FRIEDA RIVER

Frieda River Limited
Sepik Development Project
Environmental Impact Statement
Chapter 8 – Physical and Biological Impact Assessment

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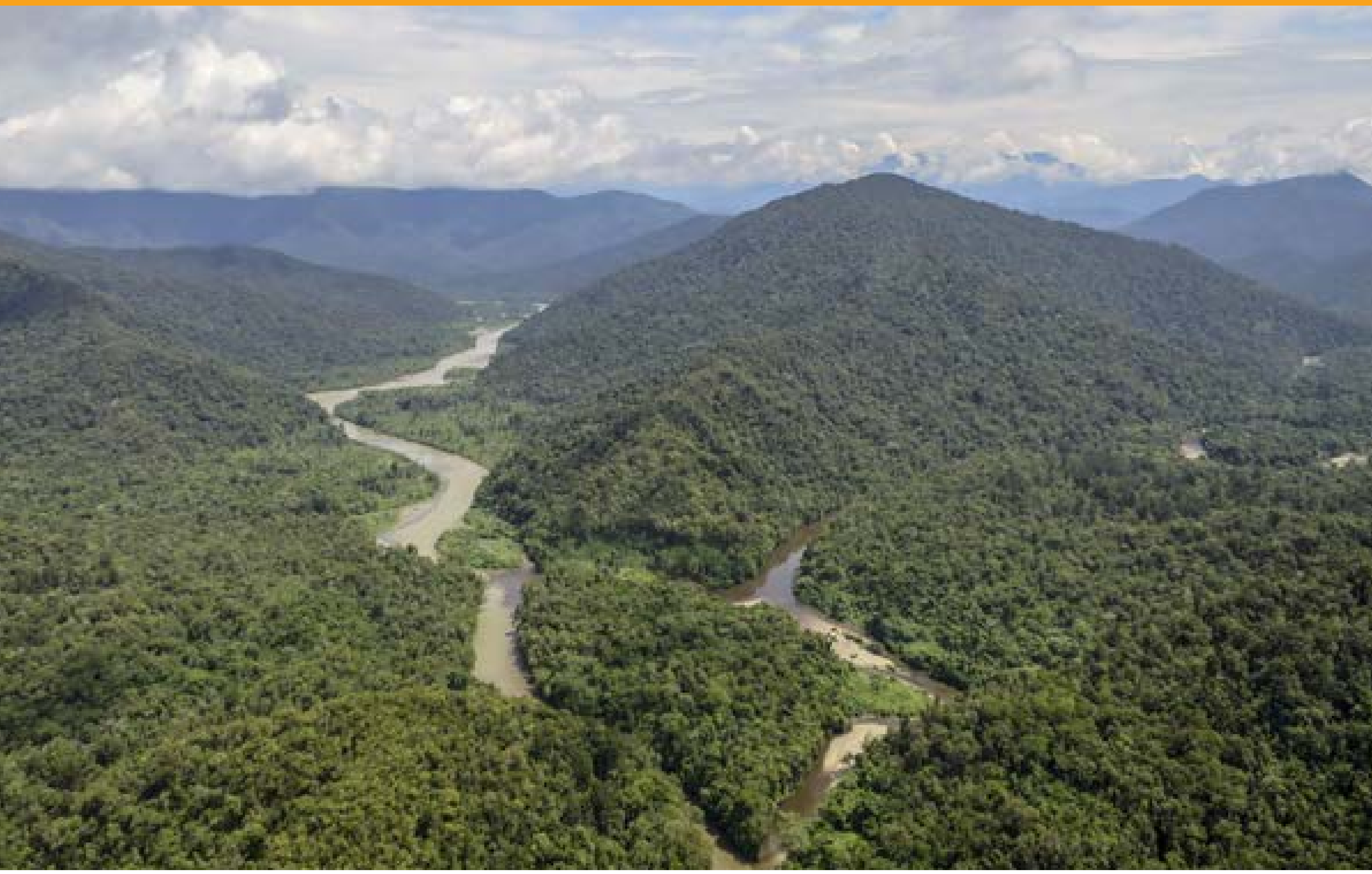

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8. PHYSICAL AND BIOLOGICAL IMPACT ASSESSMENT

This chapter presents the findings of the assessment of the predicted physical and biological impacts of the Project. The chapter starts with an overview of the framework used for the impact assessments; nine subsequent sections present the findings of these impact assessments for the various physical and biological aspects. Each section follows a consistent structure and comprises: an overview of the approach to the impact assessment; a description of the potential impacts; a summary of the key management measures which FRL proposes to use to limit the physical and biological impact of the Project; and the residual impact assessment.

The chapter comprises:

- The impact assessment framework (Section 8.1).
- Soils and landforms (Section 8.2).
- Landscape and visual amenity (Section 8.3).
- Groundwater (Section 8.4).
- Surface water and aquatic ecology (Section 8.5).
- Terrestrial biodiversity (Section 8.6).
- Noise and vibration (Section 8.7).
- Air quality (Section 8.8).
- Greenhouse gas emissions (Section 8.9).
- Nearshore marine (Section 8.10).

Unless otherwise stated, the impact assessment was conducted by Coffey.

8.1 Impact Assessment Framework

This section provides a description of the framework used to assess the physical and biological impacts presented in this chapter. In particular, it describes the use of the significance and compliance methods to predict the residual significance of physical and biological impacts as a result of the Project.

The physical and biological impact assessment approach that has been adopted for the Project involves the following:

- Description of the existing environmental conditions of the Project footprint and surrounds, including the sensitivity of receptors[1], which may be affected by changes in the existing conditions as a result of the Project.

- Consideration of potential, credible environmental issues associated with all phases of the Project, and the consequent potential, credible impacts in the context of the existing conditions. Identification of the potential impacts is based on knowledge of the existing environment, the Project description, experience with similar operations in similar physical and biological environments and issues of concern to stakeholders.

- Identification of appropriate management measures, where the measures described are technically and economically feasible within the context of the Project and reflect FRL's commitments. FRL's commitments include (i) preservation of the long-term health, function

[1] Reference to 'receptors' also includes 'sites', 'environmental values' and/or 'resources', where relevant.

and viability of the natural environments, and (ii) contribution to the social and economic development of sustainable communities.

- Assessment of credible (i.e., they will or are expected to occur as a result of the Project) residual impacts, assuming the successful implementation of the proposed management measures.

This framework is consistent with that used in other recently completed environmental and social impact assessments for resource development projects in PNG and elsewhere, and reflects the approach described in IFC (2012b).

Impacts associated with extreme natural hazards and incidental events are addressed in Chapter 11. Examples of such events include earthquakes and tsunamis of sufficient size to adversely affect the Project and/or its surrounds.

Two different methods have been adopted to assess the level of impact of the Project on the identified environmental values. The methods that have been adopted are dependent on the environmental aspect that is assessed. These are:

- **Significance assessment.** The significance assessment method has been adopted where a qualitative (or semi-qualitative) assessment is required. This method allows for the development of the most suitable and practical management measures as it only considers credible impacts with a likelihood of occurring.

- **Compliance assessment.** The compliance assessment method has been adopted where a quantitative assessment is required. The method relies on international, national or best practice limits or guidelines to measure an impact. As part of the EIS, the compliance assessment has been adopted for air quality, noise and water quality which can be modelled and compared to existing standards.

These are further described below.

8.1.1 Environmental Values

Environmental values encompass the qualities, characteristics and conditions of the physical and biological environments. For the purposes of the EIS, an environmental value can be defined as a:

- Quality or physical characteristic of the environment that is important to ecological health, public benefit, amenity, safety or health.

- Quality of the environment identified and declared to be an environmental value under an environmental regulation.

The technical specialists adopted environmental values set out in regulations, policy or guidelines, and, where not provided, defined values based on their experience, accepted practice and input from key stakeholders.

8.1.2 Significance Assessment

The significance assessment method uses the sensitivity of the environmental value and the magnitude of the impact to assess the significance of potential impacts. The assessment of residual impacts assumes the effective implementation of avoidance and management measures.

Most impact assessments have to combine both objective (technical) and subjective analysis in order to represent value-based issues, on which differences of opinion about significance are inevitable. The approach adopted herein therefore relies on the professional judgement of specialists as well as scientific evidence based on field data, technical assessment and the scientific literature. Particular emphasis has been placed on ensuring that the EIS describes the basis of the judgements so that others can understand the rationale of the assessment.

Analysis of the likelihood of the impact has not been included in this assessment per se, since the impacts described herein are all viewed as being credible outcomes of the Project.

Sensitivity of Environmental Values

Sensitivity is defined as the susceptibility of the environment to change, including its capacity to adapt to, or accommodate, the kinds of changes that the Project may bring about. This definition reflects:

- The formal status of the value, e.g., does the environmental value have local, regional, national or international recognition?
- Its vulnerability to material damage or loss.
- Its iconic or symbolic importance to cultural value systems.
- Its importance to society and the community.

The general criteria for sensitivity used in this assessment are provided in Table 8.1. Where required, specific criteria have been defined for each environmental aspect in the relevant section of this chapter.

Table 8.1 Criteria for sensitivity of environmental value

Sensitivity	Low	Medium	High
Formal status/value; importance to society and community	Zero or only local value or recognition.	A regional or provincial recognised site or value.	A critical asset, national or international recognised site or value. Iconic or symbolic importance to cultural value systems.
Vulnerability	Abundant, widespread, numerous representative examples occur.	Abundance and distribution are limited.	Restricted distribution.
	Easily adaptable to change.	Some resilience to change.	Limited or no capacity to adapt to change.
	Site, receptor or value is in poor to moderate condition prior to Project development.	Site, receptor or value is in moderate to good condition prior to Project development.	Site, receptor or value is intact and retains its intrinsic value prior to Project development.
	Widespread natural resource.	Restricted natural resource.	Rare natural resource.

Magnitude of Impact

The magnitude of an impact is defined as the amount and type of change, including the severity, geographic extent and duration of the impact:

- **Severity.** Considers the scale or degree of change from the existing conditions as a result of the impact; severity can also be considered in terms of the intensity of the impact.

- **Geographic Extent.** Considers if the effect is national (or international), regional, local or limited.
- **Duration.** Considers the timescale of the impact, i.e., if it is temporary, short-term or long-term. This takes into account reversibility of the effect, where an irreversible impact is one where recovery on a reasonable timescale is not possible.

The general criteria for defining the magnitude of an impact used for this assessment are provided in Table 8.2. Where required, specific criteria have been defined for each environmental aspect in the relevant section of this chapter.

Table 8.2 Criteria for magnitude of impact

Consequence Category	Low	Medium	High
Severity of impact	Effect barely detectable with respect to natural variability.	Effect will be readily detectable with respect to natural variability but not severe.	Effect likely to be very large (severe) with respect to natural variability.
Geographic extent	Local effects confined within the Project footprint or to a small, isolated location(s) outside the Project area.	Effects extend beyond the area of disturbance to the surrounding area, but are contained within the region.	Effects are widespread and extend beyond the region. Effects may be national or international in extent.
Duration	Temporary or short-term effects that are easily recoverable.	Effects are recoverable in the medium term.	Effects are either long-term or permanent, i.e., changes not able to be practically or significantly rehabilitated or alleviated.

Impact Assessment

The significance of an impact on an environmental value is determined by the sensitivity of the value itself and the magnitude of the impact it experiences. Prior to the residual impact assessment, management measures were applied to reduce impacts to as low as reasonably practicable within the Project's context. It is assumed that the stated measures are successfully implemented. The model significance assessment matrix (Table 8.3) shows how, using the criteria above, the significance of an impact is determined.

Table 8.3 Matrix of significance

Magnitude of Impact	Sensitivity of Receptor		
	High	**Medium**	**Low**
High	Extreme	Major	Moderate
Medium	Major	Moderate	Minor
Low	Moderate	Minor	Negligible

In general terms, it is the magnitude of an impact, i.e., the degree of change, geographic extent and/or duration of impact, that can be reduced, as necessary, by application of engineering or other management solutions. The sensitivity of the receptor, as assessed, is fixed at a particular point in time, although it may change over time, e.g., with Project phases. The resultant residual impact, therefore, primarily reflects the reduction in magnitude that can be achieved by the proposed management measures.

It should be emphasised that the individual impact assessments for each environmental aspect had flexibility in using the criteria described in Tables 8.1 and 8.2, and the matrix of significance shown in Table 8.3, with these tables being used as 'default' or 'guideline' options. Where variations or further definition of the criteria were warranted, or an alternative matrix was developed, these have been clearly documented in the relevant sections and are consistent with the above approach and the underlying principles.

Generally, only impacts that received a residual rating of moderate or higher have been discussed within this chapter. The exception to this is residual impacts that are negligible or minor but are likely to be of particular interest or concern to stakeholders, in which case they are also included in the EIS. Other residual impacts rated as negligible or minor may be contained in the relevant appendices, which also contain more detailed discussion of the moderate and major residual impacts.

8.1.3 Compliance Assessment Method

The compliance assessment method uses the results of modelling or other predictive techniques to determine compliance with statutory limits or guidelines. Compliance assessment was adopted for environmental aspects where objective, quantitative criteria, guidelines or standards for specific aspects of the Project were available, e.g., effects of toxicants on water quality and associated environmental values.

Assessments using this method typically use modelling to predict emissions or discharges from project infrastructure and operations. This enables compliance with published limits or thresholds to be determined and the need for additional avoidance, mitigation or management measures to be applied. As described in Chapter 3, where PNG has no such published limits or thresholds then surrogate limits or thresholds from other jurisdictions or guidelines have been adopted.

8.1.4 Direct and Indirect Impacts

Where relevant, impacts have been discussed in terms of direct and indirect impacts that were defined as follows:

- Direct impacts are those resulting from direct interaction between the Project and the biophysical environment, and there is an immediate cause-and-effect relationship.
- Indirect impacts are those that are at least one step removed from Project activities in terms of cause-and-effect links.

Induced effects, which are those resulting from other development stimulated by the Project, have been considered within the categories described above.

8.2 Soils and Landforms

This section assesses potential impacts on soils and landform values during construction, operation and closure of the Project, and draws on information from a soil and rehabilitation study (Golder Associates, 2011) and from the Papua New Guinea Resource Information Systems Handbook 3rd Edition (PNGRIS) (Shearman and Bryan, 2011).

8.2.1 Approach to Impact Assessment

The impact assessment method adopted for soils and landforms is consistent with the approach described in Section 8.1. The impact assessment applies the following approach to determine the

Project’s impact on 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.

Soil and Landform Values

Environmental values of soil and landforms within the Project area are defined as:

- Physical integrity and stability of landforms.
- Soil capacity (quantity and quality).

Both values relate to the land’s ability to support growth. The stability of landforms directly 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. Soil capacity relates to having sufficient quantity of soil of suitable physical and chemical characteristics to support biological growth, either natural or agricultural.

Table 8.4 defines the sensitivity levels applied in the assessment and Table 8.5 presents the soil and landform characteristics of each terrain unit and their assessed sensitivity. The levels of the magnitude of potential impacts to the environmental values are defined in Table 8.2 in Section 8.1.

Table 8.4 Definitions for the sensitivity of soil and landform environmental values

Sensitivity	Definition
High	• Poorly-developed soils with low organic matter nutrients. • Highly erodible soils and/or potentially contaminated soils from previous land use. • Highly unstable and erodible landforms in steep to undulating terrain. • Soil type and/or landform is limited in its regional distribution. • Soil type is fragile and will not recover; landforms are fragile and will be difficult to stabilise, requiring extensive remedial work.
Medium	• Developed soils with some organic matter and nutrients. • Potentially unstable landform in undulating terrain. • Soil type and/or landform is represented regionally. • Soil type is moderately robust and will recover in time; landforms are moderately robust and will recover over time with some remedial work required.
Low	• Well-developed, fertile soil type with high organic matter. • Highly stable landform in flat or gently undulating terrain that is not susceptible to erosion. • Soil type and/or landform is widely distributed and represented regionally. • Soil type is robust and will quickly recover from disturbance; landforms are resilient and will quickly stabilise without remedial work.

Table 8.5 Sensitivity of soil and landform environmental values

Environmental Value	Landform Unit	Associated Landform / Soil Characteristics	Sensitivity of the Environmental Value
Physical integrity and stability of landforms	Mountainous terrain with deeply incised valleys and ridges and escarpments	Mountains and hills with weak or no structural control with moderate to highly erodible soils.	Medium
	Alluvial plains and terraces	Fluvial depositional landform. Floodplains that are moderately erodible and poorly drained.	Low
	Back swamps	Marshy semi-permanently to permanently inundated depressed areas of floodplains with drainage impounded or impeded.	Low
Soil capacity (quantity and quality)	Mountainous terrain with deeply incised valleys and ridges and escarpments	Moderate soil depth and drainage, erodible with low soil fertility.	Medium
	Alluvial plains and terraces	Alluvial soils with moderate sand and silt content that are poorly to very poorly drained. Areas that contain sulphidic material within or permanently saturated with water. Moderate to highly fertile with deeper soils.	Medium
	Back swamps	Permanently saturated fine textured, fine sand, clay or peat. Generally consists as freshwater swamp with bog soil.	Low

8.2.2 Potential Impacts

This section describes the potential impacts to soil and landform values from Project activities.

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

- Physical disturbance of landforms and soils including vegetation clearance and major earthworks.
- Chemical alterations to soils from accidental spills and leaks, and exposure of acid sulphate soils (ASS) and/or potential acid sulphate soils (PASS).

Physical disturbance exposes soils and, if unmanaged, this may lead to erosion and/or compaction of soils causing reduced or lost capacity to support vegetation, gardens or crops. Physical disturbance may also destabilise landforms causing or increasing the potential for landslips and erosion. Soil contamination may reduce the capacity of soils to support soil biota, natural vegetation, gardens or crops.

Physical disturbance will be greatest during construction and decommissioning, due to the concentration of ground-disturbing works. The potential impacts resulting from chemical alterations to soils will be greatest during operations and without appropriate management may extend into closure.

The types of soils to be disturbed by the Project (shown in Figure 7.11) and their characteristics are described in Table 8.6.

Table 8.6 Disturbance of soil types

Soil Type	Landform	Characteristics	Project Component	Proportion of Disturbance*
Dystropepts	Hills and mountains	Moderately erodible, have moderate water holding capacity and are well drained	Transmission line, roads, concentrate pipeline and mine infrastructure	30%
Haplorthox	Hills and mountains	Predominantly acid red to brown clay soils, which are poorly structured, highly erodible with low fertility	Open-pit, road, spoil dumps, quarry and spillway	20%
Tropofluvents	Alluvial floodplains	Moderately erodible, moderately fertile and well drained	Roads, transmission line and concentrate pipeline	14%
Fluvaquents	Alluvial floodplains and back swamps	Poorly draining in the lower lying areas	Roads, transmission line, concentrate pipeline, quarry, airport	15%
Eutropepts	Hills and mountains	Moderately well drained with low to moderate organic matter	Roads, transmission line and concentrate pipeline	5%
Hydraquents	Alluvial floodplains and back swamps	Waterlogged, highly to moderately erodible, moderately fertile and are saturated for six or more months a year	Roads, transmission line and concentrate pipeline	4%
Troporthents	Hills and mountains	Moderately erodible, moderately fertile and well drained	Open-pit, process plant, roads, transmission line and concentrate pipeline	4%
Rendolls	Hills and mountains	Shallow, which lie on calcareous parent rock, with low erodibility	Roads, transmission line and concentrate pipeline	3%
Tropofibrists	Hills and mountains	Waterlogged soils are highly to moderately erodible, and moderately fertile	Roads, transmission line and concentrate pipeline	2%

Smaller areas of Plinthaquults, Tropudults, Paleaquults, Tropaquents, Tropudalfs make up the remaining 3% of disturbed areas
*Disturbance excludes the area inundated by the ISF.

Destabilisation of Landforms

The mine and FRHEP areas, and portions of the infrastructure corridor, are located within an area of mountainous terrain with incised valleys, which receives approximately 8 m of annual rainfall. Added to this, the region is seismically active. As a consequence, these areas are prone to landslides. This has the potential to be exacerbated by Project-related physical disturbance, for example, vegetation removal, changes to surface water drainage and excavation of slopes such as for new road developments. Other Project infrastructure is located in flat areas; much of the infrastructure corridor is less susceptible to landslides.

The steepness of the terrain and the scale of the Project facilities will necessitate excavation, filling or cut-and-fill of the ground surface during construction. Constructed landforms such as spoil dumps within the mine and FRHEP areas, and cut and fill areas for newly constructed roads will be prone to erosion. The geographic extent of landform erosion is likely to be localised; however, over time and without revegetation, the area of erosion could expand due to the high rainfall.

During construction of the regional road, most of the excess spoil will be sidecast in close proximity to the road alignment. Areas where sidecasting is not preferred are those where the sidecast volumes will impact with the natural flow of drainage channels, creeks and rivers. In steep terrain that is not suitable for long term stability of large volumes of material, excess spoil will be hauled a short distance to a suitable location where the material will be co-located with other sidecast material. The impacts associated with sidecasting are considered in the sediment transport assessment described in Section 8.5 and are not considered further here. Alteration to surface water flows within alluvial floodplains of the Project area during the construction of infrastructure may lead to the erosion along roads, pipelines and spoil dumps. This is more likely to occur in areas adjacent to steeper landforms, where water flow is higher velocity than the surrounding plains.

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. The following potential impacts to soil capacity due to Project activities have been identified:

- Erosion.
- Soil compaction.
- *In situ* leaching of acidic water.
- Accidental spills and leaks.
- Spread of dieback.

Erosion

The Project is located in a high rainfall environment with infrastructure located in areas of moderately steep slopes. Soil types of the mountainous and hill landform unit are naturally shallow and exposed to weathering and eroding processes (wind and rain) (see Table 8.6). These natural characteristics and ground-disturbing work will lead to the exposure and potential loss of soils through erosion. Over time, erosion can lead to a permanent loss of substrate for vegetative growth, particularly in steeper areas. With the exception of poorly drained areas, all of the terrain units in the Project area are susceptible to erosion, particularly those with soils situated on unstable landforms and those left exposed. Further degradation of soils may result through the transport of eroded soils and subsequent burial of fertile topsoil in downstream areas on alluvial plains.

Localised areas of soil erosion may occur in the alluvial floodplains within the Project area. However, the non-dispersive nature of the soils in these landform units will limit the extent of erosion.

The exposure and subsequent use of subsurface soils and regolith incompatible with local vegetation has the potential to reduce successful revegetation during rehabilitation.

Soil Compaction

The construction of Project infrastructure will lead to soil compaction throughout the Project area. 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 the mine infrastructure, roads and the concentrate pipeline.

Acid Sulphate Soils

The presence and extent of acid sulphate soils within the Project area is not yet well understood. Information presented in PNGRIS (Shearman and Bryan, 2011) and the soils and rehabilitation study by Golder Associates (2011) suggests that ASS and PASS are likely to occur within the alluvial floodplains in the Project area. Therefore, construction activities along the infrastructure corridor may result in exposure of ASS or PASS material, which could cause acid water from the ASS to leach into the soil profile. If this were to occur, it will negatively impact the capacity of the soil to support vegetation growth and it is unlikely that vegetation would be able to establish itself in areas affected by acid leaching.

Accidental Spills and Leaks

There is a potential for the release of 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.

Spread of Dieback

Various species of dieback (*Phytophthora* genus) exist within PNG. Dieback is a soil-borne water mould that infects roots of native and crop plant species. It can be spread through spores attaching to vehicles that pass through infected areas to non-infected areas, negatively impacting vegetation growth. There is potential for dieback to spread within the Project area either through internal sources (within the Project area), or external sources (outside the Project area) through vehicular movement.

Potential impacts associated with diseases caused by a range of organisms including those of the *Phytophthora* genus, pests and weeds are addressed in Section 8.6.

Project Phases

Table 8.7 describes the phases of the Project in which the potential impacts on soil and landform values are predicted to be most applicable.

Table 8.7 Potential impacts to soil and landform values and relevance to Project phases

Potential Impact	Phase			Comment
	Construction	Operation	Closure	
Destabilisation of landforms	✓	✓	✓	Primarily limited to construction when most soil disturbance will occur, but the risk of instability of landforms will continue through operation to a substantial degree and potentially closure.
Soil compaction reducing soil capacity	✓			Primarily limited to construction when most soil disturbance will occur.

Table 8.7 Potential impacts to soil and landform values and relevance to Project phases (cont'd)

Potential Impact	Phase			Comment
	Construction	Operation	Closure	
In situ leaching of acidic water from ASS reducing soil capacity	✓	✓	✓	Would commence during construction, but most likely to be an impact during the operation and closure phases of the Project.
Accidental spills and leaks reducing soil capacity	✓	✓	✓	Could occur during all phases of the project while these consumables are in use.
Spread of dieback reducing soil capacity	✓	✓	✓	Could occur throughout all phases of the Project as potentially affected soils are disturbed and transported throughout the Project site and beyond.

Potential impacts associated with acid and metalliferous drainage (AMD) are addressed in Section 8.5.

8.2.3 Management Measures

Table 8.8 presents an overview of the proposed management measures that will be adopted to limit the predicted impacts of the Project on soils and landform values during construction, operation and closure.

Table 8.8 Soils and landform management measures

No.	Management Measure
Erosion of Constructed Landforms from Surface Water Flows	
MM001	Constructed landforms will be designed to cope with high surface water flows.
MM002	Appropriate diversion structures will be designed to channel surface water away from constructed landforms.
MM003	Ongoing monitoring and management of surface water flows and landform erosion during the duration of the Project will be implemented to identify areas that require maintenance.
MM004	Constructed landforms (such as spoil dumps) in the mountain and hill zones will be designed and constructed to form safe and stable landforms, recognising the locally steep terrain and high rainfall of the mine area. Specific rehabilitation measures to be considered in mountain and hill zones include: • Reprofiling the ground surface to original or stable and safe contours and surface drainage lines. • Applying brush matting, mulching or compost to prepared surfaces to assist with moisture retention and erosion control. • Utilising quick-growing groundcovers to reduce the erosive impacts of rainfall and surface water flow in rehabilitation areas. • Conduct progressive rehabilitation.
MM005	Rehabilitate cleared areas to reduce erosion and runoff as soon as possible after clearance. Store and re-use suitable topsoil wherever practicable.
Soil Compaction	
MM006	Limit the Project footprint during the design phase.
MM007	Restrict vehicles to only those areas that need to be accessed or trafficked.

Table 8.8 Soils and landform management measures (cont'd)

No.	Management Measure
Soil Compaction (cont'd)	
MM008	Instigate ripping and soil reinstatement in disturbed areas prior to revegetation efforts where practicable.
Erosion of Disturbed Areas	
MM009	Develop and implement an erosion and sediment control plan, including procedures for avoiding and minimising erosion of disturbed areas.
MM010	Implement control measures to minimise concentrated water flow and to protect the soil surface of disturbed areas, where practicable, which may include: • Applying vegetative debris (e.g., logs) or coarse material (e.g., rock armouring). • Diverting surface water around disturbed areas. • Progressively revegetating disturbed areas. • Applying erosion control matting.
Unsuitable Soils for Rehabilitation	
MM011	Implement a risk based soil survey for individual disturbance areas prior to disturbance to identify potentially problematic surface and subsurface soils (i.e., ASS, PASS, dispersive soils). Where problematic soils are encountered, develop appropriate management controls.
MM012	Rehabilitation techniques will be designed to facilitate the application of salvaged soils to appropriate areas. Specific measures to be considered where soils can be used for progressive rehabilitation (i.e., in areas of flatter terrain) include: • Collect topsoil (i.e., the upper 0.2 m to 0.3 m of soil, including organic material). The steep terrain and limited access over much of the Project area is likely to restrict topsoil stripping to relatively small, accessible areas. • Retain vegetation material and coarse soil fragments with stripped surface soil material, where practicable, to minimise the risk of erosion when reused as a rehabilitation medium. • Strip surface material and place in stockpiles no greater than 2 m in height. • Respread stockpiled topsoils in rehabilitation areas as soon as practicable. • Avoid locating soil stockpiles in areas that will impede the natural drainage patterns. • Revegetate stockpiles either by seeding or natural colonisation as soon as possible. • Cover rehabilitated areas with salvaged surface topsoil material (where possible). • Rip surfaces of reconstructed landforms and rehabilitation areas to a depth of more than 0.5 m following topsoil application and reseed with native species.
Spread of Dieback	
MM013	Carry out pre-construction survey of work sites for weeds, exotic fauna and dieback using a risk-based approach to identify areas susceptible to invasion of exotic species. If dieback is recorded, testing for Phytophthora will be completed and if present, procedures for managing the spread of dieback will be developed.
MM014	Access to dieback infested areas will be restricted within the Project tenements.
In Situ Leaching of Acidic Water	
MM015	Manage encountered ASS by: • Mixing the ASS material with a neutralising agent such as fine-ground lime that inhibits oxidation and increases pH. • Burying excavated ASS material at least 1 m below the permanent watertable at a disposal site without prior treatment. • Stockpiling ASS material in a bunded area with a very low permeability base (e.g., acid-resistant liner or clay layer).

Further measures to minimise erosion are described in Section 8.5 and details will be included in the EMMPs. Wastes and hazardous materials management is discussed in Chapter 5 and will be further addressed in the EMMPs.

8.2.4 Residual Impact Assessment

The significance of the residual impacts has been assessed assuming the implementation of mitigation and management measures identified in Section 8.2.3. The key residual impacts on soil and landform values are summarised in Table 8.9 and discussed in detail below.

Table 8.9 Summary of soil and landform residual impact assessment

Impact Description	Residual Impact after Implementation of Management Measures		Impact Significance
	Magnitude	Sensitivity of Receptor	
Mountainous terrain with deeply incised valleys			
Reduced physical integrity and stability of landforms and soils	Medium	Medium	Moderate
Reduced soil capacity (quantity and quality)	Medium	Medium	Moderate

Landform Stability

Impacts to the stability of landforms (naturally occurring and constructed) are predicted to occur mainly across the mountain and hill terrain within the Project area.

The naturally occurring mountain and hill landforms within the Project area will be exposed to instability as a result of vegetation clearance, topsoil removal, blasting and drilling, and excavation of regolith. The mountain and hill terrain is inherently susceptible to instability due to its steep slopes (greater than 30 degrees in some areas), weak soil structure as well as the high rainfall and seismicity in the region.

Constructed landforms susceptible to instability include the Ok Binai waste dump, spoil dumps and major cut-and-fill construction activities. These landforms are also prone to instability due to their physical characteristics (i.e., dispersive nature and weak structure). Again, the mountain and hill terrain is inherently susceptible to instability and therefore constructed or engineered landforms within these areas have greatest potential to result in impacts. The stability of the Ok Binai waste dump and limestone quarry spoil dump and the rate at which they are predicted to erode over the life of the Project is discussed further in Section 8.5.

The proposed management measures developed to address this issue include avoidance and engineering design to reduce the potential for unstable landforms to be created. Measures to minimise physical disturbance and control erosion and sedimentation will be detailed in the erosion and sediment control management sub-plan of the EMMPs.

The low relief zones of the narrow alluvial floodplains and composite alluvial plains are less susceptible to instability compared to the mountain and hill terrain. Alterations to surface water flows may, however, destabilise constructed landforms, such as spoil dumps and major cut and fill areas within these alluvial landscapes. Impacts will most likely be greatest in areas adjacent to mountain and hill zones or near cleared land, where surface water flow velocities will be greater than in areas of low gradient and vegetation.

Considering the **medium** sensitivity of the mountain and hill landform unit and the **medium** magnitude of residual impacts on the stability of this landform, the residual impact significance is **moderate**.

The magnitude of reduced physical integrity and stability of the alluvial floodplain landform unit is predicted to be **low**. As a result, and considering the **low** sensitivity of alluvial floodplain landforms to instability, the overall residual significance is **negligible**. Likewise, back swamps are unlikely to be affected in terms of stability as these are not predicted to be impacted by the Project (see Section 8.5).

Soil Capacity

Soils in the mountainous terrain unit are shallow and are typical of those elsewhere in the Sepik River catchment and PNG more generally. These soils consisting of Haplorthox, Dystropepts and Troporthents types are of moderate to low depth, moderately erodible and have lower soil fertility in comparison to flatter areas. Overall, the sensitivity of soil capacity in these areas is **medium**.

The capacity of the soil to support vegetation growth will be negatively impacted within the Project area, even after the implementation of management measures. The mountain and hills landforms are sensitive to soil erosion due to the unstable soil types, steepness of slopes and high rainfall in the region. Vegetation clearing in the mine area will increase the susceptibility of soils to erosion. Changes to the physical and chemical properties of the soil from these processes will negatively alter the capacity of the soil to support vegetation growth. These combined effects have the potential to negatively influence rehabilitation of disturbed areas potentially resulting in reduced revegetation success. As such, the mountain and hill landform unit were rated as having **medium** sensitivity in terms of soil capacity.

To minimise the magnitude of soil erosion in the mountain and hill regions, areas of disturbance in this landform unit will be limited to the extent practicable. Areas disturbed by Project activities will be managed through the implementation of an erosion and sediment control management sub-plan of the EMMPs and the implementation of measures including diverting surface water away from areas of disturbance, and progressively rehabilitating disturbed areas. A soil ripping program during rehabilitation activities will be undertaken, to improve the soil’s physical structure to support vegetation growth. The magnitude of impacts to the capacity of mountainous and hill soils is predicted to be **medium**, being localised to the Project area, resulting in a **moderate** residual impact significance.

Alluvial floodplains and flanking terraces, and composite alluvial plain landform units contain a mosaic of soil types (including Fluvaquents and Hydraquents types), which are common in major river floodplains such as the Sepik River floodplain. They have a greater recovery potential compared to mountain and hill landforms, as they are the product of the dynamic environment that results in deposition of alluvial sediments. Overall, the sensitivity of the soil capacity is assessed as **medium,** primarily due to their productivity value.

In comparison to the shallow soils of the mountainous and hilly soils, soils of alluvial floodplains and terraces are less susceptible to degradation and/or loss from erosion. Nonetheless, alterations and concentration of surface water flows, for example along roads and the pipeline corridor, has the potential result in localised areas of erosion within these alluvial landscapes.

Based on the information available, including the landform units and soil types identified within the Project area and wider region, it is likely that ASS and/or PASS exist within the alluvial floodplains and back swamps. In terms of Project components, only the infrastructure corridor and access road to the Frieda River Port coincides with these high risk areas for ASS. Disturbance and exposure of ASS and PASS during Project activities will be managed to minimise the potential of acid water forming and leaching into underlying soils.

Implementation of proposed management measures based on appropriate management of erosion, hazardous materials, and topsoil management for rehabilitation, will limit chemical alterations to soil and degradation of soil capacity and reduce the severity and duration of the impact. The magnitude of predicted impact to the capacity of alluvial soils was assessed to be **low**, with a corresponding **minor** residual impact significance. Due to the scale of disturbance and the low sensitivity of back swamps a **negligible** residual impact significance was predicted.

8.3 Landscape and Visual Amenity

This section outlines the findings of the landscape and visual impact assessment for the Project. A landscape and visual impact assessment was previously completed by AECOM in 2011 for an alternative project design. Aspects of the AECOM (2011) assessment remain relevant to the current Project and have therefore been used to inform some sections of this impact assessment.

8.3.1 Approach to Impact Assessment

The assessment of impacts on landscape character and visual amenity is essentially subjective, since individuals and cultures have different perspectives about what is or is not visually important. As a result, the impact assessment method as described in Section 8.1 has not been used and a qualitative assessment is presented instead. The qualitative assessment includes consideration of the sensitivity of the existing landscape and receptors and the magnitude of changes or degree of visual modification as a result of the Project. Focus is given to elements of the Project that are likely to have the greatest impact on landscape character and visual amenity.

No primary information exists on visual preferences or perceptions of the local population with regard to changes in the landscape resulting from the Project. In general terms, the natural landscapes hold particular importance for individuals from remote PNG villages and if these are physically distorted – such as by cutting into hills to build a new road – then this is likely to cause concern. On the contrary, a view of a newly built structure may be perceived to improve the visual amenity of an area – for instance, a telecommunication tower in a backdrop – and may provide a sense of progress for a local villager. As a result, perceptions of change in the landscape may be positively influenced by perceived opportunities that the Project may bring such as employment, or improved access to infrastructure, education and health care facilities (see Chapter 9). Experience from other projects in PNG also suggests that people may actively move and/or modify the landscape to enable them to better see projects, rather than choosing to remain visually shielded from them. Despite this experience, this assessment has conservatively assumed that people are sensitive to changes to landscape and visual amenity.

8.3.2 Potential Impacts

Potential impacts on landscape and visual amenity are associated with Project activities that can be viewed by people and are close to their village or daily activities.

Potential impacts will occur during construction, operation and closure of the Project. While some potential impacts associated with construction may be temporary (e.g., excavation of borrow material from quarries that will revegetate naturally over time), the changes in the landscape arising from the construction and operation of Project facilities will result in permanent changes to the landscape. Changes to the landscape and visual amenity and potential impacts associated with this are discussed below.

Mine and FRHEP Infrastructure

A 10 km radius was chosen as the limiting distance at which facilities could reasonably be expected to be seen with the unaided eye (AECOM, 2011). Only the villages of Wameimin 2, Ok Isai, Wabia and Paupe are currently located within a 10 km radius of the open-pit, mine infrastructure area, ISF and hydroelectric power facility. Construction and eventual flooding of the reservoir in the Frieda River catchment means the villages of Ok Isai and Wabia will be resettled. It is proposed that Wameimin 2 and Paupe will also be resettled due to their proximity to the Project.

The majority of vegetation to be cleared or inundated to construct the mine and FRHEP infrastructure will be in the immediate vicinity of the open-pit and ISF. The ISF, open-pit, haul roads and access road for the mine are unlikely to be visible from villages or rivers as they are largely visually enclosed from view (see Chapter 7, Figure 7.1).

There will be no direct views to night lighting of the open-pit and mine infrastructure area; however, brightening of the night sky above these facilities may be seen from some vantage points.

Post closure, the open-pit will be allowed to flood and will resemble a lake with exposed highwalls. Exposed areas will be allowed to regenerate. Other mine infrastructure will be decommissioned and removed or recycled, where possible, or utilised by stakeholders, where agreed. The ISF will remain in place after mine closure. While the mine and FRHEP infrastructure will permanently change the landscape, it is not discussed further as it is unlikely to be visible to residents from nearby villages or travelling on rivers.

Infrastructure Corridor

The infrastructure corridor includes the pubic road from Vanimo to Hotmin, mine access road, concentrate pipeline, Green River Airport, Northern Transmission Line and other ancillary infrastructure.

The existing road from Vanimo to Green River will be upgraded and a new public road constructed from Green River to Hotmin (Hotmin Road). As an existing road, the Vanimo to Green River Road is already a visually prominent feature in the landscape and as such is not discussed further. Construction of the 110 km Hotmin Road from Green River to Hotmin will involve the following activities that will affect the landscape character in essentially the same way as the existing Vanimo to Green River Road, i.e.,

- Clearing an approximately 40-m-wide road corridor.
- Steep cuttings in the sides of hills.
- Construction of bridge crossings. The Sepik River bridge will be constructed from a steel box girder superstructure and will be the largest of the bridges. The bridge will consist of a dual lane deck and have a total length of 350 m. It will be approximately 25 m above the river bed.

