500	9,000
Condition	1	1	1	1
Value	1	1	1	1
Habitat hectare	3,700	4,500	7,500	9,000
Habitat hectare losses	1,722	1,722	1,722	1,722
Gain	1,978	2,778	5,778	7,278

The biodiversity impact assessment with application of habitat hectare approach compared the habitat losses associated with project disturbance against potential habitat gains associated with reduced floodplain stress and vegetation recovery. The existing dieback across the floodplain recorded between 1992 and 2024 exceeds 214,000 ha and is projected to continue expanding if the current riverine disposal practices are continued. The biodiversity impact assessment conservatively assumed that construction of the project is expected to disturb approximately 2,042 ha of land. This equates to a net biodiversity loss of 1,722 habitat hectares, with most impacts occurring within the low altitude forest on uplands, comprising 1,563 ha.

Conversely, the project has the potential to reduce dieback-related stress and support gradual recovery of floodplain vegetation across a much larger area downstream. The assessment estimated recovery of 3,700 to 9,000 ha of stressed floodplain vegetation by applying assumed reductions in silt loads of 10% and 20% to the mapped extent of stressed vegetation within the floodplain (Marshall 2002, 2006, 2025; Pickup and Ridd 2024; Appendix B) (see Table 10.43), with further gains possible through long-term regeneration of existing dieback areas. The potential gains associated with reduced stress and recovery of floodplain habitats ranged from approximately 1,978 ha (lower) to 2,778 ha (upper) for the pessimistic scenario, while optimistic recovery has potential gains of between 5,778 ha (lower) and 7,278 ha (upper) respectively.

The assessment indicates that even under conservative assumptions, the project has the potential to achieve a net positive biodiversity habitat outcome through avoidance of further vegetation loss beyond that already

predicted, with the TSF potentially improving habitat condition and bringing forward long-term floodplain recovery.

The low altitude forest on uplands has medium sensitivity as while it has high conservation value, it is widespread across the region (it comprises approximately one-third the vegetation in PNG) and generally demonstrates strong regenerative capacity. Considering the **medium** sensitivity of low altitude forest on uplands and the **positive** magnitude of impact, the residual significance of impacts on low altitude forest on uplands is **positive**.

Caves

Caves and cave fauna are considered highly sensitive; however, direct impacts are expected to be low as the project avoids known cave systems and no caves occur within the TSF development area or infrastructure corridor. Potential impacts may occur if quarrying is undertaken near the Lukwi caves, although proposed mitigation measures are expected to minimise disturbance to caves and associated fauna. Indirect impacts are primarily associated with increased access and hunting pressure on cave fauna, particularly flying fox colonies, although the Lukwi area has been accessible to people from Tabubil and surrounds for decades and subject to existing hunting activity. Considering the **high** sensitivity of cave habitats and the **very low** magnitude of direct impact, the residual significance of direct impacts on caves is **low**. Considering the **high** sensitivity of cave habitats and the **low** magnitude of indirect impacts, the residual significance of indirect impacts on caves is **moderate**.

Streams and riparian vegetation

Streams within the TSF development area will be permanently lost, while streams crossed by the infrastructure corridor may be disturbed and affected by sedimentation downstream of construction areas. Management measures, including erosion and sediment, groundwater and water management measures, are expected to minimise downstream impacts.

Streams and riparian vegetation have medium sensitivity as they are naturally dynamic and generally capable of recovering from some disturbance. Considering the **medium** sensitivity of streams and riparian vegetation and the **moderate** magnitude of direct impact, the residual significance of direct impacts on streams and riparian vegetation is **medium**. Considering the **medium** sensitivity of streams and riparian vegetation habitats and the **moderate** magnitude of indirect impacts, the residual significance of indirect impacts on streams and riparian vegetation is **moderate**.

Summary of residual impacts - habitats

Table 10.44 presents the residual impact assessment for habitats.

Table 10.44 Residual impact assessment: habitats

Value	Conservation status	Sensitivity	Residual impact assessment – direct impacts		Residual impact assessment - indirect impacts	
			Magnitude	Significance	Magnitude	Significance
Low altitude forest on uplands	N/A	Medium	Positive	Positive	Positive	Positive
Caves	N/A	High	Very Low	Low	Low	Moderate
Streams and riparian vegetation	N/A	Medium	Moderate	Moderate	Moderate	Moderate

10.6.4.2 Species

IUCN Endangered tree species

Impacts on all IUCN Endangered tree species listed in are discussed collectively as these species all have the same sensitivity and potential exposure to the same impacts.

There are eight tree species recorded within the project area listed as Endangered on the IUCN Red List. These species have limited known distributions and are susceptible to habitat loss and logging. Recent records (described in Appendix G), including the surveys undertaken for the project (described in Appendix F), extend the known ranges of most species and suggest some may be more widespread than previously understood. While habitat disturbance associated with the project may result in some localised impacts, propagation and revegetation measures using these species, together with broader biodiversity benefits associated with reduced floodplain vegetation stress are expected to result in an overall positive impact that is unlikely to be materially altered by indirect impacts.

Considering the **very high** sensitivity of IUCN Endangered tree species and the positive magnitude of direct impacts, the residual significance of direct impacts on IUCN Endangered tree species is **positive**. Considering the positive magnitude of direct and indirect impacts, the residual significance of direct and indirect impacts on IUCN Endangered tree species is **positive**.

Flagship mammals

Flagship mammals include four mammal species of high conservation significance that potentially occur within or near the project area, although confirmed records are limited and largely based on local informants. The potential presence of these mammals is summarised below:

- ***Zaglossus bartoni* (eastern long-beaked echidna)**: While local informants indicated the species may occur within the TSF development area, it is highly unlikely that they occur at such low elevations. It is more likely to occur within higher elevation forest along the northern end of the infrastructure corridor.
- ***Dendrolagus spadix* (lowlands tree kangaroo)**: While local informants indicated potential presence of this species near the project area, the nearest known records of the lowlands tree kangaroo are approximately 150 km east of the project area. Its occurrence within the project area is uncertain.
- ***Dendrolagus stellarum* (Seri's tree-kangaroo)**: Seri's tree kangaroo is unlikely to occur within the TSF development area or infrastructure development area as the species is generally associated with elevations above approximately 2,600 m, well above the elevation range of the infrastructure development area.
- ***Aproteles bulmerae* (Bulmer's fruit bat)**: Bulmer's fruit bat has not been recorded within the project area. While the Lukwi cave system near the infrastructure corridor potentially provides suitable habitat, there are no known records of the species occurring there. Bulmer's fruit bat was originally rediscovered approximately 25 km northeast of the northern part of the infrastructure corridor. While Bulmer's fruit bat could visit the TSF development area to forage, it is unlikely, there is no evidence of this occurring and it would have extensive tracts of similar habitat to forage in.

Direct impacts are expected to be limited, as disturbances to higher-elevation intact forest (along the infrastructure corridor) will be minimal within approximately 50 ha with most impacts expected to occur along the lower-elevation areas (TSF development area). The key risks to flagship mammals and sensitive habitats will be managed through implementation of mitigation measures, including prohibition on hunting by project personnel and protection of cave habitats.

Indirect impacts associated with increased access, in-migration and hunting pressure along the infrastructure corridor present a greater risk than direct impacts, particularly for species vulnerable to hunting, such as the eastern long-beaked echidna and, in the unlikely event it was present, Bulmer's fruit bat.

Considering the very **high** sensitivity of *Aproteles bulmerae* and the **very low** magnitude of direct impacts, the residual significance of direct impacts on *Aproteles bulmerae* is **moderate**. Considering the **very low** magnitude of direct and indirect impacts, the residual significance of direct and indirect impacts on *Aproteles bulmerae* is **moderate**.

Considering the **high** sensitivity of *Zaglossus bartoni*, *Dendrolagus spadix* and *Dendrolagus stellarum*, and the **very low** magnitude of direct impacts, the residual significance of direct impacts on these species is **low**. Considering the **moderate** magnitude of direct and indirect impacts on *Zaglossus bartoni*, the residual significance of direct and indirect impacts on this species is **moderate**. Considering the **low** magnitude of direct and indirect impacts on *Dendrolagus spadix* and *Dendrolagus stellarum*, the residual significance of direct and indirect impacts on these species is **low**.

Hunted species

The two mammal and four bird species listed in are recorded or potentially occurring within the project area and may be impacted. These species are commonly hunted but are generally widespread, tolerant of habitat disturbance and may benefit from long-term recovery of floodplain habitats associated with reduced dieback stress. Management measures include prohibition of hunting by project personnel; however, indirect impacts associated with improved access, in-migration and associated hunting pressure may still occur, particularly along the infrastructure corridor. Indirect impacts are expected to vary between species. Positive direct outcomes relate primarily to long-term floodplain habitat recovery, whereas indirect negative impacts are associated with increased access and hunting pressure along the infrastructure corridor.

While the sensitivity of hunted species listed in varies, the potential impacts are **positive**. Considering the positive magnitude of direct impacts on assessed hunted species, the residual significance of direct impacts on these species is **positive**.

The magnitude of direct and indirect impacts is **low** for *Harpyopsis novaeguineae* and *Psitttrichas fulgidus*, and moderate for all other assessed hunted species. Considering the sensitivity of each species and the magnitude of impacts, the residual significance of direct and indirect impacts is **high** for *Dorcopsis luctuosa*, **low** for *Echymipera echinista* and **moderate** for all other species.

Upland species

Dasyurus albopunctatus (New Guinea quoll) and the frog *Kallistobatrachus majikthise* were recorded within the infrastructure development area, and several damselfly species may occur in higher elevation streams. As these habitats are not expected to benefit from reduced floodplain dieback stress (and positive impacts on low altitude forest on uplands), impacts are primarily associated with loss of intact forest and localised disturbance to streams along the infrastructure corridor. The extent of intact forest loss is limited, and management measures will be implemented to minimise impacts on streams during construction. Indirect impacts are unlikely to materially increase impacts on upland species.

Considering the **medium** sensitivity of assessed upland species and **low** magnitude of direct impacts, the residual significance of direct impacts on these species is **low**. Considering the **low** magnitude of direct and indirect impacts, the residual significance of direct and indirect impacts on these species is **low**.

Species new to science

Several flora and fauna species potentially new to science were identified within the TSF development area and infrastructure development area (described in Appendix F). It is unlikely that these species are restricted solely to the project area and may occur more broadly within the Ok Tedi catchment or elsewhere in PNG.

Reductions in floodplain dieback stress may benefit plant species that occur more widely across the floodplain. Proposed revegetation and propagation of potentially new plant species are expected to support

persistence of local populations within disturbed areas. Impacts to these plant species may therefore be positive where species occur more broadly across the floodplain (south of the Ok Birim catchment) and benefit from habitat recovery and revegetation, or negative where species have more restricted distributions and are therefore more susceptible to direct habitat disturbance.

Considering the **high** sensitivity of plant species potentially new to science (*Choerophryne* sp. 1 cf. *gracilirostris*, *Hylophorbus* sp. 1 (fast call), *Teinobasis* sp. 1 (long, slender), *Idiocnemis* sp. 1 and *Nososticta* sp. 1) and **positive** to **low** magnitude of direct impacts, the residual significance of direct impacts on these species is **positive to moderate**. Considering the **positive** to **low** magnitude of direct and indirect impacts, the residual significance of direct and indirect impacts on these species is **positive to moderate**.

Three potentially new damselfly species are associated primarily with streams and two or three potentially new damselfly species are associated with higher elevation habitats. Loss and disturbance to intact forest habitat in the higher elevation areas is expected to be limited. Implementation of stream and erosion management measures are expected to manage impacts on the new damselfly species.

Potentially new frog species are associated with forest floor and stream habitats and may be affected by vegetation clearing and disturbance to waterways. However, these species are likely to occur more broadly beyond the project area and impacts are expected to range from low to moderate significance.

Considering the **high** sensitivity of *Teinobasis* sp. 2 (yellow), *Palaiargia* sp. 1 and *Papuargia* sp. 1, and **very low** magnitude of direct impacts, the residual significance of direct impacts on these species is **low**.

Considering the **very low** magnitude of direct and indirect impacts, the residual significance of direct and indirect impacts on these species is **low**.

Considering the **positive** magnitude of direct impacts on *Begonia* sp. 1, *Begonia* sp. 2, *Calophyllum* sp. 1, *Garcinia* sp. 1, *Dillenia* sp. 1, *Aglaia* sp. 1, *Dysoxylum* sp. 1, *Glochidion* sp. 1, the residual significance of direct impacts on these species is **positive**. Considering the **positive** magnitude of direct and indirect impacts, the residual significance of direct and indirect impacts on these species is **positive**.

Turtles

Considering the **high** sensitivity of *Pelochelys bibroni* and *Carettochelys insculpta*, and **low** magnitude of direct impacts, the residual significance of direct impacts on these species is **moderate**. Considering the **moderate** magnitude of direct and indirect impacts, the residual significance of direct and indirect impacts on these species is **high**.

Considering the **medium** sensitivity of *Chelodina parkeri* and *Chelodina reimanni*, and **low** magnitude of direct impacts, the residual significance of direct impacts on these species is **moderate**. Considering the **moderate** magnitude of direct and indirect impacts, the residual significance of direct and indirect impacts on these species is **moderate**.

Other species

A further 78 flora and fauna species recorded or likely to occur within the project area are not of conservation significance. These species may be impacted during construction due to habitat loss, they are generally expected to benefit from the long-term reduction in floodplain dieback stress associated with the project, increasing habitat availability over the medium term. Indirect impacts are not expected to materially alter this outcome.

Summary of residual impacts – species

Table 10.45 presents the residual impact assessment for species.

Table 10.45 Residual impact assessment: species

Value	Conservation status*	Sensitivity	Residual impact assessment – direct impacts		Residual impact assessment – direct and indirect impacts	
			Magnitude	Significance	Magnitude	Significance
Endangered trees						
<i>Calophyllum collinum</i> *	EN	Very high	Positive	Positive	Positive	Positive
<i>Cryptocarya albifrons</i>	EN	Very high	Positive	Positive	Positive	Positive
<i>Cryptocarya brevipes</i>	EN	Very high	Positive	Positive	Positive	Positive
<i>Cryptocarya fluminensis</i>	EN	Very high	Positive	Positive	Positive	Positive
<i>Cryptocarya sulcata</i>	EN	Very high	Positive	Positive	Positive	Positive
<i>Endiandra engleriana</i>	EN	Very high	Positive	Positive	Positive	Positive
<i>Timonius argenteus</i>	EN	Very high	Positive	Positive	Positive	Positive
<i>Palaquium morobense</i>	EN	Very high	Positive	Positive	Positive	Positive
Flagship mammals						
<i>Zaglossus bartoni</i>	VU and P	High	Very Low	Low	Moderate	High
<i>Dendrolagus spadix</i> *	VU and P	High	Very Low	Low	Very Low	Low
<i>Dendrolagus stellarum</i> *	VU and P	High	Very Low	Low	Very Low	Low
<i>Aproteles bulmerae</i> *	CR and P	Very high	Very Low	Moderate	Very Low	Moderate
Hunted species						
<i>Echymipera oriamo</i> *	NE	Medium	Positive	Positive	Moderate	Moderate
<i>Echymipera echinista</i> *	DD	Low	Positive	Positive	Moderate	Low
<i>Dorcopsis luctuosa</i>	VU	High	Positive	Positive	Moderate	High
<i>Dorcopsulus vanheurni</i>	NT	Medium	Positive	Positive	Moderate	Moderate
<i>Goura sclaterii</i>	NT	Medium	Positive	Positive	Moderate	Moderate
<i>Harpyopsis novaeguineae</i>	VU and P	High	Positive	Positive	Low	Moderate
<i>Probosciger aterrimus</i>	NT and P	Medium	Positive	Positive	Moderate	Moderate
<i>Psitttrichas fulgidus</i>	VU and P	High	Positive	Positive	Low	Moderate
<i>Cicinnurus regius</i>	LC and P	Medium	Positive	Positive	Moderate	Moderate

Value	Conservation status*	Sensitivity	Residual impact assessment – direct impacts		Residual impact assessment – direct and indirect impacts	
			Magnitude	Significance	Magnitude	Significance
<i>Paradisaea raggiana</i>	LC and P	Medium	Positive	Positive	Moderate	Moderate
<i>Paradisaea apoda</i> *	LC and P	Medium	Positive	Positive	Moderate	Moderate
Upland species						
<i>Dasyurus albopunctatus</i>	NT	Medium	Low	Low	Low	Low
<i>Kallistobatrachus majikthise</i>	LC	Medium	Low	Low	Low	Low
<i>Teinobasis cuneata</i> *	DD	Medium	Low	Low	Low	Low
<i>Teinobasis flavolineata</i> *	DD	Medium	Low	Low	Low	Low
<i>Idiocnemis schorri</i> *	DD	Medium	Low	Low	Low	Low
<i>Nososticta oculata</i> *	DD	Medium	Low	Low	Low	Low
Species new to science						
<i>Choerophryne sp. 1 cf. gracilirostris</i>	NE	High	Positive to Low	Positive to Moderate	Positive to Low	Positive to Moderate
<i>Hylophorbus sp. 1 (fast call)</i>	NE	High	Positive to Low	Positive to Moderate	Positive to Low	Positive to Moderate
<i>Teinobasis sp. 1 (long, slender)</i>	NE	High	Positive to Low	Positive to Moderate	Positive to Low	Positive to Moderate
<i>Teinobasis sp. 2 (yellow)</i>	NE	High	Very Low	Low	Very Low	Low
<i>Idiocnemis sp. 1</i>	NE	High	Positive to Low	Positive to Moderate	Positive to Low	Positive to Moderate
<i>Nososticta sp. 1</i>	NE	High	Positive to Low	Positive to Moderate	Positive to Low	Positive to Moderate
<i>Palaiargia sp. 1</i>	NE	High	Very Low	Low	Very Low	Low
<i>Papuargia sp. 1</i>	NE	High	Very Low	Low	Very Low	Low
<i>Begonia sp. 1</i>	NE	High	Positive	Positive	Positive	Positive
<i>Begonia sp. 2</i>	NE	High	Positive	Positive	Positive	Positive
<i>Calophyllum sp. 1</i>	NE	High	Positive	Positive	Positive	Positive
<i>Garcinia sp. 1</i>	NE	High	Positive	Positive	Positive	Positive
<i>Dillenia sp. 1</i>	NE	High	Positive	Positive	Positive	Positive
<i>Aglaia sp. 1</i>	NE	High	Positive	Positive	Positive	Positive
<i>Dysoxylum sp. 1</i>	NE	High	Positive	Positive	Positive	Positive

Value	Conservation status*	Sensitivity	Residual impact assessment – direct impacts		Residual impact assessment – direct and indirect impacts	
			Magnitude	Significance	Magnitude	Significance
<i>Glochidion sp. 1</i>	NE	High	Positive	Positive	Positive	Positive
Turtles						
<i>Pelochelys bibroni</i>	VU	High	Low	Moderate	Moderate	High
<i>Carettochelys insculpta</i> *	EN	High	Low	Moderate	Moderate	High
<i>Chelodina parkeri</i> *	NT	Medium	Low	Low	Moderate	Moderate
<i>Chelodina reimanni</i> *	NT	Medium	Low	Low	Moderate	Moderate

* IUCN Listings: CR – Critically Endangered, E – Endangered, VU – Vulnerable, NT Near Threatened, DD – Data Deficient, LC – Least Concern, NE – Not Evaluated.
 PNG Fauna (Protection and Control) Act 1966: P – Protected

10.6.5 Star Mountains Key Biodiversity Area

Approximately 158 ha of the northern end of the infrastructure corridor from about Ok Ma to the mine site are in the Star Mountains KBA. This is a 120,000 ha area originally designated as an Alliance for Zero Extinction (AZE) site because of the presence of six species of mammals and twenty species of amphibians. These are now considered legacy species and would not now qualify the site as a KBA under new rules (Key Biodiversity Areas Partnership 2026). Regardless, OTML will use a risk-based approach to survey for AZE-listed species in this part of the infrastructure corridor and minimise impacts to these species (see Section 10.6.4.2).

Of the part of the infrastructure corridor within the KBA, 9.6 ha of this is Intact Forest, 30 ha Agricultural Land and 118 ha is road. This will have no impact on the KBA, noting the Ok Tedi Mine sits entirely within it.