The Northern Transmission Line will be a new 370 km 275 kV transmission line from the hydroelectric power facility to the Indonesian boarder, via Vanimo. The transmission line will be located within the infrastructure corridor and will follow the existing Vanimo-Jayapura Highway from Vanimo to the Indonesian border. Towers will typically be located adjacent to the road except where the transmission line alignment deviates from the road in order to follow the straightest possible alignment, and the transmission line will sit within a 50-m-wide right of way. Three substations will be located along the Northern Transmission Line for the transformation of voltage. Two of these will be located along the infrastructure corridor, near Green River and at Vanimo.

River Port Facilities

The Frieda River Port, Upper Sepik River Port and May River Port will be used during construction.

The large visually prominent floodplain hills and smaller river edge knolls located at the river port facilities will be excavated in part and their resultant shaping is likely to contrast with the surrounding environment.

Vanimo Ocean Port

The Port of Vanimo will be upgraded to support the FRCGP and other regional users. The upgraded port will have two international berths, a range of multi-user facilities such as a port office building and night lighting. A concentrate export facility will be developed at the Vanimo Ocean Port for concentrate dewatering and handling. Infrastructure associated with the concentrate export facility will include a concentrate thickener and filter plant, concentrate storage shed, ship loading facility, water treatment plant, bulk diesel pipeline and diesel generators.

Residents of Wesdeco, Lido and parts of Vanimo will experience views of the Vanimo Ocean Port including the concentrate export facility.

Phase of Project

Table 8.10 describes the phases of the Project in which impacts on landscape and visual amenity are predicted to be most applicable.

Table 8.10 Potential landscape and visual amenity impacts in relation to phase of Project

Landscape and visual changes as a result of the Project	Phase			Comment
	Construction	Operation	Closure	
Infrastructure corridor	✓	✓	✓	Construction of the Hotmin Road will result in clearing of a 40 m-wide corridor where dense vegetation currently exists in steep terrain and on the floodplain. The road will remain in operation post-mining and the effects will remain as long as the facilities are maintained (i.e., indefinitely).
Infrastructure corridor (cont'd)	✓	✓	✓	Visually uncharacteristic infrastructure including visually prominent transmission line towers will remain in the landscape following FRCGP closure.
River port facilities	✓	✓		Construction will include clearing of riverbank vegetation and establishment of infrastructure and security lighting that currently does not exist within the vicinity of the river port facilities. The Upper Sepik River Port and the May River Port will be visible to river traffic during construction only. The Frieda River Port will remain visible to river traffic throughout operation. There may be night time glow from security lighting at the port facilities.

Table 8.10 Potential landscape and visual amenity impacts in relation to phase of Project (cont'd)

Landscape and visual changes as a result of the Project	Phase			Comment
	Construction	Operation	Closure	
Vanimo Ocean Port	✓	✓		Construction of the Vanimo Ocean Port will result in additional infrastructure and night lighting. Infrastructure associated with the concentrate export facility will be dismantled and removed following cessation of FRCGP operations, however the Vanimo Ocean Port will remain as a permanent facility.

8.3.3 Management Measures

Progressive rehabilitation will be undertaken where possible, particularly for areas that will be viewed by people from nearby villages. This rehabilitation and revegetation will, to a large degree, act to ameliorate the visual impact of construction activities.

Section 8.6 outlines management measures to limit impacts on biodiversity that will also assist in managing landscape and visual amenity impacts. Additional measures proposed to limit the visual impact from various infrastructure components and activities are detailed in Table 8.11.

Table 8.11 Landscape and visual amenity management measures

No.	Management Measure
MM016	Landscape restoration (i.e., revegetation) will be undertaken on cut faces of hills where access roads are constructed, where practicable.
MM017	Landscape restoration (i.e., revegetation) will be undertaken at all disturbed areas associated with the Sepik River bridge and other river crossings.
MM018	Security lighting on the river ports and Vanimo Ocean Port will be designed to limit obtrusive light, including light spill and glare.
MM019	The form, materials and colour of built form associated with the river port facilities and Vanimo Ocean Port will be designed with consideration of the landscape within which it will sit.

8.3.4 Residual Impact Assessment

Infrastructure Corridor

Construction of the Hotmin Road and associated bridge crossings will result in the establishment of a permanent corridor and features in the landscape that will be retained once mining has ceased. Impacts are expected to be most prominent during construction and the early phases of operation until regeneration begins to provide some degree of cover to disturbed areas such as hillside cuttings and sidecast areas on the verge of the Hotmin Road. Once construction is complete and regeneration is well advanced, the Hotmin Road will look similar to the existing Vanimo to Green River Road.

The Hotmin Road and associated bridge crossings will be visually prominent features for villages in close proximity to the road corridor such as Dioru, Uramesin 2 and Hotmin (Figure 7.30). The village of Simaiye (Figure 7.30) is approximately 2.5 km south of the Sepik River bridge and may be able to see the bridge, depending on the vantage point (Plate 8.1). The area of the view affected by the proposed works will be relatively small within the scale of the landscape. The road cuttings in particular will initially comprise a moderately visually intrusive element within this view, and the proposed construction works will also be a focal point within the view. However, the road cuttings will be revegetated following construction which will reduce their visual prominence, and the regrowth of forest to disturbed areas immediately in front of the cuttings will provide substantial screening.

Excavation and reshaping of the distinctive floodplain hills will cause a permanent change to substantial elements of the landscape in these areas, which will impact on the long-term scenic amenity of residents living in villages in close proximity to the road corridor. These changes will be permanent but will have a negligible effect on the overall landscape. Construction of the Northern Transmission Line, including substations, will result in the establishment of a permanent right of way. The alignment seeks to avoid high ridges and disturbance to villages and will be located to the side of villages where possible, which will limit the impact to visual amenity. Likewise, low lying vegetation within the powerline right of way will be allowed to re-establish once construction is complete, which will also limit the impact to visual amenity. Despite this, the Northern Transmission Line will be a prominent feature in the landscape for public road users and villages located in close proximity to it such as Sumumini, Kilifas, Dioru and Uramesin 2 (Figure 7.30). This infrastructure is also likely to be visible from the upper Sepik River.

Impacts are expected to be most prominent during construction and the early phases of operation until regeneration begins to provide some degree of cover to disturbed areas. Following regeneration, the transmission line will remain as a prominent feature in the landscape for public road users and villages located in close proximity.

River Port Facilities

The river port facilities will be visible to users of the Sepik, Frieda and May rivers. The duration of the view is anticipated to be in the order of an hour or more for hand-paddled canoes to as little as 10 to 15 minutes for canoes powered with outboard motors (AECOM, 2011). While these ports will operate 12-hours-per-day, there will be night time glow from lighting of these facilities for security. From a broad perspective, the river port facilities will be seen as components of a longer journey by local community members when travelling between villages upstream and downstream of the facilities. These journeys may take them past existing concrete jetty structures such as at Pagwi and Timbunge. It can therefore be anticipated that, once the facilities have been observed by river travellers on several occasions, the view of these facilities will be seen as one of passing interest.

From distant locations the river port facilities will be seen as relatively small components within a broad panoramic view of the Sepik River, Frieda River and May River floodplains and floodplain hills, and a backdrop of the highlands. However, when viewed directly, the river port facilities are predicted to considerably change the landscape and visual amenity for the following reasons:

- The development along the edge of these rivers will be highly visible and comprise a detailed view when observed at close range.
- The composition of the river edge elements will be a visual contrast to the surrounding landscape and present a visually dominant and incongruent element.
- Visually important landscape elements in the form of the river edge knolls and hills will be reshaped with engineered forms that will be in strong contrast to other existing examples of

these features within the landscape. The capacity of the landscape for natural regeneration will continue to mitigate visual impacts to the reshaped floodplain hills and floodplain areas rehabilitated post closure (AECOM, 2011) such as at the Frieda River Port, but will only partially remedy the permanent changes brought about by the reshaped hills in what was a previously undisturbed landscape.

- There will be a night time glow from security lighting at the facilities.

Vanimo Ocean Port

A visualisation has been prepared of the Vanimo Ocean Port as viewed from the shoreline near the Vanimo fish market (plates 8.2 and 8.3), which depicts that the facility will be a visually prominent element when viewed from the Vanimo shoreline. In particular, the concentrate shed, bulk diesel tanks, conveyor and to a lesser extent, vessels at berth will dominate the view from this location. The visual amenity of settlement of Wesdeco is already affected by its location behind the Vanimo Forest Products wharf facility and corrugated iron fence, which limits views of the coast and so is unlikely to be significantly impacted by the Vanimo Ocean Port. The Vanimo Ocean Port, including the concentrate export facility, will also change the character of the view from parts of Vanimo and Lido village, situated approximately 8 km west of Vanimo on the other side of Dakriro Bay. These areas look directly at the Vanimo Ocean Port. The night light source from the Vanimo Ocean Port will add to existing lighting in the night time landscape around Vanimo creating additional night time glow.

8.4 Groundwater

This section describes the potential impacts to groundwater-related environmental values (groundwater values) as a result of Project activities. It presents the assessment method adopted, the potential impacts to groundwater values, the management measures that will be employed to reduce these impacts, and the residual impact assessment.

The discussion presented in this section is primarily based on groundwater modelling completed by Australasian Groundwater and Environmental Consultants (AGE) (Appendix 4) and a subsequent impact assessment by Coffey described within this section.

8.4.1 Approach to Impact Assessment

The impact assessment method adopted for this groundwater study is consistent with the significance assessment described in Section 8.1. It considers both the sensitivity of groundwater values and the magnitude of potential impacts on the values to determine the significance of the impact.

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 any potentially significant impacts.
- Assess the magnitude of impacts, and the significance of potential impacts to groundwater values, following the application of management and mitigation measures.
- Identify and assess the significance of any potential cumulative impacts.

Plate 8.1
Visualisation of the proposed Sepik River bridge crossing when viewed from the Sepik River

Plate 8.2
Visualisation of the proposed Vanimo Ocean Port when viewed from the shoreline of Vanimo

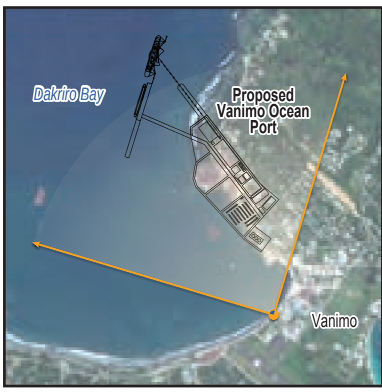


Plate 8.3
Proposed Vanimo Ocean Port visualisation viewpoint location and field of view

Groundwater Values

Based on the description of the existing environment (Section 7.1.5), groundwater is identified as having the potential to support the following beneficial uses:

- Consumptive purposes (i.e., drinking water).
- Ecosystems (i.e., baseflow contribution to watercourses, springs, wetlands and some terrestrial vegetation).

Impairment of either groundwater availability (quantity) or groundwater quality as a result of Project activities may impact these beneficial uses of groundwater. Therefore, the following groundwater values are defined:

- Groundwater quantity.
- Groundwater quality.

The use of groundwater and groundwater dependent surface water features (e.g., springs and watercourses) by local communities is summarised in Section 7.3.4.

Sensitivity of Groundwater Values

Sensitivity is defined as the susceptibility of groundwater systems to changes in quantity or quality, including the capacity of groundwater systems to adapt to, or accommodate, the kinds of changes that the Project may bring about. It also considers the intrinsic importance of the resource to groundwater users.

The groundwater-specific criteria for defining the sensitivity of groundwater values adopted in this assessment are provided in Table 8.12.

Table 8.12 Criteria for sensitivity of groundwater values

Sensitivity	Low	Medium	High
Formal status/value; importance to society and community	Reliance on groundwater for consumptive and productive uses and/or maintenance of ecosystems is low or on a local scale only.	Reliance on groundwater for consumptive and productive uses and/or maintenance of ecosystems is moderate.	Reliance on groundwater for consumptive and productive uses and/or maintenance of ecosystems is high or groundwater provides a regionally important resource.
Vulnerability	Similar groundwater resources occur locally and regionally.	Some similar groundwater resources occur locally or regionally.	The groundwater resource does not have local or regional equivalents.
Vulnerability (cont'd)	The groundwater system can readily adapt to change.	The groundwater system has some capacity to adapt to change.	The groundwater system has limited or no ability to adapt to change.
	The groundwater system is able to fully recover from change.	The groundwater system can recover from change over a medium term period.	The groundwater system has a long recovery period or cannot fully recover from change.

Based on these criteria and the understanding of the existing environment established in Chapter 7, the assessment of groundwater value sensitivity is presented in Table 8.13.

Table 8.13 Groundwater value sensitivity

Groundwater value	Sensitivity	Justification
Groundwater quantity	Low	Limited/no reliance on groundwater resources in the study area and an expected ability of groundwater systems to adapt to and recover from change as a result of high recharge rates (recovery from groundwater drawdown) and/or relatively high hydraulic conductivity (dissipation of groundwater mounding).
Groundwater quality	Low	Limited/no reliance on groundwater resources in the study area, similar systems are expected to occur on local and regional scales and the expected ability of groundwater systems to recover from change as a result of high recharge rates.

Magnitude of impact

The magnitude of an impact is defined as the amount and type of change, including the severity, geographic extent and duration of the impact. Taking into account these factors, groundwater-specific magnitude criteria were developed for the Project and are presented in Table 8.14.

Table 8.14 Criteria for impact magnitude

Consequence Category	Low	Medium	High
Severity of impact	Effects to groundwater quantity and/or quality are not likely to result in a reduced capacity to provide water supply and/or suitable water quality.	Effects to groundwater quantity and/or quality will result in a reduced capacity to provide water supply and/or suitable water quality but effects will not be severe.	Effects to groundwater quantity and/or quality will result in a reduced capacity to provide water supply and/or suitable water quality and effects will be severe.
Geographic extent	Adverse effects to groundwater quantity and/or quality are localised, confined within the Project footprint or to small isolated location(s) outside the Project area.	Adverse effects to groundwater quantity and/or quality extend beyond the area of disturbance to the surrounding area but are contained within the general area (within 10 km of Project area).	Adverse effects to groundwater quantity and/or quality are widespread and may affect groundwater quantity and quality on an intermediate to regional scale (more than 10 km from Project area).
Duration	Project activities will result in temporary or short term (less than 5 years) effects to groundwater quantity and/or quality.	Project activities will result in medium term (less than 20 years) effects to groundwater quantity and/or quality.	Project activities will result in long term (greater than 20 years) or permanent effects to groundwater quantity and/or quality.

8.4.2 Potential Impacts

The process of identifying potential groundwater impacts assumes that Project facilities will be constructed, operated and maintained according to good practice, and consistent with the Project environmental design objectives. In addition, it also assumes that the hazardous materials management plan (including spill response) in the Project's EMMP will be implemented where required and specific groundwater management measures have been developed to limit the potential for hazardous material spills and leaks.

Potential impacts with regards to changes in groundwater quantity and quality during construction, operation and closure of the Project include:

- Groundwater drawdown, mounding and changes to groundwater flow caused by:
  - Extraction of groundwater as part of open-pit dewatering during operation.
  - Permanent changes to the natural surface topography and local groundwater system during mine development and following mine closure.
  - Permanent lowering of groundwater elevation post closure due to the establishment of open-pit spill points.
  - Hydraulic loading from the ISF resulting in increased recharge to groundwater systems.
- Solute migration caused by:
  - Seepage from the ISF (during operation and closure).
  - Seepage from the open-pit lakes (closure).
  - Landfill seepage.
  - Accidental spills and leaks of hazardous materials directly or indirectly (infiltration) to the shallow groundwater systems.

As a result of the above, potential impacts on groundwater quantity are:

- Permanent or temporary impairment of the aquifer or groundwater system.
- Permanent or temporary loss or reduction of baseflow contributions to surface water features including rivers, springs and groundwater-dependent ecosystems.

As a result of the above, potential impacts on groundwater quality are:

- Reduced quality of groundwater discharging to rivers and springs and supporting local groundwater dependent ecosystems.

Potential impacts on groundwater are primarily associated with Project activities in the mine and ISF area. The majority of effects, and therefore this assessment, concentrate on these areas.

The establishment of access roads, the concentrate pipeline, transmission lines and other mine ancillary infrastructure may interfere with shallow groundwater systems to a limited extent through compaction of softer sediments in the lowlands. Potential effects on aquifer characteristics will be limited and highly localised, and therefore are not subject to further assessment.

Groundwater impacts resulting from natural hazards and/or Project accidents are considered in Chapter 11 and are not discussed further in this section.

Table 8.15 presents a summary of the potential groundwater impacts that are carried through the significance assessment, and the relevant Project phases.

Table 8.15 Potential groundwater impacts in relation to phase of the Project

Project activity	Potential Impact	Phase			Comment
		Construction	Operation	Closure	
Groundwater Quantity					
Open-pit dewatering during mine operation.	Reduced groundwater availability for existing groundwater users including ecosystems.	✓	✓		Dewatering will be undertaken during mining and will cease at the end of the operation period.
Permanent changes to the natural surface topography and local groundwater system	Reduced groundwater availability for existing groundwater users including ecosystems.		✓	✓	Some permanent lowering of groundwater levels will result due to the open-pit spill points below current groundwater elevation.
Operation of the ISF.	Mounding or increased recharge of groundwater systems caused by increased hydraulic loading from the ISF.		✓	✓	Mounding as a result of ISF inundation will commence during operation and the effects will remain as long as the facility is maintained (assumed indefinitely).
Groundwater Quality					
Disposal of waste rock and tailings to the ISF.	Infiltration of low quality water from the ISF to shallow groundwater affecting the quality of groundwater resources in receiving environments.		✓	✓	Seepage will commence during operation following placement of tailings and waste rock in the ISF and will continue post mining.
Storage of impacted water in the open-pit lakes.	Seepage from open-pit lakes affecting the quality of groundwater resources used by villagers and ecosystems.			✓	The open-pit void (i.e., the combined HITEK open-pits) will fill at closure, resulting in the potential for AMD-impacted open-pit water to seep into the shallow aquifer and impact down-gradient receiving environments.
Operation of the Project landfill	Seepage (leachate) from the landfill affecting the quality of groundwater resources in receiving environments.	✓	✓	✓	The landfill will receive domestic and industrial waste, medical and laboratory waste and hydrocarbon impacted soil.
Uncontrolled release of chemicals and fuel	Spills and leaks from chemicals and fuel causing contamination of shallow groundwater	✓	✓		There are a number of construction, mining and mineral processing activities that require the use of hazardous liquid chemicals, additives and hydrocarbon fuel.

The following sources of information have been referenced when considering and assessing impact magnitude arising from Project activities:

- The baseline groundwater characterisation (Section 7.1.5).
- The Regional Groundwater Assessment completed by AGE, the results of which are provided

in Appendix 4. This assessment including numerical groundwater modelling to predict:

  – The rate of groundwater flow into the open-pit and the associated decline of groundwater levels (drawdown) in the surrounding aquifers.
  – The increase in groundwater levels (mounding) associated with seepage from the ISF.
  – Changes to the hydrogeological regime with respect to groundwater contribution to watercourses.
  – The fate of groundwater sourced from the open-pit and ISF (particle tracking) following cessation of mining.

- The Site-wide Water Balance and Site-wide Load Balance reports completed by SRK, the results of which are provided in Appendix 6a and 6b. This includes summaries of relevant inputs from other technical studies regarding water chemistry modelling to predict the quality of water entering and leaving the open-pit and the ISF, and estimates of seepage through the ISF embankment.

8.4.3 Management Measures

Table 8.16 presents an overview of the proposed management measures that will be adopted to limit the potential impacts of the Project on groundwater quality and quantity during construction, operation and closure.

Table 8.16 Groundwater management measures

Groundwater management ID	Management Measure Description
MM020	Limit potential impacts to groundwater during all Project phases including: • Comply with the relevant statutory requirements and Australian standard AS 2243.10 (Standards Australia, 2004) for hazardous materials transportation, storage, handling and disposal. • Conduct leak detection during commissioning of pipelines and manage hydrotest water appropriately. • Develop and implement a waste minimisation, waste handling and disposal strategy.
MM021	Divert clean water upstream of the open-pit, where practicable, around the open-pit to avoid generating additional contact water (i.e., water making contact with the open-pit walls and therefore assumed to be contaminated).
MM022	Upon closure, the open-pit lake will be allowed to form over as short a period as possible and surface water from non-AMD contact areas around the open-pit will be diverted to: • Allow groundwater levels to return to static conditions/prescribed spill point levels as quickly as possible. • Reduce the amount of time that PAF materials in the open-pit wall below the final inundation level and floor are exposed to atmospheric conditions, therefore minimising the potential for acid generation and mobilisation of metals.
MM023	Design and operate the ISF to limit the potential for AMD including: • Store PAF materials subaqueously. • Manage potentially contaminated water from the open-pit. From Year 1 and during operations, treat open-pit contact water (using a high-density sludge lime treatment system) with treated water discharged to Ubai Creek which flows into the ISF. Deposit the water treatment solids (sludge) within tailings in the ISF. • Maximise the upslope diversion of ‘clean’ non-contact water around mining and other disturbed areas.

Table 8.16 Groundwater management measures (cont'd)

Groundwater management ID	Management Measure Description
MM024	Design, construct and operate the Project landfill in accordance with the *Environmental Code of Practice for Sanitary Landfill Sites, PNG* (2001).
MM025	Prior to excavation of open-pits or filling of the ISF, a groundwater monitoring program (quality and level) will be developed. The monitoring program will provide a baseline for monitoring impacts during operation of the Project.

8.4.4 Residual Impact Assessment

An assessment of predicted residual impacts on groundwater quantity and quality has been made following application of the proposed management measures outlined in Section 8.4.3. Residual impacts on groundwater values and their significance are discussed below and are summarised in Table 8.17.

A calibrated numerical groundwater model was developed by AGE to predict drawdown, open-pit seepage rates, groundwater mounding, change to surface water baseflow, and post closure groundwater recovery. The modelling outputs are the primary source of the information used to assess predicted residual impacts on groundwater values unless otherwise referenced. Details of the model development, data inputs, model calibration and results are presented in Appendix 4.

Groundwater Quantity

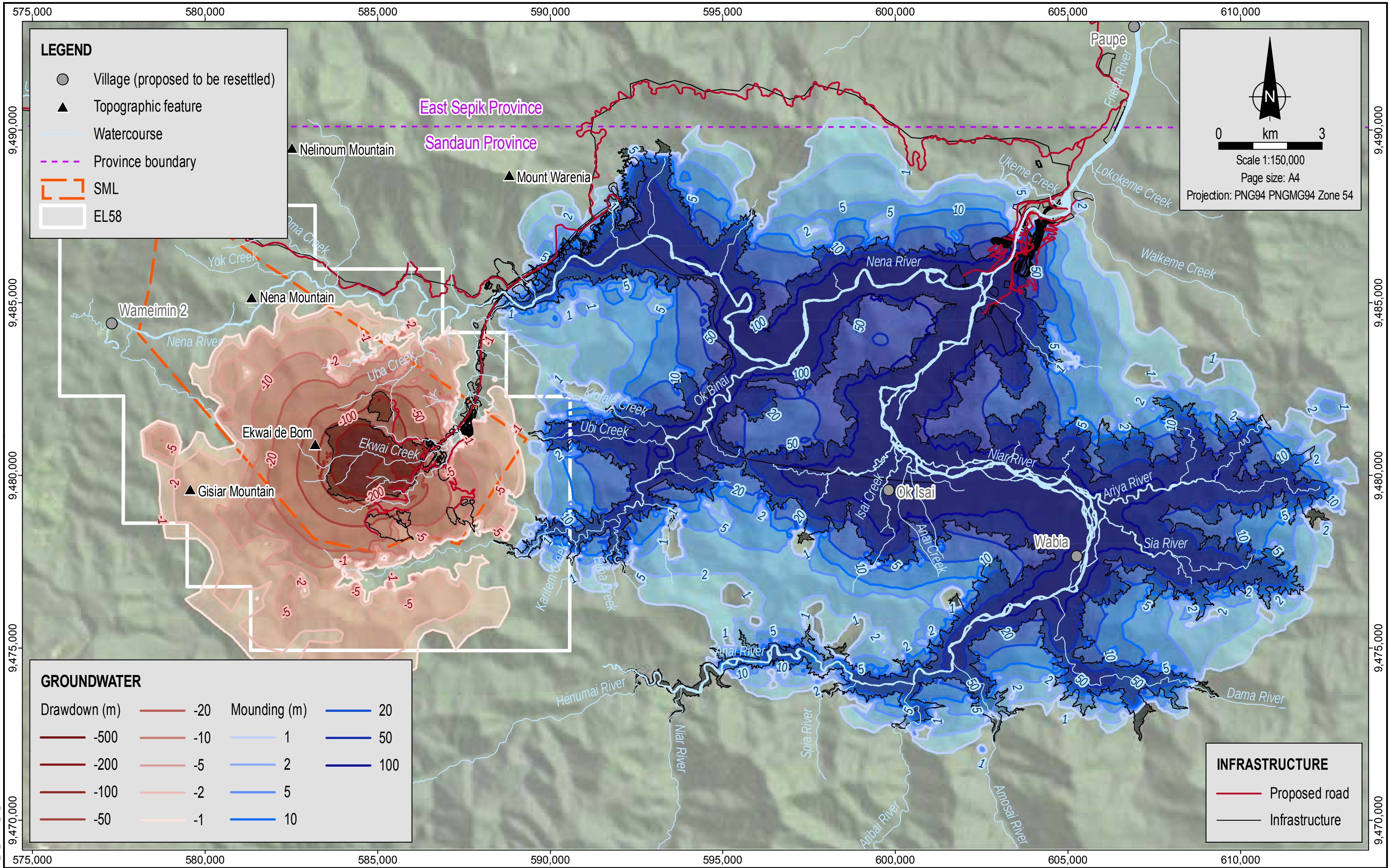
Permanent or Temporary Reduction of Groundwater Availability

Groundwater extraction over the life of mining operations is required to depressurise and dewater the open-pit to enable mining to proceed safely and productively. This will result in lowering of surrounding groundwater levels and an altered hydrogeological regime, with the open-pit acting as a groundwater sink (i.e., point of groundwater discharge). At the completion of mining, dewatering activities will cease and the open-pit void (i.e., the combined HITEK open-pits) is predicted to fill within three years to form the final open-pit lake, to the prescribed spill points. Groundwater will continue to flow through the open-pit lake to the ISF following open-pit lake formation.

Numerical groundwater modelling was carried out to simulate the influence of mining and post-mining operations on groundwater levels. Figure 8.1 presents the predicted groundwater drawdown from static conditions at the final year of mining (Year 33) and Figure 8.2 presents the predicted groundwater drawdown post closure.

The model outputs presented in Figures 8.1 and 8.2 are representative of regional groundwater level changes in the weathered geological profile at a catchment scale in response to mining activities. These figures show that the spatial extent of drawdown (defined as the 1 m drawdown contour) extends 5 to 6 km radially from the open-pit centre at the end of mining, impacting primarily the Nena River, Ekwai Creek and Ok Binai catchments, as well as a small portion of the upper Anai River catchment. The numerical model predicts that groundwater drawdown around the mine will be offset by recharge contributed by nearby surface water features, primarily Ok Binai to the south.

The predicted drawdown presented in Figures 8.1 and 8.2 represents the maximum localised drawdown within shallow aquifers in the immediate vicinity of the open-pit. The maximum



Source:
Groundwater drawdown data from AGE.
Infrastructure, roads and tenements from FRL.
Villages, topographic features, watercourses and water bodies from FRL and Coffey.
Provinces from NMB.
Hillshade DEM from SRTM.

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Date: 14.09.2018
Project: 754-ENAUABTF11575A
File Name: 11575_11_F08.01_GIS

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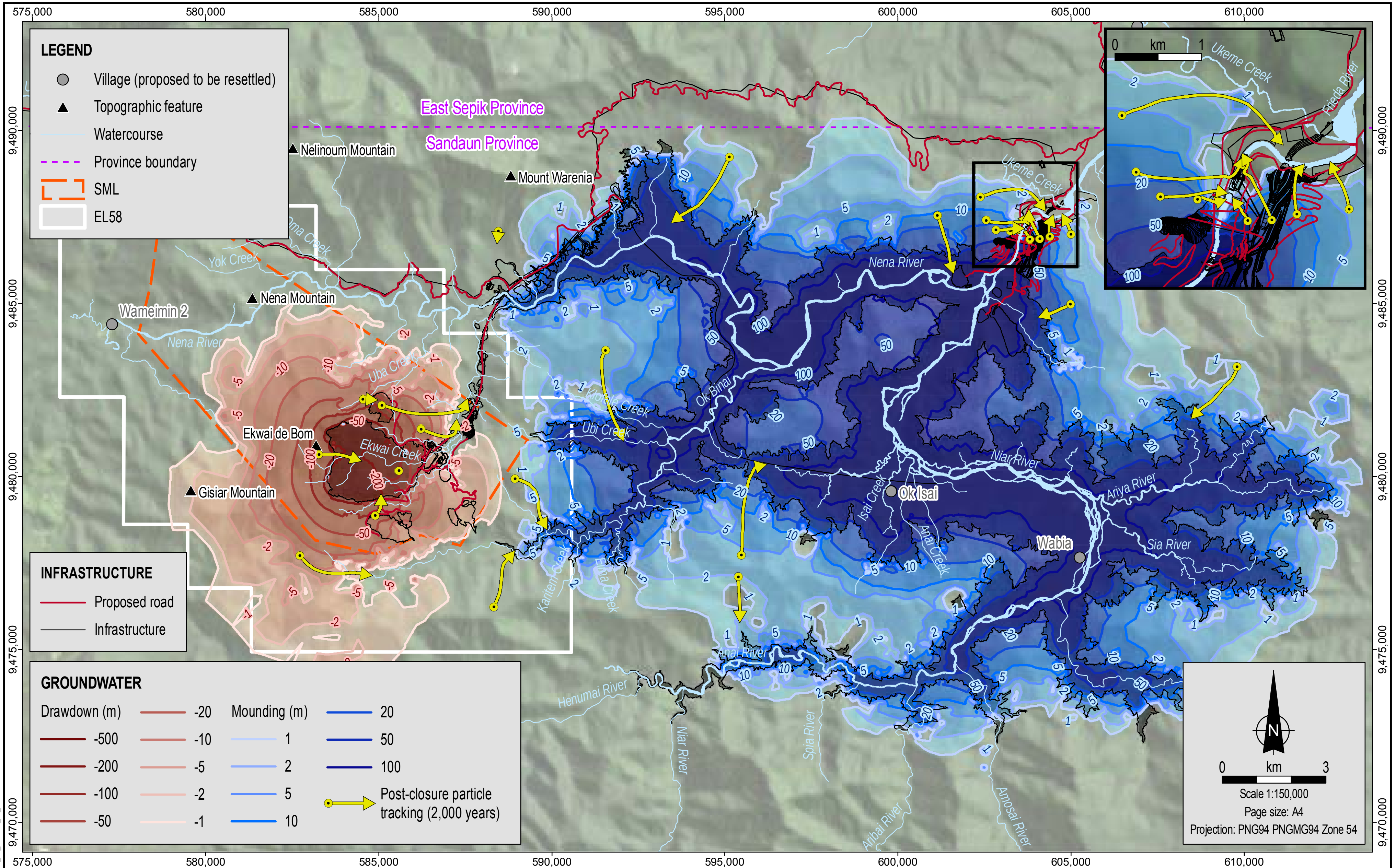
Sepik Development Project

FRIEDA RIVER

Predicted groundwater drawdown at end of mining

Figure No: 8.1

MXD Reference: 11575B_11_GIS023_v0_5



Source:
Groundwater drawdown data from AGE.
Infrastructure, roads and tenements from FRL.
Villages, topographic features, watercourses and water bodies from FRL and Coffey.
Provinces from NMB.
Hillshade DEM from SRTM.

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Project: 754-ENAUABTF11575A
File Name: 11575_11_F08.02_GIS

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Sepik Development Project

FRIEDA RIVER

Predicted groundwater drawdown post closure

Figure No: 8.2

predicted drawdown within other (deeper) modelling layers will be confined to the main HIT open-pit area and is consistent with the final depth of the open-pit below the watertable/potentiometric surface (i.e., up to 500 m).

Reduced groundwater availability during mine dewatering is predicted to result in reduced baseflow contribution to the major rivers and creeks in the mine area. After approximately two years of mining, reduced groundwater levels around sections of Ekwai Creek that are outside the open-pit footprint are predicted to result in the loss of all baseflow contributions from groundwater. After 33 years of operation, it is predicted that baseflow in Nena River and Ok Binai catchments will reduce by 19% and less than 3%, respectively. These effects may be less noticeable during wet periods where rainfall runoff accounts for a high proportion of stream flow. However, during dry periods the inverse is true, with baseflow accounting for most of the total stream flow. Therefore, the potential exists for aquatic ecosystems particularly of Ekwai Creek and the upper reaches of Nena River to be impacted by reduced flow rates particularly during dry periods. Section 8.5 presents the assessment of this impact on aquatic ecosystems.

Dewatering of the open-pit is required throughout the period of active mining. Inundation of the mine voids will commence immediately following the termination of dewatering. While groundwater levels immediately surrounding the open-pit lake are predicted to recover rapidly following the cessation of mining, permanent groundwater level drawdown will occur due to the establishment of open-pit spill points at elevations ranging from 100 to 200 m below the pre-mining groundwater level.

The zone of groundwater drawdown at the end of mining (shown by the 1 m drawdown contour in Figure 8.1) remains largely unchanged post closure, and represents the maximum zone of potential impact to groundwater and groundwater dependent ecosystems (if found to exist). While the total area of groundwater drawdown is likely to remain unchanged post closure, groundwater levels within the drawdown zone undergo a period of flux towards a new point of equilibration. Following inundation of the open-pit, groundwater in the immediate vicinity will recover quickly towards the new spill point elevation. Groundwater drawdown continues to occur at distances further from the open-pit with the 20 m and 50 m drawdown contours predicted to expand by a further 300 m to 500 m away from the open-pit.

The closest mapped swamp woodland and forest complexes, which typically include stands of sago, are located in the Sepik floodplains (refer Appendix 8b) well downstream of the mine area. Therefore, impact to sago as a result of groundwater drawdown around the open-pit is not predicted.

The predicted reduction of baseflow contribution to Ekwai Creek, Nena River and the Ok Binai catchments at the end of mining are likely to remain permanently post closure. The assessment of impacts on aquatic ecosystems resulting from reduced baseflows post closure is discussed further in Section 8.5.

As groundwater drawdown is contained to within 5 to 6 km of the open-pit, and groundwater is not used by villages in this area, the residual impact magnitude on groundwater users resulting from reduced groundwater availability is assessed as **low**. The **low** sensitivity of groundwater quantity to open-pit dewatering, combined with a **low** residual impact magnitude, results in a **negligible** residual impact significance.

The magnitude of the residual impact to ecosystems is assessed as **medium**, as the predicted impacts extend beyond the area of disturbance and permanent lowering of the watertable will occur. The **low** sensitivity of groundwater quantity to open-pit dewatering, combined with a **medium** residual impact magnitude, results in a **minor** residual impact significance.

Mounding due to ISF

The ISF will receive a substantial volume of water from natural and Project sources. The ISF will inundate portions of the Nena and Niar river catchments, and their tributaries, with a total footprint of 12,700 ha. This will result in hydraulic loading of the underlying groundwater systems.

Groundwater mounding is predicted in the vicinity of the ISF during operation (see Figure 8.1) with modelling predicting mounding in excess of 150 m above the current elevation of the Frieda River and its tributaries. Groundwater mounding (1 m or greater) is predicted to extend 2 to 4 km from the Nena River and lower sections of the Niar River. Mounding in the upper sections of the Niar River and its major tributary, Anai River, is predicted to be limited to a narrower zone extending 200 to 800 m from the edge of the inundation zone. Groundwater modelling indicates the ISF will maintain a groundwater mound post closure (see Figure 8.2). Given the steep topography surrounding the ISF, catchment scale groundwater flow continues to be towards the reservoir as demonstrated by particle tracking in Figure 8.2. The only significant movement of groundwater will occur near the ISF embankment, with the steepest hydraulic gradient occurring through the embankment.

The magnitude of residual impacts on groundwater users as a result of groundwater mounding is **low** as there will be no reduction in groundwater availability. Combined with a **low** groundwater value sensitivity, the residual impact significance is **negligible**.

The residual impact magnitude to groundwater-dependent ecosystems is assessed as **medium** as increased groundwater levels may result in waterlogging in some areas and/or affect ecosystem health due to the altered timing of groundwater accessibility. The sensitivity of groundwater systems to changed recharge conditions is **low**, therefore the residual impact significance is **minor**.

Groundwater Quality

Existing groundwater quality reflects the nature of the orebody mineralisation (Section 7.1.5), including some dissolved metal concentrations exceeding the adopted guidelines for protection of ecosystems and drinking water.

Mining operations have the potential to result in impaired groundwater quality, in particular via the generation of AMD from oxidation of PAF materials which is selectively present in the extracted ore and waste rock, process tailings from the concentrator and open-pit walls.

Impact of Seepage from the Open-Pit Lake

Much of the open-pit material has been identified as PAF and water quality issues associated with AMD may arise during and following the cessation of mining. Throughout the mine life, surface water runoff and groundwater seepage into the pit is predicted to be acidic (pH ranging from 2.8 to 3.7) and contain elevated concentrations of metals, in particular copper (up to 43 mg/L) and iron (up to 295 mg/L). This AMD contaminated water will be collected in the in-pit sumps and treated prior to release. Water quality modelling completed by SRK (Appendix 6b) assumes the treatment of acidic open-pit water with lime during operation. The resultant water quality of discharge to Ubai Creek will meet the specified treatment criteria. Diversion drains directing water around the open-pit (i.e., surface water from non-AMD contact areas) will be constructed to reduce the volume of impacted water requiring treatment.

At closure, the open-pit void will be allowed to fill as soon as possible to reduce the potential for AMD generation. Post closure, the open-pit lake will become a flow-through surface water feature, gaining groundwater from up-hydraulic gradient and discharging down-gradient via the open-pit lake spill point, where contaminated water will be collected for treatment until closure water quality criteria are met.

The magnitude of the impact of seepage from the open-pit lake, including during operation and post closure, affecting the quality of groundwater resources for groundwater users is assessed as **low** as there are no known groundwater users within the area of predicted impact, and contaminated groundwater generated flowing across PAF surfaces during mine activities will be collected and treated. As the sensitivity of the receptor is **low**, the residual impact significance is assessed to be **negligible**.

The residual impact of open-pit water seepage on groundwater-dependent ecosystems is assessed as having a magnitude of **medium** as there may be some localised groundwater-dependent ecosystems affected by altered groundwater quality. The **low** sensitivity of groundwater quality, combined with a **medium** residual impact magnitude, results in a **minor** residual impact significance.

Impact of Seepage from the ISF

The ISF has been designed to prevent the stored materials from becoming desaturated and exposed to atmospheric conditions, thus eliminating the risk of further AMD development once tailings and waste rock are placed under water. Seepage from the ISF is predicted to discharge through and around the ISF embankment.

Groundwater particle tracking (Appendix 4) indicates that groundwater sourced from the ISF is likely to migrate slowly, with the rate of movement predicted to be 2,500 m after 2,000 years.

Water quality predictions for the ISF are presented in Appendix 6b. These show:

- pH is neutral throughout operations.
- Sulphate concentrations are below relevant human health and ecological water quality guidelines.
- Concentrations of aluminium, copper and zinc exceed ANZECC/ARMCANZ (2000) 95% species protection for freshwater ecosystems. Dissolved zinc concentrations are within the natural range of background concentrations. Under low flow conditions the concentration of dissolved chromium within the ISF may also exceed the adopted freshwater ecosystem protection criteria.

Seepage discharging from the ISF is predicted to be constrained to the Frieda River catchment with the primary movement of groundwater occurring towards and through the ISF embankment. The magnitude of the impact of seepage from the ISF on groundwater quality supporting existing users is assessed as **low** as there are no known users of groundwater in the area predicted to be impacted, and the seepage rate is **low**. The sensitivity of the groundwater system to altered water quality is also assessed as being **low**, therefore the residual impact significance is **negligible**.

Frieda River is likely to be the primary discharge point for groundwater migrating beyond the embankment. The chemistry of the Frieda River downstream of the ISF has been modelled to reflect the chemistry of water discharging from the ISF. The contribution of water from the ISF to the Frieda River via groundwater will be insignificant compared to surface water flow, therefore the magnitude of impact from groundwater seepage from the ISF to the aquatic ecosystem of Frieda River will be **low**.

The assessment of impact on groundwater-dependent ecosystems other than the Frieda River as a result of impaired groundwater quality due to ISF seepage is assessed as having a magnitude of **medium** because discharge of contaminated water to groundwater-dependent features may occur and may affect ecosystem health. The sensitivity of the groundwater system to change in water quality is **low**, therefore the residual impact significance is **minor**.

The closest mapped swamp woodland and forest complexes, which typically include stands of sago, are located in the Sepik floodplains (refer Appendix 8b) well downstream of the ISF area. Therefore, impact to sago as a result of impaired water quality seepage from the ISF is not predicted.

Impact of Seepage from the Landfill

The landfill will receive a range of domestic and industrial waste streams. The landfill will be designed and constructed in accordance with relevant standards and conditions of the Project's environment permit, including lining the landfill with an impermeable barrier and establishing a leachate management system.

The magnitude of the impact of landfill leachate seepage on groundwater quality supporting existing users is assessed as **low** as appropriate design, construction and operation of the landfill will reduce the potential for leachate seepage to shallow groundwater, and there are no known users of groundwater in the vicinity of the upstream disturbance area where limited impact may occur. The sensitivity of the groundwater system to altered water quality is also assessed as being **low**, therefore the residual impact significance is **negligible**.

The assessment of impact on groundwater-dependent ecosystems as a result of impaired groundwater quality due to landfill leachate seepage is assessed as having a magnitude of **low** as Project design, construction and operation of the landfill in accordance with relevant standards will limit the potential for leachate seepage. Where seepage does occur, the effects will be highly localised and are not likely to result in a reduced capacity to support ecosystems given the abundance of surface water contribution. At the cessation of mining the landfill will be rehabilitated (i.e., capped) such that leachate production is reduced. The sensitivity of the groundwater system to change in water quality is **low**, therefore the residual impact significance is **negligible**.

Table 8.17 Summary of groundwater residual impact assessment

Impact				Relevant management measures	Residual Impact Assessment		
Project infrastructure or activity	**Potential impact**	**Project phase**	**Potentially affected groundwater value**		**Magnitude of impact**	**Sensitivity**	**Residual impact significance**
Open-pit dewatering during operation and permanent groundwater lowering post closure due to spill points.	Reduced groundwater supply to village springs/wells	Operation and closure	Groundwater quantity	• MM017 (rapid open-pit lake development post closure) • MM020 (establishment of a groundwater monitoring program)	Low	Low	Negligible
	Reduced groundwater supply to ecosystems	Operation and closure	Groundwater quantity	• MM017 (rapid open-pit lake development post closure) • MM020 (establishment of a groundwater monitoring program)	Medium	Low	Minor
	Contamination in seepage from the open-pit lake affecting the quality of groundwater resources to village springs/wells	Operation and closure	Groundwater quality	• MM015 (impacted water collection and treatment) • MM016 (contact water management) • MM020 (establishment of a groundwater monitoring program)	Low	Low	Negligible
	Contamination in seepage from the open-pit lake affecting the quality of groundwater resources to ecosystems	Operation and closure	Groundwater quality	• MM015 (impacted water collection and treatment) • MM016 (contact water management) • MM020 (establishment of a groundwater monitoring program)	Medium	Low	Minor
Formation and operation of the ISF.	Increased groundwater levels in systems that support village springs/wells	Operation and closure	Groundwater quantity	• MM020 (establishment of a groundwater monitoring program)	Low	Low	Negligible

Table 8.17 Summary of groundwater residual impact assessment (cont'd)

Impact				Relevant management measures	Residual Impact Assessment		
Project infrastructure or activity	**Potential impact**	**Project phase**	**Potentially affected groundwater value**		**Magnitude of impact**	**Sensitivity**	**Residual impact significance**
Formation and operation of the ISF (cont'd)	Increased groundwater levels in systems that support ecosystems	Operation and closure	Groundwater quantity	• MM020 (establishment of a groundwater monitoring program)	Medium	Low	Minor
	Contamination in seepage from the ISF affecting the quality of groundwater resources to village springs/wells	Operation and closure	Groundwater quality	• MM018 (ISF designed to minimise AMD) • MM020 (establishment of a groundwater monitoring program)	Low	Low	Negligible
	Contamination in seepage from the ISF affecting the quality of groundwater resources to ecosystems	Operation and closure	Groundwater quality	• MM018 (ISF designed to minimise AMD) • MM020 (establishment of a groundwater monitoring program)	Medium	Low	Minor
Operation of the Project landfill.	Contamination in seepage from the landfill affecting the quality of groundwater resources to village springs/wells	Construction, operation and closure	Groundwater quality	• MM014 (general waste and hazardous material management) • MM019 (adoption of Landfill code of practice) • MM020 (establishment of a groundwater monitoring program)	Low	Low	Negligible
	Contamination in seepage from the ISF affecting the quality of groundwater resources to ecosystems	Construction, operation and closure	Groundwater quality	• MM014 (general waste and hazardous material management) • MM019 (adoption of Landfill code of practice) • MM020 (establishment of a groundwater monitoring program)	Low	Low	Negligible

8.5 Surface Water and Aquatic Ecology

This section discusses the potential effects of the Project on the three main physico-chemical aspects of the surface water environment: hydrology, sediment transport and water quality. The potential impacts on freshwater aquatic ecology are assessed with management measures and residual impacts described. This chapter is based upon the results of sediment transport modelling completed by Golder Associates, which are reported in Appendix 5, and the results of the hydrology and water quality modelling completed by SRK Consulting, which are reported in the Site-wide Water Balance Report and the Site-wide Load Balance Report presented in Appendices 6a and 6b, respectively. The findings of the ISF Bioaccumulation Report, undertaken by Tetra Tech (Appendix 7b), have also been incorporated into this section. The aquatic ecology impact assessment also draws on the information in the Water Quality, Sediment Quality and Aquatic Ecology Baseline Report presented in Appendix 7a.

8.5.1 Approach to Impact Assessment

The likely effects of the Project on downstream receiving systems are assessed in this section taking into account physical, chemical and biological considerations. This has involved:

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

Spatial and Temporal Scope

Watercourses within the mine area include Uba Creek and Ubai Creek which both discharge into the Nena River upstream of the ISF. The Ok Binai flows into the Nena River to meet the Niar River 9 km downstream. The ISF embankment is located approximately 1 km downstream of the confluence of the Niar and Nena rivers, below which the river is known as the Frieda River which extends 70 km to the confluence with the Sepik River. The Sepik River flows 400 km east to the coast and into the Bismarck Sea.

The spatial extent of the assessment has been determined by the physical transport pathways that link possible sources of stressors to freshwater receiving waters[2]. This assessment therefore

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[2] Assessment of the nearshore marine environment at Vanimo Ocean Port is described in Section 8.10.

focuses on the following locations (see figures 7.17 and 7.18):

- FRCGP and FRHEP area which includes:
  - Creeks and streams in the immediate mine area that drain north to the Nena River including Uba and Ubai creeks.
  - Rivers that will flow into, and will be inundated by, the ISF including the Nena and Niv rivers and Ok Binai and their tributaries.
  - Upper Frieda River, below the confluence of the Nena and Niar rivers, on which the ISF embankment is located.
  - Upstream reaches isolated by Project development.
- Frieda River and off-river waterbodies (ORWBs) downstream of the ISF embankment to the Sepik River.
- The Usake/May and Idam rivers which flow north to meet the Sepik River. These rivers will be intercepted by the infrastructure corridor from the mine site to Green River.
- Sepik River and ORWBs downstream of the confluence with the Frieda River.

The assessment of impacts on surface water and aquatic ecology values focusses primarily on the watercourses within and downstream of the FRCGP and FRHEP area that are likely to be subject to the greatest impact as a result of the Project. Watercourses intersecting the infrastructure corridor between the mine area and Vanimo (within Usake/May, Idam and Horden river catchments) have been assessed at a reduced intensity. These assessments are commensurate with the anticipated duration (i.e., short-term during construction) and intensity (i.e., localised to the immediate vicinity of the infrastructure corridor) of Project activities in each of the respective areas.

The temporal extent of the assessment considers the seven-year implementation period, 33 years of FRCGP operations and FRCGP post closure.

Potential Stressors

Table 8.18 summarises activities associated with the Project that are likely to generate stressors which may impact downstream watercourses.

Table 8.18 Summary of activities and associated stressors

Activity	Pathway	Primary Stressors
Land clearing/earthworks for construction of infrastructure including roads	Erosion	Total suspended solids (TSS) and turbidity Sediment loads Particulate-associated metals and metalloids
Diversion of watercourses (i.e., construction of roads and bridges)	In-stream construction (i.e., watercourse crossings)	Altered hydrology TSS and turbidity
Formation of engineered hard surfaces of Project facilities	Runoff Aggradation or scour of watercourses	Altered hydrology TSS and turbidity

Table 8.18 Summary of activities and associated stressors (cont'd)

Activity	Pathway	Primary Stressors
Quarrying	Erosion	TSS and turbidity Sediment loads Particulate-associated metals and metalloids
Construction and operation of spoil dumps including Ok Binai waste dump	Erosion Aggradation or scour of watercourses	TSS and turbidity Sediment loads Particulate-associated metals and metalloids Dissolved metals and metalloids
Inundation of ISF	Inundation and filling with waste rock and tailings AMD Decomposition of inundated vegetation ISF discharge Bioaccumulation Biomagnification	Physical disturbance Altered flow regime Dissolved oxygen TSS and turbidity Particulate-associated metals and metalloids Dissolved metals and metalloids Sulphate Nutrients
	Dam wall barrier	Altered hydrology Physical obstruction of movement of fish and other aquatic species
	ISF stratification/overturning	Reduced dissolved oxygen and temperature in the ISF at depth Increased dissolved metals and metalloids in the ISF at depth
Mining	Open-pit water discharge AMD	TSS and turbidity Sediment loads Particulate-associated metals and metalloids Dissolved metals and metalloids Sulphate Altered pH Nutrients
Ore processing	Tailings disposal Runoff/spills/seepage	TSS and turbidity Particulate-associated metals and metalloids Dissolved metals and metalloids Processing reagents Flocculants
Open-pit diversion drains/stormwater	Open-pit diversion water discharge Drains/stormwater runoff	TSS and turbidity Particulate-associated metals and metalloids Dissolved metals Altered pH
Road traffic	Runoff Leaks and spills	TSS and turbidity Particulate-associated metals and metalloids Fuel/lubricant/coolant/hydraulic fluid leaks

Table 8.18 Summary of activities and associated stressors (cont'd)

Activity	Pathway	Primary Stressors
Vehicle maintenance	Runoff Leaks and spills	Oil and grease/solvents Fuel/lubricant/coolant/hydraulic fluid leaks Detergents
Accommodation villages/offices	Discharges/runoff/spills/landfill leachate/sewage	TSS and turbidity Particulate-associated metals Dissolved metals Pathogens Nutrients
Mine closure and formation of open-pit lake	Open-pit water discharge AMD Open-pit diversions	Altered flows Dissolved metals and metalloids Sulphate Altered pH

During construction, the primary activity to impact the Nena and Niar river aquatic ecosystems will be the construction and inundation of the ISF as well as mine pre-stripping and bulk earthworks for Project infrastructure. Construction activities and pre-production land clearing with attendant vegetation removal have the potential to expose soils to accelerated rainfall-induced erosion, thereby allowing sediment-laden surface runoff to enter the natural drainage. This will take the form of both washload and bedload sediment. Washload sediment is that which remains in suspension while bedload sediment is that which is transported along the bottom of the watercourse.

Construction of the infrastructure corridor is expected to result in impacts, primarily related to increased sediment loads and TSS; however, these are expected to be short-term (i.e., during construction) and localised due to it traversing mostly flat terrain.

During operations, the primary mine-derived stressors will be trace metals which are naturally contained within the material mined which, upon exposure the atmospheric conditions, can lead to AMD resulting in reductions in pH and increases in dissolved metals and metalloids concentrations. Other chemicals that are typically used during mining and ore processing (e.g., oils, grease and process reagents) and stressors associated with treated sewage effluent are considered to be of minor concern, since wastes and wastewaters will be collected and managed to appropriate standards as described in Chapter 5. Hazardous materials will be managed as described in Chapter 5.

In addition to sediment and water quality stressors, construction and operation of the ISF will potentially impact beneficial values due to changes in stream flow.

Post closure, potential impacts will primarily be from water quality stressors (originating from AMD) discharged from the open-pit and the behaviour of waste rock and tailings stored in the ISF, as well as continued modification of flows downstream of the ISF embankment.

During operations and FRCGP and FRHEP post closure, there is also the possibility that the ISF reservoir may undergo complete mixing, whereby the warmer upper layers mix with the lower cooler layers. This may result in reduced dissolved oxygen and temperature in the upper layers, as well as increased dissolved and particulate-associated metals and metalloids from the deposited waste rock and tailings being released downstream of the ISF.

Surface Water Beneficial Values

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

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

Defining beneficial values requires an understanding of the needs of the biophysical environment, local communities and other relevant stakeholders.

Beneficial values in the Project area can be grouped into the two overarching aspects of aquatic ecosystem health and social values, where protection of aquatic ecosystem health generally protects human health. The discussion below focusses on these two aspects.

Aquatic Ecosystem Protection

Ecological values of the surface water environment were defined through surveys of the Project area as discussed in Section 7.2. These were grouped under the areas of aquatic habitat, aquatic flora and aquatic fauna.

The upper and middle reaches of the Sepik River catchment have high aquatic habitat integrity and conservation value. However, the composition of the fish community within the catchment, particularly in the middle reaches of the Sepik River, has been significantly changed as a result of introduced non-native species.

There were no significant beds of native aquatic flora species observed during the surveys, although there have been extensive lists of species historically reported in the catchment. Non-native aquatic flora species were observed throughout the lower catchment, with infestations of weeds causing issues in the past within the Sepik-Ramu floodplain, such as the blocking of waterways from light penetration and boat traffic.

In regard to aquatic fauna, 60 native species and nine non-native species have been reported in the Sepik River catchment. Seventeen species of fish are of conservation significance, reflecting their threatened or potentially threatened listing, or because of their restricted range (endemism). Of main concern are the IUCN Red List species. These are:

- The sawfish, *Pristis pristis (*formerly *Pristis microdon)*, listed as Critically Endangered, which may occur in the Sepik River and lowland river areas.
- The freshwater gudgeon, *Eleotris aquadulcis*. This species is a Sepik River endemic and listed as Near Threatened. It is likely to be present upstream of the confluence of the Sepik and Frieda rivers.
- The spinach pipefish, *Microphis spinachioides*, which occurs in the Sepik River and lowland river areas.
- The obscure goby, *Mugilogobius fusculus*, which occurs in the lower Sepik River.

A total of 33 native fish species and seven non-native fish species were collected during the 2008 to 2010 baseline surveys and a total of 28 native and seven non-native species were recorded during the 2011 surveys (Appendix 7a). In 2017, fish sampled from sites adjacent to the infrastructure corridor included nine native and one non-native species. Of the IUCN Red List species, only the freshwater gudgeon was sampled upstream of the Sepik-Frieda confluence during the baseline surveys. All three Sepik endemic species were sampled during the surveys, as well as eight of the ten Northern New Guinea endemic species.

There are also two freshwater turtles and two crocodiles recorded in the Sepik River system that are listed under the IUCN Red List as Least Concern or Vulnerable. With the exception of *C. novaeguineae* (Least Concern), all of these species have been observed during field surveys for the Project: the variegated giant softshell turtle (*Pelochelys signifer*a; Vulnerable) was observed at Idam River; and the saltwater crocodile (*Crocodylus porosus*; Least Concern) was recorded at three locations *en route* to sampling sites within large turbid rivers (Section 7.2.6). Schultze's snapping turtle *(Elseya schultzei)*, listed as Least Concern under IUCN, was observed in a small tributary of the Frieda River (Frieda Bend Site). It was also reported as being abundant at a number of sites in the study area by villagers in 2011.

Based on the baseline assessment, the freshwater ecological values potentially affected by the Project were identified as:

- Aquatic habitat.
- Aquatic flora.
- Fish communities.
- Aquatic macroinvertebrates.
- Conservation significant aquatic species.

Social Values

Social values have been generated based on community surveys and a social values workshop with mine area landowners in August 2015. The social values are regarded as qualities of the social environment that are conducive to individual wellbeing, now and into the future, and for which community stakeholders have a high regard. As presented in Chapter 9, six key social values were identified.

Indicators associated with the social values in relation to rivers are:

- Sources of drinking water and water for washing, cleaning and cooking.
- Source of income, e.g., sale of fish, crocodiles (including eggs), shellfish, hard-shell turtles and ecotourism.
- Sources of staple food items, such as fish and sago (which requires washing with clean water) and aquatic plants.
- Transport corridor to access gardens, other villages and health and other services elsewhere.
- Processing of sago.
- Traditional customary activities.

The communities surveyed in 2011, 2015 and 2017 (from Social Catchments 1A to 1D and Social Catchment 2; refer Chapter 7 and Appendix 13) are particularly dependent on sago and fish and highlighted their concern that riverine impacts would impact their food supply and livelihood. The level of participation in, and frequency of, fishing activity ranged from nearly every day to once per month depending on the village's proximity to a river or stocked creek/stream. The most common fish caught were locally referred to as 'rubber mouth' (*Prochilodus argenteus*) and 'bolkata', or

Pacu (*Piaractus brachypomus*), with both being species introduced during the FISHAID program since 1990.

People throughout the Sepik River catchment believe that the river is central to the spiritual and physical wellbeing of people living along its banks.

Summary of Beneficial Values and Potential Issues

The main recognised beneficial values of the surface water environment identified through various studies and surveys are:

- Aquatic ecosystem protection.
- Drinking water supply.
- Domestic uses (e.g., washing, laundry, cooking).
- Agricultural use (e.g., sago making) for both subsistence livelihoods and income production.
- Recreational use and aesthetic enjoyment (e.g., swimming, passive recreation).
- Resource use for consumption of aquatic species (i.e., fishing).
- Navigation.
- Spiritual use.

The main issues and potential impacts on beneficial values associated with development of the Project and which are assessed in the following sections, are identified as being:

- Changes in environmental flow and barrier effects due to construction of Project infrastructure (such as the ISF) with associated physical impacts on aquatic biota and habitat.
- Elevated suspended solids concentrations and sedimentation downstream of disturbed areas, with associated physical impacts on aquatic biota, and acceptability of water quality for human consumption or other beneficial values (use for cooking or washing, navigation, recreation and aesthetic enjoyment).
- Elevated concentrations of metals downstream of the FRCGP and FRHEP area, causing toxic effects on aquatic biota or people who may drink or use the water for gardens or consume the aquatic biota.

The assessment conducted in this section generally refers to potential environmental stressors arising from normal operating conditions. Upset scenarios such as those events involving a significant spill of a hazardous chemical, rupture of the concentrate pipeline or the failure of the ISF are considered in Chapter 11 and not addressed here.

Assessment Criteria

Beneficial values associated with protection of aquatic ecosystems, drinking water and recreational use drive the compliance criteria for contaminants in the aquatic environment.

Dissolved metal concentrations have been used for comparison to aquatic ecosystem protection guidelines since it is the dissolved fraction that is the most directly toxic to organisms in the water column. In contrast, guidelines for human consumption (i.e., drinking water guidelines) have been compared to total metals concentrations since metals in both dissolved and particulate form are potentially available when ingested. This is a conservative approach as it is likely that water taken from rivers or creeks in the Project area would be allowed to settle before consumption (as is common practice in PNG), reducing the sediment, and therefore total metals content, of the water.

Drinking water guidelines have been considered for comparison to predicted concentrations of parameters throughout this chapter. Further assessment of impacts on human health are summarised in Chapter 9 and presented in Appendix 13 and not addressed here.

Surface Water Standards and Guidelines

The surface water impact assessment has been undertaken considering the following regulatory requirements in PNG, as well as referring to other guidelines and standards from elsewhere for guidance:

- PNG regulatory requirements including PNG Ambient Water Quality Standards and the PNG Drinking Water Guidelines.
- Environmental Code of Practice for the Papua New Guinea Mining Industry.
- IFC effluent discharge guidelines.
- International guidelines.

The adopted criteria from these guidelines are provided in Attachment 3 and discussed in the sections below.

PNG Regulatory Requirements

PNG Ambient Water Quality Standards. In PNG, discharges to water are regulated under the Environment Act whereby application for an environment permit is required. When granted, the permit will contain a number of conditions, one of which is expected to be the need to comply with prescribed water quality criteria at the downstream limit of a site-specific mixing zone (described in further detail in the 'Water Quality Objectives: Mixing Zones and Compliance Points' section below) that is applied at the time the permit is granted. These legally enforceable water quality criteria are contained in Schedule 1 of the Environment (Water Quality Guidelines) Regulation 2002.

PNG Drinking Water Guidelines. Schedule 2 of the Public Health (Drinking Water) Regulation 1984 describes legally enforceable standards for drinking water quality which are adopted from WHO International Standards for Drinking Water, 1971.

Environmental Code of Practice for the Papua New Guinea Mining Industry.

The environmental code of practice (ECP), released by the Department of Environment and Conservation (now known as CEPA) (OEC, 2000), describes water quality criteria for protection of freshwater aquatic life and raw drinking water. The ECP is linked to Section 38 of the Environment Act and Section 43 of the *Mining Act 1992* and provides guidance for good environmental practice. Compliance with the ECP is voluntary.

International Guidelines

IFC Effluent Discharge Guidelines*.* The IFC Environmental, Health and Safety Guidelines for Mining (IFC, 2007d) provides water quality guidelines for discharge of effluent from open-pit mining and milling operations. IFC (2007d) is generally accepted, particularly by financiers, as a de facto international standard. These guidelines are mainly adopted in countries that lack adequate national water quality standards. The specified limits are applicable to effluent discharged to receiving waters from tailings impoundments, mine drainage, sedimentation basins, sewage systems and stormwater drainage. These levels should be achieved (without dilution) at least 95% of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours. Any deviation from these levels to account for specific, local project conditions require justification. These guidelines also state that discharges to surface water should not result in contaminant concentrations in excess of local ambient water quality criteria outside a scientifically established mixing zone (IFC, 2007d).

The existing PNG Ambient Water Quality Standards and the PNG Drinking Water Guidelines are based on water quality criteria that have been superseded by advances in knowledge and assessment methods. Meeting these criteria cannot therefore be assumed to provide adequate protection for aquatic ecosystems or human health based on the current state of knowledge of toxicant exposure to biota and people. That is, a possible consequence of the application of only the existing PNG standards is that discharges from the Project could result in adverse impacts while still being in compliance with PNG regulations. Therefore, in addition to the PNG standards, this assessment has also considered the current version of the WHO Guidelines for Drinking-Water Quality (WHO, 2017) and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000) for protection of aquatic ecosystems, as triggers for further investigation.

WHO Drinking Water Guidelines. The current version of the WHO Guidelines for Drinking-Water Quality (2017) is considered in the assessment for human health protection. The guidelines for chemicals in drinking water, in most cases, represent the concentration of a chemical that is not expected to result in any significant risk to health over a lifetime of exposure and assumes the water consumed is the primary drinking water source.

Australian and New Zealand Water Quality Guidelines for Aquatic Ecosystem Protection. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000) are widely regarded as one of the more robust sets of ecosystem protection guidelines available internationally and have therefore been considered for the assessment of impacts to aquatic ecosystems.

ANZECC/ARMCANZ (2000) defines a slightly to moderately disturbed ecosystem as one in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity. Some metals and metalloids concentrations within the watercourses in the FRCGP and the FRHEP areas naturally exceed ANZECC/ARMCANZ (2000) 95% ecosystem protection trigger values based on their proximity to the mineralised zone. Furthermore, historically, a number of exotic fish species have been introduced to the Sepik-Ramu river system for mosquito control; to increase protein sources for people in the catchment; to generate income; and through accidental release from aquaculture facilities. There are now 11 exotic species of fish present in the Sepik-Ramu catchment, nine of which were recorded in the Project baseline studies from 2008 to 2017. Non-native fishes were dominant in lowland river and ORWB habitats comprising approximately three-quarters of the total catch. The downstream aquatic ecosystem within the Project area is therefore considered slightly to moderately disturbed due to the impacts associated with the introduction of non-native fish species. The trigger level for 95% protection of species is generally applied for slightly to moderately disturbed ecosystems and this has been conservatively used for comparison with predicted concentrations of contaminants.

In the context of the assessment conducted here it should be noted that the ANZECC/ARMCANZ (2000) guideline values are intended to be used as trigger values for further investigation, not as primary compliance values. A hierarchy of assessment is recommended when applying these guidelines. A guideline exceedance does not necessarily indicate an environmental impact will occur. Instead, it indicates the need to further investigate site-specific factors. In the case of metals, the following hierarchy is recommended by ANZECC/ARMCANZ (2000):

- Compare total metals concentration to guideline value.
- Compare dissolved metals concentration to guideline value.

- Correct guideline for hardness.
- Consider metal speciation.
- Compare bioavailable metals concentration against guideline value.
- Conduct a biological effects assessment (e.g., direct toxicity assessment) in the event the bioavailable concentration of a toxicant exceeds the guideline value.

Consideration of site-specific factors is especially important when applying these guidelines outside the Australian or New Zealand environment for which they were developed. Derivation of site-specific criteria for protecting aquatic ecosystems is advocated in the ANZECC/ARMCANZ (2000) guidelines since generic water quality guidelines cannot adequately account for the many environmental factors that may affect toxicity at a particular site. Further detailed guidance on derivation of site-specific guidelines is documented in Van Dam et al. (2013). Multiple lines of evidence approaches, integrating both laboratory and field data, are recommended for deriving site-specific water quality guidelines.

As described in Section 8.5.5, aluminium and copper are predicted to be the primary contaminants of concern based on the ANZECC/ARMCANZ (2000) 95% ecosystem protection trigger values in the Frieda River.

In relation to copper, a site-specific trigger value for copper is proposed. This is based on site-specific investigations into copper speciation and its bioavailability (i.e., natural copper complexing capacity) as well as adsorption capacity in the Nena, Frieda and Sepik rivers in line with the ANZECC/ARMCANZ (2000) assessment hierarchy listed previously. Exceedance of the trigger value will activate further investigations, such as additional water quality testing, biological monitoring, water treatment or toxicity testing.

A detailed discussion in relation to the copper complexing capacity of the river system and the site-specific copper criterion proposed to be adopted for the Project is provided in Section 8.5.5.

Particular to aluminium, significant advances in scientific knowledge have been made since the ANZECC/ARMCANZ (2000) guidelines were compiled. Recent research indicates that the aluminium ANZECC/ARMCANZ (2000) guideline is an overly conservative guideline value, especially under pH circumneutral conditions. A new approach for derivation of aluminium water quality guidelines is to take into consideration site-specific factors, including pH, dissolved organic carbon (DOC) and hardness, which have been shown to greatly affect aluminium toxicity. The calculation of aluminium criteria that vary as a function of site-specific factors is suggested to represent a significant improvement over the use of a single parameter (DeForest et al., 2017). Some of the key papers used in the assessment of predicted aluminium concentrations in the subsequent sections include:

- US EPA, 2017a. Draft aquatic life ambient water quality criteria for aluminium. This report and associated toxicity calculator (US EPA, 2017b) factor in the influence of DOC, pH and water hardness to allow predictions of site-specific acute and chronic aluminium toxicity to aluminium-sensitive freshwater test organisms.

- DeForest et al., 2017. Multiple Linear Regression (MLR) models for predicting chronic aluminium toxicity to freshwater aquatic organisms and developing water quality guidelines including a calculator to determine the effects of dissolved organic carbon, pH and water hardness on dissolved aluminium toxicity.

- Gensemer at al., 2018. Evaluating the effects of pH, hardness and dissolved organic carbon on the toxicity of aluminium to freshwater aquatic organisms under circumneutral conditions.

Water Quality Objectives: Mixing Zone and Compliance Point

As indicated above, in PNG a mixing zone can be included in an environment permit under the Environment Act. A mixing zone is the body of water into which waste (water) is discharged and where the prescribed water quality guidelines are not required to be met. The downstream end of the mixing zone is normally the first location downstream of the proposed discharge point where local people use the river and is likely to be the compliance point under the environment permit.

Only one freshwater environment compliance point is proposed for the Project[3]. This is located at Assessment Point (AP) 7, situated approximately 4 km downstream of the ISF spillway, 0.4 km upstream of the village of Paupe, which is the first village downstream of the ISF spillway, and approximately 30 km upstream of the junction of the Frieda and Sepik rivers. This will serve as the regulatory point for discharges from the ISF (and, therefore, all surface water discharges from the mining and processing operations). Notwithstanding this, the village of Paupe is proposed to be relocated to avoid construction impacts from the Project. The location of AP7 is shown on Figure 8.3.

Where maximum background dissolved and total concentrations of parameters measured in the Frieda River at AP7 exceed the regulatory criteria, the 90th percentile background concentrations have been adopted as the site-specific criteria.

Further discussion in relation to compliance points and site-specific trigger values are provided in the sections below.

Impact Assessment Method

The surface water impact assessment structure and method involved numerical modelling of the predicted changes to hydrology, sediment transport and water quality in the Project area due to Project activities. These modelling results were then used to assess the impacts to freshwater ecology using a significance assessment method.

Significance Assessment

The general approach to the biophysical impact assessment is described in Section 8.1. This section presents the specific definitions for sensitivity and magnitude relevant to aquatic ecological impacts, as described in Tables 8.19 and 8.20, respectively.

Table 8.19 Sensitivity of an aquatic environmental value

Sensitivity	Definition
High	• An environmental value that has restricted distribution. • A site or environmental value that is intact and retains its intrinsic value prior to Project development. • An environmental value that has limited or no capacity to adapt to change. • An environmental value of essential (local) subsistence, artisanal or commercial requirement or importance in maintaining ecological integrity (even if not otherwise listed). • Rare natural resource.

[3] All distances are point to point aerial distances, not river length distances.

Table 8.19 Sensitivity of an aquatic environmental value (cont'd)

Sensitivity	Definition
Medium	• An environmental value that is limited in abundance and distribution. • A site or environmental value that is in moderate to good condition prior to Project development. • An environmental value that has some resilience to change. • An environmental value of common or frequent subsistence, artisanal or commercial importance locally. • Restricted natural resource.
Low	• An environmental value that is abundant, widespread, numerous representative examples occur. • A site or environmental value that is in poor to moderate condition prior to project development. • An environmental value that is easily adaptable to change. • An environmental value of occasional subsistence, artisanal or commercial importance locally. • Widespread natural resource in PNG and/or elsewhere.

Potential impacts on species of listed conservation significance, such as IUCN-listed species, species of national conservation priority (listed as protected or restricted under the Fauna Act) or species endemic to the Sepik River catchment or Northern New Guinea have been assessed separately in Section 8.6. Impacts on species of conservation significance are predicted to be the same as impacts on non-listed species since they would likely also have sensitivities similar to other native species. Listed and non-listed species will experience the same Project impacts and react to these impacts in the similar ways. Furthermore, the majority of listed and non-listed species are sediment-tolerant and experience highly variable TSS and turbidity naturally. Therefore, an aquatic species having conservation significance is not necessarily any more sensitive compared to other introduced or native fish species within an area.

Table 8.20 Magnitude of aquatic ecological impacts

Magnitude	Definition
High	• Widespread and severe impacts occurring at the regional spatial scale (i.e., extends beyond the catchment of a single river) which may be of long-term duration (beyond the life of mine). • Physical effects: major aquatic habitat damage or deterioration from heavy sediment deposition and consequential watercourse bed aggradation and increased downstream bed sediment transport. • Water quality effects: major deterioration of water quality due to changes in TSS concentrations, turbidity, nutrients, metals or other parameters. • Biological effects: – Major reductions in aquatic biological community population densities, species diversity and richness, or growth, biomass and productivity. – Result in persistent and major adverse changes to an ecological community's life cycle including breeding, feeding and migration.

Table 8.20 Magnitude of aquatic ecological impacts (cont'd)

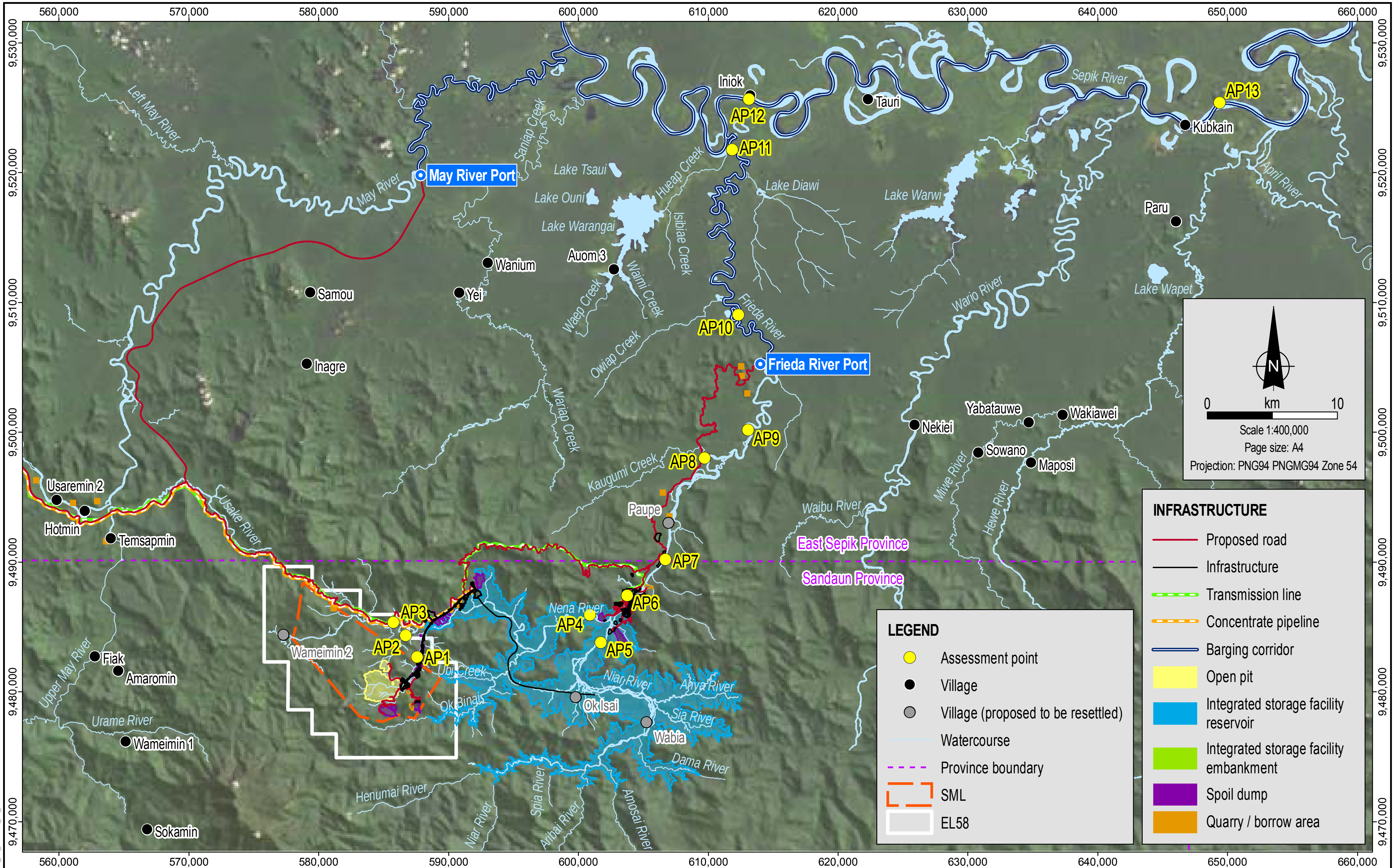
Magnitude	Definition
Medium	• Moderate impacts occurring at the local spatial scale (i.e., contained within the catchment of single river) which may be of medium-term duration (within the life of mine). • Physical effects: moderate aquatic habitat damage or deterioration from moderate sediment deposition and consequential watercourse bed aggradation and increased downstream bed sediment transport. • Water quality effects: moderate deterioration of water quality due to changes in TSS concentrations, turbidity, nutrients, metals or other parameters. • Biological effects: – Moderate reductions in aquatic biological community population densities, species diversity and richness, or growth, biomass and productivity. – Result in moderate changes to an ecological community's life cycle including breeding, feeding and migration.
Low	• Minor and highly localised impacts occurring at the site spatial scale (i.e., contained within the catchment of a single creek or steam, or a reach of larger river) which may be of short-term duration (only during construction or less than five years during operations). • Physical effects: minor aquatic habitat damage or deterioration from light sediment deposition and that may be flushed from impacted river reaches in the short-term occasioning high flows. • Water quality effects: minor deterioration of water quality due to changes in TSS concentrations, turbidity, nutrients, metals or other parameters. • Biological effects: – Minor reductions in aquatic biological community population densities, species diversity and richness, or growth, biomass and productivity. – Result in minor changes to an ecological community's life cycle including breeding, feeding and migration.
Negligible	• Impacts are not detectable with respect to natural variability, regardless of the geographic extent or duration of the impact.

The significance of an impact on an environmental value is determined by the product (i.e., the impact rating) of the sensitivity of the value and the magnitude of the expected change. Table 8.21 shows the resulting matrix of significance which is slightly modified from the impact matrix in Section 8.1, whereby a negligible magnitude of impact is included.

Table 8.21 Matrix of significance

Magnitude of Impact	Sensitivity of Receptor		
	High	**Medium**	**Low**
High	Extreme	Major	Moderate
Medium	Major	Moderate	Minor
Low	Moderate	Minor	Negligible
Negligible	Negligible	Negligible	Negligible

The assessment is based upon consideration of the existing aquatic environment and the beneficial values to be impacted, identifying the nature of impacts and assessing the magnitude of an individual impact or combined impacts on those values.