10.6.6 Biodiversity offset

The biodiversity impact assessment indicates that the project will achieve a net positive outcome that its operations will naturally support biodiversity offsets requirements. This is achieved as discussed in Section 10.6.4.1, where the habitat gains exceeded losses under all assessed scenarios.

The predicted potential recovery ranges are estimated between 3,700 to 9,000 ha relative to a disturbance footprint of 1,722 habitat hectares. The difference represents the significant net biodiversity gain, providing the basis of minimal efforts to additional offset requirements.

The primary driver supporting habitat and biodiversity recovery will be the reduction of sediment and riverine disposal into Ok Tedi and Fly River system. The avoidance to riverine disposal will result in:

- Reduction in ongoing vegetation stress and dieback across the degraded floodplain, including in areas near the impact footprints.
- Facilitating gradual and long-term recovery of the degraded floodplain.
- Minimising further extension of impacts on the degraded floodplain.

The biodiversity impact assessment also recognises the uncertainty regarding the rate and extent of floodplain recovery, the future spread of dieback and the timeframe over which ecological benefits may occur. However, even when applying time discounting to account for delayed recovery, predicted habitat gains remain greater than habitat losses associated with project disturbance. Ongoing monitoring of vegetation condition, floodplain recovery and rehabilitation outcomes will be required to verify these predicted biodiversity benefits over time.

10.7 AIR QUALITY

This section outlines the potential impacts to air quality arising from the project based on the air quality assessment by Tetra Tech provided in Appendix H and the characterisation of existing air quality conditions across the project area in Section 8.7.

10.7.1 Approach to impact assessment

The air quality assessment was undertaken using a combination of quantitative dispersion modelling and qualitative dust risk-based assessment methods to evaluate potential impacts associated with construction and operation of the project. The assessment considered emissions associated with construction of the TSF, construction of the tailings pipeline and associated access roads, and operation of the TSF and supporting infrastructure.

Pollutants assessed included total suspended particulates (TSP), particulate matter (PM₁₀ and PM_{2.5}), and nitrogen oxides (NO_x, assessed as NO₂). Emission estimates were derived using project activity data, fuel estimates, traffic calculations, and emission factors from the *Australian National Pollutant Inventory Emissions Estimation Technique Manuals* (DSEWPC 2012).

Concentrations of arsenic, cobalt, copper, manganese, nickel and zinc in tailings were measured by EGi (2026). These concentrations were below the *Australian National Environment Protection (Assessment of Site Contamination) Measure* (NEPC 2013) soil health investigation levels (HILs) for a residential setting with garden/accessible soil (HIL-A Low Density Residential). These HILs provide a conservative screening level for exposure to metal concentrations in the tailings. Given these metals were below the residential HILs, modelling of exposure to metals in dust from the TSF was not conducted as the exposure is expected to be lower than a residential setting.

Quantitative dispersion modelling was undertaken using an atmospheric dispersion modelling system (AERMOD) to predict the dispersion of particulate matter and combustion-related pollutants from key project emission sources. To predict ground-level pollutant concentrations at nearby sensitive receptors, the modelling incorporated source characteristics, estimated emission rates, terrain, and site-representative meteorological conditions. Conservative assumptions were adopted for the assessment, where possible.

Due to the transient and mobile nature of some construction activities, including pipeline works, road construction, bridges and crossings, quantitative modelling was supplemented by a qualitative dust assessment undertaken in accordance with the Institute of Air Quality Management (IAQM) *Guidance on the Assessment of Dust from Demolition and Construction* (2024). The IAQM assessment considered dust emission magnitude, receptor sensitivity, receptor proximity and residual dust risk following implementation of mitigation measures.

Assessment results considered the identified air quality sensitive receptors in Figure 10.17. These include nearby villages, settlements and community facilities potentially impacted by dust and air emissions resulting from project activities.

As PNG regulations do not specify air quality criteria, the modelled air quality parameters were compared with a combination of applicable international air quality guidelines and standards presented in Figure 10.17. These air quality goals are not legally binding criteria.

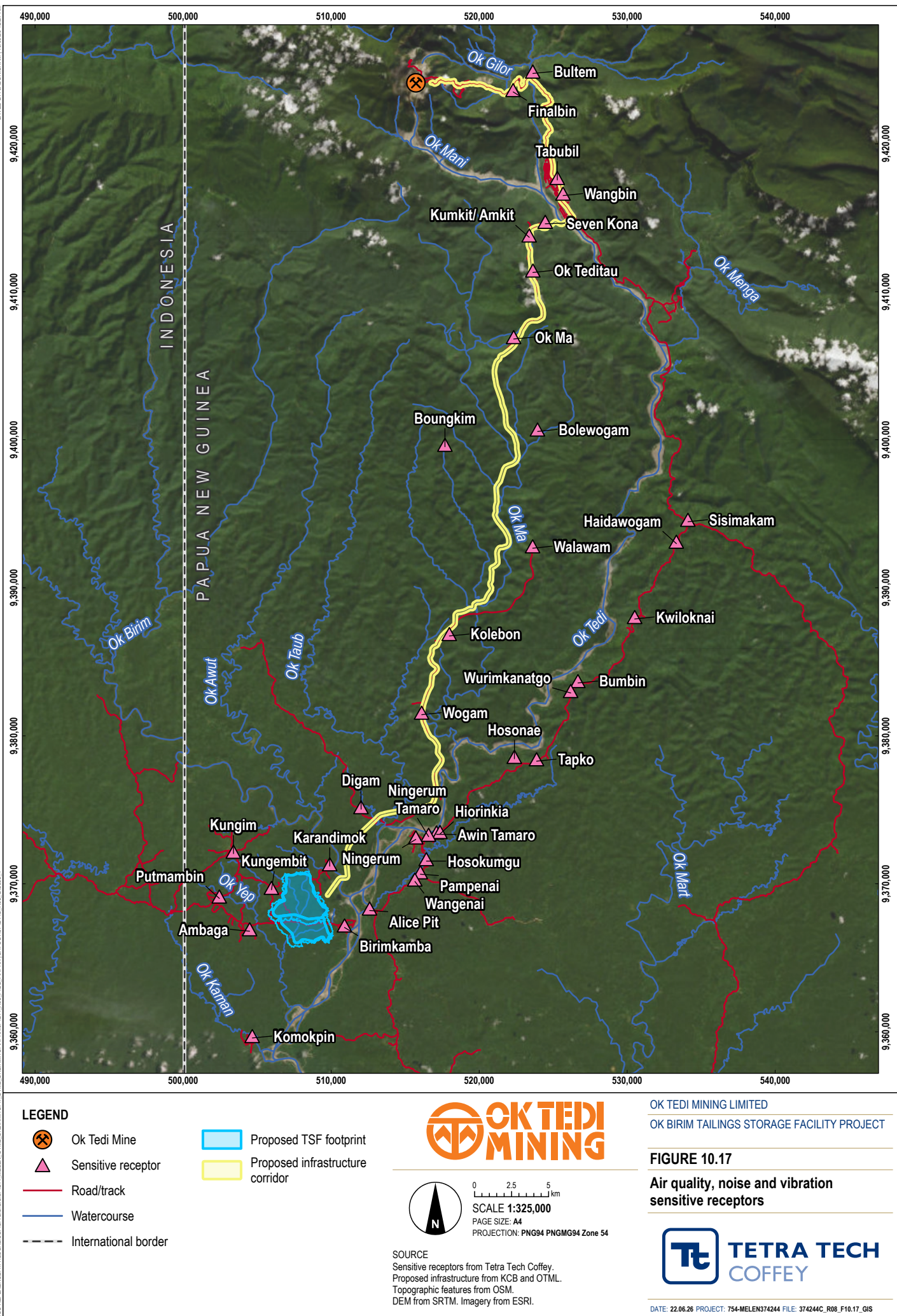


Table 10.46 Adopted project ambient air quality assessment goals

Pollutant	Averaging period	Goal
PM _{2.5} ^a	24-hour	15 µg/m ³
	Annual	5 µg/m ³
PM ₁₀ ^a	24-hour	45 µg/m ³
	Annual	15 µg/m ³
Nitrogen dioxide (NO ₂) ^b	1-hour	188 µg/m ³
	Annual	100 µg/m ³
TSP ^b	24-hour	150 µg/m ³
	Annual	75 µg/m ³
Incremental dust deposition ^c	Monthly	2 g/m ² /30 days
Total deposited dust ^c	Rolling annual average	4 g/m ² /30 days

Source: a. WHO 2021; b. US EPA 2024; c. NSW EPA 2022. µg/m³ = micrograms per cubic metre. g/m²/30 days = grams per square metre per 30 days.

10.7.2 Potential impacts

This section identifies the key project activities that may emit or generate air emissions with the potential to impact nearby sensitive receptors. Table 10.47 presents a summary of potential impacts on sensitive receptors resulting from project activities across each project phase.

Table 10.47 Potential impacts to air quality values according to project phases

Potential impact/stressor	Key source/project activity	Phase*			Comment/rationale
		C	O	D	
Impacts to human health and amenity due to increased particulate matter and nuisance dust (TSP, PM ₁₀ and PM _{2.5})	Vegetation clearance, grubbing and site preparation Bulk earthworks, excavation, trenching, backfilling and material handling Construction of TSF embankments, access roads, bridges and crossings Vehicle movement on unsealed roads and disturbed surfaces Wind erosion of exposed soils, stockpiles, borrow areas and TSF surfaces TSF operational earthworks and maintenance activities Decommissioning activities	X	X	X	Fugitive dust emissions are expected to be greatest during construction due to extensive earthworks, trenching, exposed soils and frequent vehicle movement. Dust impacts associated with pipeline and access road construction are expected to be transient and localised due to the progressive nature of the works. During operations, particulate matter emissions are expected to be substantially lower and primarily associated with intermittent wind erosion from exposed TSF surfaces, stockpiles and other disturbed areas, particularly if unmanaged during prolonged dry periods, as well as vehicle movement on unsealed surfaces. Dust impacts during decommissioning are expected to be similar to the construction phase but to a lesser extent.
Impacts to human health due to combustion emissions (primarily NO _x)	Diesel-powered generators Diesel-powered heavy machinery and mobile equipment Haul trucks, maintenance vehicles and service vehicles Transport of personnel and materials along access roads and the infrastructure corridor	X	X	X	Combustion emissions are generated through operation of diesel-powered equipment, vehicles and generators during all project phases. Construction emissions are associated with intensive equipment use and vehicle movements. During operations, continuous operation of on-site diesel generators represents the primary long-term combustion emission source.

Potential impact/stressor	Key source/project activity	Phase*			Comment/rationale
		C	O	D	
Reduced amenity of sensitive receptors due to dust deposition and visible dust generation	Bulk earthworks and excavation activities Material handling and stockpiling Vehicle movement on unsealed surfaces Wind erosion from exposed surfaces and disturbed areas	X	X		Dust deposition impacts are expected to occur primarily during construction when large areas of exposed surfaces and active earthworks are present. Dust deposition during operations is expected to be intermittent and localised, associated mainly with exposed TSF surfaces, material handling and stockpiling, maintenance activities and vehicle movement on unsealed surfaces.
Temporary localised reductions in air quality associated with transient linear construction activities	Pipeline trenching and backfilling Construction of roads, bridges and crossings Mobile construction vehicles and equipment along the infrastructure corridor	X	X		Air quality impacts associated with linear infrastructure construction are expected to be temporary, mobile and localised, with short-duration exposure at individual receptors as construction progresses.

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.7.2.1 Construction

Primary air emissions from the construction phase are expected to include:

- Fugitive emissions (dust and particulate matter) from land clearing and site preparation, earthworks, trenching and backfilling, blasting (if required), exposed surfaces, borrow fill extraction activities, stockpiling and materials transfer. These emissions are expected to increase in severity during periods of dry and windy conditions.
- Particulate matter from vehicle movement on unpaved roads, including access road works and road surfacing.
- Combustion emissions from the operation of heavy construction plant and mobile equipment (e.g., excavators, cranes, loaders), diesel-powered generators and haulage trucks.
- Combustion emissions from project transportation for workforce, materials and goods/supplies. This includes haul trucks transporting borrow fill and gravel to/from the TSF site, infrastructure corridor and local borrow areas (e.g., up to 207 one-way daily truck movements anticipated along the Infrastructure Tax Credit Scheme (ITCS) Road).

10.7.2.2 Operations

Air emissions during the operation phase are expected to include the following:

- Fugitive emissions associated with TSF operations such as tailings placement and compacting.
- Fugitive emissions associated with activities for TSF raising, development of TSF Cell 2, and re-location of the ITCS Road.
- Particulate matter from vehicle movement on unsealed surfaces and roads.
- Combustion emissions from diesel generators, maintenance plant and light vehicles.
- Particulate emissions from routine maintenance, repair and vegetation clearance/maintenance works that involve ground disturbance.

10.7.2.3 Decommissioning and closure

Potential air quality impacts during the closure phase include activities associated with operating plant, equipment and vehicles for the decommissioning and closure of project facilities.

10.7.3 Avoidance, management and mitigation measures

Table 10.48 lists specific air quality measures proposed to be implemented by OTML to manage potential impacts during construction, operation and decommissioning and closure phases of the project.

Table 10.48 Proposed air quality management measures

Measure ID	Key measures	Phase*		
		C	O	D
MM138	When required (i.e., during extended dry periods), suppress dust on unsealed roads (particularly those heavily trafficked), exposed stockpiles and work areas using water applied by water trucks	X	X	X
MM139	Maintain vehicles and machinery on a regular basis and operate in accordance with manufacturers' specifications to limit emissions.	X	X	X
MM140	Restrict vehicle movements and heavy works near sensitive receptors during high-wind or extremely dry conditions, where feasible.	X		
MM141	Minimise fugitive emissions from dusty material transported by trucks by covering it or making sure material is not above the level of the vehicle sidewalls.	X	X	
MM142	Prohibit unauthorised lighting of fires by project personnel and contractors.	X	X	X
MM143	Conduct blasting in accordance with the current OTML practices using controlled blasting techniques.	X		
MM097	Implement speed limits via posted speed limit signs on project unsealed roads and tracks.	X	X	X
MM144	Minimise extent of vegetation cleared at any one time to reduce exposed areas susceptible to erosion.	X	X	
MM145	Undertake progressive rehabilitation of disturbed areas as soon as practicable to reduce wind erosion	X	X	X
MM146	Control material track-out to limit the transfer of fine materials and mud from active construction areas onto tracks and roads.	X	X	X

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.7.4 Residual impact assessment

This section presents the findings of the air quality assessment.

10.7.4.1 Construction

Air quality impacts during the construction phase were assessed using a combination of quantitative air dispersion modelling and qualitative IAQM dust assessment for construction within the TSF development area and along the infrastructure corridor.

Quantitative assessment

Table 10.49 summarises estimated dust, particulate and combustion emissions during the construction period, while Table 10.50 presents the maximum values predicted of daily and annual concentrations for the construction of the TSF and infrastructure corridor compared against the adopted air quality goals. This provides a conservative upper bound on potential air quality impacts.

Table 10.49 Construction emissions

Combustion Source	TSP (kg/yr)	PM ₁₀ (kg/yr)	PM _{2.5} (kg/yr)	NO _x (kg/yr)
Dust emissions				
Pipeline	453,000	190,000	19,000	N/A
TSF	2,042,000	949,000	94,900	N/A
Combustion emissions				
TSF	13,600	13,600	12,634.7	169,655.4
Pipeline	17,000	17,000	15,900	202,000

Table 10.50 Predicted daily and annual concentrations of TSP, PM_{2.5}, PM₁₀ and NO_x during construction

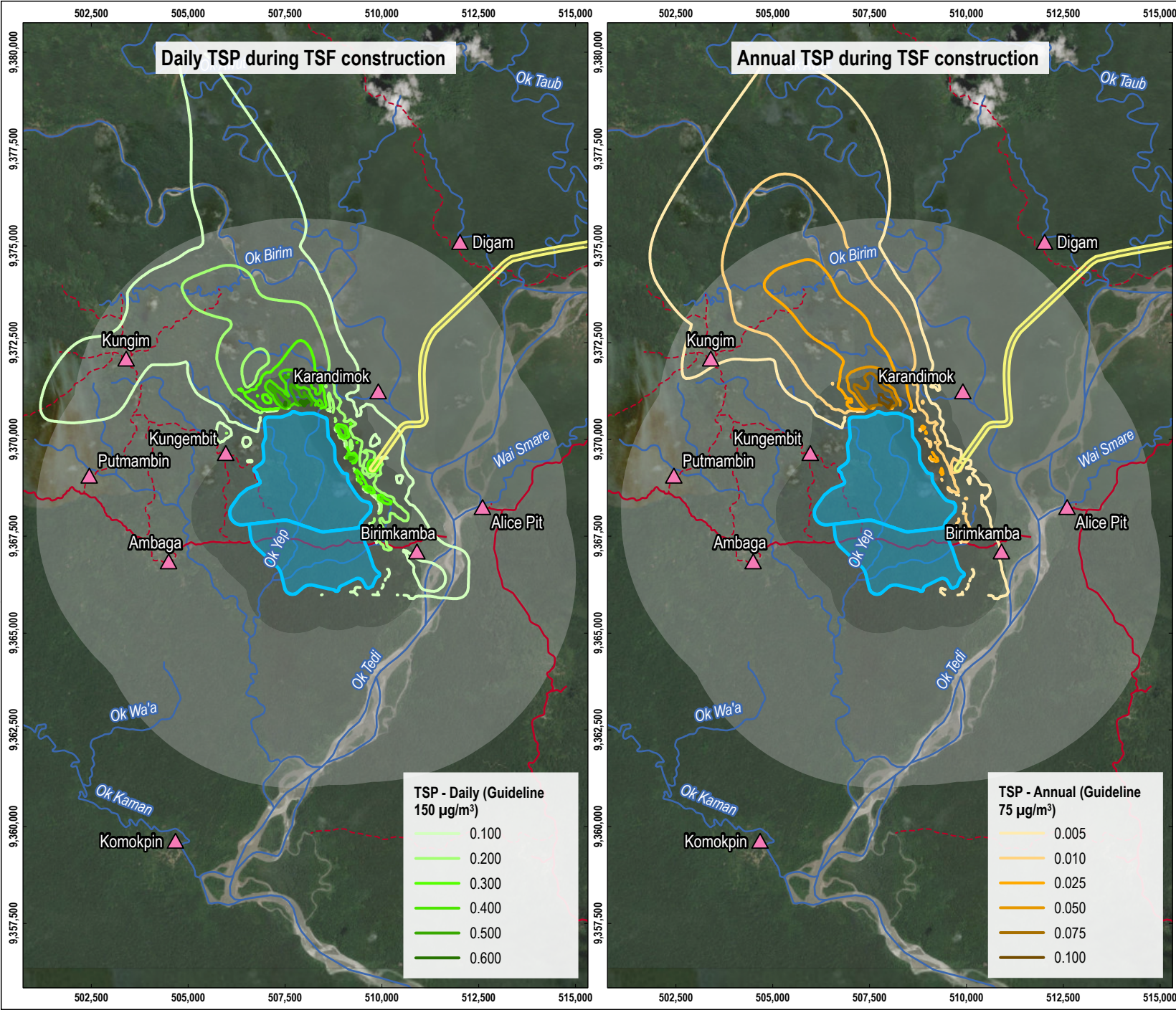
	Modeled Concentrations (µg/m ³)							
	TSP (24 hr)	TSP (Annual)	PM ₁₀ (24hr)	PM ₁₀ (Annual)	PM _{2.5} (24hr)	PM _{2.5} (Annual)	NO _x (1hr)	NO _x (Annual)
TSF development area	0.69	0.13	0.69	0.13	0.67	0.13	63.58	1.83
Infrastructure corridor	3.56	0.26	1.57	0.11	0.26	0.02	6.85	0.11
Adopted air quality goal	150	75	45	15	15	5	188	100

Figure 10.18 spatially shows modelled results of dust, particulate and combustion emissions associated with TSF construction. The result indicated that particulate matter emissions are large in magnitude, but impacts are expected to be temporary and localised, with predicted short-term and annual average concentrations remaining well below adopted air quality goals. Dust impacts will be short-term, greatest during active earthworks and extended dry conditions. Combustion-related emissions from diesel-powered construction equipment are negligible relative to particulate matter emissions. All modelled concentrations are well below the adopted air quality goals.