Source:
Assessment points from SRK and Coffey.
Infrastructure, roads and tenements from FRL.
Villages, topographic features, watercourses and water bodies from FRL and Coffey.
Provinces from NMB.
Landsat satellite imagery from FRL (capture date unknown). Hillshade DEM from SRTM.

coffey
A TETRA TECH COMPANY

Date: 14.09.2018
Project: 754-ENAUABTF11575B
File Name: 11575_11_F08.03_GIS

Frieda River Limited
Sepik Development Project

FRIEDA RIVER

Assessment points

Figure No: 8.3

MXD Reference: 11575B_11_GIS017_v0_3

Where feasible, engineering design measures have been included to avoid impacts. However, where impacts are unavoidable, management measures are proposed to limit each impact to as low as is practicable. The residual impact is then assessed assuming that the management measures are successful.

The residual impact assessment for freshwater ecology has included discussion of all impacts regardless of their significance for the following reasons:

- Aquatic biodiversity values are important at local, regional and potentially international scales.
- The importance of social values in the downriver environment.
- The significant level of stakeholder concern in relation to this topic, particularly along the Sepik River.
- There is no separate technical appendix for the freshwater ecology impact assessment.

Impacts ranked as either minor or negligible are discussed briefly but are not included in the impact summary tables.

8.5.2 Management Measures

Proposed management measures for the protection of surface water values are described in this section. Table 8.22 presents management measures to mitigate against physical disturbance of aquatic habitat and changes to hydrology due to Project activities.

Table 8.22 Physical disturbance and hydrology management measures

No.	Management Measure
MM026	Install rip-rap or other forms of armouring for stabilisation around the base of bridges to avoid scour and river bed erosion.
MM027	Mark the extent of vegetation to be cleared on relevant technical drawings and mark clearing limits in the field ahead of clearing. Do not clear beyond design limits.
MM028	Do not place any infrastructure, permanent or temporary in ORWBs. These areas will be marked as 'No Go Zones' on relevant figures.
MM029	Do not use ORWBs for waste disposal, including for domestic and industrial waste, or for discharge of treated or untreated waste waters.
MM030	Locate, design and construct linear infrastructure to avoid impacts on the hydrology of ORWBs.
MM031	Avoid wetland traverses as far as practicable by routing the road corridor across higher terrain, such as hill slopes and ridges, where present.
MM032	Construct culverts in creeks and streams, as necessary during road construction, to allow the normal cross-flow of water.
MM033	Maintain environmental flows downstream of the ISF embankment in the Frieda River at 50 $m^{3/s}$ except for a short period during initial impoundment.

The ISF constructed downstream of the mine area to contain waste rock and tailings will provide the primary means of sediment control to prevent sediment being transported downstream. Table 8.23 provides other measures for the management of sediment.

Table 8.23 Sediment management measures

No.	Management Measure
MM023	Divert clean water upstream of the open-pit, where practicable, around the open-pit to avoid generating additional contact water (i.e., water making contact with the open-pit walls and therefore assumed to be contaminated).
MM034	During the construction phase, where practicable, construct sediment ponds downstream of major sediment sources.
MM035	Develop and implement erosion and sediment control plans for disturbance works.
MM036	Mark boundaries along cleared areas to limit machinery movement outside the clearance area and ensure that only trees/vegetation within the defined zone are removed.
MM037	Restrict watercourse crossings to designated to crossing points where riparian vegetation clearing widths will be limited. Maintain riparian vegetation buffer zones elsewhere.
MM038	In areas that will be rehabilitated, use land clearing techniques that preserve the rootstock of removed vegetation in the ground, where practicable.
MM005	Rehabilitate cleared areas to reduce erosion and runoff as soon as possible after clearance. Store and re-use suitable topsoil wherever practicable.
MM039	Divert runoff, to the extent practicable, around disturbed areas including roads.
MM040	Use rip-rap, gabions and check dams to reduce velocity flow of water in constructed drainage channels where practicable.
MM041	Apply the following principles during construction of benches and batters: • Construct benches that are graded to shed water so as to avoid erosion or batter slumping. • Retain vegetation at the top of cut batters and at the toe of fill batters where practicable in order to minimise erosion. Plant vegetation including shrubs/grasses/legumes on benches. • Install dikes and swales at the top of batters (where practicable) and divert runoff to a slope drain and into stabilised areas. • Stabilise batters using brush layers or geotextile/fibrous matting. • Install slope drainage such as cut-off trenches or horizontal drains at the top edge of the batter or slope. Construct adequate drainage at the toe of the bench/slope to ensure controls are not compromised with undercutting erosion.
MM042	Treat open-pit water using an engineered water treatment plant to mitigate poor water quality downstream. Discharge treated open-pit water to Ubai Creek where it will flow into the ISF for further dilution prior to entering the downstream environment. Discharge treatment residues to the bottom of the ISF.
MM043	Conduct a risk assessment prior to commencing works in areas of steep terrain where sidecasting is to be undertaken to determine potential impacts downslope and identify appropriate controls.
MM044	Where practicable, locate valley-bottom access alignments so as to provide a buffer strip of natural vegetation between the access ways and watercourses.

The treatment of open-pit water during operation and post closure, and subaqueous disposal and storage of waste rock and tailings in the ISF to prevent AMD, are the primary controls to mitigate impacts of the FRCGP on downstream water quality. Table 8.24 describes these and other mitigation measures to manage water quality impacts from Project activities.

Table 8.24 Water quality management measures

No.	Management Measure
MM045	Deposit tailings to the bottom of the ISF so that they follow the underwater beach slope and disperse radially out from the diffuser head deposition location, thereby reducing suspension of tailings solids in the ISF.

Table 8.24 Water quality management measures (cont'd)

No.	Management Measure
MM046	Store tailings subaqueously via a pipeline with barge-dumped PAF waste rock in the ISF to limit the potential for formation of AMD.
MM047	At closure of the FRCGP maintain a permanent water cover with a depth of approximately 40 m over the waste rock and tailings.
MM042	Treat open-pit water runoff using an engineered water treatment plant to mitigate poor water quality downstream. Discharge treated open-pit water to Ubai Creek where it will flow into the ISF for further dilution prior to entering the downstream environment. Discharge treatment residues to the bottom of the ISF.
MM048	Post closure, treat water from the open-pit lake before release to Ubai Creek until closure criteria are met. Store water treatment solids within the open-pit lake.
MM049	Where PAF materials are encountered within road and infrastructure cuts, conduct a risk based assessment to determine appropriate controls such as addition of limestone.
MM021	Divert clean water upstream of the open-pit, where practicable, around the open-pit to avoid generating additional contact water (i.e., water making contact with the open-pit walls and therefore assumed to be contaminated).
MM050	Store, handle and transport hazardous substances in accordance with Australian Standards AS1940:2017 and AS3780:2008, and the PNG Environmental Code of Practice for Vehicle/Machinery Workshops and Petroleum Storage/Resale/Usage Sites.
MM051	Manage sewage in an appropriate manner to limit environmental contamination.
MM052	Provide appropriate spill response equipment for Project facilities, vehicles and vessels.
MM053	Design and construct project facilities involving the storage, handling, or use of hazardous materials to intercept potentially contaminated water for treatment if required prior to discharge.
MM054	Develop and implement oil spill prevention and response plans.
MM055	Place only NAF material in the limestone quarry waste dump and in the Ok Binai waste dump.
MM056	Minimise time of exposure for PAF waste rock prior to subaqueous deposition within the ISF impoundment.

8.5.3 Hydrology

Study Method

A site-wide water balance model for the Project was developed by SRK Consulting and the results are reported in Appendix 6a.

The purpose of the water balance modelling was to determine the Project-related changes to flows and volumes of water in watercourses in the Project area and downstream over the mine life.

Hydrological predictions were calculated for dry (10th percentile[4]), average and wet (90th percentile) conditions for existing conditions (i.e., pre-construction), the operational period of the FRCGP (including two years of construction to incorporate the commencement of the FRHEP, i.e., Year -2 to Year 33 inclusive) and the post closure period (Year 34 to Year 54). This modelling used two stochastic datasets; one for each of the uplands and lowlands regions, of which the lowlands is 40% drier than the uplands. This involved generation of rainfall sequences with the

[4] The percentile refers to the percentage of time that modelled flows are equal to or less than this amount, i.e., 10th percentile means that modelled flows are equal to or less than this value for 10% of the time.

same statistical characteristics as the historical datasets for a range of parameters (such as mean, variance, skew, and number of wet days or dry days). Modelling was undertaken using a daily timestep for a 56-year period commencing in Year -2 (i.e., filling of the ISF reservoir).

Results for hydrology, as well as water quality and sediment transport, have been reported at the assessment points shown in Figure 8.3. The results at assessment points AP1 to AP7 have been generated using the uplands stochastic data and the results at assessment points AP8 to AP13 have been generated using the lowlands stochastic data.

Further details of the model inputs and assumptions are provided in Appendix 6a.

Results

The main Project-related effects on hydrology are related to ISF reservoir, operation and closure and include:

- Reduction in downstream flow during filling of the ISF.
- Alteration in flow patterns from natural conditions.

The sections below summarise the outputs of the water balance model.

Operations: Modelled Flows

Average daily flows over the mine life for dry, average and wet flow conditions at each of the assessment points are predicted to be lowest in the upland catchments of the mine area (i.e., AP1 in Ubai Creek down to AP6 in the Nena River) and generally increase as the assessment points progress into the lowland areas of the Frieda and Sepik rivers (i.e., AP6 in the Frieda River to AP13 in the Sepik River) (Table 8.25). This is generally consistent with existing conditions with some key differences for the upstream catchments that will occur due to the presence of mine infrastructure, namely the open-pit and the ISF, as described below. In general, at average flows during operations, modelled average daily flows are similar to pre-construction average flows with the exception of the predicted flows at AP2 in Uba Creek and AP1 in Ubai Creek. Average daily flows at AP2 are predicted to decrease slightly due to development of the Koki open-pit and the redirection of flows away from Uba Creek. At AP1 in Ubai Creek, daily average flows are predicted to increase during operations as a result of open-pit development through increased capture of groundwater, diversion of runoff from the surrounding catchment to upstream of this assessment point, including discharge of treated pit water.

Under dry conditions, predicted daily flows at most assessment points increased by around 65% in the Frieda River, while during wet conditions predicted flows decreased by around 30 to 40% in the Frieda River. These changes are associated with the regulation of flows resulting from the operation of the hydroelectric power facility. Changes to flows in the Sepik River (at AP12 and AP13) are predicted not to be detectable as a result of the Project.

Table 8.25 Average modelled daily flow at each assessment point during operations (ML/day)*

Assessment point†	Description	Pre-construction conditions			Stochastic - operations			Difference between pre- and post-operations stochastic flows (%)		
		Dry	Average	Wet	Dry	Average	Wet	Dry	Average	Wet
AP1	Ubai Creek upstream of Nena River	81	353	693	218	403	630	63	14	-9

Table 8.25 Average modelled daily flow at each assessment point during operations (ML/day)* (cont'd)

Assessment point†	Description	Pre-construction conditions			Stochastic - operations			Difference between pre- and post-operations stochastic flows (%)		
		Dry	Average	Wet	Dry	Average	Wet	Dry	Average	Wet
AP2	Uba Creek upstream of Nena River	24	106	208	54	98	153	56	-8	-26
AP3	Nena River upstream of Uba Creek	614	2,665	5,232	1,500	2,736	4,284	59	3	-18
AP6	ISF discharge	4,202	18,250	35,826	12,187	18,226	21,936	66	0	-39
AP7	Frieda River (airstrip)	4,254	18,479	36,276	12,187	18,226	21,936	65	-1	-40
AP8	Frieda River (upstream of Kaugumi Creek)	4,579	18,813	36,276	13,219	18,805	22,591	65	0	-38
AP9	Frieda River (Frieda Mountain)	5,402	19,689	37,565	13,709	19,706	24,573	61	0	-35
AP10	Frieda River (Lower Frieda River Gauging Station)	6,224	20,691	38,703	14,258	20,737	27,029	56	0	-30
AP11	Frieda River (upstream of Sepik River confluence)	6,887	21,589	39,777	14,743	21,661	29,145	53	0	-27
AP12	Sepik River (Iniok)	-	197,760	-	-	202,890	-	-	3	-
AP13	Sepik River (Kubkain)	-	229,678	-	-	235,724	-	-	3	-

* AP4 and AP5 were not modelled as they are located in the ISF reservoir.
† Dry and wet flows for the Sepik River sites (AP12 and AP13) have not been included as the predicted changes generated by the model in Appendix 6B are not reflective of the overall system.

Figure 8.4 shows the predicted daily average flows at AP6 in the upper Frieda River (or ISF discharge) for existing conditions and during construction, operations and FRCGP post closure. The high and low flow rates at AP6 and downstream (to AP11 on the Frieda River) are highly modified compared to the natural flows, which is driven by the regulation of the flows for power generation.

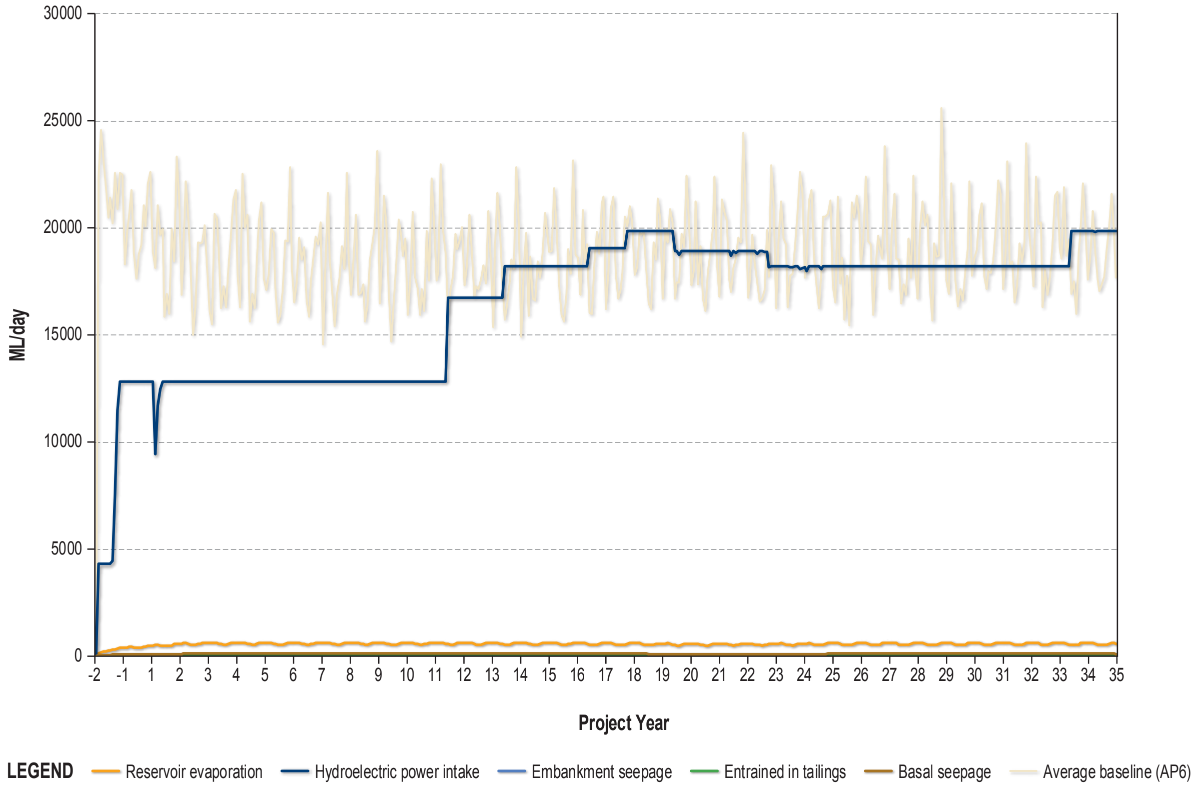
During operations, environmental flows downstream of the ISF embankment in the Frieda River will be maintained at 50 m^3/s. While maintaining the environmental flow, the maximum and minimum reservoir depths will be controlled by the spillway invert height (as the upper limit) and the minimum operating water level of the hydroelectric power facility of RL 202.5 m.

When the capacity of the reservoir is exceeded (predicted during years of lower hydroelectric power demand and occasionally during higher demand periods under wet conditions), flows will be released via the ISF spillway (averaging approximately 100 ML/day during the mine life under average conditions). Flows through the spillway are predicted to reduce once the FRCGP power demand increases, requiring increased flows through the hydroelectric power intake, around Year 8 of operations[5].

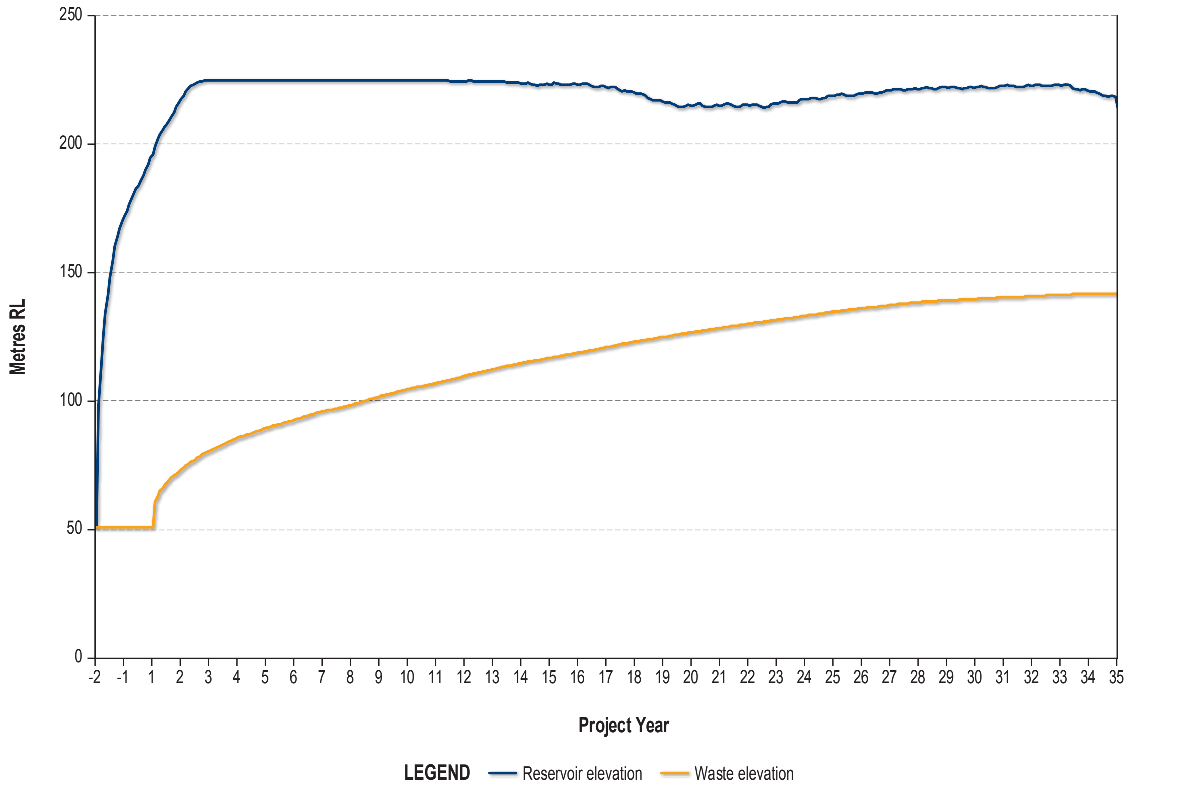
When the water level is lower than the elevation required for hydroelectric power generation, predicted during dry flow conditions, it has been assumed for modelling that no flow is directed through the hydroelectric power system. It is likely, however, that hydroelectric power will continue to operate during these periods of low water level but at a reduced capacity.

[5] At the time of modelling the increased power demand occurred in Year 11. This subsequently changed to Year 8 due to updates to the project design, however this did not change the predicted impacts.

Existing and predicted daily average outflows from the ISF



Average predicted ISF reservoir and waste elevations



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Frieda River Limited

Sepik Development Project

FRIEDA RIVER

ISF outflows and water management levels

Figure No: 8.4

AI Reference: 11575_11_GRA042.ai_6

Operations: ISF

As discussed in Chapter 5, waste rock and tailings will be deposited into the ISF for subaqueous storage to limit oxidation of PAF material and subsequent water quality impacts downstream. As shown in Figure 8.4, water cover depth above the waste rock and tailings to be stored in the ISF is predicted to remain above approximately 40 m for the life of the FRCGP.

Operations: Open-pit Water Management

Modelled water quality draining from the HIT, Ekwai and Koki open-pits will result in poor quality runoff (i.e., low pH and elevated metals concentrations) and will require treatment in a dedicated water treatment plant prior to discharge to ensure the protection of beneficial values downstream of the ISF.

Runoff from the open-pit will be transferred to the water treatment plant from which treated water will be discharged to Ubai Creek to flow into the ISF.

Open-pit surface areas from three representative stages during open-pit development (Year 7, Year 18 and Year 33) were used to calculate open-pit sump volumes.

To facilitate the management of water in the open-pit area, each open-pit was modelled to have an in-pit sump to collect water coming into contact with the open-pit walls and a series of diversion structures to divert non-contact water around the open-pit. Within each open-pit, two zones were defined including an upper zone and a lower zone. Non-contact runoff from the upper zone will be channelled around and through the HIT open-pit to the surrounding catchment to the north and south of the open-pit. Towards the end of mine life, upper zone runoff will come into contact with a small section of the HITEK open-pit wall within the oxidised zone; however, this is not expected to affect water quality downstream.

Runoff from the lower zone will either drain to an in-pit sump, which will be pumped to the water treatment plant, or to sumps higher in the catchment which will drain to the water treatment plant via gravity. Treated water will be released to Ubai Creek. After mining has been completed within the Ekwai and Koki pits in approximately Years 4 and 7, respectively, the voids will be used as contact water storage sumps to regulate flows to the water treatment plant.

Predictions of contact water volumes from the HIT-Ekwai and Koki open-pits that will report to the open-pit sumps average around 65 ML/day and 6.3 ML/day, respectively. Average flows to the water treatment plant will therefore be around 71.3 ML/day. To maintain minimal flows in the open-pit sumps, if required, the maximum pumping requirements would be 123 ML/day and 9.2 ML/day for the HIT-Ekwai and Koki open-pits, respectively, with predicted maximum flows to the water treatment plant peaking at 132.2 ML/day.

It is not possible for open-pit water to report to the Frieda River without flowing through the ISF.

Post Closure: Modelled Flows

At the end of the 33-year mining period, the ISF will remain in place and flows through the ISF may continue to be regulated for power generation. The spillway gates will be removed after an additional approximate 70-year operation of the hydroelectric power facility. Water will continue to flow into the facility via direct rainfall and inflow from the upstream catchment and excess water will pass over the ungated spillway which will operate as a flow-through facility.

Therefore for the purposes of the water balance, three scenarios of 20 years[6] each were modelled to represent:

- Scenario 1: the continued generation of power after cessation of mining assuming a water demand of 18,144 ML/day (210 m^3/s).
- Scenario 2: the cessation of power generation after closure of the FRHEP, whereby all flow from the reservoir is via the spillway. While no active management of outflows was considered in this scenario, the likelihood that flows will be less than the environmental flow of 50 m^3/s was very low (0.025%).
- Scenario 3: the cessation of power generation after closure of the FRHEP with maintenance of the environmental flow of 50 m^3/s.

Results for all three scenarios indicate that, in general, flows trends at the assessment points are similar to those during operations. Flows in the Frieda River will be highly modified from the baseline flow conditions arising from the regulation of flows within the ISF reservoir. In addition, flows at AP1 (Ubai Creek) are increased due to discharge from the open-pit.

Post Closure: Open-pit Water Management

Modelling shows that after mining and open-pit dewatering operations cease, and under average flow conditions, the HIT-Ekwai open-pit will take approximately three years to fill to RL 440 m, assuming the operational diversions are removed and flows from the open-pit catchments are directed to the open-pit sump. The Koki open-pit will already be inundated since its flooding after approximately Year 7 and excess water will be transferred to the HIT-Ekwai open-pit.

During the open-pit filling period, flows downstream from the open-pits will reduce and pumping to the water treatment plant will cease for a period of time. After the open-pits fill, water treatment will recommence post closure and flows are expected to be similar to those predicted at the end of mining. During the post closure period, open-pit water volumes requiring treatment during average flows are predicted to be approximately 90 ML/day.

Post Closure: ISF Water Management

At closure, a permanent water cover with a depth of at least 2 m over the waste rock and tailings will be required to preclude oxidation of the material into the future. The modelling outputs indicate that the water cover depth will far exceed 2 m with water depths of greater than 40 m predicted over the waste material. Silt deposition will occur in the ISF over the very long-term and it is expected that the underlying waste rock and tailings material will be buried under a layer of saturated material, maintaining protection from oxidation.

8.5.4 Sediment Transport

Study Method

Golder Associates was engaged to complete a sediment transport assessment to quantify the likely impacts of the Project on sediment loads in watercourses draining areas of disturbance. The results of this are presented in Appendix 5. The purpose of the study was to:

- Estimate existing sediment transport rates at key locations in the river network.
- Evaluate sediment transport implications of the Project.

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[6] A period of 20 years was modelled for each scenario for assessment purposes and results are expected to be representative for each of the scenarios.

- Predict Project-related changes in sediment transport rates (assuming implementation of management measures) and predict the nature and extent of changes to bed levels, stream morphology, flooding, over-bank sedimentation and ORWBs in the river network.

To achieve this for the FRCGP and FRHEP area, numerical modelling was performed using a Mobile Bed Sediment Transport model as part of the Hydrologic Engineering Centre's River Analysis System (HEC-RAS) platform (USACE, 2016). A semi-quantitative sediment transport assessment was conducted for the infrastructure corridor, consistent with the short-term duration and moderate intensity of construction activities for this Project component.

The initial step in the modelling process was to define the river network including establishment of the following three models:

- Pre-Project:
  - Ubai/Uba/Nena/Ok Binai/Frieda/Sepik model (including the Niar River catchment) to define sediment concentrations (suspended and bed load), sediment loads and changes in river bed levels under pre-Project (baseline) conditions.
- Construction, operation and post closure:
  - Ubai/Uba/Nena/Ok Binai/Niar model to define sediment concentrations and sediment loads along watercourses, loads entering the ISF and changes in river bed levels during construction, operations and post closure as a result of sediment inflow. Sediment concentrations and loads, and river bed changes occurring from non-impacted catchments (as for the pre-Project condition), were modelled as were changes from the mine-impacted areas along Ubai Creek, Uba Creek, Ok Binai, Nena River and Frieda River (including the Niar River catchment) to the ISF embankment.
  - Frieda/Sepik model to define sediment concentrations, sediment loads and changes in river bed levels during construction, operations and post closure as a result of outflows from the ISF, local inflows to the Frieda River downstream to the Sepik River confluence, inflows from the Sepik River upstream of this confluence and along the Sepik River downstream of the confluence (including inflows from the Wario and April rivers) to Ambunti approximately 200 km downstream of the confluence. Naturally occurring sediment from the catchments (as for the pre-Project condition), outflow from the ISF and sediment from the mine-impacted areas adjacent to Frieda River downstream of the ISF were included in this model.

The construction, operations and post closure model included:

- Definition of channel cross-sections along the river network from available topographic information including Light Detection and Ranging data in the upper Frieda and Nena river catchments, Shuttle Radar Topography Mission data along the lower Frieda and Sepik rivers and field-validated cross sections along the Sepik River.
- Hydraulic analyses along the river network to define flow velocities, depths and cross-sectional flow areas using the HEC-RAS model Version 5. Stochastic streamflow estimates were generated by SRK (Appendix 6a) based on historic streamflows and catchment runoff data.
- Estimation of sediment inflows under existing conditions based on sediment–discharge relationships established from available TSS and flow data, and as a result of mine operation during construction, operations and closure, based on the Revised Universal Soil Loss Equation (Renard et al., 1997).

- Estimation of sediment transport along the river network using the Mobile Bed Sediment Transport model within HEC-RAS.

Details of the model development, inputs, process and assumptions are described in full in Appendix 5.

Impacts associated with total metals concentrations are discussed in Section 8.5.5.

Results

Changes in Sediment Loads and Concentrations of Total Suspended Solids

Existing Conditions

Annual total sediment loads were modelled at four key gauging stations in the catchment over a period of 44 years to cover a range of flow conditions comparable to the overall period of construction, operation and five years post closure. The modelled sediment loads broadly corresponded with observed sediment loads at these locations.

The predicted TSS concentration results at each of the assessment points shown in Figure 8.3 indicated that the average of the annual median TSS concentrations in tributaries to the Nena River range from about 30 to 60 mg/L for Ubai and Uba creeks and is approximately 60 mg/L for the Ok Binai. Downstream of the Nena River confluence with the Ok Binai (AP4), the average of the annual median TSS concentrations increases to approximately 180 mg/L reflecting the higher contribution of the main stem of the Nena River. Downstream of the confluence of the Nena and Niar rivers, the average of the annual median values is around 160 mg/L. Values remain similar along the Frieda River (down to AP11) reflecting contributions of fine sediment from adjacent floodplains and limited inflows.

In the Sepik River downstream of the confluence with the Frieda River, the average of the annual median TSS concentrations is initially similar to the Frieda River, at around 160 mg/L (AP12), predominantly reflecting the sediment contribution from the upper Sepik River catchment. The Wario and April rivers also contribute to sediment load further downstream along the Sepik River with an average of the annual median TSS concentrations downstream of Kubkain increasing to range from 200 to 270 mg/L (AP13).

The contribution to sediment loads in the Sepik River from the Frieda River catchment is minimal. The Frieda River catchment contributes approximately 8% of the combined sediment load of the Frieda River and upper Sepik River at their confluence. Annual flows from the Frieda River contribute approximately 14% of the flows in the Sepik River at their confluence and the Frieda River catchment comprises 6% of the catchment area of the Sepik River. This indicates the upper Sepik River has a similar sediment contribution per unit flow and per unit area as the Frieda River.

Suspended sediment in the Sepik River comprises extremely fine silts and clays which have very low settling velocities. It is likely that much of the sediment being transported through the modelled section of the Sepik River will remain in suspension further downstream to the mouth of the Sepik River unless flow velocities reduce considerably.

In addition to sediment concentrations, predicted changes in existing bed levels, including aggradation and degradation, were also derived from the modelling. These are natural changes that are predicted to occur even if the Project does not proceed. In the lower Nena River and Frieda River, bed level variations are predicted to be only of the order of plus or minus 1 m, indicating stability under current conditions. Along the Frieda River, the changes are variable with increases in some areas and reductions in others with no pattern evident. This is possibly due to inaccuracies in the current bed profile of some sections or impacts of recent high flow events in localised areas. Within the Sepik River, there is both aggradation and degradation of up to 3 m modelled in the vicinity of the confluence of the Frieda and Sepik rivers, and elevations are predicted to reduce by approximately 2 m downstream of Kubkain under existing conditions. This indicates ongoing bed load movement under existing conditions and a tendency for the channel to move towards a natural lower level.

Due to the semi-quantitative nature of the assessment for the infrastructure corridor, Project-derived sediment loads only have been estimated and these are discussed in the section below.

During Project

Ubai/Nena/Ok Binai/Niar Model

Project-related disturbances in this watercourse network are distributed as follows:

- Ubai Creek – the majority of mine related infrastructure is located in this catchment including the laydown areas, spoil dumps, primary crushers and sections of the conveyor, road and transmission line corridors, mine infrastructure area, quarry, haul roads and the HITEK open-pit.
- Uba Creek – the Koki open-pit is located in this catchment.
- Ok Binai – the Ok Binai waste dump, limestone quarry, spoil dump adjacent to the limestone quarry and a section of the ISF reservoir will be located in this catchment.
- Upper Nena River (upstream of Uba Creek confluence) – will contain a section of the infrastructure corridor.
- Lower Nena River (downstream of Uba Creek confluence) – access roads, transmission line and substation, process plant, ore stockpile, conveyor, barge loading facility, site accommodation village and a section of the ISF reservoir are located in this catchment.
- Niar River – the ISF reservoir is partially located within this catchment.

Flows from Ubai Creek, Uba Creek, Ok Binai, Niar River and Nena River will report to the ISF reservoir.

The largest contributing areas to Project-related sediment are the open-pit and haul roads, ISF embankment, the Ok Binai waste dump, spoil dump adjacent to the limestone quarry, other spoil dumps, access roads, infrastructure corridor and quarries. Given that the spoil dump adjacent to the limestone quarry (to be developed in Year -4 prior to ISF impoundment) and the Ok Binai waste dump (to be developed from Year -1 following ISF impoundment) will be erodible dumps (i.e., they will not be constructed as bottom-up, stable dumps and so will erode continuously and will not be actively rehabilitated), fugitive sediments generated by these facilities is substantial.

The open-pit wall contact runoff water will report to sumps before being transferred to the water treatment plant; these sumps will allow some sediment to settle and the water treatment plant will also remove a portion of the suspended sediment as part of the treatment residue sludge. Where required and practical, sediment ponds will be constructed at the toe of spoil dumps to allow for settling of sediment and potential treatment before water is discharged to the river system.

During construction, annual median TSS concentrations are expected to increase in Ubai Creek at AP1 from approximately 30 mg/L under current conditions to around 3,000 mg/L as the mine infrastructure is developed. Peak sediment concentrations during periods of higher flows is estimated to be far larger. Concentrations of TSS are predicted to be highest in the immediate vicinity of the open-pit and reduce further downstream along Ubai Creek during construction and early operations.

During operations, annual median TSS concentrations are predicted to reduce considerably to 500 mg/L to 700 mg/L in the vicinity of AP1 in Years 1 to 2 of operations. Non-impacted upslope runoff will be diverted around the open-pit and be discharged directly into Ubai Creek. Pumping of water (with likely elevated sediment concentrations) from the open-pit sumps to Ubai Creek will occur via the water treatment plant following its installation in Year 1 and, if required, sediment ponds. Sediment contributions from the open-pit to downstream river systems were therefore assumed to be negligible.

Bed levels in the vicinity of the open-pit are predicted to increase during mine life by up to about 5 m along Ubai Creek downstream of the mine infrastructure area. These changes in levels are predicted to perpetuate until the source inputs of sediment decline and/or sufficiently high flows remobilise deposited material downstream and into the ISF, which has been designed to accommodate such sediment. While this increase in bed level is considerably higher than the negligible change modelled for current conditions, it is estimated around 99% of the sediment inflow, and tailings and waste rock inputs to the ISF, will be retained within this storage and not transported further downstream.

In Uba Creek, annual median TSS concentrations at AP2 are modelled to increase from approximately 60 mg/L under current conditions to 1,000 mg/L during the initial two years of construction before reducing to approximately 200 mg/L by the commencement of operations. During operation, the annual median TSS concentrations are estimated to gradually reduce to current concentrations. Changes in bed levels along Uba Creek are modelled as being similar to those predicted under existing conditions and the Project is unlikely to influence bed level in this watercourse.

The spoil dump adjacent to the limestone quarry in the headwaters of the Ok Binai will store approximately 10 Mt of NAF material over a period of two years (from Year -4). The Ok Binai waste dump will be developed in the upper reaches of the Ok Binai catchment in Year -1. Pre-strip material, including topsoil as well as vegetation and some NAF waste rock from the progressive development of the open-pit, will be transported to the Ok Binai waste dump throughout the majority of mine operation (until approximately Year 26 of operations). Given that the spoil dump adjacent to the limestone quarry and the Ok Binai waste dump are assumed to gradually erode (i.e., they will not be constructed as bottom-up, stable dumps and so will erode continuously and will not be actively rehabilitated), sediment losses from these dumps into the Ok Binai and then the ISF are predicted to remain high throughout the Project. During construction and prior to development of the spoil dump adjacent to the limestone quarry and the Ok Binai waste dump, annual median TSS concentrations in the Ok Binai are estimated to range up to approximately 120 mg/L compared to existing levels of around 60 mg/L. After the dumps are developed, annual median TSS concentrations are predicted to increase significantly to approximately 15,000 mg/L (with infrequent maximum concentrations up to 25,000 mg/L).

It is predicted that the spoil dumps adjacent to the limestone quarry and the Ok Binai waste dump will take approximately 20 years from commencement of their development to fully erode into the ISF. This timeframe has been predicted based on annual erosion losses of 20% of the cumulative volume remaining in the spoil dump, equating to a loss of approximately 15,000 t/ha/y, which is around three times that predicted using the RUSLE equation. Episodic events (i.e., intense storm rainfalls) which would increase the erosion rate, were assumed to occur randomly on 5% of days in each year with the sediment loss on those days assumed to be five times higher than would normally occur. The adopted erosion rates are considered as conservative but appropriate given the waste dumps will erode continuously.

During the first 5.5 years of construction, a sediment load of approximately 13 Mt is predicted at AP6 compared to a baseline of approximately 9 Mt. This increased load is primarily related to the development of the spoil dump adjacent to the limestone quarry in Year -4.

In the Nena River upstream of the ISF and downstream of Ubai Creek (AP3), annual median TSS concentrations are predicted to increase from existing concentrations of 150 mg/L to around 300 mg/L during the initial years of construction, after which TSS concentrations are estimated to gradually reduce to approximately 180 mg/L during operations. The relatively minor changes in TSS at AP3 and the Upper Nena River reflect the limited infrastructure to be developed along this tributary.

Prior to ISF impoundment, Nena River (AP4), annual median sediment concentrations are predicted to increase from around 300 mg/L during Year -7 up to around 700 mg/L compared to an existing average annual median sediment concentration of around 150 mg/L. This location will be impounded by the ISF from Year -2.

Stream bed levels in the Ok Binai are predicted to increase by approximately 2 to 3 m over the modelled period and are expected to continue increasing until the spoil and waste dumps are fully eroded after 20 years. These bed levels will remain elevated until sufficiently large floods remobilise the deposited material and transport it further downstream to be ultimately deposited in the upper reaches of ISF.

Changes in bed levels along the Nena River upstream of the ISF are similar to those occurring under existing conditions and the Project is unlikely to influence bed level in this section of the watercourse. The Nena River will largely be impounded by the ISF downstream from the confluence of Ubai Creek and the Nena River. Approximately 1% of the total amount of sediment predicted to be deposited in the ISF is expected to be discharged further downstream of the ISF via the hydroelectric power facility or the spillway. The bed level within the ISF will be largely shaped by the deposition pattern of the waste rock and tailings rather than deposited fugitive sediment from upstream catchments.

Following FRCGP closure, TSS concentrations in all watercourses are predicted to reduce progressively as rehabilitation of Project disturbance areas takes place. Sediment loads are likely to reduce to about 75% of those estimated in the latter stages of operations within five years after closure. This downward trend is expected to continue throughout operation of the FRHEP. There are likely to be temporary spikes in TSS concentrations in watercourses downstream of earthworks required as part of FRCGP closure and rehabilitation.

Frieda/Sepik Model

The upstream boundary of the Frieda/Sepik model is the discharge point of the ISF. The model incorporates the watercourses downstream of this point to the boundary of the model at Ambunti on the Sepik River, approximately 200 km downstream of the confluence with the Frieda River.

The ISF plays a major role in attenuating the outflows from the reservoir as well as reducing the median, and variability of, TSS concentrations in the Frieda River to well below those estimated under existing conditions, particularly from about Year 21 of operations and into the post closure period.