Modelling of the pipeline and access road construction along the infrastructure corridor indicates that associated air quality impacts will be temporary, localised and short-term due to the progressive and transient nature of activities. The modelled daily dust and particulate matter concentrations are expected to be well below the adopted air quality criteria. Exposure at a given receptor is expected to be limited to short durations as construction works move along the corridor, resulting in annual average dust and particulate matter concentrations remaining well below adopted air quality goals. Combustion-related NO_x emissions from construction equipment and vehicles are also predicted to be well below adopted air quality goals.

Qualitative assessment

Table 10.51 summarises the outcomes of the qualitative assessment undertaken in accordance with the IAQM method. Appendix H provides further detail about this method.





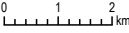
LEGEND

-  Sensitive receptor
-  Road
-  Track
-  Watercourse
-  Proposed TSF footprint
-  Proposed infrastructure corridor

Distance from TSF (km)

-  1
-  5

SOURCE
Villages from Tetra Tech Coffey.
Air quality contours from Tetra Tech.
Proposed infrastructure from KCB and OTML.
Roads and watercourses from OSM.
Imagery from ESRI and Google Earth.



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FIGURE 10.18
Average daily and annual TSP emissions during TSF construction



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Table 10.51 Qualitative assessment

Project component	IAQM activity type	Dust emission magnitude (Step 2A)	Receptor sensitivity (Step 2B)	Unmitigated dust risk (Step 2C)	Residual dust risk (Step 4)
TSF development area	Earthworks/Construction/Track-out	Large	High (Communities ~190 m from TSF footprint)	High (Amenity and PM ₁₀ health impacts)	Low–Medium (temporary, intermittent; controlled through enhanced mitigation)
Infrastructure corridor	Earthworks/Construction/Track-out	Medium	High (Residential and villages immediately adjacent to works)	High (Amenity and PM ₁₀ health impacts)	Low–Medium (temporary, localised, manageable with mitigation)

TSF development area

TSF construction activities, including land clearance, bulk earthworks, materials handling and vehicle movements on exposed surfaces, are estimated to generate particulate emissions of approximately 320 kg/hr of TSP and 94.4 kg/hr of PM₁₀, predominantly from mechanically generated dust sources. These emission rates indicate a large dust emission magnitude under IAQM criteria due to the scale and duration of construction activities within the TSF development area. However, the dispersion models remain well below the adopted air quality goals and NO₂ concentration modelling results are negligible.

The nearest communities are located approximately 190 m from the TSF development area and are sensitive receptors due to the potential for temporary nuisance dust impacts, including dust deposition and short-term exposure to elevated particulate matter concentrations during active earthworks. Dust impacts will be greatest during peak construction periods and under unfavourable meteorological conditions. However, frequent heavy rainfall in the TSF development area will likely attenuate impacts.

Implementation of mitigation measures including dust suppression, stabilisation of exposed surfaces, haul road controls, management of track-out and operational controls during adverse conditions, is expected to substantially reduce the intensity and duration of dust emissions. Residual dust impacts are expected to be temporary, localised and manageable, with overall residual risk (as per IAQM) assessed as low to medium. Localised dust impacts may still occur during peak periods, particularly during dry weather.

Infrastructure development corridor

Construction activities for the infrastructure corridor including trenching, spoil handling, backfilling and construction traffic are estimated to generate particulate emissions of approximately 0.85 kg/hr/km of TSP, 0.44 kg/hr/km of PM₁₀ and 0.09 kg/hr/km of PM_{2.5}. These emission rates indicate a medium dust emission magnitude under IAQM criteria due to the sustained daily duration of pipeline trenching and construction traffic along the corridor. The emission rates indicate elevated short-term dust generation intensity, particularly where multiple construction activities occur concurrently along sections of the infrastructure development corridor. However, the dispersion and NO₂ concentration modelling remain well below air quality goals.

Dust generation will occur primarily from exposed soils, material handling and vehicle movement on unsealed surfaces during active construction works. Due to the linear and progressive nature of the construction activities, dust impacts will move along the corridor as works advance, resulting in temporary and localised exposure at individual receptors rather than continuous long-term impacts.

The infrastructure development corridor passes nearby several villages and settlement areas, with some dwellings located only a short distance from active construction works and haul routes. As a result, nearby

communities are sensitive receptors with the potential for temporary nuisance dust impacts, including dust deposition on buildings, vegetation and outdoor areas, as well as short-term exposure to elevated particulate matter concentrations during peak construction activities and dry weather conditions.

The implementation of mitigation measures, including dust suppression, traffic controls, minimisation of exposed surfaces and management of track-out, is expected to reduce the intensity and duration of impacts. Residual dust impacts are therefore expected to be temporary, localised and manageable, with overall residual risk (as per IAQM) assessed as low to medium. Localised dust impacts may still occur during peak periods, particularly during dry weather.

10.7.4.2 Operation

Table 10.52 summarises estimated dust emissions during TSF operations. Table 10.53 summarises the predicted maximum particulate matter and combustion emission concentrations from TSF operations, across the entire modelling domain.

Table 10.52 Dust generation during TSF operations

Dust generation source	TSP (kg/yr)	PM ₁₀ (kg/yr)	PM _{2.5} (kg/yr)
TSF	2,028,000	951,000	95,000

Table 10.53 Predicted maximum concentrations of emissions from TSF operations

	Modelled Concentrations (µg/m ³)							
	TSP (24 hr)	TSP Annual	PM ₁₀ (24hr)	PM ₁₀ (Annual)	PM _{2.5} (24hr)	PM _{2.5} (Annual)	NO _x (1hr)	NO _x (Annual)
TSF	1.48	0.32	1.48	0.32	1.44	0.31	112	5.05
Adopted air quality goals	150	75	45	15	15	5	188	100

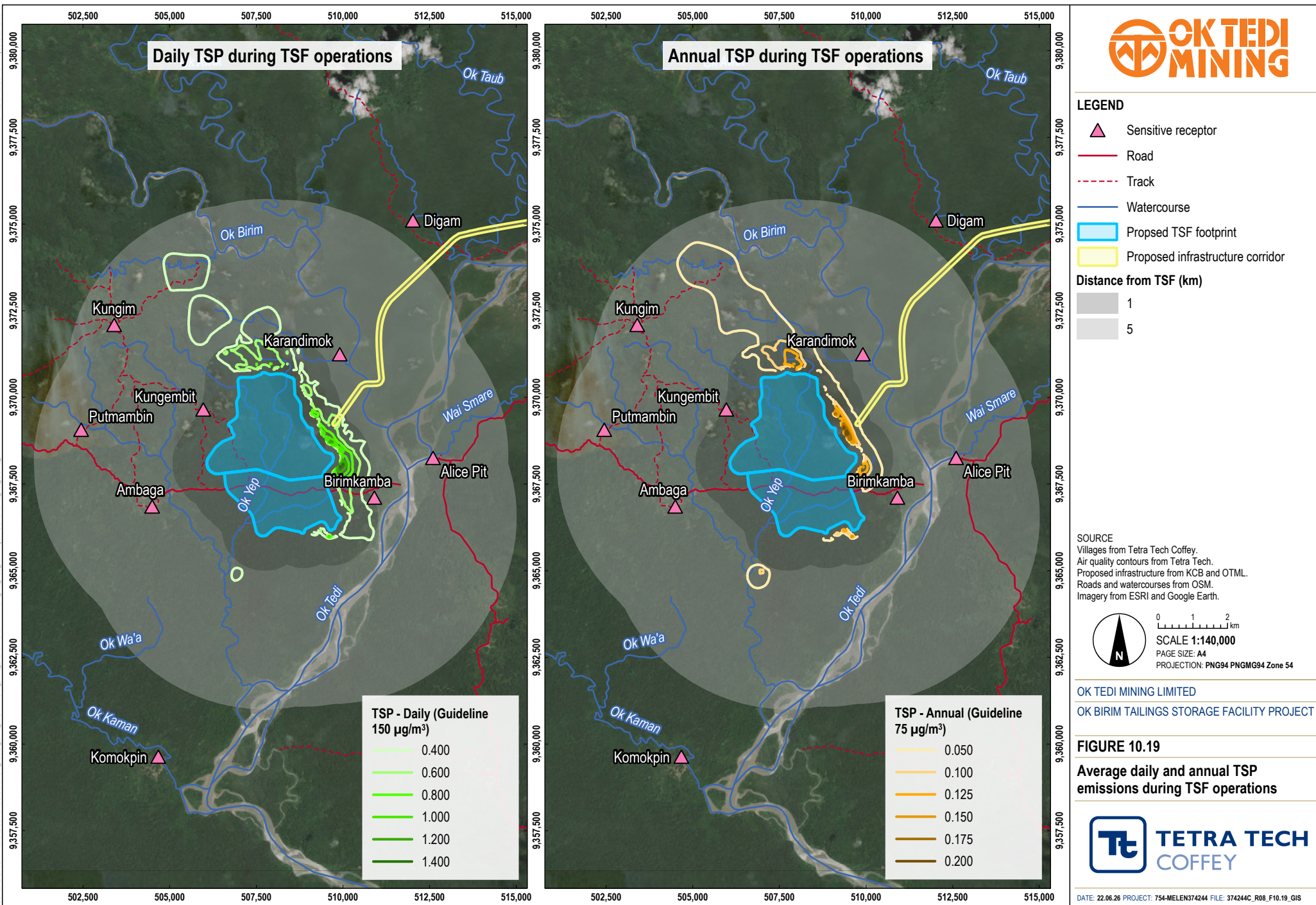
Operational air quality impacts are primarily associated with combustion emissions from on-site diesel generators and, to a lesser extent, fugitive dust from exposed TSF surfaces and vehicle movements on unsealed surfaces and roads. Figure 10.19 and Figure 10.20.

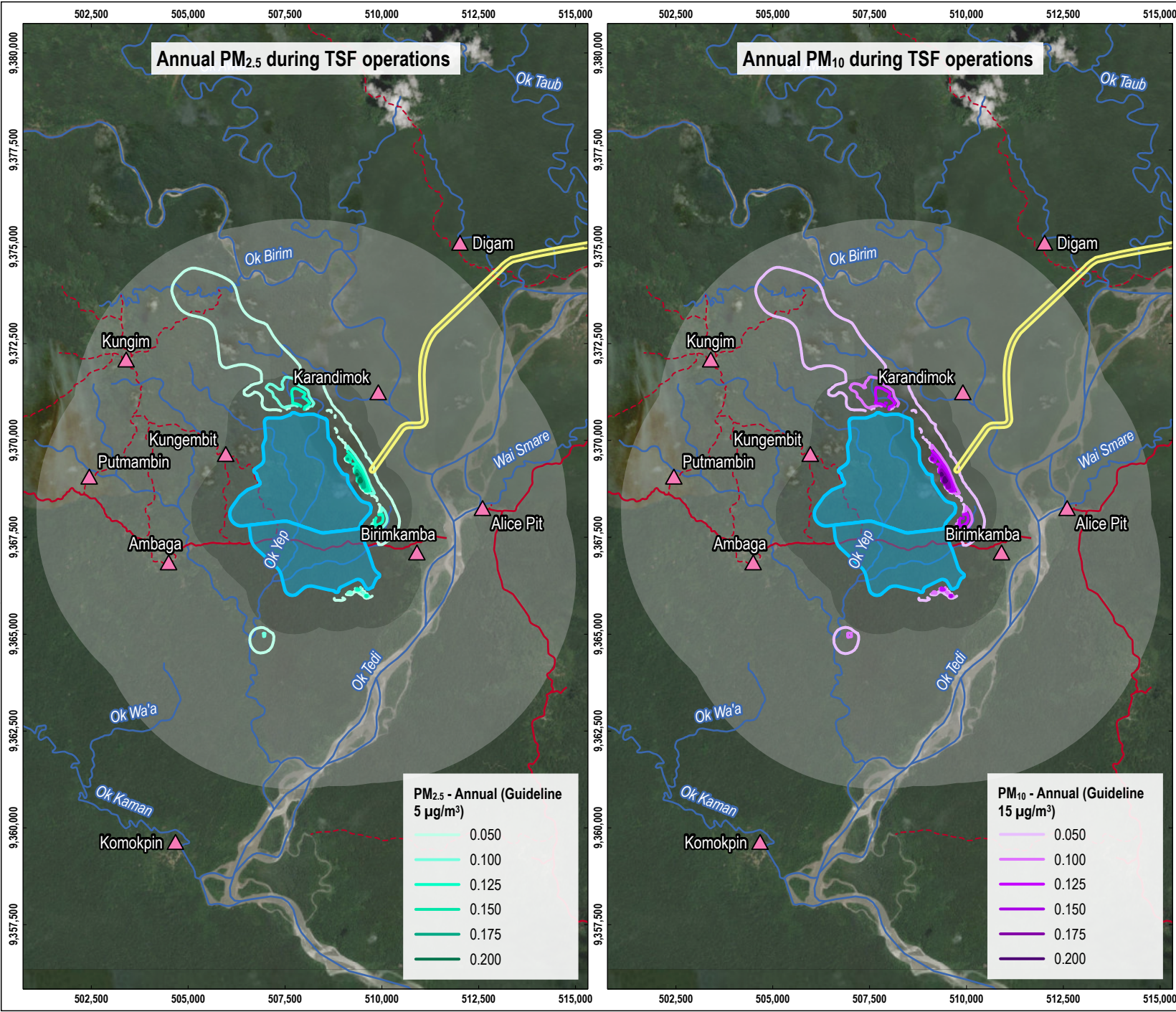
spatially show modelled results of dust, particulate matter and combustion emissions associated with TSF operations. Particulate matter emissions are predicted to be intermittent, associated mainly with dry conditions and operational traffic, and predicted concentrations remain below adopted air quality goals and lower than those during construction. Modelling indicates that predicted PM₁₀ and PM_{2.5} concentrations at identified sensitive receptors remain below applicable short-term and long-term air quality goals and are generally an order of magnitude lower than concentrations predicted during construction.

In contrast, modelling indicates that NO_x emissions from continuous on-site diesel power generation represent the dominant operational air quality impact, resulting in increases in ambient NO₂ concentrations from construction. While short-term goals have modelling showing levels higher than the adopted goals, the modelled 1-hour NO₂ concentration for TSF operations was 112.3 µg/m³, which is below the US EPA 1-hour reference value of 188 µg/m³. Operational combustion emissions represent a meaningful fraction of applicable annual ambient air quality goals to sensitive receptors, indicating NO_x will be a persistent and long-term contribution to local air quality.

10.7.4.3 Decommissioning

Similar to construction, dust generated from these activities will be similar in nature but to a lesser extent. Residual air quality impacts will be temporary, and air emissions from associated project activities are expected to be lower than those during the construction and operations phases.







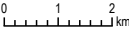
LEGEND

-  Sensitive receptor
-  Road
-  Track
-  Watercourse
-  Proposed TSF footprint
-  Proposed infrastructure corridor

Distance from TSF (km)

-  1
-  5

SOURCE
Villages from Tetra Tech Coffey.
Air quality contours from Tetra Tech.
Proposed infrastructure from KCB and OTML.
Roads and watercourses from OSM.
Imagery from ESRI and Google Earth.



SCALE 1:140,000
PAGE SIZE: A4
PROJECTION: PNG94 PNGMG94 Zone 54

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FIGURE 10.20
Average annual PM_{2.5} and PM₁₀ emissions during TSF operations



TETRA TECH
COFFEY

DATE: 22.06.26 PROJECT: 754-MELEN374244 FILE: 374244C_R08_F10.20_GIS

10.8 GREENHOUSE GAS EMISSIONS

This section describes the potential GHG emissions associated with the project during the construction, operations, and decommissioning and closure phases, based on the GHG emissions assessment presented in Appendix H.

10.8.1 Approach to assessment

The GHG assessment was undertaken in accordance with the *GHG Protocol for Project Accounting* (WBCSD 2003), the *IPCC Guidelines for National Greenhouse Gas Inventories* (2006), the *IPCC Guidelines for National Greenhouse Gas Inventories revision* (2019), and other internationally accepted reporting methodologies. GHG emission scopes are defined by the *GHG Protocol for Project Accounting* (WBCSD 2003) as follows:

- Scope 1 (direct) emissions: All direct emissions from sources that are owned or controlled by the project proponent or project infrastructure.
- Scope 2 (indirect) emissions: Indirect emissions associated with the generation of purchased or acquired electricity, steam, heat or cooling that the project consumes.
- Scope 3 (indirect) emissions: All other indirect emissions which are a consequence of the activities of the company but occur from sources not owned or controlled by the company.

The assessment considered direct Scope 1 emissions only. Scope 2 emissions were not assessed as power supply required for the project will be produced onsite by diesel generators while scope 3 emissions were excluded as insufficient data was available to accurately estimate indirect emissions for the project.

GHG emissions were estimated using standard emission factors and available project activity data. Emission factors used to quantify GHG emissions from the project were primarily sourced from:

- Australian Government Department of Climate Change, Energy, the Environment and Water, *Australian National Greenhouse Accounts Factors for Individuals and organisations estimating greenhouse gas emissions* (2025).
- IPCC Guidelines: *National Greenhouse Gas Inventories for agriculture, forestry and other land use* (IPCC 2006).
- IFC *Environmental, Health and Safety (EHS) guidelines* (IFC 2007a).
- *United Nations Framework Convention on Climate Change Estimation of GHG emissions due to clearing, burning, and decay of existing vegetation attributable to a CDM A/R project activity* (Version 03) (UNFCCC 2007).
- *PNG Second National REDD+ Forest Reference Level, January 2023* (PNG Government 2023), specifically for the country-specific emission factor applied to GHG estimates for vegetation clearing of 'primary low-altitude forest on plains and fans'.

Other key inputs and assumptions used for the GHG emissions assessment are specified in Appendix H.

Section 10.8.2 outlines key sources of GHG emissions associated with the project. Other emission sources are expected to be minor relative to the project's overall emissions profile.

10.8.2 Potential sources of GHG emissions

Potential GHG sources vary through each phase of the project depending on construction scheduling, differences in activities, equipment and personnel movements required, as well as energy generation requirements. A full description of GHG emissions sources are detailed in Appendix H.

The main sources of Scope 1 emissions during the construction phase are expected to be:

- Emissions from the vegetation clearance of approximately 1,980 ha required for project development.
- Fuel combustion associated with operating heavy vehicles, mobile equipment and machinery (e.g., excavators, dozers) for construction activities, and project transportation of construction materials, supplies, workforce and equipment along roads.
- Diesel combustion from on-site generators.

Sources of Scope 1 emissions during the 20-year operational phase are predominantly associated with the TSF, and include:

- Fuel combustion associated with operating heavy vehicles, mobile equipment and machinery (e.g., excavators, dozers) for TSF operations (e.g., tailings placement and compaction, TSF raising) and development of Cell 2 (e.g., starter embankment construction and re-location of ITCS Road) as well as project transportation of operational materials, supplies, workforce and equipment along roads.
- Fuel combustion in vehicles, heavy machinery and mobile equipment, including heavy vehicles and light vehicles doing maintenance activities.
- Diesel combustion from on-site generators.

Detailed information on fuel consumption during the decommissioning and closure phase is not currently available. GHG emissions during this phase are anticipated to be substantially lower than those generated during construction and operations as decommissioning involves limited, lower intensity activities such as minor earthworks, decommissioning of facilities and rehabilitation. These activities will be minor in comparison to construction and operational activities.

Rehabilitation and revegetation activities planned over the life of the project, including during decommissioning and closure, may partially offset a small amount of GHG emissions from vegetation clearing through gradual carbon sequestration in rehabilitated areas. This will depend on the final land use and vegetation type established and maintained in the long term. Recent research on post-mining land use indicates that soil organic carbon sequestration potential may also vary significantly by vegetation type; with the highest sequestration potential associated with mixed forest, followed by broad-leaved forest, coniferous forest, grassland, shrubland, and farmland (Zhu et al. 2024). The potential for carbon sequestration in rehabilitated areas will be investigated once more detailed revegetation plans become available.

10.8.3 Avoidance, management and mitigation measures

Table 10.54 lists measures proposed to be implemented by OTML to manage or reduce GHG emissions generated by the project during construction, operation and decommissioning and closure phases. These measures align with applicable regulatory requirements and international standards.