Following closure of the ISF diversion tunnel in Year -2 and through to the modelled FRCGP post closure period (comprising four years), approximately 29 Mt of sediment is predicted to be discharged from the ISF (AP6) compared to a total sediment input and inflow of approximately 3,152 Mt, comprising inflow from the natural catchment upstream (66 Mt) plus fines from placement of waste rock and tailings. Therefore, throughout operation and four years FRCGP post closure (Year -2 to 37), the overall sediment load discharged from the ISF is less than half of the natural sediment load for the same period. This indicates that of the total volume of waste rock and tailings to be stored in the ISF, it is predicted that approximately 1% of waste rock and tailings will report to downstream watercourses as very fine fractions, with 99% of waste rock and tailings to be retained within the ISF.

Downstream of the hydroelectric facility outlet in the Frieda River (AP6), prior to impoundment median TSS concentrations are predicted to be around 250 mg/L to 300 mg/L up to Year -5, increasing to a peak of 750 mg/L in Year -4 compared with a median baseline concentration of approximately 190 mg/L. Following closure of the diversion tunnels and subsequent filling of the ISF, median concentrations are predicted to reduce to around 40 mg/L to 60 mg/L in Years -2 to -1. During operations, TSS concentrations increase up to approximately 240 mg/L over the first 14 years of operations after which concentrations begin to decrease. From Year 28, median TSS concentrations are predicted to reduce to about 30 mg/L to 40 mg/L which is much lower than the predicted median TSS concentrations at AP6 (about 191 mg/L) under existing conditions.

Along the middle reaches of the Frieda River (AP7, AP8 and AP9), annual median sediment concentrations are predicted to show a similar pattern to that estimated for AP6. This highlights the limited sediment inflow from the adjacent natural catchment and minimal impact of the limited Project-related infrastructure along this reach.

Reductions in bed levels in the Frieda River in the vicinity of AP6 (up to around 3 m) and AP7 (approximately 1 m) are predicted compared to a reduction of less than 1 m over the long-term (i.e., 60 years) under existing conditions. Modelling extended to 100 years duration to simulate the long-term impacts on bed levels in the Frieda River indicated:

- At AP6, bed levels stabilise around Year 30 of operations with a final minimum channel elevation some 3 m below the existing bed level.
- At AP7, bed levels stabilise around 37 years FRCGP post closure with a final minimum channel elevation of around 1 m below the existing bed level.
- At AP8, bed levels stabilise around 17 years FRCGP post closure with a final minimum channel elevation approximately 0.8 m below the existing bed level.
- At AP9, it is predicted that there will be a reduction to a final minimum channel elevation around 1.2 m below the existing bed level.

In the Sepik River, annual median TSS concentrations reflect increased natural (non-Project related) sediment loads from the Wario and April rivers, which are large tributaries of the Sepik, and local sediment inflows.

In the Sepik River at Iniok (AP12), TSS concentrations are predicted to fluctuate between 120 mg/L to 200 mg/L which is comparable to the natural variability for existing conditions. During Year 23 of operations, however, when TSS concentrations in the ISF outflow reduce, TSS concentrations are predicted to reduce slightly to 130 mg/L to 170 mg/L in the Sepik River at Iniok (AP12) (compared to existing concentrations between 170 to 185 mg/L). An overall comparison of the annual median TSS concentrations in the Sepik River at AP12 and AP13 does not indicate any considerable differences between those estimated under existing conditions and with the Project in operation. Concentrations of TSS in the Sepik River reflect the dominance of sediment load coming from the upper Sepik catchment relative to inputs from the Frieda River. Project influences on TSS concentrations in the Sepik River, particularly during operations, are predicted to be comparable to the natural variability for existing conditions.

Bed level changes are also predicted to be negligible in the Sepik River. Changes of up to about 2.5 m (increases and reductions) are comparable to those modelled under existing conditions. This variation reflects the natural transport processes controlling deposition and erosion of fine sediments in the Sepik River. These bed level changes along the Sepik River reflect predicted changes that will occur naturally even if the Project does not proceed.

Infrastructure Corridor

The estimated sediment loads generated as a result of construction of the infrastructure corridor (the area of which was conservatively assumed to be 50% larger to account for sidecasting) include:

- May River: 1.02 Mt.
- Idam River south of where the infrastructure corridor crosses the Sepik River: 0.94 Mt.
- Faringi, Bapi and Horden rivers north of where the infrastructure corridor crosses the Sepik River: 2.26 Mt.

Increases in TSS concentrations are likely within tributaries of the upper reaches of the May River, particularly where the infrastructure corridor crosses into and leaves the May River watershed. This is a function of the larger natural upslope contributing areas of the May River, higher discharges and naturally occurring sediment loads relative to other catchments along the infrastructure corridor. However, the impact is predicted to reduce closer to Hotmin where the terrain becomes flatter.

Along the infrastructure corridor within the catchments of the Idam, Faringi, Bapi and Horden rivers, ground slopes are generally flatter and rainfall intensities lower than those associated with the more elevated areas of the May River catchment through which the infrastructure corridor passes. Catchment areas of the Idam, Faringi, Bapi and Horden rivers in the vicinity of the infrastructure corridor are sufficiently large with the additional sediment loads from construction being negligible in relation to natural sediment loads. With sediment control management measures in place, and considering natural and assisted revegetation, localised impacts within these catchments will be short-term and are anticipated to recover to close to existing conditions within 18 months to 2 years.

The existing road from Green River to Vanimo will be upgraded only, thereby not contributing significantly to sediment loads.

Impact on Overbank Flooding and Floodplain Sedimentation

Periodic high flows along the lower Frieda and Sepik rivers currently result in overbank flooding and deposition of sediment on adjacent floodplains. In the upper catchments (upper Frieda River, Nena River, Ok Binai, and Ubai and Uba creeks), the valleys are deeply incised and as a consequence negligible overbank flooding currently occurs. All flows in the upper catchments are predicted to be contained within the river channels and therefore impacts of overbank sediment deposition occurring along these rivers as a result of the Project are expected to be low.

In the lower reaches of the Frieda River, almost all flow (and sediment) is conveyed within the river channel and the volume of water discharging onto the overbank areas is low. It is expected that the regulation of flows through the ISF will result in a reduction of overbank flows. Over the life of the Project only 1% of the total sediment load deposited in the ISF will be mobilised downstream. Overbank deposition is predicted to be reduced compared to existing conditions since there are minimal increases predicted in sediment concentrations at higher discharges above those observed under existing conditions.

Along the Sepik River, overbank flooding is estimated to naturally occur about 5% of the time. Given the very flat longitudinal river gradient and dense undergrowth on the overbank areas, it is predicted that in excess of 95% of the total flow will be naturally conveyed within the Sepik River channel during high floods. During operations, the predicted TSS concentrations and sediment deposition that would occur during overbank flooding in the Sepik River are comparable with existing conditions and is not expected to be affected by the Project.

Impact on Off-river Waterbody Sedimentation

A number of ORWBs are located adjacent to the downstream reach of the Frieda River and along the Sepik River downstream of its confluence with the Frieda River. These include:

- Lake Warangai and Lake Diawi adjacent to the Frieda River.
- Lake Warwi, Lake Mhowi, Wasui Lagoon, Amer Lagoon, Biimba Lagoon and Chambri Lakes adjacent to the Sepik River downstream of the Frieda River confluence.
- Oxbow lakes adjacent to the Sepik River.

Overbank flooding occurs in these areas under existing conditions and a similar flooding regime is predicted to occur during Project construction, operation and post closure. On an annual basis, overbank flooding probabilities in the lower reaches of the Frieda River as a result of the Project are expected to reduce considerably from those currently expected due to the regulation of flows from the ISF for power generation. However, the frequency of higher water levels is expected to remain comparable to those currently expected. Therefore, conditions in the river adjacent to the channels linking the Frieda River with Lake Warangai and Lake Diawi are likely to result in inundation to the extent currently observed, both in frequency and duration. The impacts of the Project on sediment inflows into Lake Warangai and Lake Diawi from Frieda River are expected to be negligible, with inflow TSS levels predicted to remain comparable to those estimated to occur under existing conditions.

Flows and TSS concentrations of the Sepik River are predicted to remain comparable to those currently observed and no Project-related impact on the ORWBs and oxbows along the Sepik River is predicted.

8.5.5 Water Quality

Study Method

A load balance model for the FRCGP and FRHEP was developed by SRK Consulting with the results reported in the Site-Wide Load Balance Report (Appendix 6b).

The purpose of the load balance modelling was to determine the concentrations of contaminants within the mine area watercourses, including the ISF reservoir, as well as the downstream receiving river system. The load balance results used the hydrology modelling results summarised in Section 8.5.3 as the basis for estimating contaminant loads and hence downstream concentrations.

Water quality predictions were calculated for each of the assessment points for dry (10th percentile), average and wet (90th percentile) conditions for the FRCGP operational period from impoundment of the ISF (Year -2 to Year 33) as well a FRCGP post closure period of 20 years (Year 34 to Year 54) using stochastically generated flow data.

Deterministic modelling was also undertaken to consider potential water quality effects that may result for three scenarios considering different combinations of wet and dry flow conditions in the upland (represented by flows at AP6) and lowlands areas. The deterministic modelling was conducted to test the sensitivity of the modelling results and to capture extreme weather conditions that were potentially not reflected in the stochastic modelling. The three scenarios were:

- Scenario 1 – Wet conditions in the Frieda River at AP6 with average conditions in the lowland areas.
- Scenario 2 – Average flow in the Frieda River at AP6 and dry conditions for lowland areas.
- Scenario 3 – Dry conditions in the Frieda River at AP6 and dry conditions for lowland sites.

Key Modelling Assumptions

Key assumptions for the modelling are:

- Pit water is treated from Year 1 of operations. Once the pit water is treated, its discharge into the ISF is not expected to significantly influence water quality within the ISF and downstream.
- Waste rock, which contains a high proportion of PAF material, is exposed to atmospheric conditions for a period of 12 weeks before being deposited subaqueously in the ISF. There is a degree of uncertainty regarding this time period as some waste rock in the pit walls may be exposed for years (prior to its removal and subsequent transport to the waste rock stockpile and barge dumping into the ISF) and some rock may be exposed for a much shorter period (in the order of days) depending of the mine production schedule. SRK Consulting deems this timeframe reasonable and defensible based on the information currently available and from a practical operational perspective. Sensitivity analyses have been undertaken by SRK Consulting for a three-week and six-week exposure period with the results discussed in the 'Sensitivity Analyses' section in Section 8.5.5 and further described in Appendix 6B.
- Based on site-specific data collected for the Project, the modelled data has considered the natural ability of the watercourses within, and downstream of, the FRCGP and FRHEP area to reduce bioavailable fractions of dissolved metals and metalloids (hereafter referred to as metals) as a result of forming stable complexes with dissolved organic matter (known as complexing capacity) (Section 7.2.3). A reduction in the bioavailable fraction of a dissolved metal also implies an associated reduction in potential toxicity to aquatic organisms depending on concentration and exposure duration. With regards to aluminium, chromium and zinc, for which there are no site-specific organic complexing capacity data available, the default complexing capacity values present in the model were used. The model assumes various metals compete in the complexation reactions and the outputs combine the complexation of all of the metals with the dissolved organic matter that is present in the river water (typically measured as dissolved organic carbon (DOC)). In general, aluminium, zinc and chromium have lower binding constants (i.e., lower affinities) than copper for dissolved organic matter. As well as DOC, pH and hardness also affect the bioavailability of dissolved metals. These factors have been considered in the modelling outputs.

Further details with regards to inputs and assumptions for water quality modelling are provided in Appendix 6b.

Factors Affecting Toxicity Not Considered in the Model

Other factors, which were not addressed by the physico-chemical modelling results, can also play a substantial modifying role in the toxicity of dissolved metal species. Some of these key additional factors include:

- Metals adsorption to suspended particulate matter (both organic and inorganic) is an additional natural factor present in the watercourses of the FRCGP and FRHEP area that may reduce bioavailable dissolved metals concentrations.
- In relation to dissolved aluminium in particular:
  - A proportion of the predicted dissolved aluminium is anticipated to exist in or be rapidly transformed to a colloidal particulate form (i.e., small solid particulates that are less than 0.45 µm in size) within the ISF. The effects of aging (i.e., aggregation) of these colloidal particles in the ISF reservoir were not addressed by the model. The colloidal particles in natural systems are expected to be less toxic than dissolved forms of aluminium (Teien et al., 2004) and freshly precipitated forms of aluminium colloidal particles are more toxic than aged forms. The modelling outputs are therefore highly conservative given that dissolved aluminium is reported as the maximum possible dissolved concentration based on saturation at the reported pH and that colloidal aging has not been considered in the model (SRK, pers. comm., 2018).
  - The toxicity of aluminium is affected by aging (i.e., whereby freshly generated and transient species of aluminium in solution become less toxic with time) (Gensemer et al., 2018). The transformative behaviour of aluminium at circumneutral pH is difficult to model and therefore predicting the dynamic toxicity of transient aluminium species to freshwater organisms is challenging. This is because monomeric species of aluminium quickly (over periods of a few hours) transform into insoluble polymers that precipitate out of solution. As a result, these transformative processes would largely be expected to occur within the ISF rather than downstream, based on residence time of water in the ISF of 10 to 12 days during average flows, and 2 to 3 days for infrequent ’storm flows’ (Appendix 2a). Transient species responsible for toxicity of aluminium are, therefore, unlikely to persist long enough to present a chronic risk to aquatic organisms except where aluminium-rich acidic or basic waters mix with more neutral pH waters, leading to the continual precipitation of aluminium within the mixing zone.
  - Dissolved aluminium is known to co-precipitate with iron hydroxides, which would further contribute to a loss of dissolved aluminium concentrations in the ISF reservoir (see ‘Dissolved Metals’ section below). This process has been well documented by Bertch et al. (1989) and Kimball (1997).

While these factors were not incorporated in the water quality modelling, they have been considered as part of the assessment in the following sections owing to their importance in reducing dissolved concentrations of metals and hence potential toxicity.

Results

The most significant Project-related changes to water quality are likely be associated with:

- Open-pit water discharges.
- Disposal of waste rock and tailings within the ISF.

- Fugitive sediment and eroded soils (addressed in Section 8.5.4).

Construction

During construction, the principal stressors within the surface water environment will be physical and primarily related to changes in flow regimes and increased TSS concentrations and associated turbidity, addressed in Section 8.5.3 (hydrology) and Section 8.5.4 (sediment transport) respectively. Project impacts to water quality are predominantly related to activities conducted during operations and therefore downstream water quality modelling did not predict changes to background water quality with respect to pH and dissolved metals during construction.

Operations: Open-pit Water Management

Management of water from the HITEK open-pit will be important considering that the runoff from the open-pit is expected to be poor quality due to the exposure of PAF material located in the open-pit walls and on the mined benches, and subsequent generation of AMD. Collection and treatment of the open-pit runoff within a water treatment plant is anticipated to mitigate water quality impacts downstream of the open-pit.

For the purposes of the contaminant load modelling, contaminants reporting to the pit sumps could originate from two sources. During mining, the fragmented rock on the mined benches has been assumed to accumulate to a depth of 0.3 m across all benches and oxidise at the maximum rates. In addition, leaching of contaminants from the open-pit walls is expected to continue for the life of the mine and FRCGP post closure given that oxygen will diffuse into the blast-damaged open-pit walls and oxidise PAF material that can release contaminants into surface runoff. Release of contaminants from open-pit wall rock depends on a number of factors such as the degree of fracturing, depth of fracture zone, reactivity of the exposed wall rock (e.g., pyrite content) and the depth of oxygenation. Based on oxygen diffusion calculations, overall oxidation rates for the model assumed a 90 to 100 mm depth of accessible reactive material in the open-pit walls. These rates were used to predict the contaminant load from wall rock oxidation, as described in Appendix 6b.

Modelling for the HITEK open-pit indicates that the untreated open-pit water and water stored in the open-pit sumps will be of poor quality, because of low pH and elevated dissolved metals concentrations, and will therefore require treatment prior to discharge.

Open-pit Water Treatment

An engineered water treatment plant will commence operation in Year 1 to treat the poor quality open-pit water. The treated water will be discharged into Ubai Creek from where it will flow into the ISF and be further diluted prior to entering the downstream environment. Clean water diversions upstream of the open-pit will be constructed to divert water around the mining area, to avoid contact with exposed wall rock, and reduce the volume of water requiring treatment.

Open-pit contact water will be treated with quicklime or hydrated lime to neutralise acidity and precipitate metals prior to release to the Ubai Creek and thereafter the ISF. The conceptual lime dosing rates to treat open-pit water during operations are given in Section 5.5.6. Modelling shows that as open-pit development progresses, and water flow and acidity increases during operation, the lime dosing rate will need to correspondingly increase to maintain the required discharge water quality. Sludge generated from treatment of the open-pit contact water will be pumped to the tailings thickener at the process plant for final co-disposal with tailings into the ISF. All results presented in the following sections assume that open-pit water is treated throughout operations and into the FRCGP post closure period, with the exception of the period at the end of operations when the open-pit is being flooded and there is no discharge from the open-pit. During FRCGP post closure, once downstream water quality can be maintained below permit conditions and FRCGP closure objectives are met, pit water treatment will cease.

Operations: Water Quality Predictions

This section summarises the predicted downstream water quality in comparison with guidelines and background water quality during operations. Predicted water quality parameters are based on the results of stochastic modelling, with the results of the sensitivity analyses (i.e., deterministic modelling) presented at the end of the section.

Table 8.26 presents water quality for pre-mining background concentrations of key parameters for the Frieda and Sepik rivers. Average, 90th percentile and maximum values have been provided. The 90th percentile is the value below which 90% of recorded values fall, giving an indication of the typical upper concentrations that occur within these rivers. As discussed in Section 7.2, dissolved metals concentrations in these two rivers are generally low and metals concentrations are predominantly associated with the particulate fraction. Total metal concentrations increase with the level of TSS. Natural background (baseline) recorded maximum concentrations of copper and zinc exceed ANZECC/ARMCANZ (2000) 95% aquatic ecosystem trigger values in the Frieda River, while the guideline trigger values for aluminium, cadmium, copper and zinc are exceeded in the Sepik River.

In summary, modelling shows that under dry, average and wet conditions (i.e., low, average and high flows in both the Frieda and Sepik rivers) during operations:

- PNG Ambient Water Quality Standards will be met in the Frieda and Sepik rivers.
- PNG Standards for Drinking Water will be met in the Frieda River at AP7 and the Sepik River at AP13, with the exception of lead (Sepik River) and iron (Frieda and Sepik rivers) that are naturally elevated in these rivers. Predicted concentrations of all total metals are not expected to exceed background concentrations.
- WHO Guidelines for Drinking Water Quality will be met in the Frieda and Sepik rivers at AP7 and AP13, respectively, with the exception of iron and lead which are naturally elevated in these rivers. All predicted total metals concentrations are not expected to exceed background concentrations.
- ANZECC/ARMCANZ (2000) aquatic ecosystem trigger values will be met in the Frieda River with the exception of aluminium, chromium and copper where their respective guideline values are predicted to be exceeded during average and low flows. Further discussion with regards to labile concentrations and site-specific criteria are provided in the ‘Factors affecting water quality: speciation modelling results’ section below. In the Sepik River, ANZECC/ARMCANZ guideline values are predicted to be met with the exception of aluminium and copper. While concentrations of cadmium and zinc are also predicted to marginally exceed their ANZECC/ARMCANZ (2000) trigger values, the concentrations of these parameters are within the natural variability of the background concentrations within the Frieda and Sepik rivers.
- IFC discharge criteria for metals in the ISF discharge are predicted to be met, with the exception of iron which is naturally elevated in the receiving Frieda River at the ISF discharge location.

Table 8.26 Summary of background key water quality parameters at assessment points downstream of the ISF

Site	Location	Statistic	TSS	Dissolved parameters															
				Field pH	Hardness	DOC	SO_4	Al	Sb	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Se	Zn
			mg/L	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Lower Detection Limit			< 1	-	<1	<1	<1	<0.005	<0.001	<0.001	<0.0001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005
Upper Detection Limit			<10	-	-	-	<5	<0.01	-	-	-	-	-	<0.05	-	-	-	<0.01	-
W23	Frieda River downstream of airstrip (AP7)	Average	97	7.3	32	1	3	0.0273	0.0010	0.0010	0.0001	0.0010	0.0011	0.0619	0.0010	0.0074	0.0015	0.0094	0.0077
		p90	244	7.8	37	2	4	0.0470	0.0010	0.0010	0.0002	0.0010	0.0010	0.0970	0.0010	0.0107	0.0020	0.0100	0.0150
		Max	449	7.9	39	2	5	0.0500	0.0010	0.0010	0.0002	0.0010	0.0020	0.1100	0.0010	0.0120	0.0030	0.0100	0.0200
W71	Frieda River road crossing (AP10)	Average	86	7.1	80	2	2	0.0267	0.0010	0.0010	0.0001	-	0.0013	0.1083	0.0010	0.0188	0.0023	0.0100	0.0180
		p90	154	7.4	80	2	4	0.0450	0.0010	0.0010	0.0001	-	0.0020	0.1600	0.0010	0.0345	0.0030	0.0100	0.0300
		Max	193	7.6	80	2	4	0.0500	0.0010	0.0010	0.0001	-	0.0020	0.1600	0.0010	0.0460	0.0030	0.0100	0.0300
W38A	Lower Frieda River (AP11)	Average	144	7.1	32	2	2	0.0229	0.0010	0.0010	0.0001	0.0010	0.0011	0.0993	0.0010	0.0171	0.0021	0.0100	0.0104
		p90	339	7.6	43	3	3	0.0470	0.0010	0.0010	0.0001	0.0010	0.0010	0.1400	0.0010	0.0314	0.0030	0.0100	0.0197
		Max	389	7.9	43	3	3	0.0500	0.0010	0.0010	0.0003	0.0010	0.0020	0.1400	0.0010	0.0350	0.0030	0.0100	0.0390
W34	Sepik River @ Iniok (AP12)	Average	343	7.2	57	3	5	0.0164	0.0010	0.0011	0.0001	0.0010	0.0013	0.1043	0.0010	0.0142	0.0010	0.0100	0.0079
		p90	685	7.6	70	4	8	0.0270	0.0010	0.0017	0.0002	0.0010	0.0020	0.1570	0.0010	0.0267	0.0010	0.0100	0.0084
		Max	1,010	8.0	77	4	8	0.0300	0.0010	0.0020	0.0003	0.0010	0.0020	0.2500	0.0010	0.0360	0.0010	0.0100	0.0380
W35	Sepik River @ Kubkain (AP13)	Average	375	7.5	53	3	4	0.0185	0.0010	0.0010	0.0001	0.0010	0.0015	0.1185	0.0010	0.0193	0.0010	0.0100	0.0112
		p90	822	7.9	62	5	6	0.0360	0.0010	0.0010	0.0002	0.0010	0.0020	0.2160	0.0010	0.0426	0.0010	0.0100	0.0240
		Max	992	8.0	65	8	7	0.0400	0.0010	0.0010	0.0005	0.0010	0.0020	0.3100	0.0010	0.0460	0.0010	0.0100	0.0450

s.u. refers to standard units

pH and Sulphate

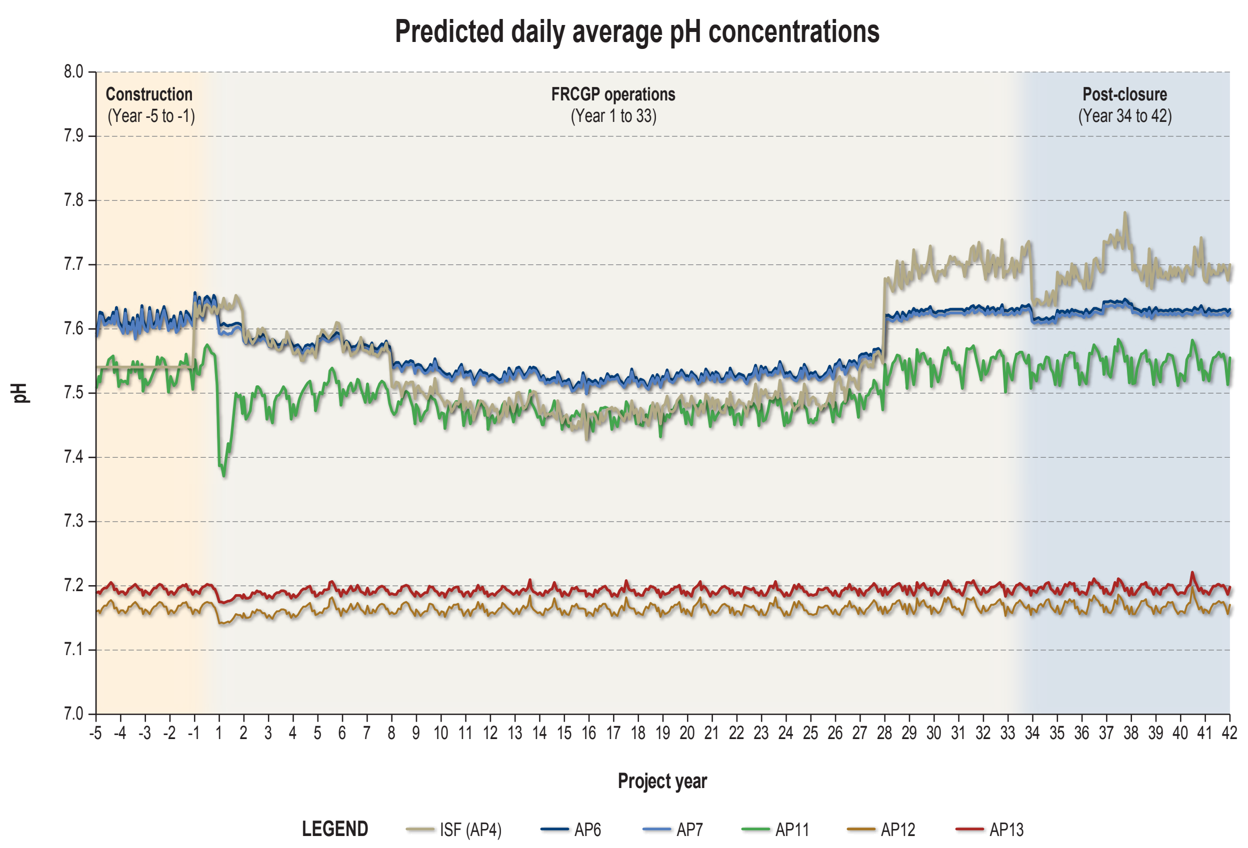
Background pH in the Frieda and Sepik rivers is typically between pH 7 and 8. Under existing conditions, sulphate concentrations reach a maximum of 5 mg/L in the Frieda River near AP7 and a maximum of 8 mg/L in the Sepik River. Figure 8.5 shows the modelled average daily pH and sulphate concentrations at assessment points under average flow conditions over the mine life. The results indicate that pH in the ISF (AP4) will be relatively stable around circumneutral pH, with a range of 7.4 to 7.7 during operations. At AP6 and AP7 in the Frieda River downstream of the ISF embankment, average daily pH shows little fluctuation and will remain above pH 7.5.

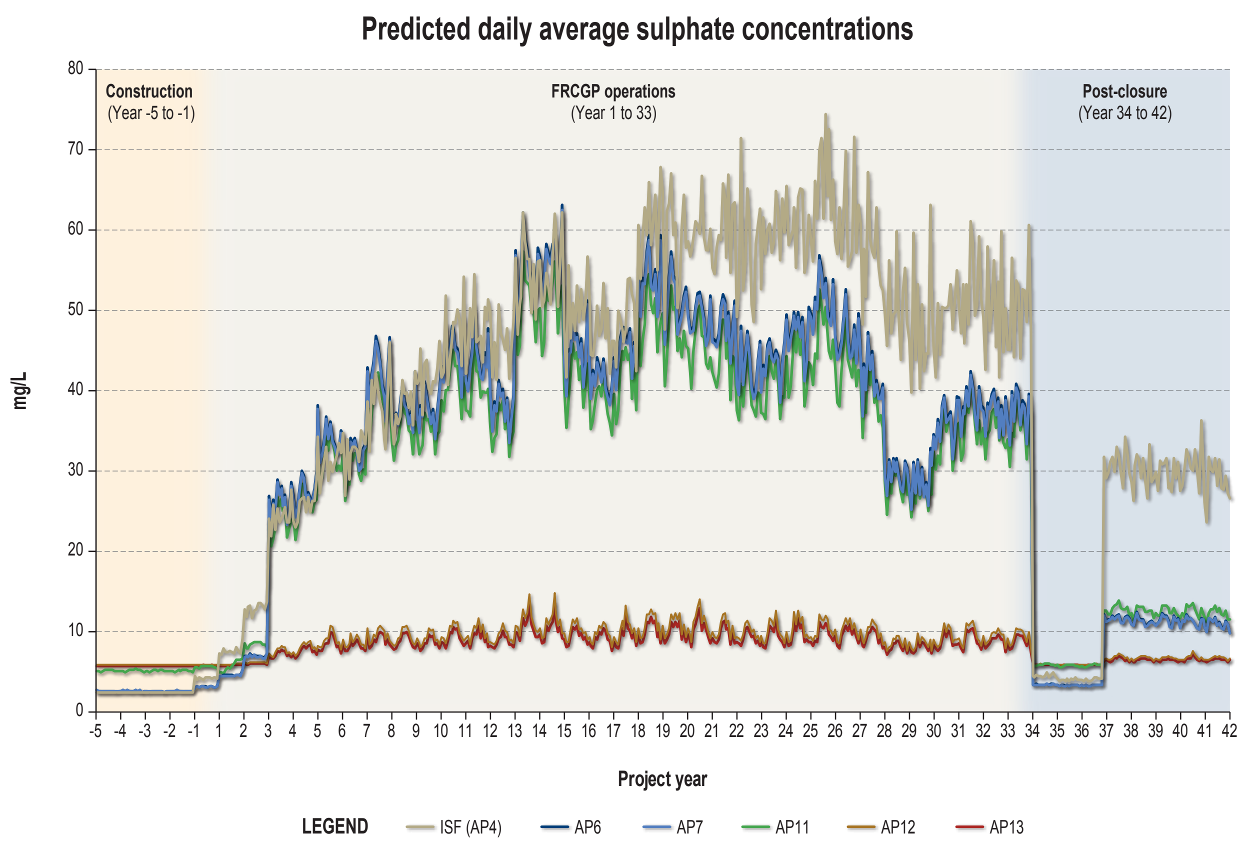
A slight reduction in pH to 7.4 at AP11 (compared to AP6 and AP7) in the Frieda River is predicted at the beginning of operations during the ISF filling period, which then increases to around pH 7.5 for the remainder of operations. This is due to the increased proportion of natural runoff from the floodplains adjacent to the lower Frieda River, which is of lower pH, compared to the flows coming through the ISF. Circumneutral pH conditions are also predicted in the Sepik River (AP12 and AP13) during operations, which are comparable to the background pH range.

Sulphate concentrations are predicted to increase to a maximum of 74 mg/L during operations in the ISF (AP4) and to about 63 mg/L in the ISF discharge (AP6), compared to a maximum background (baseline) concentration of 5 mg/L in the upper Frieda River. The average sulphate concentration in the Sepik River is expected to increase slightly to approximately 10 mg/L at average flows compared to a 90th percentile baseline concentration of approximately 6 mg/L. The primary sources of sulphate are the tailings and treated open-pit water discharge, and its concentrations are predicted to decrease in Year 25 in the ISF and Frieda and Sepik rivers. By Year 27, concentrations of sulphate increase at the assessment points shown in Figure 8.5, after which they begin to fall again by Year 31. This is due to changes in the mine schedule, whereby the mill feed reduces in Year 25 (which results in a reduction in tailings deposition and therefore sulphate concentrations), followed by a slight increase in the mill feed in Years 26 and 27. Volumes of waste rock to be deposited in the ISF also begin to reduce in Year 26. At the end of operations, there is a sharp decrease in sulphate concentrations while the open-pit is being flooded, during which time there are no discharges of treated or untreated open-pit water.

Under high flow conditions (i.e., wet conditions, 90th percentile flows) and low flow conditions (i.e., dry conditions, 10th percentile flows), pH and sulphate concentrations follow a trend similar to the average flow conditions. In general, pH values are predicted to be higher for the high flow conditions compared to average flows as a result of the higher dilutions provided by the mine area watercourses, which are naturally more basic. Sulphate concentrations in the Frieda and Sepik rivers are predicted to increase to a similar magnitude for high flow conditions as those expected for average flows. At low flows in the Frieda and Sepik rivers, however, sulphate concentrations are predicted to increase compared to average flows (as well as baseline concentrations), with average concentrations during operations of 68 mg/L compared with a maximum background concentration of 5 mg/L for the Frieda River (AP7) and 29 mg/L compared to the maximum background concentration of 8 mg/L for the Sepik River (AP13). These concentrations represent worst-case conditions and would occur for short periods when flows in both the uplands and lowlands are low.

These modelling results indicate that, during mine operations, water quality in the ISF and at assessment points downstream of the ISF is driven largely by contaminant sources from the barge dumping of waste rock and, to a lesser degree, by deposition of tailings at depth in the ISF and discharge of treated open-pit water to the ISF via Ubai Creek.





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Date: 13.09.2018 Project: 754-ENAUABTF11575B File Name: 11575_11_F08.05_GRA	Frieda River Limited Sepik Development Project	FRIEDA RIVER	Predicted daily average pH and sulphate concentrations at selected assessment points during average flows	Figure No: 8.5

Total Dissolved Metals

Predicted daily average dissolved concentrations for average and dry flow conditions at key assessment points during operations are shown in Table 8.27. This includes the ISF reservoir northern arm (AP4) that represents worst-case water quality in the ISF, the ISF discharge (AP6), the upper Frieda River (AP7), and the Sepik River at Kubkain (AP13). All modelled data are presented as total dissolved concentrations[7]. Modelled data for high flow conditions are not shown given that they are lower than predicted concentrations during average and low flows.

Once the ISF embankment is constructed in the upper Frieda River and filling of the reservoir is complete, the surface water environment will change from a lotic (flowing) environment to a lentic (still or very slow flowing) environment. This change will affect site AP4 located in the Nena River. Concentrations of contaminants in the ISF are expected to be elevated above background concentrations and water quality guidelines (if they were applied) given that it will be a repository for waste rock and tailings and this facility is considered an integral part of the Project footprint. However, water quality guidelines will be applied at the end of a mixing zone in the upper Frieda River, the proposed location of which will be negotiated and agreed with CEPA for inclusion in the environment permit for the Project.

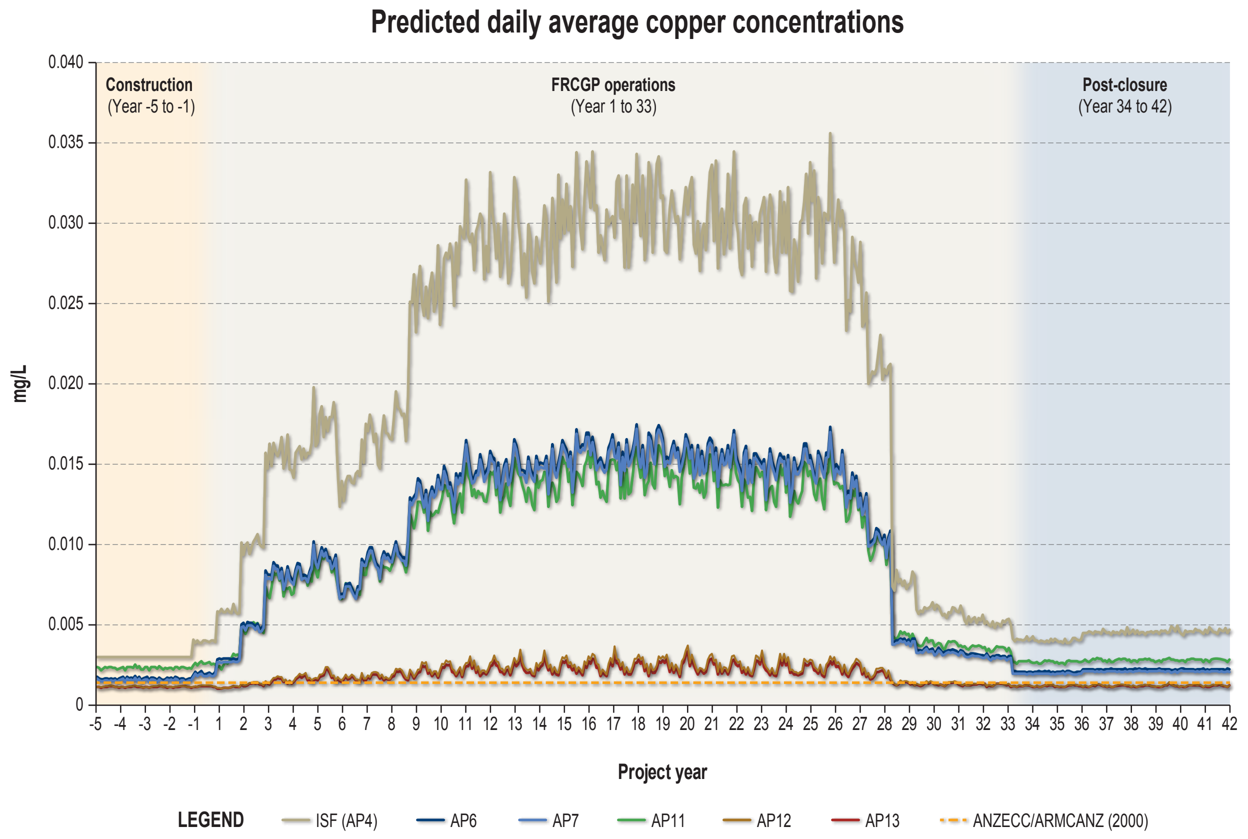
Modelled concentrations of contaminants are predicted to be similar along the length of the river (from AP7 to AP11) based on the limited additional dilution from tributaries of the Frieda River downstream of the ISF embankment. Flows in the Frieda River contribute approximately 14% of the flows in the Sepik River and therefore contaminant concentrations reduce in the Sepik River owing to the large degree of dilution offered by waters from the Sepik River catchment.

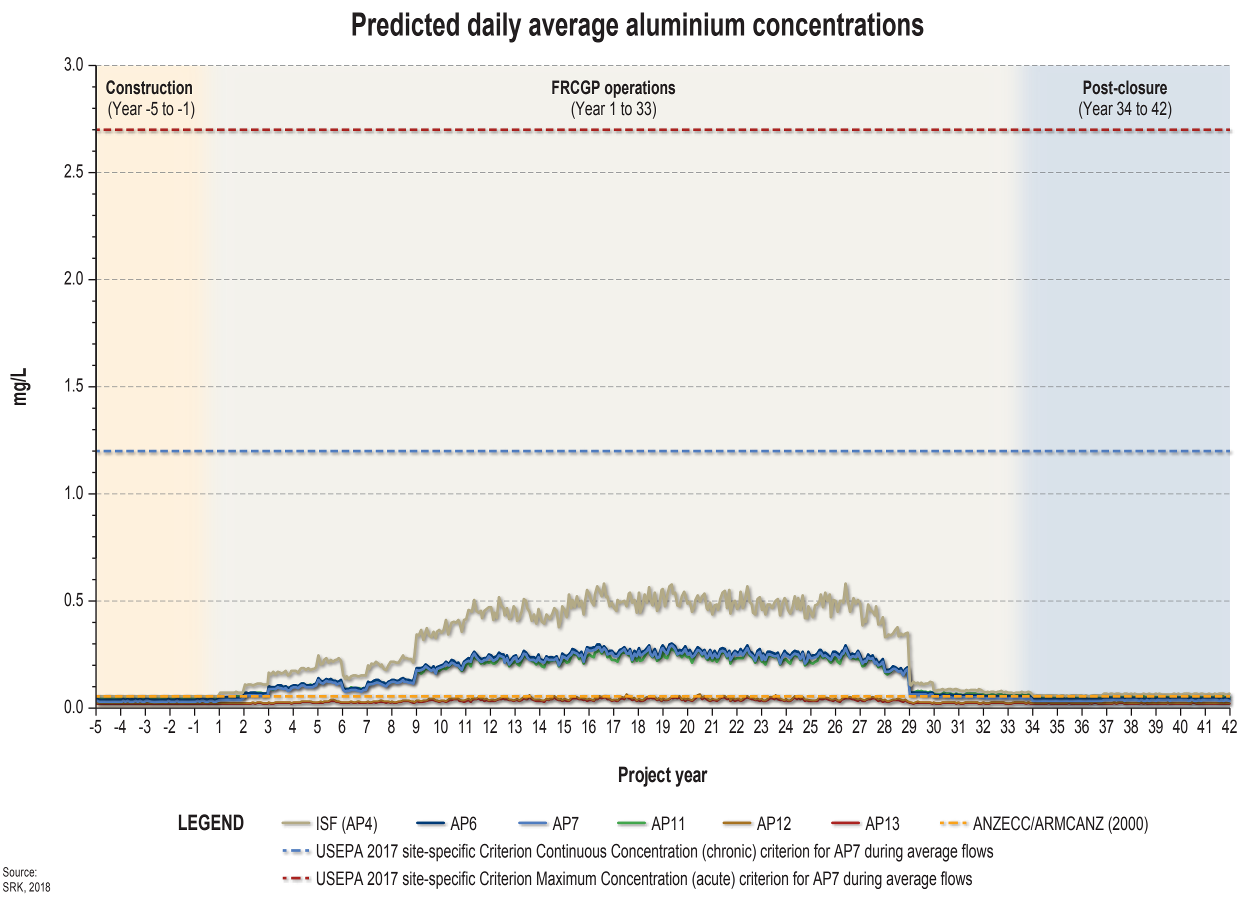
Average metals concentrations are predicted to meet ambient PNG Schedule 1 criteria (Table 8.26) in the ISF and the Frieda and Sepik rivers (i.e., AP4, AP6, AP7, AP11, AP12 and AP13) under all flow conditions during operations. Total dissolved concentrations of aluminium, cadmium, chromium, copper and zinc are predicted to exceed the ANZECC/ARMCANZ (2000) 95% ecosystem protection trigger values during average flows and low flows in the Frieda River. Exceedances of ANZECC/ARMCANZ (2000) trigger values for total dissolved concentrations of chromium and copper are predicted during average flows, and for aluminium, chromium, copper and zinc during low flows, in the Sepik River.

Dissolved cadmium and zinc concentrations in the ISF and Frieda River during average and low flows, and zinc concentrations in the Sepik River during low flows, are predicted to marginally exceed their respective ANZECC/ARMCANZ (2000) trigger values. However, the predicted concentrations are comparable to their 90th percentile background dissolved concentrations at these locations. The modelling results in Appendix 6B also indicate that silver concentrations in the Frieda and Sepik rivers exceed the ANZECC/ARMCANZ (2000) silver guideline value; this is primarily related to the limits of detection used for the analysis of baseline concentrations being higher than the guideline value. The following discussion therefore focusses on the key metals of interest, namely total dissolved copper, aluminium and chromium.

As shown in Figure 8.6, total dissolved aluminium and copper concentrations are predicted to increase from Year 1 of operations. The main source of dissolved contaminants (about 75%) will be from the barge-dumped crushed waste rock in the ISF reservoir and 25% is anticipated to

[7] Total dissolved concentration includes all species that pass through a 0.45 µm filter, including colloidal, labile and non-labile concentrations.





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SRK, 2018

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Project:	754-ENAUABTF11575B
File Name:	11575_11_F08.06_GRA

Frieda River Limited

Sepik Development Project

FRIEDA RIVER

Predicted daily average dissolved copper and aluminium concentrations at selected assessment points during average flows

Figure No: 8.6

originate from the tailings liquor (which includes the treated open-pit water component). Predicted concentrations of dissolved metals and other contaminants begin to reduce towards the end of operations in Year 26 as the waste rock deposition volumes reduce.

Copper. During average and low flows, average copper concentrations in the Frieda River at AP7 are predicted to reach 0.011 mg/L and 0.0183 mg/L, respectively, which is approximately 8 and 13 times higher than the ANZECC/ARMCANZ (2000) trigger value of 0.0014 mg/L and higher than the 90th percentile background concentration (0.001 mg/L) at this location. In the Sepik River at AP13 during average flows, copper concentrations of 0.0019 mg/L are predicted to slightly exceed the trigger value. During low flows, the copper concentration at this location (0.0068 mg/L) is predicted to exceed the ANZECC/ARMCANZ (2000) trigger value by approximately five times and is approximately 3.4 times the 90th percentile background concentration (0.002 mg/L) at AP13.

Aluminium. During average and low flows, average aluminium concentrations in the Frieda River at AP7 are predicted to be 0.174 mg/L and 0.279 mg/L, respectively, which is approximately 3 and 5 times higher than the ANZECC/ARMCANZ (2000) trigger value of 0.055 mg/L and also higher than the 90th percentile background concentration (0.047 mg/L) at this location. In the Sepik River at AP13 during average flows, predicted aluminium concentrations are below the ANZECC/ARMCANZ (2000) trigger value. During low flows, aluminium concentrations at this location are predicted to exceed the guideline value by a factor of approximately two.

Chromium. During average and low flows, the predicted average chromium concentrations of 0.0012 mg/L and 0.0013 mg/L respectively in the Frieda River at AP7, and 0.0011 mg/L and 0.0012 mg/L respectively in the Sepik River at AP13, only marginally exceed the ANZECC/ARMCANZ (2000) trigger value of 0.001 mg/L and are higher than the 90th percentile background concentrations at these two locations.

By the end of FRCGP operations (Year 34) dissolved aluminium and chromium concentrations are predicted to fall below their respective ANZECC/ARMCANZ (2000) trigger values in the Frieda and Sepik rivers. Dissolved copper concentrations in the Frieda River are predicted to decline at the end of FRCGP operations but remain above the ANZECC/ARMCANZ (2000) trigger value for copper. In the Sepik River, dissolved copper concentrations reduce and are predicted to be below the ANZECC/ARMCANZ (2000) trigger value in Year 34.

Site-specific factors affecting the bioavailability, and therefore toxicity, of copper, aluminium and chromium are discussed in further detail below.

Factors affecting water quality: speciation modelling results

As discussed above, based on modelling of mine-derived contaminants relative to their respective ANZECC/ARMCANZ (2000) trigger values for 95% ecosystem protection and compared to background concentrations in the Frieda and Sepik rivers, dissolved copper, aluminium and chromium concentrations are predicted to be the most challenging metals in terms of likely exceedance. The ANZECC/ARMCANZ (2000) trigger values for these metals provide an initial screening point for assessing the potential for environmental risk and it is well accepted by regulators in many jurisdictions that regionally specific environmental factors can modify the intrinsic toxicity of metals to aquatic organisms in surface waters. These factors include occurrence of the metal in solid phases (as metal hydroxides and carbonates or adsorbed on the surfaces of suspended particulate matter) or forming complexes in solution with naturally occurring dissolved organic matter (e.g., humic and fulvic acids). Both solid phases and moderately strong metal complexes in solution can substantially reduce the toxicity of the free metal ion (the most toxic form).

The hierarchical risk assessment framework, on which the ANZECC/ARMCANZ (2000) water quality guidelines are based, addresses this issue by taking a top down approach as described in Section 8.5.1. Firstly, the total (dissolved plus particulate) metal concentration is compared with the applicable guideline trigger value. If the total concentration exceeds the trigger value then the next step is to examine the dissolved concentration. If this value also exceeds the guideline then the next step is to assess the potential for amelioration by assessing the potential for formation of moderate to strong complexes in solution with naturally occurring dissolved organic matter and/or the influence of water hardness and pH.

Speciation modelling results for aluminium, copper and chromium, taking into account some of these site-specific factors, are presented in Table 8.28. The discussion of predicted speciation results is supported by field data (specific to copper), speciation case studies in the literature and advancements in deriving site-specific guidelines that vary as a function of other variables (i.e., pH, DOC and hardness). The labile concentrations of each metal are compared to water quality guidelines.

Aluminium

As shown in Table 8.28, most of the dissolved aluminium is predicted to be in the labile (i.e., bioavailable) form (approximately 99% at AP4 in the ISF and AP7 in the Frieda River, and 96% at AP13 in the Sepik River) and therefore labile concentrations are similar to the total dissolved concentrations discussed previously. While the labile aluminium concentrations exceed the ANZECC/ARMCANZ (2000) trigger value of 0.055 mg/L in the Frieda River at AP7 (during average and low flows) and in the Sepik River at AP13 (during low flows), this guideline does not consider site-specific factors such as pH, DOC and hardness, nor the recent advancements in scientific knowledge relating to aluminium toxicity at circumneutral pH.

As discussed in Section 8.5.1, recent studies by the US EPA (2017a) and others including Gensemer et al. (2018) and Deforest et al. (2017) have shown that pH, hardness and DOC act together to greatly modulate the toxicity of aluminium. The US EPA has generated a user-friendly Aluminium Criteria Calculator (V.1.0 (Aluminium Criteria Calculator v10.xlsx, US EPA, 2017b) that allows users to enter site-specific values for pH, total hardness and DOC to calculate applicable freshwater acute and chronic criteria. Using this calculator, and inputting the SRK Consulting-predicted pH, DOC and hardness, the site-specific Criterion Maximum Concentration (CMC) (or freshwater acute criterion) and the Criterion Continuous Concentration (CCC) (or freshwater chronic criterion) were derived and are presented in Table 8.29.

In the ISF reservoir (AP4) and the Frieda (AP7) and Sepik (AP13) rivers, the predicted site-specific labile aluminium concentrations during low and average flows are below the calculated acute and chronic site-specific criteria. This comparison to the site-specific criteria is conservative as the assessment does not take into account additional reductions in labile concentrations of aluminium as a result of adsorption onto suspended particulate matter nor co-precipitation with iron hydroxides and sedimentation of these particles in the ISF.

Table 8.27 Predicted average dissolved concentrations for modelled average and low flow conditions during operations

Location	Site description	pH	SO_4	Hardness (as $CaCO_3$)	TOC	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Average flows															
AP4	ISF reservoir (northern arm)	7.5	47	58	2.1	***0.330***	0.0017	***0.00028***	***0.0013***	***0.022***	0.166	0.0012	0.0136	0.0052	***0.0150***
AP6	Nena River upstream of Frieda River	7.6	40	67	1.7	***0.171***	0.0013	0.00019	***0.0012***	***0.0121***	0.106	0.0012	0.0138	0.0028	***0.0100***
AP7	Frieda River (airstrip)	7.6	39	67	1.7	***0.169***	0.0013	0.00019	***0.0012***	***0.011***	0.105	0.0012	0.0137	0.0028	***0.0100***
AP11	Frieda River (upstream of Sepik River confluence)	7.5	37	90	2.6	***0.166***	0.0021	***0.00026***	***0.002***	***0.01***	0.148	0.0020	0.0203	0.0036	***0.0150***
AP12	Sepik River (Iniok GS)	7.2	10	64	3	0.032	0.0011	0.00012	***0.0011***	***0.0021***	0.097	0.0011	0.0134	0.0013	0.0060
AP13	Sepik River (Kubkain)	7.2	9	63	3	0.031	0.0011	0.00012	***0.0011***	***0.0019***	0.094	0.0011	0.0133	0.0013	0.0060
Low flows															
AP4	ISF reservoir (northern arm)	7.5	83	88	2.2	***0.5607***	0.0024	***0.0005***	***0.0018***	***0.0368***	0.261	0.0014	0.0217	0.0088	***0.0231***
AP6	Nena River upstream of Frieda River	7.5	68	94	2	***0.2813***	0.0010	***0.0003***	***0.0013***	***0.0184***	0.149	0.0013	0.0189	0.0043	***0.0141***
AP7	Frieda River (airstrip)	7.5	68	93	1.9	***0.2792***	0.0016	***0.0003***	***0.0013***	***0.0183***	0.148	0.0013	0.0188	0.0043	***0.0141***
AP11	Frieda River (upstream of Sepik River confluence)	7.5	68	121	2.9	***0.2867***	0.0025	***0.0004***	***0.0020***	***0.0184***	0.194	0.0022	0.0254	0.0051	***0.0188***
AP12	Sepik River (Iniok GS)	7.2	29	83	3	***0.1166***	0.0015	0.0002	***0.0012***	***0.0074***	0.129	0.0014	0.0171	0.0025	***0.0099***
AP13	Sepik River (Kubkain)	7.2	27	81	3	***0.1072***	0.0015	0.0002	0.001	***0.0068***	0.124	0.0014	0.0167	0.0024	***0.0094***

Table 8.27 Predicted average dissolved concentrations for modelled average and low flow conditions during operations (cont'd)

Location	Site description	pH	SO_4	Hardness (as $CaCO_3$)	TOC	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Water quality guidelines															
PNG Schedule 1 criteria[a]		[b]	400	-	-	-	0.05	0.01	0.05	1	1	0.005	0.5	1	5
PNG Standards for Drinking Water [c]		6.5 to 9.2	-	600	-	-	0.05	0.01	-	1.5	1	0.5	0.5	-	15
WHO drinking water[d]			-	-	-	-	0.01	0.003	0.05	1	0.3	0.01	-	0.07	3
IFC Effluent Guidelines[e]		6	-	-	-	-	0.1	0.05	0.1	0.3	2	0.2	-	0.5	0.5
ANZECC/ARMCANZ[f]		6 to 8[g]	-	-	-	0.055	0.013	0.0002	0.001[h]	0.0014	-	0.0034	1.9	0.011	0.008

All units are in mg/L except for pH, which are in standard units.

Exceedances are indicated by: IFC – italics; PNG Schedule 1 – bold; WHO or PNG Drinking Water Standards – underlined, ANZECC/ARMCANZ – bold italics. Where multiple guidelines are exceeded, the least stringent guideline exceedance is indicated.

[a] PNG Environment (Water Quality Criteria) Regulation 2002, Schedule 1. Metal concentrations are for dissolved substances, passing through a nominal 0.45 µm filter.

[b] No alteration to natural pH.

[d] WHO, 2017.

[e] IFC effluent guidelines (2007). Applicable to total metals concentrations.

[f] Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000), aquatic ecosystem trigger values for slightly to moderately disturbed system.

[g] Lowland rivers.

[h] Chromium VI.

Table 8.28 Predicted concentrations of aluminium, copper and chromium species under average and low flow conditions during operations*

Location	Site description	Hardness (as mg/L $CaCO_3$)	pH	Total Organic Carbon (mg/L)	Aluminium				Copper				Chromium			
					Total dissolved (mg/L)	Complexed		Labile species (mg/L)	Total dissolved (mg/L)	Complexed		Labile species (mg/L)	Total dissolved (mg/L)	Complexed		Labile species (mg/L)
						mg/L	%			mg/L	%			mg/L	%	
Average flows																
AP4	ISF reservoir (northern arm)	58	7.5	2.1	0.332	0.002	0.7	***0.329***	0.022	0.0156	71.2	***0.0063***	0.0013	0.0012	91.8	0.0001
AP6	Nena River upstream of Frieda River	67	7.6	1.7	0.176	0.002	1.4	***0.174***	0.011	0.0087	77.9	***0.0025***	0.0012	0.0011	94.1	0.0001
AP7	Frieda River (airstrip)	67	7.6	1.7	0.174	0.002	0.9	***0.173***	0.011	0.0078	70.4	***0.0033***	0.0012	0.0011	93	0.0001
AP11	Frieda River (upstream of Sepik River confluence)	90	7.5	2.6	0.17	0.002	1.4	***0.167***	0.01	0.0074	70.8	***0.0031***	0.002	0.0019	95.5	0.0001
AP12	Sepik River (Iniok GS)	64	7.2	3	0.032	0.001	3.9	0.031	0.0021	0.0018	87.3	0.0003	0.0011	0.0011	96.7	0.00004
AP13	Sepik River (Kubkain)	63	7.2	3	0.031	0.001	3.9	0.029	0.0019	0.0017	87.3	0.0002	0.0011	0.0011	96.7	0.00004
Low flows																
AP4	ISF reservoir (northern arm)	88	7.5	2.2	0.5607	0.0045	0.8	***0.556***	0.0368	0.0200	54.3	***0.0168***	0.00181	0.0017	92.3	0.00014
AP6	Nena River upstream of Frieda River	94	7.5	2	0.2813	0.0020	0.7	***0.279***	0.0184	0.0123	66.9	***0.0061***	0.00129	0.0012	91.6	0.00011

Table 8.28 Predicted concentrations of aluminium, copper and chromium species under average and low flow conditions during operations* (cont'd)

Location	Site description	Hardness (as mg/L $CaCO_3$)	pH	Total Organic Carbon (mg/L)	Aluminium				Copper				Chromium			
					Total dissolved (mg/L)	Complexed		Labile species (mg/L)	Total dissolved (mg/L)	Complexed		Labile species (mg/L)	Total dissolved (mg/L)	Complexed		Labile species (mg/L)
						mg/L	%			mg/L	%			mg/L	%	
Low flows (cont'd)																
AP7	Frieda River (airstrip)	93	7.5	1.9	0.2792	0.0015	0.5	***0.278***	0.0183	0.0110	60.0	***0.0073***	0.00128	0.0011	89.7	0.00013
AP11	Frieda River (upstream of Sepik River confluence)	121	7.5	2.9	0.2867	0.0031	1.1	***0.284***	0.0184	0.0124	67.1	***0.0061***	0.00202	0.0019	94.5	0.00011
AP12	Sepik River (Iniok GS)	83	7.2	3	0.1166	0.0029	2.5	***0.114***	0.0074	0.0062	83.0	0.0013	0.00124	0.0012	96.0	0.00005
AP13	Sepik River (Kubkain)	81	7.2	3	0.1072	0.0029	2.7	***0.104***	0.0068	0.0057	84.0	0.0011	0.00120	0.0011	96.1	0.00005
Water quality guidelines																
PNG Schedule 1 criteria[a]		-	[b]	-	-				1				0.05			
PNG Standards for Drinking Water standards[c]		600	6.5 to 9.2	-	-				1.5				-			
WHO (2017) drinking water[d]		-		-	-				1				0.05			
IFC Effluent Guidelines[e]		-	6	-	-				0.3				0.1			

Table 8.28 Predicted concentrations of aluminium, copper and chromium species under average and low flow conditions during operations* (cont'd)

Location	Site description	Hardness (as mg/L $CaCO_3$)	pH	Total Organic Carbon (mg/L)	Aluminium				Copper				Chromium			
					Total dissolved (mg/L)	Complexed		Labile species (mg/L)	Total dissolved (mg/L)	Complexed		Labile species (mg/L)	Total dissolved (mg/L)	Complexed		Labile species (mg/L)
						mg/L	%			mg/L	%			mg/L	%	
Water quality guidelines (cont'd)																
ANZECC/ARMCANZ[f]		-	6 to 8[g]	-	0.055				0.0014				0.001[h]			

Guidelines are compared with the labile concentration of metals.
Exceedances are indicated by: IFC – italics; PNG Schedule 1 – bold; WHO or PNG Drinking Water Standards – underlined, ANZECC/ARMCANZ – bold italics. Where multiple guidelines are exceeded, the least stringent guideline exceedance is indicated.
[a] PNG Environment (Water Quality Criteria) Regulation 2002, Schedule 1. Metal concentrations are for dissolved substances, passing through a nominal 0.45 µm filter.
[b] No alteration to natural pH.
[c] Public Health (Drinking Water) Regulation 1984, Schedule 2.
[d] WHO, 2017.
[e] IFC effluent guidelines (2007). Applicable to total metals concentrations.
[f] Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000), aquatic ecosystem trigger values for slightly to moderately disturbed system.
[g] Lowland rivers.
[h] Chromium VI.

Table 8.29 Predicted site-specific labile aluminium acute and chronic criteria

Location	Site description	Average baseline and SRK predicted data				Predicted calculated site-specific value	
		DOC (mg/L)	Hardness (mg/L as $CaCO_3$)	pH (s.u.)	Labile Al [a] (mg/L)	CMC (i.e., acute) (mg/L)	CCC (i.e., chronic) (mg/L)
Baseline[a]							
AP4	Lower Nena (W29)	2.2	26	7.8	0.062	2.7	1.4
AP7	Frieda River (airstrip) (W23)	1.0	32	7.3	0.04	1.6	0.8
AP13	Sepik River (Kubkain) (W35)	3.0	53	7.5	0.038	3.4	1.5
Average flows - predicted							
AP4	Lower Nena	2.1	58	7.5	0.329	2.9	1.2
AP7	Frieda River (airstrip)	1.7	67	7.6	0.173	2.7	1.2
AP13	Sepik River (Kubkain)	3.0	63	7.2	0.029	2.8	0.9
Low flows - predicted							
AP4	Lower Nena	2.2	88	7.5	0.556	3.0	1.0
AP7	Frieda River (airstrip)	1.9	93	7.5	0.278	2.7	0.9
AP13	Sepik River (Kubkain)	3	81	7.2	0.104	2.8	0.9

Source: US EPA, 2017a and b. s.u. denotes pH standard units.
[a] Baseline data refers to total dissolved concentration.

The use of site-specific derivation of criteria for dissolved aluminium is supported by recent research documented in the literature (e.g., Deforest et al., 2017; Gensemer et al., 2018). The water chemistry of total dissolved aluminium (including labile, organically or particle-bound, colloidal or particulate species) is complex and depends on the site-specific conditions. A review of the aluminium toxicity information in ANZECC/ARMCANZ (2000) and more recent sources outlining significant advances in the understanding aluminium toxicity has been undertaken and the general key findings are discussed below in terms of factors affecting toxicity.

pH. The aluminate cation, $Al(OH)^{2+}$ is the most toxic species of aluminium (Driscoll et al., 1980) which is dominant in acidic waters (range of pH 4 to pH 6). The predicted speciation for dissolved aluminium in the Frieda/Sepik river system indicates that only 1% of the total dissolved aluminium is in this cationic form due to the higher circumneutral pH in these rivers (SRK, Pers. Comm, 2018). An unknown proportion of the dissolved aluminium is also likely to be present as colloids (i.e., particulate aluminium species <0.45 µm which are operationally defined as being dissolved in most jurisdictions). The bottom cut-off for the colloidal size range is defined as 0.001 µm (Kimball, 1997).

Detailed particle sizing work in rivers reported by Hill and Aplin (2001) and the speciation of AMD-generated metals subject to in-river neutralisation reported by Kimball (1997), indicate the majority of dissolved aluminium is likely to be in colloidal form around pH 7. This colloidal proportion (0.001 to <0.45 µm size range) is likely to be less bioavailable and therefore potentially less toxic than truly dissolved forms (Teien et al., 2004).

Dissolved organic carbon. The distribution of aluminium species can change dramatically in the presence of even moderate amounts of DOC (Santore et al., 2018) in the absence of other competing metals. For example, when 5 mg/L of DOC is present, organic aluminium complexes are the dominant dissolved aluminium species at pH values below pH 8. However, in the presence of other competing metals such as copper, which has a stronger affinity for DOC as shown in the modelling predictions, less of the dissolved aluminium will be able to be bound by DOC and will be present as both colloids (particulate) and labile forms (i.e., not complexed). In surface freshwaters with neutral to slightly basic pH values greater than pH 7.5, dissolved aluminium concentrations are typically low and organic complexing is assumed to dominate (Ball et al., 2005). This has been found to be the case in numerous studies by directly analysing for organically bound aluminium (Driscoll et al., 1984; Driscoll and Postek, 1996; Hendershot et al., 1996; Nordstrom, 2011).

Hardness. While pH dependant, the uptake and toxicity of aluminium in freshwater organisms generally decreases with increasing water hardness (Deforest et al., 2017). Predicted water hardness in the Frieda River during operations ranges from 67 to 98 mg/L $CaCO_3$ equivalents (which is much higher than baseline hardness ranging from 21 to 39 mg/L in the Frieda River at AP7), indicating moderately hard to hard waters based on the ANZECC/ARMCANZ (2000) categorisation. In the Sepik River, water hardness is predicted to range from 63 to 83 mg/L at average and low flows during operations which is similar to baseline hardness at AP13.

Aging. Freshly precipitated colloidal particles are more toxic than aged forms, noting in this context that a recent study suggests that it is difficult to separate the toxicity of dissolved and monomeric aluminium forms from the physical effects of freshly precipitated aluminium, such as smothering of respiratory organs and effects on iono-regulatory membranes (Gensemer et al., 2018). However, given that the residence time of water in the ISF is 10 to 12 days during average flows, and 2 to 3 days for infrequent ’storm flows’ (Appendix 2A), the aluminium precipitate initially formed in the waste rock discharge zone in the ISF will have substantially aged by the time it reaches the ISF embankment and is thus likely to be less toxic once it enters the Frieda and Sepik rivers. Furthermore, the aging aggregation process will also facilitate removal of dissolved aluminium by settling to the bottom of the ISF, thereby lowering the amount transported to the spillway.

Summary. Based on the comparison of the US EPA (2017a and 2017b), calculated acute and chronic site-specific criteria (that consider the recent advancements in aluminium research and site-specific factors) in Table 8.29, during low and average flows in the ISF reservoir, and the Frieda and Sepik rivers, acute or chronic aluminium-related toxicity is unlikely as the predicted labile aluminium concentrations are below these calculated criteria. This assessment is more appropriate than the use of the ANZECC/ARMCANZ (2000) trigger value for aluminium as it considers site-specific factors that are known to significantly reduce aluminium toxicity and endorses the development of site-specific compliance criteria for aluminium.

Chromium

Based on the predicted modelling data presented in Table 8.28, most (approximately 93 to 97%) of the dissolved chromium is complexed with organic matter and thereby is unlikely to be bioavailable to aquatic biota. The predicted labile chromium concentrations in the ISF reservoir (AP4), Frieda (AP7) and Sepik (AP13) rivers during average flows, forming approximately 3 to 7% of the dissolved fraction, are an order of magnitude below the ANZECC/ARMCANZ (2000) trigger value for chromium of 0.001 mg/L. As such, no further discussion of chromium is undertaken.

Summary. No site-specific guideline for chromium is required given that labile chromium concentrations are well below the ANZECC/ARMCANZ (2000) trigger value.

Copper

Predicted labile copper concentrations in the Frieda River at AP7 during average and low flows are 2.3 times and 5.2 times higher than the ANZECC/ARMCANZ (2000) trigger value (0.0014 mg/L) based on the speciation modelling predictions in Table 8.28. At average and low flows in the Sepik River (AP13), predicted labile copper concentrations of 0.0002 mg/L and 0.0011 mg/L, respectively, are below the 90th percentile background concentration of 0.002 mg/L at this site (Table 8.25) and therefore no copper-related water quality impacts in the Sepik River are anticipated. As such, the discussion below focusses primarily on copper-related impacts in the Frieda River.

While these predictions take into account copper complexing capacity, it is important to note that the results do not consider adsorption of dissolved metals onto suspended particulate matter, which could further reduce labile concentrations of copper.

Copper complexing capacity. As discussed in Section 7.2.3, site-specific copper complexing capacity data was collected over two sampling surveys (2015 and 2017) to determine the natural capacity of the Nena, Frieda and Sepik rivers to form strongly bound complexes between the dissolved organic matter and dissolved metals, thereby making the metals less bioavailable (i.e., less toxic) to aquatic biota than labile copper (i.e., free unbound copper ions in solution). These data indicated that under existing conditions in the Frieda and Sepik rivers, most, if not all, of the dissolved fraction of copper is bound with DOC and thereby reduces its toxicity to aquatic biota (i.e., labile copper concentrations are low or not detectable). The proportion of copper that is predicted by SRK Consulting (Appendix 6b) to be complexed (approximately 70 to 78% in the Frieda River and 87% in the Sepik River) in Table 8.28 generally reflects the measured field data for the Frieda and Sepik rivers.

As for aluminium, key factors that can influence copper complexing capacity are the DOC concentration and pH. However, the chemistry of copper is significantly different to that of aluminium. Dissolved copper has a strong affinity to DOC and therefore dissolved copper will outcompete other metals to complex with DOC at higher DOC concentrations. This reduces labile copper bioavailability and therefore toxicity to aquatic biota. Typically, as pH increases, copper complexing also increases. Therefore, in neutral or alkaline water bodies, it is more likely that dissolved copper will be bound with DOC if it is present. Other variables affecting copper complexing capacity include the nature of the dissolved organic matter (number of metal binding sites and binding affinity), conductivity, hardness, concentrations of major ions and temperature.

Relevant published literature and case studies have been reviewed to provide the basis for assessing the potential significance of the modelled metal and metalloid concentrations. A comprehensive regionally relevant case study for copper toxicity in PNG rivers is provided by the extensive work performed over many years by the CSIRO in the Ok Tedi-Fly River system. While there are key differences to the Frieda River system, the Ok Tedi-Fly River system provides a reasonable case study of the potential fate, transport and toxic effects of copper in a PNG river system. Based on data collected for the Ok Tedi-Fly River system during mine operation from 1996 to 2004, total dissolved copper concentrations ranged from approximately 0.006 to 0.028 mg/L, of which only 0.0005 to 0.0092 mg/L was measured as labile copper, which is potentially bioavailable and toxic (Stauber et al., 2009).

While there has been a substantial loss of fish from the Ok Tedi and middle Fly River, copper toxicity was ruled out as the cause of this loss because the dissolved copper levels have not been sufficiently elevated to exceed the available complexing capacity of copper by DOC, with the residual labile (potentially bioavailable) copper concentrations being too low to account for the loss of fish. The reduced fish populations were attributed to other factors relating to mine-derived sediments such as the loss of riverine habitat due to bed aggradation and the smothering of natural habitat, as well as high TSS concentrations. Despite these findings, the labile copper concentrations were reported at levels that have the potential to cause chronic effects, such as toxicity of dissolved copper to eggs or juveniles of fish, although monitoring of the Ok Tedi-Fly River system has not shown any evidence of these effects.

In a review of 120 papers, Chariton and Apte (2005) identified that copper concentrations below 0.002 mg/L have no observable effect on the composition, diversity and abundance of biota; however, changes in composition and biomass (growth inhibition) of copper-sensitive algae have been observed at concentrations ranging from 0.0037 to 0.018 mg/L. Chariton and Apte (2005) summarised the likelihood of effects at the following ranges of dissolved copper concentrations:

- 0.001 to 0.002 mg/L – no ecological threats to algae, invertebrates or fish.
- 0.002 to 0.01 mg/L – impacts to microalgae and to benthic invertebrates.
- 0.01 to 0.05 mg/L – adverse impacts to algal and invertebrate communities, with significant changes in biomass and abundance.
- 0.05 to 0.15 mg/L – algae still present but with significant alterations to composition and dominance.
- >0.15 mg/L – substantial impairment to algae, invertebrates and fish. Declines in salmon fry at 0.16 mg/L and complete loss of benthic fauna at 0.26 mg/L. Studies of acute copper toxicity to juvenile barramundi (mean length 306±21mm) collected from the Fly River, reported 96-h LC_{50} values between 0.41 mg/L (initial measured concentration) and 0.27 mg/L (final measured concentration at 96 hrs) (Australian Water Technologies, 2002).

Based on this information, concentrations of labile copper predicted to occur in the Frieda River (sites AP7 through AP11) during low and average flow conditions may result in some impacts to copper-sensitive species of microalgae and to benthic invertebrates. However, the adsorption of a proportion of the labile copper onto suspended particulate matter is likely to further reduce the bioavailable concentration of dissolved copper (as described in Section 7.2.3 and below) and thus reduce the impact below that which would occur in the absence of suspended particulate matter onto which labile copper species can adsorb.

Copper adsorption. Copper adsorption measurements were performed on separate water samples collected from the Frieda and Sepik rivers to determine the ability of the naturally present suspended particulate matter in the water to reduce dissolved copper concentrations via adsorption onto the particulate matter, known as adsorption capacity (see Section 7.2.3). This mechanism for reducing dissolved copper concentration acts in addition to the reduction of bioavailable copper produced by copper complexing with DOC as described previously.

In the Frieda River, copper spike tests showed that the proportion of copper removed from the dissolved phase through adsorption onto suspended particulate matter ranged from 46 to 85% based on 55 mg/L TSS, with the highest proportion being measured in the middle Frieda River (Site W71, AP10). In the Sepik River, the proportion of copper removed from the dissolved phase through adsorption onto suspended particulate matter ranged from 50 to 71% based on 275 mg/L TSS. At higher concentrations of TSS, removal of labile copper from the dissolved phase is expected to be higher. Furthermore, as discussed in Section 7.2.3, while the measured adsorption affinity of the Sepik River sample was relatively low compared to the Frieda and Nena river samples (i.e., the binding sites per gram of TSS is lower), the higher TSS concentrations present are likely to reduce dissolved copper concentrations by more overall.

Based on the lowest measured proportion of copper removed from solution as a result of adsorption (46%[8] in a Frieda River sample, see Section 7.2.3, Table 7.16), the remaining labile copper concentration in the Frieda River at AP7 during average and low flows is predicted to be 0.0018 mg/L and 0.004 mg/L, which is approximately 1.8 and 4 times higher than 90th percentile background concentration at this location. During average flows, there would be no ecological threat to algae, invertebrates or fish based on the effects observations of Chariton and Apte (2005) as summarised above. During low flows, which occur only 10% of the time (or approximately 36 days per year), there is the possibility of impacts to copper-sensitive microalgae and benthic invertebrates in the Frieda River but there is unlikely to be any significant changes in algal or invertebrate community biomass and abundance.

Summary. The measured labile copper concentrations and predicted labile copper concentrations in the Frieda and Sepik rivers during average flows are much lower than the total dissolved copper, approaching the ANZECC/ARMCANZ (2000) aquatic ecosystem trigger value for copper of 0.0014 mg/L. During low flows in the Frieda River, however, the estimated labile copper concentration is 4 times higher than the background concentration at AP7, potentially resulting in impacts to copper-sensitive microalgae and benthic invertebrates. In addition to copper complexing capacity, the adsorption of copper by the substantial concentrations of natural suspended particulate matter (test range of 55 to 275 mg/L) will also act to further reduce the concentrations of dissolved copper in the Frieda and Sepik rivers. This finding suggests that site-specific criteria for bioavailable copper (and therefore potential toxicity) that take account of modifying factors such as complexation and adsorption (absent in the ANZECC/ARMCANZ (2000) trigger value for copper) are justified for the Project.

Sensitivity analyses

Sensitivity analyses have been undertaken for the effect of the exposure period of waste rock (i.e., in relation to oxidation of sulphide minerals and acid generation potential) prior to subaqueous disposal in the ISF. Specifically, three-week and six-week waste rock exposure periods were compared with the base case 12-week waste rock exposure period for the average flow condition, and these results are presented in Table 8.30. Shorter exposure times for waste rock result in significantly reduced dissolved concentrations of aluminium and copper (and other contaminants) due to the shorter time available for oxidation of sulphide minerals and production of soluble acid and metals dissolution.

The results indicate that in the ISF reservoir (AP4) and in the Frieda River (AP7), concentrations of copper and aluminium reduce by approximately 40% when exposed for six weeks compared with 12 weeks, and reduce by approximately another 30% when exposed for three weeks compared to six weeks. The clear conclusion is that minimising the exposure period, where practical, will be critical to limiting the inputs of metals to the water column in the ISF.

As expected, the dissolved metals reductions in the Sepik River are not as markedly reduced as in the Frieda River, with an approximately 15% reduction in dissolved aluminium and copper

[8] The experimental TSS concentration associated with this proportional copper reduction was 55 mg/L at AP7. The average TSS concentration predicted during operations at AP7 is 271 mg/L (Appendix 5, Table 21).

concentrations when the waste rock is exposed for six weeks compared to 12 weeks, and a further approximately 10% when exposed for three weeks compared to six weeks.

While concentrations of labile aluminium and dissolved copper are substantially reduced for shorter waste rock exposure periods during average flows in the Frieda River, the respective ANZECC/ARMCANZ (2000) trigger values for aluminium and copper are still exceeded.

Table 8.30 Total dissolved copper and labile aluminium concentrations at selected assessment points during operations at average flows

Location	Site description	12 weeks		6 weeks		3 weeks	
		Labile Al (mg/L)	Dissolved Cu* (mg/L)	Labile Al (mg/L)	Dissolved Cu * (mg/L)	Labile Al (mg/L)	Dissolved Cu* (mg/L)
AP4	ISF reservoir (northern arm)	0.329	0.0220	0.199	0.0134	0.133	0.0092
AP7	Frieda River (airstrip)	0.173	0.0110	0.106	0.0070	0.074	0.0049
AP13	Sepik River (Kubkain)	0.029	0.0019	0.025	0.0016	0.023	0.0014

* Predicted total dissolved copper results are presented.

Total Metals

Total metals in Project watercourses were based on Golder Associates' predicted TSS concentrations presented in Appendix 5 and summarised in Section 8.5.3. As a result, the predicted total metals concentrations include the mine-derived component as well as the natural background concentrations. This is particularly important when assessing total metals concentrations in the Sepik River, as the mine-derived metals component is expected to be only a minor fraction of the modelled predicted total metals values, and natural total metals concentrations are likely to be in thermodynamically more stable forms (i.e., potentially less bioavailable). The predicted total metals concentrations do not consider the proportion of metals that is expected to precipitate from the dissolved fraction nor the proportion of dissolved metals that may adsorb to suspended particulate matter.

TSS levels are highly variable in the Frieda and Sepik rivers and dependent on flow. In general, TSS levels increase progressively from upland streams to lowland floodplain rivers. For example, this natural variation is observed in the Frieda River (Site W23) near AP7 where background TSS concentrations range from 8 mg/L to 449 mg/L, and in the Sepik River at Kubkain (Site W35) where TSS concentrations range from 112 mg/L to 992 mg/L. The higher TSS concentrations are generally associated with high flow events and the lower concentrations are associated with low flow events.

Similarly, total metals concentrations fluctuate depending on TSS concentrations. Existing total iron concentrations in the Frieda River (Site W23) range from 0.12 to 12.2 mg/L. In the Sepik River (Site W35), total iron concentrations range from 0.59 to 37.9 mg/L. The maximum background concentrations of iron naturally exceed the WHO drinking water guideline value (0.3 mg/L), the PNG Public Health (Drinking Water) Regulation Schedule 2 (1 mg/L), the raw drinking water quality criterion (0.3 mg/L) described in OEC (2000) as well as IFC effluent guideline for iron (2 mg/L). Iron is naturally elevated in the Sepik River due to existing background TSS concentrations where it forms a major component of the mineral phases in the sediment particles. Therefore, for a naturally turbid river system such as the Frieda/Sepik river system where background concentrations are higher than the guidelines, the background concentrations (90^{th} percentile) are used for comparison to predicted concentrations.