Table 10.54 Proposed GHG management measures

Measure ID	Key measures	Project phase*		
		C	O	D
MM139	Maintain vehicles and machinery on a regular basis and operate in accordance with manufacturers' specifications to limit emissions.	X	X	X
MM147	Maintain project inventory of GHG emissions in accordance with applicable reporting guidelines	X	X	
MM148	Optimise haul distances and haulage scheduling to reduce idling times to minimise diesel usage in vehicles.	X	X	
MM149	Use efficient lighting and energy-saving devices in project accommodation, administrative buildings, site offices and other project-related buildings	X	X	

Measure ID	Key measures	Project phase*		
		C	O	D
MM150	Optimise pumping systems to minimise energy use for water management		X	
MM054	Restore and rehabilitate disturbed areas no longer required for use as early as possible and progressively throughout project construction	X	X	X
MM055	Minimise vegetation clearance and ground disturbance as far as practicable, including locating project infrastructure, including vehicle parks, laydown areas, storage sites, fuel storage, non-mining waste dumps in cleared areas, in secondary and/or degraded forest areas.	X	X	
MM151	Investigate fuel-switching opportunities to cleaner alternatives (e.g., from diesel to natural gas) as part of broader OTML investigations regarding this.	X	X	X
MM152	Restrict the use of ozone depleting substances in accordance with the IFC General Environmental Health and Safety Guidelines	X	X	X

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.8.4 Calculated GHG emissions

Total Scope 1 GHG construction emissions are estimated at 1,031,020 tonnes of carbon dioxide equivalent (t CO₂e), comprising 30,670 t CO₂e from mobile and stationary combustion sources and 1,000,350 t CO₂e from total carbon stock loss due to vegetation clearing of 1,980 ha. This is a conservative estimate as it assumes all vegetation clearance will occur in the three-year construction period, but some will occur in the operational phase as the cells of the TSF are progressively developed. Construction emissions are predominantly associated with vegetation clearance, which represents over 97% of total emissions. As construction emissions are generally considered once-off emissions staged over a three-year period, these emissions are not typically compared with PNG's annual national emissions inventory.

Table 10.55 provides further details on the breakdown of these emissions.

Table 10.55 Summary of estimated project GHG emissions during construction and operations

Source	Total TSF construction (t CO ₂ e)*	Total infrastructure corridor construction (t CO ₂ e)*	Annual project operation – average (t CO ₂ e/year)*
Vegetation clearing	1,000,350		-
Diesel combustion from on-site power generation	590	590	30,940
Diesel combustion from machinery and plant	9,100	13,660	10,690
Diesel combustion from transport vehicles	3,360	3,360	3,170
Total	1,013,410	17,610	44,790

* Indicative only, rounded to the nearest 10 ha.

During the operational phase, a total of 44,790 t CO₂e per year is estimated to be emitted from mobile and stationary combustion sources. This is predominantly from on-site diesel generators and gensets, which make up 30,941 t CO₂e per year, which equates to 68% of annual emissions.

PNG's GHG emissions in 2024 were 10,761,000 t CO₂e per year, excluding emissions associated with land-use, land use-change and forestry (EDGAR 2025). Overall, the project's estimated annual average Scope 1 GHG emissions of 44,793 t CO₂e during operations represent approximately 0.42% of PNG's 2024 national emissions. This indicates the project is expected to result in a relatively minor contribution to PNG's national emissions during operations.

A climate change risk assessment (CCRA) has been developed with a focus on physical climate change risks (Appendix J). The project does not trigger additional requirements under The Equator Principles IV, e.g., transition risks or a GHG alternatives analysis, if Scope 1 and Scope 2 Emissions are expected to be more than 100,000 t CO₂e.

10.9 NOISE AND VIBRATION

This section outlines the potential noise and vibration impacts arising from the project, based on the noise assessment completed by Sonus Pty Ltd presented in Appendix I and characterisation of existing noise conditions across the project area in Section 8.9.

10.9.1 Approach to assessment

Noise and vibration emissions from key project activities were modelled to predict levels at nearby sensitive receptors during the construction and operation phases. The predicted noise emissions during the construction phase are likely representative of the decommissioning phase as the emission levels are expected to be similar and so decommissioning impacts are therefore not discussed further.

The noise assessment uses the compliance assessment method (see Section 10.1.2) and so the sensitivity and magnitude of values are not described.

10.9.1.1 Assessment criteria

As PNG regulations do not specify noise criteria, the following guidelines have been considered:

- IFC *General EHS Guidelines: Environmental Noise Management* (2007a).
- Australian and New Zealand Environment Conservation Council's (ANZECC) *Technical Basis for Guidelines to Minimise Annoyance due to Blasting Overpressure and Ground Vibration* (1990).
- New South Wales Department of Environment, Climate Change and Water NSW *Road Noise Policy* (2011).

Table 10.56 presents the assessment goals adopted for the noise and vibration assessment, based on these guidelines. These noise goals are not legally binding criteria.

Table 10.56 Assessment goals for noise

Project aspect	Criteria
Construction – TSF starter embankments	55 dB(A) (LAeq, 1 hour) at nearby noise sensitive receptor locations during the daytime (i.e., 7:00 am to 10:00 pm)
Construction – other aspects	85 dB(A) (LAeq, 8 hour) and 140 dB(C) (LCpeak) when occurring near noise sensitive receptors during the day-time, otherwise no criteria 45 dB(A) (LAeq, 1 hour) when occurring at night
Construction – blasting	Airblast overpressure: 115 dB (Lin, Peak) Ground vibration: 5 mm/s (peak particle velocity)
TSF operations	55 dB(A) (LAeq, 1 hour) at nearby noise sensitive receptor locations during the daytime (i.e., 7:00 am to 10:00 pm) 45 dB(A) (LAeq, 1 hour) at nearby noise sensitive receptor locations during the nighttime (i.e., 10:00 am to 7:00 pm)
Road traffic	55 dB(A) (LAeq, 15 hour) at nearby noise sensitive receptor locations during the daytime (i.e., 7:00 am to 10:00 pm) 50 dB(A) (LAeq, 9 hour) at nearby noise sensitive receptor locations during the nighttime (i.e., 10:00 am to 7:00 pm)

10.9.1.2 Noise modelling

The SoundPLAN three-dimensional computer noise modelling software and the Conservation of Clean Air and Water in Europe (CONCAWE) noise propagation model were used to predict noise from each aspect of the project. The method for predicting noise considers the noise source and location, the distance between noise sources and sensitive receptors, air and ground absorption, reflections and shielding by the ground and structures, and meteorological conditions.

The assessment adopted conservative modelling assumptions, including meteorological conditions corresponding to CONCAWE Category 6, representing conditions that provide the least attenuation of noise. Topography was incorporated using 1 m LiDAR-derived elevation data, and modelling considered both initial and final TSF landforms where relevant.

10.9.1.3 Vibration

The vibration study assessed the relationship that air-blast overpressure and ground vibration have on the environmental setting. Air-blast overpressure and ground vibration can be expected to decrease with increasing distance from blast site centre. However environmental setting factors such as, rock type, rock formation, source-receptor geometries and site-specific geological conditions have an influence on the outcome of blasting. Blasting will be undertaken in accordance with current OTML practice and good international industry practice, with final blast design being developed during detailed design and construction planning to achieve project blast criterion.

Indicative setback distances were assessed in based on AS2187.2-2006 and ANZECC guidance to provide an indication of the likelihood of ground and vibration impacts at sensitive receptors.

10.9.1.4 Sensitive receptors

Noise and vibration sensitive receptors within the TSF development area and infrastructure development corridor primarily comprise villages and settlements. The nearest sensitive receptors (villages) to the TSF include Kungembit, Karandimok, Birimkamba and Ambaga, located approximately 900 m to 1,800 m from the TSF. The nearest sensitive receptors (villages) to the infrastructure corridor include Ankit, Kumkit, Ok Ma, Kolebon and Wogam, as well as communities along the Kiunga-Tabubil Highway such as Kawentikin, Finalbin, Bultem and Tabubil.

Figure 10.17 (see Section 10.7) presents identified sensitive receptors.

10.9.2 Potential impacts

Noise emissions from project activities have the potential to impact human health and wellbeing by causing the disruption of daily activities, nuisance, sleep deprivation and stress. Elevated noise levels also have the potential to impact fauna behaviour and habitat use, reducing habitat suitability close to project activities. The following subsections detail the key sources of noise emissions during the construction and operations phases of the project, and the potential impacts from these sources.

10.9.2.1 Construction

Key noise-generating activities associated with construction considered in the assessment include:

- Initial construction of the starter bund for the Cell 1 of the TSF.
- Extraction of gravel and borrow fill from the west bank of the Ok Tedi near the TSF (within 5 km one-way).
- Transport and placement of borrow fill at the TSF.

- Construction of access roads and permanent infrastructure (including the hydro-cyclone house) in the vicinity of the TSF.
- Construction of the tailings pipeline, including riverine crossings
- Construction of the pipeline access road, including bridge crossings
- Construction of the hydro-cyclone house, choke station, power generation and other temporary facilities.

These activities will include:

- Vegetation clearance.
- Topsoil stripping and grading.
- Subgrade preparation and road surfacing along new roads.
- Trenching, pipe bending, weldings, pipe placement, backfilling, and drilling associated with pipeline construction
- Use of heavy equipment (e.g., haul trucks, loaders, graders, vibratory rollers)

Potential impacts will be greatest where activities occur close to communities and residential receptors. Construction noise from heavy machinery, earthworks, pipeline construction, traffic and fixed infrastructure may temporarily increase ambient noise levels within nearby villages and settlements.

The key vibration-generating activity associated with construction will be blasting, which may cause air-blast overpressure and vibration in nearby areas. Ground vibration and air-blast overpressure can cause annoyance, disturbance and discomfort to nearby residents. Elevated vibration levels also have the potential to disturb sleep, disrupt daily activities and create concern about structural damage to buildings, even where actual damage does not occur.

At higher levels, vibration may result in cosmetic or structural damage to buildings and infrastructure, depending on factors such as blast charge size, distance to receptors, local geology and building type. Sensitive receptors closest to blasting activities are most susceptible to these impacts. Blasting may also temporarily disturb fauna behaviour in areas close to active works.

10.9.2.2 Operations

Key noise-generating activities associated with TSF operations include:

- Operation of the hydro-cyclone house.
- Operation of mobile decant pumps to recycle process water in hydro-cyclone systems.
- Tailings placement and compaction (using dozers and excavators).
- On-site power generation.

Operational noise can have the same impacts on sensitive receptors as construction noise; however, the intensity and location will vary.

Blasting is not anticipated to be conducted during the operations phase; therefore, no significant sources of air-blast overpressure and ground vibration are expected to occur during this phase of the project.