Predicted total metals concentrations at selected assessment points are shown in Table 8.31. Assuming no management measures are in place to reduce TSS concentrations in the ISF, the maximum total iron concentrations under average flows are predicted to exceed WHO (2017) and PNG drinking water guidelines in the Frieda and Sepik rivers. The predicted concentrations of iron are 4.60 mg/L in the Frieda River at AP7 and 7.47 mg/L in the Sepik River (AP14) under average flows. These predicted concentrations do not exceed the 90^{th} percentile background levels at these locations (i.e., 6.74 mg/L at AP7 and 18.8 mg/L at AP13) and therefore are expected to be within the range of natural variability.

Similar trends in the Frieda and Sepik rivers are predicted under low flows, during which slightly higher TSS concentrations (and total metals) are expected compared with average flows. Conversely, predicted TSS and total metals concentrations under high flows are slightly lower than under average flows. This finding is contradictory to what occurs during pre-mining conditions when TSS is generally higher at high flows than at low flows. For the purposes of modelling, it was assumed that any disturbed area will contribute the same mine-related sediment load over a given year regardless of flow and therefore the model conservatively predicts that there is more dilution at high flows and lower TSS concentration (and less dilution at low flows resulting in high TSS concentrations).

Lead concentrations during average and low flows are expected to marginally exceed the PNG and WHO (2017) drinking water guidelines in the lower Frieda River (AP11) and the Sepik River (AP13) but do not exceed the recorded 90^{th} percentile background concentrations of 0.02 mg/L near AP7 and 0.0168 mg/L near AP13.

In most cases, predictions of total metals concentrations in the Frieda and Sepik rivers are comparable to pre-mining background concentrations. However, given that the ISF is expected to function as a trap for natural sediments, construction-derived sediments and mine waste, only small particle sizes (i.e., less than 8 microns (μm), Appendix 2a) that do not settle within the residence time in the ISF are predicted to reach the Frieda and Sepik rivers and be transported further downstream as part of the wash load without settling. While the adsorption capacity of mine-derived particles is unknown, they will be fresh and of raw mineralogical composition lacking in surface organic matter compared to natural suspended sediments that are aged and typically have a coating of organic matter and bacteria (i.e., a biofilm). Small sized mine-derived or natural sediment particles have large surface-area-to-mass ratios that provide higher adsorption capacities than an equivalent mass of larger sized particles that have small surface-area-to-mass ratios (John and Leventhal, 2004).

Reduction in total metals concentrations discharged from the ISF could be achieved by the implementation of additional management measures such as silt curtains at the decant structures. This measure would also support the operational requirements of the hydroelectric power intake which requires a low level of suspended solids to reduce surface erosion of the turbine blades. Sediment management measures are presented in Table 8.23.

Table 8.31 Predicted average total metals concentrations during average flows in the Frieda and Sepik rivers during operations

Site	Location	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Se	Zn
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Average flows												
AP6	ISF Discharge	4.47	0.0023	0.0007	0.0054	0.1018	***4.66***	0.0087	0.0995	0.0112	0.0022	0.0738
AP7	Frieda River (airstrip)	4.42	0.0023	0.0007	0.0054	0.1006	***4.60***	0.0086	0.0983	0.0111	0.0022	0.0730
AP11	Frieda River U/S Sepik River	5.30	0.0033	0.0009	0.0069	0.1186	***5.58***	***0.0110***	0.1225	0.0136	0.0022	0.0912
AP12	Sepik River (Iniok GS)	6.48	0.0026	0.0009	0.0074	0.1378	***6.92***	***0.0124***	0.1417	0.0139	0.0017	0.1015
AP13	Sepik River (Kubkain GS)	7.00	0.0026	0.0010	0.0080	0.1486	***7.47***	***0.0133***	0.1520	0.0148	0.0018	0.1090
Low flows												
AP6	ISF Discharge	4.59	0.0025	0.0008	0.01	0.1090	***4.70***	0.0088	0.1046	0.0127	0.003	0.0778
AP7	Frieda River (airstrip)	4.53	0.0025	0.0008	0.01	0.1078	***4.65***	0.0087	0.1034	0.0126	0.003	0.0769
AP11	Frieda River U/S Sepik River	5.42	0.0036	0.0010	0.01	0.1265	***5.63***	***0.0112***	0.1276	0.0151	0.003	0.0948
AP12	Sepik River (Iniok GS)	6.56	0.0030	0.0010	0.01	0.1431	***6.95***	***0.0127***	0.1454	0.0151	0.002	0.1052
AP13	Sepik River (Kubkain GS)	7.07	0.0030	0.0010	0.01	0.1535	***7.49***	***0.0136***	0.1554	0.0160	0.002	0.1124
Baseline (90^{th} percentile)												
W23	Frieda River downstream of airstrip (AP7)	3.87	0.002	0.0001	-	0.0059	***6.74***	***0.020***	0.10240	0.0240	0.010	0.008
W35	Sepik River @ Kubkain (AP13)	9.84	0.0048	0.0001	-	0.0236	***18.88***	***0.0168***	0.4948	0.0244	0.010	0.047
Water quality guidelines												
PNG Schedule 2[a]		-	0.05	0.01	-	1.5[b]	1[b]	0.1	0.5[b]	-	0.01	15[b]
PNG raw drinking water[c]		-	0.007	0.002	0.05	1	0.3	0.01	0.1	0.02	0.01	0.3

Table 8.31 Predicted average total metals concentrations during average flows in the Frieda and Sepik rivers during operations (cont'd)

Site	Location	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Se	Zn
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Water quality guidelines (cont'd)												
WHO (2017) drinking water[d]		-	0.01	0.003	0.05	1	0.3	0.01	-	0.07	0.04	3
IFC Effluent Guidelines[e]		-	0.1	0.05	0.1	0.3	2	0.2	-	0.5	-	0.5

a Public Health (Drinking Water) Regulation 1984, Schedule 2.
b Aesthetically-based value.
c Raw drinking water quality criteria described in OEC (2000).
d WHO (2017).
e IFC effluent guidelines (2007). Applicable to total metals concentrations.
Exceedances of the PNG Schedule 2 guidelines indicated by bold text.
Exceedances of the PNG raw drinking water or WHO drinking water guidelines indicated by bold italic text.
Exceedances of the IFC Effluent Guidelines indicated by underlined text.

Nutrients

Immediately following the filling of the ISF reservoir in Year 1 (complete flooding), vegetation in the littoral zones (i.e., near the banks of the ISF and inundated river and tributary inflow zones) is anticipated to decompose at a faster rate than vegetation in the main body of the reservoir and, in the process, generate elevated nutrient concentrations that enter the main body of the reservoir, the majority of which is ammonia. This littoral zone area, to a depth of less than 7 m, covers 8% of the ISF surface area and, upon mixing with other zones within the reservoir and oxygenation as the water flows through the ISF power intake or spillway, nutrient concentrations downstream are expected to be below water quality guidelines. Nutrient concentrations are expected to reduce within the reservoir, and therefore downstream, as the ISF water chemistry stabilises.

During operations at average flows in the Frieda River (AP7), predicted concentrations of ammonia (0.071 mg/L) and nitrate (0.276 mg/L) are below their respective PNG Schedule 1 Criteria of 3.6 mg/L (assuming 25°C and pH of 7) and 45 mg/L, respectively. In the Sepik River at AP13 during average flows, predicted ammonia and nitrate concentrations of 0.037 mg/L and 0.038 mg/L are also below the PNG Schedule 1 Criteria. The predicted concentrations of these two parameters in the Sepik River (AP13) are also below their respective 90th percentile background concentrations (ammonia at 0.18 mg/L and nitrate (as NOx) at 0.08 mg/L at AP13).

Predicted total phosphorus concentrations generally increase with distance downstream of the FRCGP and FRHEP area, indicating that the mine is not anticipated to contribute to phosphorus loadings in downstream watercourses.

Organic Carbon

Modelled maximum concentrations of total organic carbon and DOC at selected assessment points are shown in Table 8.32. These concentrations were calculated based on flow-weighted modelling combining flow rates with field-measured DOC data. These concentrations indicate that, in general, DOC is higher in the Sepik River than in the Frieda River or other upstream watercourses, as well as slightly higher during low flows compared with average flows.

As described in the preceding sections, DOC is expected to form moderate to strongly bound complexes with dissolved metals including copper, chromium and aluminium. Therefore, higher concentrations of DOC means there is more DOC available to form organic metal complexes and hence reduce labile (and potentially toxic) concentrations of metals to which aquatic biota are exposed.

Table 8.32 Predicted maximum carbon concentrations (mg/L)

Location		**Total organic carbon**	**Dissolved organic carbon**
Average flow conditions			
ISF reservoir (northern arm)	AP4	2.1	1.9
ISF discharge	AP6	1.7	1.3
Frieda River (airstrip)	AP7	1.6	1.3
Frieda River (upstream of Sepik River confluence)	AP11	2.6	1.6
Sepik River (Kubkain)	AP13	3.2	2.3
Low flow conditions			
ISF decant	AP4	2.2	1.9

Table 8.32 Predicted maximum carbon concentrations (mg/L) (cont'd)

Location		Total organic carbon	Dissolved organic carbon
Low flow conditions (cont'd)			
ISF discharge	AP6	2	1.4
Frieda River (airstrip)	AP7	1.9	1.4
Frieda River (upstream of Sepik River confluence)	AP11	2.9	2.3
Sepik River (Kubkain)	AP13	3	2.8

Deterministic Modelling

Three flow combination scenarios for different low, average and high flow conditions in the uplands, represented by flows at AP6, and lowlands were generated to assess the effects of these conditions on water quality:

- Scenario 1 – High flow in the Frieda River at AP6 with average conditions in the lowland areas.
- Scenario 2 – Average flow in the Frieda River at AP6 and low flow conditions for lowland areas.
- Scenario 3 – Low flow in the Frieda River at AP6 and low flow conditions for lowland areas. This scenario conservatively reflects the worst-case conditions.

Predicted average dissolved concentrations in the ISF discharge (AP6) and in the Sepik River (AP13) at Kubkain for each of the three scenarios are presented in Table 8.33. While results are not presented for AP7 in the upper Frieda River, concentrations in the ISF discharge (AP6) are expected to be the same at AP7 due to the proximity of the sites and the lack of dilution between sites. The results indicate that compared to guidelines and existing concentrations:

- PNG Schedule 1 water quality criteria are met for all parameters for all scenarios.
- Total dissolved aluminium concentrations in the ISF discharge are predicted to exceed the ANZECC/ARMCANZ (2000) trigger value (0.055 mg/L) for all three scenarios. However, these concentrations do not exceed calculated site-specific acute and chronic criteria using the US EPA (2017a and 2017b) guidelines (Table 8.29). The ANZECC/ARMCANZ (2000) trigger value for aluminium is not exceeded in the Sepik River.
- For all three scenarios, the total dissolved copper concentrations are predicted to exceed the ANZECC/ARMCANZ (2000) guideline value of 0.0014 mg/L in the Frieda and Sepik rivers, with the highest copper concentrations of 0.0184 mg/L predicted at AP6 and 0.0024 mg/L at AP13 for Scenario 3 (i.e., under low flow and dry-year conditions). Average concentrations of total dissolved copper in the ISF discharge are predicted to be almost 17 times higher than the background concentration in the Frieda River and up to 1.6 times higher in the Sepik River.

  Based on the proportion of total dissolved copper estimated to be complexed with dissolved organic matter (i.e., approximately 70 to 78% in the Frieda River and 87% in the Sepik River as shown in Table 8.27), labile copper concentrations of approximately 0.005 mg/L at AP6 and 0.0003 mg/L at AP13 may be expected under Scenario 3 low flow and dry-year conditions.

  In the Frieda River, in addition to the effects of complexing capacity, further reductions of labile copper concentrations (of approximately 46% based on a TSS concentration of 55 mg/L) due to adsorption onto suspended particulate matter would result in a labile copper concentration of 0.003 mg/L in the Frieda River. Impacts to microalgae and to benthic invertebrates may therefore occur during Scenario 3 conditions, which could occur for 10% of the time.

In the Sepik River, additional reductions in labile copper concentrations of 50% (based on 275 mg/L TSS) in the Sepik River are anticipated (discussed above) due to adsorption on suspended particulate matter, the result of which would be no impacts to macroalgae, invertebrates or fish at AP13 (during Scenario 3).

No labile copper impacts for Scenario 1 and 2 in the Frieda and Sepik rivers are anticipated based on copper complexing capacity and copper adsorption capacity measurements.

- Predicted total dissolved chromium concentrations in the Frieda River (AP6) are slightly in exceedance of the ANZECC/ARMCANZ (2000) trigger value for chromium. However, given that most of the dissolved chromium will be complexed with organic matter, the labile concentrations are expected to be below the ANZECC/ARMCANZ (2000) trigger value.
- Total dissolved zinc concentrations in the Frieda and Sepik rivers during all three scenarios are predicted to marginally exceed the ANZECC/ARMCANZ (2000) guideline value of 0.008 mg/L by a factor of 1.8 times in the Frieda River (under Scenario 3) and 1.5 in the Sepik River. In the Sepik River, the predicted zinc concentrations are comparable to natural background concentrations. While the majority of total dissolved zinc concentrations are expected to be labile (Table 8.27), it is anticipated that a proportion of this zinc will be removed from the dissolved phase due to adsorption onto suspended particulate matter (Prusty et al., 1994), resulting in concentrations that approach the ANZECC/ARMCANZ (2000) trigger value in both rivers.

ISF Overturn

Limnological modelling results (Appendix 2a) have indicated that, within the available meteorological data record, the ISF reservoir is likely to be persistently stratified with no periods of regular (i.e., seasonal or cyclical) complete mixing (i.e., overturn), and that the addition of waste rock and tailings at the bottom of the reservoir is unlikely to alter the top-down stratification structure (i.e., the warmer upper layers remain above the cooler layers of the reservoir).

Therefore, during operations and FRCGP and FRHEP post closure, it is predicted that there will be no water quality changes (i.e., reduced dissolved oxygen and temperature, increased dissolved and particulate-associated metals and metalloids from the deposited waste rock and tailings) downstream of the ISF embankment as a result of overturning of the reservoir.

The behaviour of the ISF reservoir limnology is highly complex and while no regular complete mixing has been predicted, complete or partial mixing of tropical reservoirs may occur in response to one, or a combination of up to three processes, including surface wind stress, cooling of the upper layers of the reservoir as a result of reduced atmospheric temperature and mixing from upstream water inflows. An overturn event, which has the potential to occur in certain extreme meteorological conditions, has been addressed in Section 11.4.

Table 8.33 Average dissolved solute concentrations for different flow scenarios from deterministic modelling (mg/L)

Location	AP	SO_4	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Se	Zn
Average background (W23)	AP6/AP7	3	0.0273	0.0010	0.0001	0.0010	0.0011	0.062	0.0010	0.0074	0.0015	0.0094	0.0077
Average background (W35)	AP13	4	***0.0185***	0.0010	0.0001	0.0010	***0.0015***	0.118	0.0010	0.0193	0.0010	0.0100	***0.0112***
Scenario 1: High flows in the uplands and average flows in the lowlands													
ISF discharge	AP6	26.7	***0.119***	0.001	0.00016	0.001	***0.0077***	0.085	0.0011	0.011	0.0021	0.0007	***0.0082***
Sepik River (Kubkain)	AP13	5.4	0.025	0.001	0.00011	0.0009	***0.0019***	0.123	0.0011	0.020	0.0011	0.008	***0.0116***
Scenario 2: Average flows in the uplands and dry flows in the lowlands													
ISF discharge	AP6	41	***0.171***	0.001	0.00019	***0.0011***	***0.0112***	0.106	0.0012	0.014	0.0028	0.0011	***0.010***
Sepik River (Kubkain)	AP13	7	0.031	0.001	0.00011	0.0009	***0.0023***	0.126	0.0011	0.020	0.0081	0.00005	***0.0119***
Scenario 3: Low flows for in both the uplands and lowlands													
ISF discharge	AP6	71.3	***0.281***	0.002	0.00027	***0.0013***	***0.0184***	0.149	0.0013	0.019	0.0043	0.002	***0.0141***
Sepik River (Kubkain)	AP13	7.3	0.031	0.001	0.00011	0.0009	***0.0024***	0.125	0.0011	0.020	0.0012	0.0081	***0.0119***
Water quality guidelines													
IFC effluent guidelines[a]		-	-	0.1	0.05	0.1	0.3	2	0.2	-	0.5	-	0.5
PNG Schedule 1[b]		400	-	0.05	0.01	0.05	1	1	0.005	0.5	1	0.01	5
ANZECC/ARMCANZ[c]		-	0.055	0.013	0.0002	0.001	0.0014	-	0.0034	1.9	0.011	0.011	0.008

Exceedances are indicated by: IFC – italics; PNG Schedule 1 – bold; ANZECC/ARMCANZ (2000) – bold italics. Where multiple guidelines are exceeded, the least stringent guideline exceedance is indicated.

a IFC effluent guidelines (2007). Applicable to total metals concentrations.

b PNG Environment (Water Quality Criteria) Regulation 2002, Schedule 1. Metal concentrations are for dissolved substances, passing through a nominal 0.45 µm filter.

c Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000), aquatic ecosystem trigger values for slightly to moderately disturbed system.

FRCGP Post Closure

At the end of FRCGP operations, open-pit mining along with ore processing and tailings and waste rock deposition within the ISF, will cease. The open-pit will be allowed to flood but flows through the ISF will continue to be regulated to generate power for an expected period greater than 100 years.

As indicated above (see ‘Operations: Open-pit Water Management’ section), release of contaminants is expected to occur from accumulated material on the open-pit benches and from the open-pit wall over the mine life. Residual fragmented rock on the mined benches has been assumed to be fully oxidised and therefore contaminants have been assumed to have already been depleted in these rocks. Rates of release of contaminants from the wall rock, assuming no erosion of the wall rock, will be dependent on the sulphide content. For example, the sulphur in ‘high red’ material (containing approximately 5% sulphur) would be depleted in 15 to 20 years while ‘red’ material (containing between approximately 2 and 3% sulphur) is predicted to oxidise at a slower rate with a depletion time in the order of 20 to 25 years. Blast-damaged wall rock oxidation rates were calculated for input to the model with increasing depths of oxidation and depths of sulphide depletion over time during the post closure period. These results indicate that over a period of 50 years FRCGP post closure, the depth of oxidation is estimated to be 0.37 m and depth of sulphide depletion is predicted to be 0.31 m.

Assuming there is no erosion of the open-pit walls, the rates of contaminant release are expected to decrease by around 85 to 90% over the 50 year period. However, erosion of the open-pit wall is expected to occur during the post closure period and will expose fresh sulphide minerals and allow increased diffusion of oxygen into the walls via fissures and cracks. The rate of oxidation and production of acid and metals would therefore be higher than in the absence of erosion. Wall erosion will be very site specific within the final open-pit and is likely to occur unevenly across the pit walls. There is currently insufficient information to infer erosion rates. During operations, however, rates of erosion will be observed and recorded to refine and assess the effects of wall erosion on surface runoff water quality.

No treatment of the open-pit water (for approximately three years) will occur during post-mining flooding of the open-pit because there will be no discharge of poor quality water to the ISF during this period. Treatment will recommence when the open-pit has filled. After three years FRCGP post closure, the acid neutralisation lime demand (quick lime as calcium oxide) is expected to reduce to 55 t/day from the 72 t/day required at the end of mining, and will further reduce to approximately 38 t/day around seven years FRCGP post closure. Within a period of 50 years, it is predicted that lime demand will reduce to around 5 to 10 t per month.

Treatment of the open-pit water will continue for a period of approximately 50 years or until FRCGP closure criteria are met.

Table 8.34 shows predicted solute concentrations under average and low flow conditions for key parameters at the assessment points during FRCGP post closure assuming treatment of open-pit water, no wall erosion and depletion of sulphides in the open-pit wall over time. In comparison with background concentrations and water quality guidelines, the results indicate:

- During the FRCGP post closure period, results for average and low flows (assuming open-pit water treatment) indicate:
  - IFC effluent discharge guidelines for metals will be met at the ISF discharge.
  - PNG Schedule 1 criteria will be met at all assessment points in the Frieda and Sepik rivers.

- From AP7 on the Frieda River to AP13 on the Sepik River, the ANZECC/ARMCANZ (2000) trigger value for aluminium will be met.
- From AP7 on the Frieda River to AP13 on the Sepik River, the ANZECC/ARMCANZ (2000) guideline value for copper will be slightly exceeded.
- At AP11 (lower Frieda River upstream of the Sepik River confluence), the ANZECC/ARMCNZ (2000) guideline value for zinc will be exceeded. However, zinc is naturally elevated within the receiving environment.
- At AP7 and AP13 during low flows, total dissolved copper concentrations are predicted to be 0.0022 mg/L of which the labile copper concentration is expected to meet the ANZECC/ARMCANZ (2000) trigger value.

Based on the downstream water quality modelling, FRCGP post closure treatment of open-pit water is proposed until FRCGP closure criteria are met, which is expected to continue for at least a period of 50 years.

In the Frieda and Sepik rivers, the majority of total metals concentrations FRCGP post closure are predicted to meet PNG and WHO drinking water guidelines except for iron and lead, which are predicted to exceed the PNG Standards for Drinking Water. However, concentrations of these metals do not exceed the maximum background recorded total concentrations.

Table 8.34 Predicted downstream water quality receiving treated open-pit lake water discharges post closure – dissolved concentrations

Location	Site description	pH	SO_4	Hardness (as $CaCO_3$)	Total Organic Carbon	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Average flows															
AP4	ISF reservoir (northern arm)	7.7	23	44	1.9	***0.0622***	0.0013	0.0002	***0.0011***	***0.0045***	0.0553	0.0011	0.0084	0.0031	0.0052
AP6	Nena River upstream of Frieda River	7.6	9	41	1.3	0.0333	0.0011	0.0001	0.0009	***0.0021***	0.0517	0.0010	0.0088	0.0017	0.0051
AP7	Frieda River (airstrip)	7.6	9	41	1.3	0.0331	0.0011	0.0001	0.0009	***0.0021***	0.0516	0.0010	0.0088	0.0017	0.0051
AP11	Frieda River (upstream of Sepik River confluence)	7.5	11	68	2.3	0.0497	0.0020	0.0002	0.0016	***0.0028***	0.1018	0.0019	0.0160	0.0026	***0.0108***
AP12	Sepik River (Iniok GS)	7.2	7	61	2.9	0.0192	0.0011	0.0001	0.0009	***0.0012***	0.0914	0.0011	0.0129	0.0012	0.0057
AP13	Sepik River (Kubkain)	7.2	6	61	2.9	0.0193	0.0011	0.0001	0.0009	***0.0012***	0.0899	0.0011	0.0129	0.0012	0.0056
Low flows															
AP4	ISF reservoir (northern arm)	7.7	40	63	1.9	***0.0696***	0.0016	0.0002	***0.0014***	***0.0050***	0.0583	0.0011	0.0122	0.0049	0.0051
AP6	Nena River upstream of Frieda River	7.6	14	47	1.3	0.0352	0.0012	0.0001	0.0010	***0.0022***	0.0525	0.0010	0.0100	0.0022	0.0050
AP7	Frieda River (airstrip)	7.6	14	47	1.3	0.0351	0.0012	0.0001	0.0010	***0.0022***	0.0525	0.0010	0.0100	0.0022	0.0050
AP11	Frieda River (upstream of Sepik River confluence)	7.6	17	78	2.3	0.0541	0.0022	0.0002	0.0017	***0.0031***	0.1024	0.0020	0.0169	0.0031	***0.0102***
AP12	Sepik River (Iniok GS)	7.3	10	67	2.7	0.0306	0.0015	0.0002	0.0012	***0.0019***	0.0949	0.0014	0.0143	0.0019	0.0071
AP13	Sepik River (Kubkain)	7.3	10	67	2.7	0.0296	0.0014	0.0001	0.0011	***0.0018***	0.0935	0.0014	0.0142	0.0018	0.0069

Table 8.34 Predicted downstream water quality receiving treated open-pit lake water discharges post closure – dissolved concentrations (cont'd)

Location	Site description	pH	SO_4	Hardness (as $CaCO_3$)	Total Organic Carbon	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Water quality guidelines															
PNG Schedule 1 criteria[a]		[b]	400	-	-	-	0.05	0.01	0.05	1	1	0.005	0.5	1	5
PNG Standards for Drinking Water standards[c]		6.5 to 9.2	-	600	-	-	0.05	0.01	-	1.5	1	0.5	0.5	-	15
WHO (2017) drinking water[d]			-	-	-	-	0.01	0.003	0.05	1	0.3	0.01		0.07	3
IFC Effluent Guidelines[e]		6	-	-	-	-	0.1	0.05	0.1	0.3	2	0.2		0.5	0.5
ANZECC/ARMCANZ (2000)[f]		6 to 8[g]	-	-	-	0.055	0.013	0.0002	0.001[h]	0.0014	-	0.0034	1.9	0.011	0.008

All units are in mg/L except for pH, which are in standard units.

Exceedances are indicated by: IFC – italics; PNG Schedule 1 – bold; WHO or PNG Drinking Water Standards – underlined, ANZECC/ARMCANZ – bold italics. Where multiple guidelines are exceeded, the least stringent guideline exceedance is indicated.

[a] PNG Environment (Water Quality Criteria) Regulation 2002, Schedule 1. Metal concentrations are for dissolved substances, passing through a nominal 0.45 μm filter.

[b] No alteration to natural pH.

[d] WHO, 2017.

[e] IFC effluent guidelines (2007). Applicable to total metals concentrations.

[f] Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000), aquatic ecosystem trigger values for slightly to moderately disturbed system.

[g] Lowland rivers.

[h] Chromium VI.

Site-specific Guideline and Trigger Values

With regards to a compliance point to protect beneficial values, as described in Section 8.5.1, it is proposed that:

- There is one compliance point located at AP7 in the Frieda River upstream of the existing Paupe village. At this compliance point, water quality shall comply with PNG Ambient Water Quality Standards (Schedule 1) and PNG Drinking Water Guidelines as a regulatory requirement. This compliance point shall be the downstream boundary of the mixing zone and the waters between the discharge locations and the compliance point will be a mixing zone where PNG water quality standards and guidelines shall not be required to be met.
- IFC effluent discharge standards for metals shall be met for discharges from the ISF discharge into the Frieda River, with the exception of iron which is naturally elevated above the standard.
- Where maximum background concentrations of (dissolved and total) parameters measured in the Frieda River (at AP7) exceed the regulatory criteria, the 90th percentile background concentrations be adopted as the site-specific criteria.

The compliance point is shown on Figure 8.7 along with the proposed mixing zone.

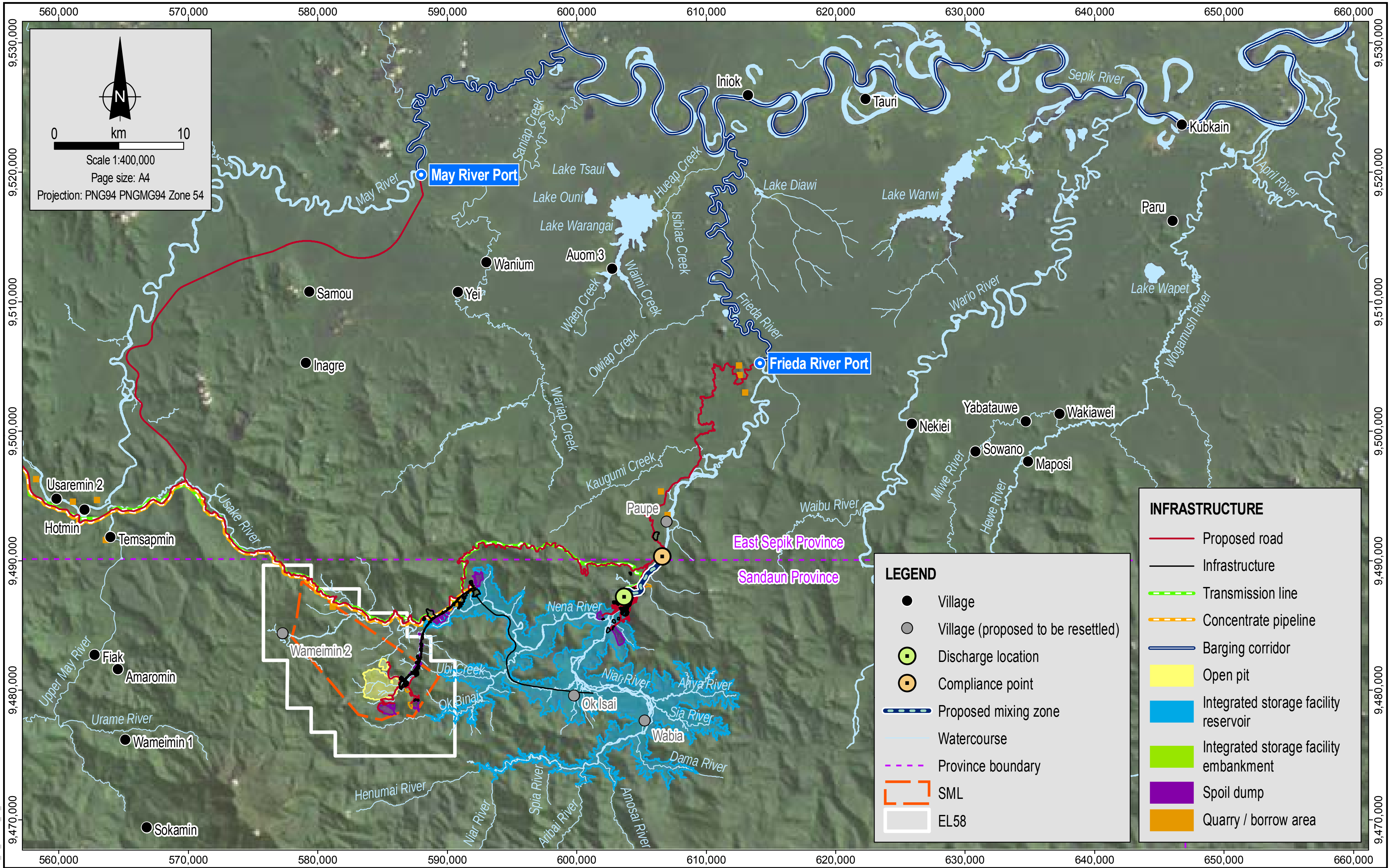
As discussed in Section 8.5.1, compliance with the PNG ambient and drinking water regulatory criteria are not expected to provide adequate protection for aquatic ecosystems or human health based on the current state of knowledge of toxicant exposure to biota and people. As such, the ANZECC/ARMCANZ (2000) trigger values for 95% aquatic ecosystem protection will provide trigger values for contaminants of concern and will indicate the need to undertake further action to characterise the physico-chemical forms of the contaminants, and their behaviour and fate in the downstream aquatic ecosystem. In relation to drinking water and human health protection, the WHO (2017) drinking water guidelines will apply.

With reference to aluminium, total dissolved concentrations are predicted to exceed background concentrations as well as the ANZECC/ARMCANZ (2000) guideline value at AP7 in the upper Frieda River. It is therefore proposed that:

- A site-specific total dissolved aluminium concentration of 0.3 mg/L apply as a trigger value for initiating further action at AP7. This concentration is the maximum concentration predicted during operation of the FRCGP and is well below US EPA-calculated site-specific acute and chronic criteria of 2.9 and 1.2 mg/L during average flows (pH = 7.5, DOC = 1.7, hardness = 67 mg/L), respectively, (and also during low flows (pH = 7.5, DOC = 1.9, hardness = 93 mg/L) of 2.7 mg/L and 0.92 mg/L, respectively). Hence it is appropriately conservative to function as an early warning trigger.

Although total dissolved copper is predicted to exceed background concentrations as well as the ANZECC/ARMCANZ (2000) trigger value for 95% ecosystem protection at AP7 in the upper Frieda River, there are strong ameliorating factors as discussed above. It is therefore proposed that:

- A site-specific total dissolved copper concentration of 0.02 mg/L apply as the primary trigger value for further action at AP7 recognising that:
  - The highest experimentally measured proportion of labile copper compared with total dissolved concentration of approximately 30% in the Frieda River based on spiking tests.



Source:
Discharge locations, mixing zones and compliance points from Coffey.
Infrastructure, roads and tenements from FRL.
Villages, topographic features, watercourses and water bodies from FRL and Coffey.
Provinces from NMB.
Landsat satellite imagery from FRL (capture date unknown). Hillshade DEM from SRTM.

coffey A TETRA TECH COMPANY

Date: 24.10.2018
Project: 754-ENAUABTF11575B
File Name: 11575_11_F08.07_GIS

Frieda River Limited

Sepik Development Project

FRIEDA RIVER

Discharge locations, mixing zone and compliance points

Figure No: 8.7

MXD Reference: 11575B_11_GIS034_v0_5

- Further reduction of labile copper through adsorption onto suspended particulate matter of 46% at AP7 (reflecting the lowest experimentally measured reduction of dissolved copper via adsorption at AP7 in the Frieda River).

Based on the above, a total dissolved copper concentration of 0.02 mg/L would correspond with a labile copper concentration of 0.003 mg/L, a value which is at the very low end of likely impact based on intensive ecotoxicological work done elsewhere in PNG. This value is also aligned with the predicted labile copper concentration of 0.004 mg/L at AP7 (see Section 'Factors affecting water quality: speciation modelling results'). Hence a primary trigger value of 0.02 mg/L dissolved copper is considered to be appropriately conservative. The labile copper to total dissolved copper proportional relationship will be established and verified on a regular basis.

Further actions may include:

- Additional site-specific aluminium or copper speciation investigations.
- Biological monitoring in the Frieda and Sepik rivers to determine if unexpected impacts to aquatic biota occur during operations.
- Laboratory toxicity testing of selected macroinvertebrates collected from the Frieda River.
- If warranted, investigation of further water treatment options.

Justification for the site-specific trigger values using the leading practice multiple lines of evidence approach detailed in the ANZECC/ARMCANZ (2000) water quality guidelines has been provided in the 'Dissolved Metals' section above.

A complete set of compliance criteria and trigger values for the Project are presented in Chapter 11.

8.5.6 Freshwater Ecology

This section assesses the impact of the Project on the freshwater ecology of the creeks, rivers and floodplain waterbodies downstream of the FRCGP and FRHEP[9] area, as well as the infrastructure corridor. The impact assessment approach that has been adopted herein is consistent with that described in Section 8.1 and is based upon consideration of the existing aquatic environmental values, identifying the nature of impacts and assessing the significance of the magnitude of combined hydrology, sediment transport and water quality impacts on those values. The potential for metals and metalloids to bioaccumulate within the aquatic ecosystem food chain was also examined and assessed (Appendix 7b) as described below.

Freshwater ecological values of the surface water environment were defined through surveys of the Project area as discussed in sections 7.2 and 8.5.1. For the purposes of this assessment, impacts on these values were assessed in terms of:

1) Aquatic habitat.

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[9] For the purposes of the freshwater ecology impact assessment, the Project phases (construction, operations and post closure) refer primarily to the FRCGP, but also apply to the FRHEP, even though the timing for each of Project's phases is staggered. This is because the impacts for each of the phases within both projects – with the exception of the FRHEP operations phase which overlaps the FRCGP post closure phase – are predicted to be the same or similar. Therefore, the assessment of freshwater impacts does not differentiate between the phases of the two projects, except where a distinction is relevant to the discussion and/or material to the prediction of residual impact significance.

2) Aquatic biota including aquatic flora, aquatic macroinvertebrates, fish communities and other aquatic species, such as turtles and crocodiles. These aquatic biota include conservation significant aquatic species.

The assessment draws extensively on the results of the hydrology, water quality and sediment transport modelling presented in sections 8.5.3 to 8.5.5. For these components, predictions of the physical and chemical water quality effects of the Project were based on numerical modelling, scientific principles and experience drawn from similar environmental settings in PNG. Unlike the predictable cause and effect relationships of the physical and chemical effects, aquatic biological systems at the organism, population and community level respond variably to many environmental factors and consequently changes are more difficult to predict in time and space.

Appendix 7b describes the methods, results and conclusions of the ISF bioaccumulation study completed by Tetra Tech. This study was undertaken to determine if contaminants originating from deteriorated water or sediment quality as a result of the deposited waste rock and tailings within the ISF have the potential to be taken up by aquatic biota and bioaccumulate in the food chain, and subsequently impact on aquatic biota (and ultimately human health). The assessment method was based on the US EPA (1999) guidance for conducting ecological risk assessments, which includes a screening method for calculating the concentration of a given contaminant in biota based on dietary uptake. The food chain model and associated bioaccumulation method used to calculate fish tissue concentrations is an accepted practice internationally.

During the initial screening process, aluminium, cadmium and copper were selected for further modelling as these metals exceeded water quality criteria and are potentially capable of bioaccumulating in the aquatic environment.

The assessment method involved determination of direct exposure pathways by which aquatic biota could be exposed to contaminants in the water column or in sediments to calculate a Bioconcentration Factor. Subsequent estimation of indirect exposure such as via the diet of aquatic biota involved calculation of a Trophic Transfer Factor based on tissue contaminant concentration and the trophic level of the organism, with phytoplankton (i.e., algae) representing trophic level 1 (TF1), macroinvertebrates that feed on algae as trophic level 2 (TF2) and omnivorous fish as trophic level 3 (TF3). These factors were then used to model potential for contaminant exposure to humans consuming fish, with the human health risks of this described in Chapter 12.

The scenarios, assessed for both the littoral (near bank) and pelagic (deep water) zones, include:

- FRCGP operations Year 10. This scenario was selected to represent a stage when tailings and waste rock is being actively deposited within the ISF.
- 50 years FRCGP post closure. This scenario was selected to represent a stage approximately 50 years after tailings and waste rock deposition within the ISF has ceased.

A baseline scenario was also modelled for the littoral zone only – given a pelagic zone does not currently exist – for comparative purposes.

Water quality in the ISF (pelagic zone) was conservatively assumed to equal the average dissolved concentrations predicted at AP4 in the northern arm of the ISF (see Section 8.5.5). Therefore, the outcomes of the study are considered as ‘worst-case’.

Aquatic biota considered in the study were selected based on their likelihood to be present in the ISF during each of the operations and post closure phases, as well as their tendency to be captured and consumed by local communities.

The findings of this study in relation to bioaccumulation in aquatic biota are included below (in the ‘Operations: Upstream of the ISF Embankment’ and ‘Post closure: Upstream of the ISF Embankment’ sections). The outcomes of the bioaccumulation study in relation to human health impacts are summarised in Chapter 9 and presented in Appendix 12 and not addressed here.

Sensitivity of Freshwater Values

This section briefly summaries the key contextual aspects in terms of the existing environment that are considered important when assessing impacts on freshwater ecological values in watercourses in the Project area. The following sensitivity ratings for freshwater values are based on a weight of evidence assessment approach, whereby the most relevant definitions of high, medium and low sensitivity (Table 8.17), and their importance in assessing sensitivity, have been applied.

Upstream of the ISF Embankment

The main catchments in this area include the Nena River (including Ekwai, Ubai and Uba creeks in the vicinity of the open-pits), Ok Binai and the Niar River.

Aquatic habitat. The aquatic ecosystem types of watercourses upstream of the ISF embankment are common throughout the region and PNG generally. They are characterised by fast-flowing, clear, circumneutral pH and well-oxygenated waters, with high riparian canopy cover and structural habitat diversity. The aquatic biological communities are common and generally widespread in the region and comprise a high diversity of aquatic macroinvertebrates but low diversity of fish compared to other aquatic ecosystem types within the Project area.