10.9.2.3 Summary of potential impacts according to project phases

Table 10.57 presents a summary of potential impacts on sensitive receptors resulting from project activities across the different phases.

Table 10.57 Potential impacts to noise values according to project phases

Potential impact/stressor	Key source/project activity	Phase*			Comment/rationale
		C	O	D	
Impacts to community health, wellbeing and amenity due to increased noise and vibration levels from project activities	Land clearing, major earthworks and site preparation for project infrastructure and TSF embankment (excavators, dozers, compactors). Access road and pipeline construction (cut/fill works, trenching, pipe stringing). Project construction and operational traffic on access roads, particularly on the ITCS Road and pipeline access road. Diesel generators. Continuous/intermittent pumps and choke/valve stations. Hydro-cyclone house and associated infrastructure.	X	X	X	Noise from project activities can disrupt daily activities such as hunting, cause nuisance, sleep disturbance and stress for communities, and reduce local amenity. Elevated noise levels can also alter fauna behaviour and reduce habitat suitability close to active works.

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.9.3 Avoidance, management and mitigation measures

Table 10.58 lists measures proposed to be implemented by OTML to manage potential noise and vibration impacts during construction, operation and decommissioning and closure phases of the project.

Table 10.58 Proposed noise and vibration management measures

Measure ID	Key measures	Phase*		
		C	O	D
MM153	Where project activities must take place outside of daytime hours, implement noise mitigation measures to achieve night-time goal of 45 dB(A) when construction activities are within 1,500 m of Kungembit.	X	X	X
MM154	Maximise distance between noisy equipment and processes and noise sensitive receptors, where practicable.	X	X	X
MM155	Install and use naturally occurring acoustic barriers when using loud equipment near noise sensitive receptors	X	X	X
MM156	Turn equipment off or reduce throttle when not in use.	X	X	X
MM157	Site the most significant fixed plant noise sources at the greatest practicable distance from noise sensitive receptors, using inherent screening provided by bunds, stockpiles or other noise attenuating buffers (e.g., vegetation) if available.	X	X	
MM158	Install major plant and equipment inside acoustically lined enclosures or buildings, limiting the size of any openings to the smallest practical size and orientating openings away from noise sensitive locations where practicable.	X	X	
MM153	Where project activities must take place outside of daytime hours, implement noise mitigation measures to achieve night-time goal of 45 dB(A) when construction activities are within 1,500 m of Kungembit.	X	X	
MM159	Where practicable, schedule noisy works to avoid working in proximity of communities on religious and cultural holidays.	X	X	X
MM160	Avoid blasting where practicable. If blasting is required, restrict blasting activities to daylight hours and inform potentially affected communities of planned surface blasting events.	X		
MM161	Train personnel via site inductions on potential community noise impacts and the appropriate management procedures, including techniques to reduce noise emissions.	X	X	X

Measure ID	Key measures	Phase*		
		C	O	D
MM162	<p>Where applicable for blasting, minimise air blast overpressure and ground vibration by implementing the following controls:</p> <ul style="list-style-type: none"> • Reduce bench height • Reduce blast hole depths • Reduce blast hole diameter • 'Deck loading' of blast holes (i.e., placing two separate charges in the same blast hole separated by a column of inert material and firing with a separate delay) • Increase stemming height • Maximise the blast distance from vibration sensitive locations. • Increase confinement (i.e., increasing standard front row burden and stemming height) • Reduce the charge mass per delay • Direct blasts away from sensitive sites where possible/practicable • Conduct blasting in locations where topography eliminates 'line of sight' to noise sensitive locations • Conduct blasting near sensitive areas during weather periods unfavourable to noise propagation 	X		

* C = Construction; O = Operations; and D = Decommissioning and closure.

10.9.4 Modelled noise and vibration

Modelled noise emissions for construction and operation of the project are summarised in this section.

10.9.4.1 Construction

Construction activities generally will be limited to between the hours of 7:00am to 10:00pm. Daytime construction noise is not assessed against a fixed criterion as the works are temporary and the ability to attenuate construction noise is often more limited than during the operations phase. Instead, reasonable and practicable management measures will be applied (see Table 10.58).

Blasting is not discussed in detail. The assessment determines that to achieve adopted assessment criteria of a blast overpressure of 115 dB(lin) and vibration criterion of 5 mm/s, setback distances of approximately 200 m and 30 m respectively are required, based on a confined blasthole charge of 1 kg per delay.

TSF development area

Table 10.59 presents modelled noise levels from construction of the TSF Cell 1 starter bund at sensitive receptors near the TSF. Modelling has considered the initial and final landforms as topography can affect noise attenuation.

Most daytime construction activities are not assessed against fixed construction noise criteria due to their temporary and mobile nature. However, long-duration construction activities associated with the TSF Cell 1 starter bund were assessed against the assessment goal of 55 LAeq, 1 hour dB(A). Noise levels at all locations assessed comply with this goal under both landform scenarios.

Table 10.59 Predicted noise levels – TSF starter bund construction

Receptor	Highest predicted noise levels (LAeq, 1 hour dB(A))		
	Cell 1 – Initial Landform	Cell 1 – Final Landform	Cell 2
Alice Pit	46	46	46
Ambaga	36	36	36
Birimkamba	51	51	51
Karandimok	42	41	34
Kungembit	47 (53)*	47 (53)*	43
Kungim	27	27	23
Putmambin	28	28	27

* The nearest structures in Kungembit are closer to the TSF than the settlement coordinates, so predicted noise levels are also shown for the nearest structure. No substantial difference is predicted for other sensitive receptors.

Table 10.60 presents modelled noise from construction of access roads and fixed infrastructure in the TSF development area. Assessment goals are not applicable during daytime construction work and therefore are not compared to these results.

Table 10.60 Predicted noise levels – TSF access roads and fixed infrastructure construction

Receptor	Highest predicted noise levels (LAeq, 1 hour dB(A))	
	Road construction	Fixed infrastructure construction
Alice Pit	33	31
Ambaga	39	18
Birimkamba	56 (62)*	35
Karandimok	48	36
Kungembit	56 (71)*	30
Kungim	27	16
Putmambin	29	15

* The nearest structures in Kungembit and Birimkamba are closer to the TSF access roads than the settlement coordinates, so predicted noise levels are also shown for the nearest structure. No substantial difference is predicted for other sensitive receptors.

The noise assessment concluded that, following implementation of the management measures outlined in Table 10.58, noise emissions from construction activities within the TSF development area are expected to comply with the adopted project noise goals.

Based on expected project traffic volumes, the noise assessment determined traffic noise levels are generally expected to be negligible in the context of the background noise environment and existing traffic on the existing road network. The exception to this is between Ok Tedi and the TSF site, where fill material will be hauled, using up to 207 trucks per day. The highest predicted traffic noise level associated with this is 46 dB(A) LAeq,15hr at Birimkamba. Road traffic noise associated with haulage between Ok Tedi and the TSF is predicted to remain below the adopted NSW Road Noise Policy criteria of 55 dB(A) criterion for arterial and sub-arterial roads.

Infrastructure corridor

Table 10.61 presents modelled noise levels from construction at sensitive receptors along the infrastructure corridor. Compared against the assessment goal of 85 LAeq, dB(A), noise levels at all locations assessed generally comply. Noise emissions from pipeline construction have the potential to exceed goals at Tabubil. Model predictions at Tabubil were 85 db(A) during access road construction and 85 db(A) if rock breaking is

required. Activities for the road through Tabubil were modelled on the assumption a new road would need to be constructed; however, the road already exists with only minor work required, making the model conservative. The activities are unlikely to exceed the assessment goal.

Table 10.61 Predicted noise levels – infrastructure development corridor construction

Locality	Highest predicted noise levels [LAeq dB(A)]		
	Access road construction	Pipeline construction	Rock breaking (where required)
Ankit	71	70	73
Finalbin	72	71	74
Kawentikin	69	68	71
Kolebon	69	68	71
Kumguit	67	66	69
Kumkit	80	79	81
Ok Ma	68	67	70
Ok Teditau	72	71	74
Tabubil	85	84	85
Wangbin	79	78	81
Wogam	80	79	81

Based on expected project traffic volumes, the noise assessment determined traffic noise levels are generally expected to be negligible in the context of the background noise environment and existing traffic on the existing road network.

10.9.4.2 Operations

Table 10.62 presents modelled noise levels from operation of both TSF cells at sensitive receptors near the TSF. Modelling considered the initial and final landforms as topography can affect noise attenuation. All assessed locations comply with the daytime goal of 55 dB(A) LAeq. Against the nighttime goal of 45 dB(A) LAeq, all sensitive receptors except those within Kungembit comply. The highest predicted noise levels were 53 dB(A) and 54 dB(A) at the nearest sensitive receptor in Kungembit.

Table 10.62 Predicted noise levels – TSF operation

Locality	Highest predicted noise levels [LAeq dB(A)]			
	TSF Cell 1		TSF Cell 2	
	Initial Landform	Final Landform	Initial Landform	Final Landform
Alice Pit	30	31	30	30
Ambaga	36	37	36	36
Birimkamba	41	43	43	44
Karandimok	42	42	35	35
Kungembit	47 (53)*	48 (54)*	40 (43)*	40 (43)*
Kungim	27	27	23	23
Putmambin	28	28	27	27

* The nearest structures in Kungembit are closer to the TSF than the settlement coordinates, so predicted noise levels are also shown for the nearest structure. No substantial difference is predicted for other sensitive receptors.

As the operational noise impacts at Kungembit are dominated by mobile plant conducting tailings placement and embankment uplift activities, the exceedance will be limited to periods when these activities occur within 1,500 m of Kungembit during the night period. Outside of this distance compliance with the nominated criteria is predicted at all noise sensitive receptor locations at any time of the day or night. Operational noise impacts from the project will therefore be localised to a single noise sensitive receptor and relatively short-lived in duration, and in this context are considered to be relatively minor.

Project traffic volumes during operations are expected to be lower than during construction. Most traffic will be related to haulage between Ok Tedi and the TSF on the planned ITCS Road, together with a small number of maintenance and inspection vehicles. The pipeline access road may attract induced community traffic to sensitive receptors not already exposed to traffic noise; however, noise levels from this are predicted to comply with adopted assessment criteria.

Overall, following the successful implementation of management measures, noise emissions from the operations phase of the project are expected to comply with the relevant goals.