Upland rivers and creeks experience high velocity and flash flows that drive the aquatic habitat structure and biological processes. The steep gradients and high flow velocities promote flushing and reduce the potential for sedimentation to occur or last long enough for potential establishment of aquatic species that prefer low energy environments, such as aquatic weeds and most non-native fish. They generally have low ambient TSS concentrations (i.e., are clear water streams) that is typical for intact forested catchments, except following landslips and high rainfall events, and biota are therefore intolerant of persistent high TSS concentrations but tolerant of short-term spikes of high TSS.

Waterways in the FRCGP and FRHEP area (e.g., Ok Binai and Nena River) are incised with very narrow floodplains that lack lakes or swamps. These catchments include very high-gradient (greater than 10% slope) and high-gradient (4 to 10% slope) upland streams, as well as medium-gradient (2 to 4% slope) in the lower reaches. Aquatic habitats are largely undisturbed and intact.

Physical habitat requirements vary among aquatic species with many species adapted to specific habitat types. The primary aquatic habitats are:

- The water column: inhabited by nekton (free-swimming invertebrates, prawns and fish).
- Riffles: shallow, swift, well-oxygenated highly productive reaches that provide habitats for a variety of benthic aquatic organisms.
- Pools: deeper, slower flowing reaches that have low to moderate velocities and little surface turbulence, except around obstructions. Also found at banks undercut by stream flow.
- Backwater pools: formed where water swirls around bedrock, rocks, boulders or stream banks.
- Plunge pools: formed where water falls over a boulder, log or other obstructions.

- Hard surfaces of substrata: rocks, boulders or large woody debris in riffle and pool reaches that offer a high structural diversity of microhabitats available to aquatic microflora (principally benthic algae, diatoms and periphyton), benthic macroinvertebrates and fish (e.g., gobies).

Microhabitats are relatively homogeneous within the above habitat types. Examples include isolated patches of sand or mud, and interstitial (pore) water of coarse sediments (e.g., pebbles, gravels and sands) that are inhabited by hyporheic[10] fauna (living in stony substrata) such as aquatic invertebrates and the early life cycle stages of substrate-spawning fish (e.g., eggs and larvae).

Aquatic habitats of the watercourses upstream of the ISF embankment are assessed as having **low** sensitivity due to their common and generally widespread abundance in the region. In addition, these habitats are relatively adaptable to change given that aquatic habitats in the Project area exist in an environment that experiences intermittently high TSS concentrations and turbidity.

Aquatic flora. Aquatic macrophytes and river phytoplankton are largely absent in the high-energy, clear-water rivers and streams upstream of the ISF. The principal aquatic flora are benthic microphytes comprising benthic green algae, diatoms and periphyton. Benthic microphytes form part of the aquatic food web in rivers and streams upstream of the ISF and are an important food resource to secondary consumers such as aquatic invertebrates, herbivorous fish and the early life stages (tadpoles) of frog species (e.g., Hylidae tree frogs).

Aquatic flora of the watercourses upstream of the ISF embankment is assessed as having **low** sensitivity due to their common and generally widespread abundance in the region.

Aquatic macroinvertebrates. Aquatic macroinvertebrates in the watercourses upstream of the ISF embankment include benthic macroinvertebrates and decapod crustaceans. The benthic macroinvertebrate communities of rivers and streams are dominated by the early life stages (e.g., nymphs and larvae) of terrestrial insects and by aquatic invertebrates such as oligochaete worms, water bugs and water mites. The higher taxonomic richness and abundance of macroinvertebrate communities in these upland streams are attributable to favourable conditions related to structurally diverse habitats (described above) and ample in-stream food resources (autochthonous inputs) (e.g., periphyton and detritus), and high inputs of plant materials (allochthonous inputs) and organic matter from the intact forested subcatchments.

The macroinvertebrate families Hydrophilidae and Philopotamidae present in upland and mid-catchment rivers included:

- Riffle beetles (Elmidae).
- Water beetles (Noteridae). Mayfly nymphs (Propistomatidae, Potamanthidae, Caenidae and Baetidae).
- Stonefly nymphs (Plecoptera).
- Net-spinning caddisfly larvae (Hydropsychidae).

The Niar River, a mid-catchment river, hosts fewer stonefly, mayfly and caddisfly taxa than in the upper rivers and creeks.

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[10] Hyporheic relates to a zone beneath and alongside a stream bed where there is mixing of shallow groundwater and surface water.

Decapod crustaceans including freshwater prawns (*Macrobrachium* spp.) and atyid prawns (*Caridina* spp.) were reported from upland rivers and creeks in the catchments upstream of the ISF embankment. Freshwater prawns of the family Palaemonidae occupy a primary role as detritivores (animals that feed on detritus) in these watercourses. Atyid prawns generally comprise a range of feeding guilds (e.g., filter feeders, detritivores and scrapers), most of which feed by scraping food particles off rocks and plants.

Due to the widespread distribution and abundance of macroinvertebrate communities recorded in the watercourses upstream of the ISF embankment, and absence of rare or threatened species, the sensitivity of this value was assigned as **low**. Furthermore, aquatic macroinvertebrates in the Project area experience high TSS concentrations and turbidity, and therefore are resilient to change.

Fish communities. Eleven native species and two non-native species were collected from the Nena River system, with small native species dominating catches. The most abundant and frequently encountered species of fish caught in the Nena River catchment were the Gjellerup's mouth almighty (*Glossamia gjellerupi*), Bulmer's goby (*Glossogobius bulmeri*) and the New Guinea rainbowfish (*Melanotaenia affinis*). Single individuals of two non-native fish species, pacu (*Piaractus brachypomus*) in the upper Nena River and Emily's fish (*Prochilodus argenteus*) in the lower Ok Binai, were also caught.

In the Niar River, a mid-catchment river, seven native species and one non-native species (Java carp, *Barbonymus gonionotus*) were collected, with small native species dominating catches. The most abundant and frequently encountered species of fish caught in the Niar River catchment were three species of rainbowfish (Melanotaeniidae) dominated by the New Guinea rainbowfish (*Melanotaenia affinis*), Gjellerup's mouth almighty (*Glossamia gjellerupi*) and the northern mogurnda (*Mogurnda aurofodinae*). No eel-tailed catfish (Plotosidae) were caught in the Niar River system. The sediment-tolerant Gjellerup's tandan or the northern tandan (*Neosilurus gjellerupi*) was caught in the lower Nena River and may also be expected to enter the Niar River.

The relatively depauperate fish community (i.e., a fish community that is lacking in biomass density and biological diversity) within upland rivers and creeks are adapted to high stream flow conditions with periodic pulses of sediment. They are somewhat sensitive to persistent high TSS concentrations but, due to the naturally occurring low ambient TSS concentrations that occur in these watercourses and short-term sediment loading during landslips and high rainfall periods, they are tolerant of short-term pulses in high TSS concentrations. The overall fish community is described as common in the region and northern PNG more generally. However, these upland watercourses have a higher potential to support a range restricted (local endemic) species. Baseline surveys reported that there was a low incidence of non-native fish species, mostly reflecting habitat preferences of most non-native species for low flow environments, as well as numerous instream barriers such as natural waterfalls. Fish in upland rivers and creeks are generally small species but are still considered as a subsistence resource for local communities throughout PNG, who use fine nets to capture the smaller species of fish and prawns, if practised in the upland rivers and streams of the Project area.

Fish communities of the watercourses upstream of the ISF embankment are assessed as having **low** sensitivity due to their common and generally widespread abundance in the region. Additionally, similar to aquatic habitats and macroinvertebrates, fish communities in the Project area are exposed to high TSS concentrations and turbidity, and therefore are relatively adaptable to change.

Other aquatic fauna. Freshwater turtles and crocodiles are unlikely to inhabit the upland rivers and streams of the catchments upstream of the ISF embankment, although saltwater crocodiles may ascend upland swift-flowing rivers in southern PNG (e.g., Ok Tedi in the Fly River system).

Conservation significant species. No threatened or near-threatened aquatic species are known to occur in catchments upstream of the ISF embankment.

Downstream of the ISF Embankment

The catchments in this area include the Frieda and Sepik rivers and their associated floodplain water bodies (e.g., oxbow lakes, remnant river channels and other ORWBs).

Aquatic habitat. Aquatic habitats in the Frieda and Sepik river systems pertain mainly to riverine habitats and to a lesser extent to ORWBs.

The Frieda River downstream of its confluence with the Nena River is a typical mid-catchment river with a medium-gradient (2 to 4% slope), characterised by substrates comprised of sands, gravel and cobbles reflecting the higher flow conditions than in lowland rivers. A range of habitat types, such as run, riffle and pool habitats, is present as in upland rivers. Gradients reduce significantly (less than 2% slope) along the lower Frieda River towards its confluence with the Sepik River and the channel is extremely sinuous. The channel is broad and deep with low flows and substrates dominated by silts and sands. The channel is turbid, and macrophyte cover is low, reflecting the typically high TSS levels. The wide floodplain is flat and is inundated during flood events. However, almost all flow and sediment is conveyed within the main river channel and the volume of water and sediment discharging overbank to the floodplain is low under existing conditions.

Rivers of similar size to the Frieda River are well represented regionally and in PNG generally. They typically have low riparian canopy cover but high structural habitat diversity.

Mid- and lowland-catchment rivers provide suitable habitat for aquatic species that prefer low energy environments (including aquatic weeds and non-native fish) and provide year-round aquatic fauna movement corridors and refuges. These rivers are characterised by low to moderate flows, high dissolved oxygen, high TSS concentrations and low water transparency due to turbidity. As a result, these ecosystems and the communities they support are moderately tolerant to changes in water quality as they are generally well flushed, allowing dispersal and dilution of contaminants even during non-flood periods.

ORWBs of the Frieda River include Lake Warangai and Lake Diawi as well as oxbow lakes which are connected to the Frieda River during high flood flows.

The Frieda River catchment has a minimal influence on the hydrology of the Sepik River. The Sepik River is more strongly influenced by other catchments. The contribution of the Frieda River to flows in the Sepik at Iniok (AP12) is only around 5% (i.e., 95% of the flow of the Sepik River at this point comes from the upper Sepik River catchment that lies upstream of the Frieda River confluence (see Appendix 6a)).

The Sepik River is turbid and varies in width from tens to hundreds of metres, meandering across a broad valley or floodplain with moderately sloping banks. The riparian zone is comprised of trees, shrubs and grasses (most dominant).

Total suspended sediment in the Sepik River comprises very fine silts and clays which have very low settling velocities. It is likely that much of the sediment being transported through the modelled section of the Sepik River will remain in suspension and be transported as washload, without settling downstream, to the mouth of the Sepik River. In the Sepik River (AP12), the existing TSS average values are around 200 mg/L reflecting the sediment contribution from the upper Sepik River catchment. Further downstream, inflows from the Wario and April rivers further contribute TSS loads to the Sepik River with values in the main channel increasing to up to 260 mg/L. The contribution to sediment loads in the Sepik River from the Frieda River catchment is minimal; the Frieda River catchment represents approximately 8% of that contributed from the upper Sepik River catchment.

The ORWBs of the Sepik River floodplain include Lake Warwi, Lake Mhowi, Wasui Lagoon, Amer Lagoon, Biimba Lagoon and Chambri Lakes. They vary in size and depth according to seasonal flow levels in the Sepik River main channel. The ORWBs typically have flat banks with dense riparian vegetation and moderate in-water macrophyte coverage. Substrate material is comprised mostly of very fine particles such as clays, silts and organic matter.

Aquatic habitats of the Frieda and Sepik rivers are assessed as having **low** sensitivity due to their common and generally widespread abundance in the region. Furthermore, aquatic habitats downstream of the ISF embankment are exposed to high TSS concentrations and turbidity, therefore these habitats are relatively adaptable to change.

Aquatic flora. In turbid rivers and streams there is limited aquatic flora and no macrophytes. Species likely to be present in the Frieda River include benthic macrophytes, benthic green algae, diatoms and periphyton. Due to the prevailing turbidity of the Frieda River, only very low abundances and biomass of aquatic macrophytes and microflora are expected to be present.

Aquatic flora (aquatic microflora or macrophytes) are not expected to be present as a significant ecosystem component of the Sepik River due to high TSS concentrations and associated turbidity and low water clarity.

In the floodplain lakes and other ORWBs, marginal, submergent and floating aquatic macrophytes occur as well as diatoms, periphyton and benthic algae.

Aquatic flora of the Frieda and Sepik rivers are assessed as having **low** sensitivity due to their common and generally widespread distribution in the region, as well as being resilient to changes as a result of the existing high TSS and turbidity to which they are exposed.

Aquatic macroinvertebrates. The fauna present in the Frieda and Sepik rivers is tolerant to high TSS and sedimentation. The population densities of sediment-intolerant PET taxa (i.e., early life stages of Plecoptera (stoneflies), Ephemeroptera (mayflies) and Trichoptera (caddisflies)) are expected to be low due to the relatively high TSS concentrations in these river main channels.

The predominant freshwater prawns present were scissor river prawns (*Macrobrachium latidactylus*) that were caught in the upper Frieda River and Lake Warangai, and Weber's freshwater prawns (*Macrobrachium weberi*) that were caught in the lower Frieda River. Scissor river prawns were also caught in the Sepik River at Kubkain while one unidentified *Macrobrachium* sp. and one new species (*Macrobrachium* sp. nov. B) of river prawns were caught in the Sepik River at Iniok.

There was a relatively low macroinvertebrate abundance and diversity in the Sepik River, which is likely due to reduced habitat structural diversity, uniform fine bed sediments and high TSS concentrations and associated turbidities. Lowland rivers were dominated by non-biting midges (Chironomidae) which tend to be generalist feeders.

Aquatic macroinvertebrates of the Frieda and Sepik rivers are assessed as having **low** sensitivity due to their common and generally widespread abundance in the region in addition to being easily adaptable to change, given that they exist in an environment that experiences high TSS concentrations and turbidity.

Fish communities. Eleven native species and five non-native species were collected from the Frieda River system, with small native species dominating catches. The most abundant and frequently encountered native species caught in the Frieda River main channel were Gjellerup's mouth almighty (*Glossamia gjellerupi*), papillate catfish (*Neoarius velutinus*) and three species of rainbowfish (*Chilatherina* spp.). The predominant non-native fish species were Java carp (*Barbonymus gonionotus*), Emily's fish (*Prochilodus argenteus*) and pacu (*Piaractus brachypomus*).

Sepik River fish assemblages were typically depauperate with only three species caught at Iniok and six species each at Kubkain and downstream of the April River. The predominant native fish species in the Sepik River were papillate catfish (*Neoarius velutinus*) and Sentani gudgeons (*Oxyeleotris heterodon*). Non-native fish species predominated in the Sepik River main channel and were dominated by Java carp (*Barbonymus gonionotus*), Emily's fish (*Prochilodus argenteus*) and pacu (*Piaractus brachypomus*).

The fish communities of the Sepik River represent an important food resource for local communities. A number of coordinated investigations on the impact of the non-native fish introductions to native fish fauna have indicated significant declines in native species abundance and richness, particularly in tributaries and ORWBs. Non-native species were recorded throughout the study area and dominated catches in the lowland rivers and ORWBs and comprised 75% of the total number of individuals caught in ORWBs. These ecosystems and the communities they support are moderately tolerant to changes in water quality as they are generally well flushed, allowing dispersal and dilution of contaminants even during non-flood periods.

The composition of the fish community within the Sepik River catchment, particularly in the middle reaches of the Sepik River, has been significantly changed as a result of introduced non-native species. This renders the river to be classified as a 'slightly to moderately disturbed ecosystem' under ANZECC/ARMCANZ (2000) classification.

Fish communities of the Frieda and Sepik rivers are assessed as having **low** sensitivity due to their common and generally widespread abundance in the region and northern PNG, as well as being easily adaptable to change as a result of being exposed to high concentrations of TSS and turbidity.

Species of conservation significance. Seventeen species of fish that have been reported in the Sepik River are of conservation significance, due either to their assessment as threatened or potentially threatened species or because of their restricted range (endemism). Three species previously reported in the Sepik River are listed in the IUCN Red List of Threatened Species; namely, the spinach pipefish (*Microphis spinachioides*) listed as Data Deficient, the freshwater gudgeon (*Eleotris aquadulcis*) listed as Near Threatened and the common sawfish (*Pristis pristis*, formerly *Pristis microdon*) listed as Critically Endangered (IUCN, 2016). Neither the spinach pipefish nor the sawfish were collected during the 2008 to 2010, 2011 or 2017 sampling events. The freshwater gudgeon was caught at two locations: within an ORWB (W39); and in the Lower May River upstream of the confluence of the Sepik and Frieda rivers during 2009 surveys.

The common sawfish (*Pristis pristis*) is unlikely to inhabit the Project area as this species favours large turbid rivers away from its typical inshore and estuarine habitat. It is likely to occur in the lower reaches of the Sepik River and its associated large floodplain ORWBs. The presence of the spinach pipefish and the freshwater gudgeon is possible in the Study Area. The common sawfish may occur in ORWBs in the Study Area while the latter species is mainly found in oxbow lakes and is only known to occur in the Sepik-Ramu River system.

A further 15 species of fish were recorded that are either endemic to northern New Guinea or locally endemic to the Sepik-Ramu River system. Thirteen of these species were recorded in one or more of the 2008 to 2010, 2011 or 2017 survey events.

Two New Guinea endemic species of freshwater turtles are known to occur in the Sepik-Ramu River system; namely, the Northern New Guinea giant softshell turtle (*Pelochelys signifera*) listed as Vulnerable under the IUCN's Red List of Threatened Species classification and Schultze's snapping turtle *(Elseya schultzei)*, listed as Least Concern under IUCN.

Two crocodile species, the New Guinea crocodile (*Crocodylus novaeguineae*) and the saltwater crocodile (*C. porosus*), occur in the Sepik River system. Both are of local conservation significance and are listed as Least Concern on the IUCN Red List and by CITES[11] (Appendix II) to which PNG is a signatory.

Conservation significant species of the Frieda and Sepik rivers are assessed as having **low** sensitivity given that they are highly sediment tolerant and moderately resilient to water quality changes.

Infrastructure Corridor

A 2017 survey of selected sites adjacent to the infrastructure corridor (within the Usake/May, Idam and Horden river catchments) indicated that aquatic habitat types were similar to those already recorded in the FRCGP and FRHEP area and could similarly be categorised as upland river, mid-catchment and lowland river sites.

While the proportion of macroinvertebrate PET (Plecoptera, Ephemeroptera and Trichoptera) taxa at these sites were comparable to other surveys, macroinvertebrate species richness at these sites differed significantly from other sites in the FRCGP and FRHEP area.

At sites sampled adjacent to the infrastructure corridor, 99% of the captured fish assemblages comprised native species which tend to dominate the communities within the upland to mid-catchment sites (compared to lowland rivers and ORWBs).

The New Guinea giant softshell turtle (*Pelochelys signifera)* was observed in the Idam River during terrestrial biodiversity surveys in 2017.

The sensitivity of these rivers and streams is assessed as **low** given that that the watercourses adjacent to the infrastructure corridor are similar to those in the FRCGP and FRHEP area watercourses.

Potential Stressors and Impacts

A range of activities associated with the Project are likely to generate stressors to downstream watercourses, which in turn lead to potential impacts on freshwater ecological values. As a result

[11] Convention on International Trade in Endangered Species of Wild Fauna and Flora.

of generating stressors on aquatic ecosystems, the Project may impact freshwater ecological values in two different ways, namely:

- Direct impairment of habitat through sedimentation (in suspension or deposited on river bed) or effects of toxicants on biota.
- Indirect effects that are at least one step removed from Project activities in terms of cause-and-effect links. Examples of indirect effects include changes to aquatic primary productivity reducing energy entering the food chain or displacement of macroinvertebrates away from waters with continuously elevated suspended sediment concentrations (e.g., atyid prawns and the larger, more mobile macroinvertebrates) to clear side tributaries. Indirect effects may result in selective survival favouring introduced species that may be more sediment tolerant than native species.

Impacts on freshwater ecological values were assessed according to each source where possible or holistically where multiple factors are present.

A general summary of stressors and potential impacts on the freshwater ecological values due to Project activities are discussed in the following sections, followed by a detailed impact assessment within the key catchments expected to be affected by the Project.

Physical Disturbance

Direct disturbance of stream reaches located within Project infrastructure footprints will occur, ranging from major stressors, such as diversion of creeks or streams, to minor stressors such as construction of infrastructure corridor watercourse crossings. Activities that could result in the physical disturbance include:

- Construction of the open-pit resulting in loss of habitat along Ekwai and Ubai creeks within the perimeter of the open-pit and the diversion of these creeks around the open-pit perimeter.
- Construction of the ISF embankment across the Frieda River valley and the subsequent impoundment of flows from the lower Nena River, Ok Binai and Niar River upstream of the ISF embankment.
- In-stream construction activities, such as watercourse crossings for the infrastructure corridor and access roads, within the Nena, Usake/May, Idam and Horden rivers.
- Creation of a barrier to movement for migratory fish with some species isolated above the ISF embankment and/or those that will have restricted movement below it.

The direct impact associated with physical disturbance of streams is loss of habitat and aquatic flora through diversions and river bed degradation or aggradation. This can have subsequent impacts on aquatic fauna due to the reduced availability of habitat and loss of food sources. The inundation of the ISF will result in loss of existing riverine (lotic or flowing) aquatic habitats in the lower reaches of the Nena River, Ok Binai and Niar River. This will be replaced with lacustrine aquatic habitats associated with much larger areas of slow-flowing (transitional) or lentic (still water) waters. This will be a highly modified ecosystem and will comprise species that are able to tolerate the altered habitat and flow regimes, as well as deteriorated water quality associated with the discharge of treated open-pit water and placement of waste rock and tailings within the ISF.

Physical barriers such as the ISF embankment will restrict movement of migratory species. Changes in species abundance or composition may occur for those species that are restricted from reaching breeding areas or require alternate habitat for different stages of their life-cycle.

Altered Hydrology

Project activities that could result in altered flow regimes include:

- Altered flow rates in the Frieda River during the ISF embankment construction period and subsequent impoundment and operation.
- Decrease in flows along Uba Creek, associated with upstream diversions, and an increase in flows to Ubai Creek, due to discharge of treated pit water, during the operations period due to development of the open-pits.
- Removal of forest and vegetation for construction activities and accelerated runoff from hard surfaces, such as the ore stockpile and process plant areas, laydown areas, accommodation villages and workshops, resulting in increased water flows in affected subcatchment streams.
- Water abstraction from the upper Nena River and local rivers upstream of the accommodation villages to supply potable water.

In general, dams may change the timing, magnitude and frequency of flows, ultimately producing a hydrologic regime that may differ significantly from the natural flow regime. The flow regime of a watercourse has a major influence on the composition of the aquatic habitat. Changes in flow can affect the shape and size of the watercourse, the stability of the substrate and the distribution of habitat types, such as riffle reaches and pools. As well as the indirect impacts of these habitat changes, the distribution of aquatic flora is also directly influenced by flood regimes, water velocity and turbulence which affect disturbance frequency and intensity, colonisation success and growth rates (Bunn and Arthington, 2002).

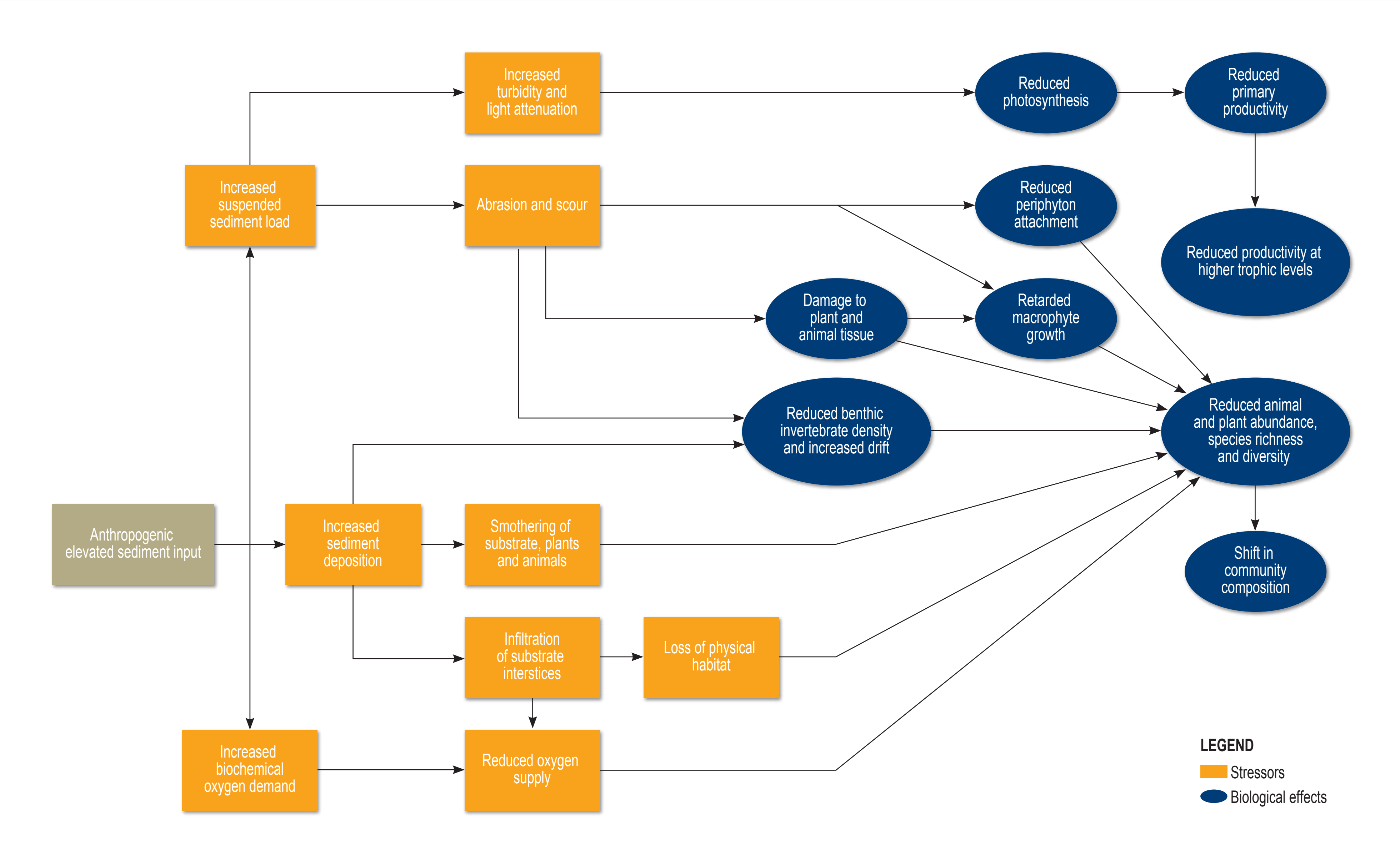
Altered flows can cause changes to fish assemblages due to the specific habitat requirements and feeding strategies of different species. Some fish species are highly dependent on flow for breeding and spawning patterns. Changes to flood regimes can also create barriers to aquatic fauna if connectivity is lost between floodplain waterbodies (Bunn and Arthington, 2002).

Erosion and Sedimentation

Erosion and sedimentation of waterways due to disturbance of exposed soils, particularly during construction, can cause a smothering effect within waterways which will be reflected by reductions in aquatic flora and fauna biomass, densities, and species richness and diversity. Figure 8.8 shows the potential impacts to aquatic ecosystems that may occur due to waterway sedimentation, including the key stressors and pathways. Sediment delivery to waterways can be separated into impacts from coarse-grained and fine-grained sediment:

- Coarse-grained (i.e., greater than 125 μm) sediment delivery to watercourses as bed load, resulting in increased bed sediment transport and attendant in-stream sedimentation and riverbed aggradation.
- Fine-grained (i.e., less than 125 μm) sediment delivery to watercourses as washload, resulting in increased suspended sediment transport and increased suspended sediment concentrations and attendant turbidity.

In-stream sedimentation can result in smothering or infilling of stream-bottom habitats such as stony substrata of riffle reaches or woody debris. Elevated concentrations of fine suspended sediments or reductions in light levels induced by turbidity in the water column can lead to a reduction in the biomass of benthic algae, diatoms and periphyton, as well as changes to species richness and diversity.



AI Reference: 11575_11_GRA045.ai_2

Source:
Modified from Kemp et al., 2011

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Project: 754-ENAUABTF11575B
File Name: 11575_11_F08.08_GRA

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Sepik Development Project

FRIEDA RIVER

Impacts of sediment input to aquatic systems, with key stressors and pathways linked to biological effects

Figure No: 8.8

Freshwater fish and macroinvertebrate communities are likely to be more sensitive to smothering of riverbed habitat, rather than suspended sediment per se, to which all rivers and associated fauna are frequently exposed from high rainfall events and occasional landslips.

Aquatic organisms vary in their level of tolerance to sedimentation and TSS. The effects of sediment may be considered both directly and indirectly at the individual, population and community level of organisation. These include lethal effects (mortality of eggs, embryos, larvae and juvenile and adult stages) and sublethal effects (suppression of fish growth or biomass) (e.g., Kemp et al., 2011). The direct effects of continuously high TSS concentrations include abrasion to eggs and gills and body integuments of larvae and adult phases. The direct effects of in-stream sedimentation include smothering of benthic species or clogging of breathing or feeding apparatus.

Indirect effects include decreases in food resources (e.g., aquatic invertebrates or plants) or alteration of benthic habitat quality that have flow-on effects to fish, prawns and benthic macroinvertebrates. Taxa most negatively affected by increased loads of fine sediment include Ephemeroptera and Trichoptera, whereas others can be benefited such as certain Diptera and Oligochaeta taxa (Jones et al., 2012). Detailed literature reviews of the direct and indirect impacts of sediments, particularly fine sediments, on macroinvertebrate and fish communities are presented in the work by Kemp et al. (2011) and Jones et al. (2012).

Water Quality

The most significant Project-related changes to water quality (other than increased TSS as discussed above) are expected to be associated with operational activities including:

- Treated open-pit water discharges.
- Waste rock and tailings disposal in the ISF and subsequent water discharges from this facility.

Other activities that may result in reduced water quality during both construction and operations include (although these impacts are anticipated to be short-term):

- Contamination from leaks or spillages of fuels, oils and chemicals due to increased transport, storage and handling of these materials during construction.
- Disturbance of acid sulphate soils along the infrastructure corridor during construction.
- Short-term increases in the concentrations of soluble nutrients in receiving streams, stimulating algal growth and primary productivity in affected reaches of streams.
- The disposal of treated hydrotest waters from pipeline integrity testing, resulting in the potential introduction of residual small quantities of toxicants (biocides) and oxygen scavengers (ammonium bisulphite or sodium sulphite) into watercourses.

The primary mine-derived stressors associated with water quality (other than increased TSS and turbidity discussed in the section above) will be the release of soluble and particulate associated metals and metalloids from the ISF into receiving waterbodies. The direct effects of higher metal concentrations to aquatic organisms can include toxicity due to disruption of physiological processes on a cellular/organ level. Indirect effects can include toxic effects to food sources or contamination of food sources that can lead to bioaccumulation and biomagnification in organisms higher in the food chain. As with sedimentation and TSS, these effects can be seen at the individual, population and community level of organisation and can include both lethal and sublethal effects depending on the toxicity of the metal and the level of exposure. In general, soluble metals are more bioavailable to aquatic organisms and therefore potentially more toxic than particulate associated metals and metalloids.

Nutrients entering watercourses from wastewater discharges and poor sanitary practices can reduce oxygen levels in water affecting fish. Reduced oxygen levels can stress fish and in extreme instances result in fish kills. Stressed fish will seek refuge in more oxygenated waters and macroinvertebrates (crustaceans) may seek refuge at the margins of pools and watercourses or on land, exposing them to predation.

Hydrocarbon slicks and spill residue can coat aquatic plants and degrade habitat reducing available food for macroinvertebrates and lead to population decline. Populations of fish species dependent on macroinvertebrates for food could also decline in response to reduced food resources.

Fish and macroinvertebrates can suffer membrane damage if they contact contaminants affecting their health. In some cases, exposure can result in death due to toxicity. Longer term exposure to contaminated water can lead to impaired growth and reproduction, reducing populations.

It is assumed in the following sections that spills and leaks of hydrocarbons or chemicals will be avoided using standard management practices described in Chapter 5 and the Project EMMPs (Attachment 2) and will not be a part of ‘normal’ operations. Therefore, impacts as a result of these incidents are addressed in Chapter 11.

Weeds and Pest Species

Nine non-native fish species have been recorded in the freshwater ecology Study Area (Appendix 7). While introductions of non-native fish have been occurring in PNG since 1949, the largest stock enhancement program in the Sepik (and PNG generally) was FISHAID[12] which was conducted by the Food and Agricultural Organization. Surveys conducted in the Study Area indicated that non-native species now dominate the fish fauna of most aquatic ecosystem types, the exception being upland rivers and creeks. Many of the non-native species recorded in the Study Area are highly invasive species that are known elsewhere to adversely affect aquatic habitats and native fish species.

Non-native exotic aquatic flora species were observed throughout the Sepik-Ramu floodplain and included water spinach (*Ipomoea aquatic)*, water hyacinth (*Eichhornia crassipes*) and giant salvinia (*Salvinia molesta)*. The latter has been a major invasive weed issue with the region, although biological control has greatly reduced its impact.

Additional invasive aquatic flora and fauna species could be introduced to the Project area either through intended introductions into the environment by communities (e.g., exotic species used as a food resource) or accidentally by Project activities.

The introduction of exotic species to supplement food resources and for aquaculture can reduce native fish population diversity and abundance as exotic fish species commonly have competitive advantages over native fish species in river systems, particularly systems that have been highly modified. In turn, this will increase the exotic fish population diversity and abundance. Exotic fish can also degrade aquatic habitat affecting native fish reproductive behaviour and success.

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[12] Fisheries Improvement through Stocking Higher Altitudes for Inland Development.

Existing Stressors and Adaptations

Aquatic biota of the Project area are naturally exposed to many of the same hydrological and physico-chemical changes to those that will result from the Project, for example through periodic sedimentation from floodwater and landslides, and in areas of naturally reduced pH. The presence of introduced exotic species described above is an additional and more recent source of competition. The existing species composition reflects the overall adaptations and tolerances to these changes, which may still be dynamic in the case of introduced exotic species. For example, species that can rely on food sources washed into the rivers will be more tolerant of periodic sedimentation than those dependent on in-stream sources whose habitats are smothered. There will therefore be existing tolerance to Project-related sedimentation effects that will favour the more tolerant species to the extent that impacts are not prolonged beyond natural tolerances or further alter survivability of some species over others.

Residual Impact Assessment

The following freshwater ecology residual impact assessment sections are separated into each phase of the Project life, i.e., construction, operations and post closure, due to the different Project activities occurring in each phase. Each phase has been further separated spatially according to impacts anticipated in: watercourses upstream of the ISF embankment; watercourses downstream of the ISF embankment; and those watercourses adjacent to the infrastructure corridor. The residual impact assessment has assumed the successful implementation of management measures presented in Section 8.5.3 and the FRCGP, FRHEP and the SIP (Road) EMMPs (Attachment 2).

The magnitude of operational-related impacts on aquatic habitats in the upper Frieda River (i.e., at AP6 and AP7) are anticipated to be greater than those in the mid to lower Frieda River (i.e., AP8 to AP11). Therefore these river reaches have been assessed separately for these periods.

For the construction, operations and post closure periods, the upper and lower Frieda River are assessed as a whole given that impacts on aquatic ecology are predicted to be essentially the same along the length of the river, with the exception of impacts on aquatic habitats during the operational period (as indicated above).

It important to note that significant impacts to aquatic ecology in the upper Frieda River are expected as a result of the Project, as they are located within the FRCGP and FRHEP footprints and within the proposed mixing zone upstream of the proposed compliance point at AP7.

As described in Section 8.5.1, while negligible and minor impacts are discussed in the residual impact text, only those assessed as moderate or major are presented in the impact significance tables.

Construction: Upstream of the ISF Embankment

This section assesses the residual construction-related impacts on aquatic habitats, flora and fauna of the watercourses upstream of the ISF embankment. During construction, there will be a concentration of activities in space and time within the catchments upstream of the ISF embankment where most of the FRCGP infrastructure will be located. Of the three main catchments upstream of the ISF, including the Nena River, Ok Binai and the Niar River catchments, construction activities will be most concentrated in the Nena River catchment.

The residual construction-related impacts on freshwater values of watercourses upstream of the ISF embankment are discussed below with the significance ratings of the residual impacts summarised in Table 8.35.

Table 8.35 Residual impacts to freshwater ecology values in watercourses upstream of the ISF embankment impacted during construction

Impact Description	Residual Impact after Implementation of Management Measures		Significance Rating
	Magnitude	Sensitivity of Receptor	
Loss or degradation of aquatic habitats due to physical disturbance (direct loss of habitat), changes to flow regimes and increased sedimentation, TSS and turbidity	High	Low	Moderate
Impacts on aquatic flora due to increased sedimentation, TSS and turbidity	High	Low	Moderate
Impacts on aquatic macroinvertebrates due to loss of habitat, increased sedimentation, TSS and turbidity	High	Low	Moderate
Impacts on fish due to loss of habitat, increased sedimentation, TSS and turbidity	High	Low	Moderate

The primary stressors resulting in impacts on aquatic ecosystems during the construction period are associated with physical disturbance, altered hydrology and increased coarse- and fine-grained sediment delivery to watercourses.

Aquatic Habitat

In terms of physical habitat loss, reaches of Ekwai, Ubai and Uba creeks located within the footprint of the open-pits will be diverted around the open-pit perimeters to maintain connectivity and flow between the headwaters and lower reaches of these streams. The aquatic habitats within these sections will be lost and habitats within the recreated diverted creeks are likely to be poor quality with low structural diversity compared to the original pre-disturbance streams (e.g., they are likely to be lacking in riffle-pool structure). Furthermore, construction of the ISF embankment across the upper Frieda River will result in permanent loss of existing river habitats, while subsequent filling of the ISF reservoir will result in the loss of existing flowing water aquatic habitat that will transform to lacustrine (lentic or slow-flowing water) habitats. After the diversion tunnels are closed, the riverine area immediately upstream of the embankment, which will form the deepest part of the reservoir will begin to fill first. The transformation from riverine to lacustrine habitat will then occur progressively upstream from the embankment, increasing the stream bed margins, to eventually impound the Nena and the Niar rivers and the Ok Binai over the initial 10-month filling period. Other direct disturbance of aquatic habitats, albeit of lower magnitude, will occur from in-stream construction activities mainly at watercourse crossings of the access roads.

In near-mine watercourses such as Ubai Creek (AP1) and Uba Creek (AP2), annual median TSS concentrations are expected to increase substantially during construction. There will also be increases in stream bed levels downstream of mining and infrastructure areas (with bed aggradation up to 4 m depth along Ubai Creek). This bed level rise will perpetuate until the source inputs of coarse sediment decline and/or sufficiently high flows remobilise deposited material and transport it further downstream to be captured in the ISF reservoir (from Year -2) which has been designed to accommodate such sediment loads.

Aquatic habitats in the upper reaches of the Ok Binai will be lost or significantly degraded due to sedimentation and bed aggradation as a result of the development of the Ok Binai waste dump (in Year -1 until Year 26 of operations) and the construction of a spoil dump adjacent to the limestone quarry (to be developed in Year -4 over a period of 2 years), both of which are predicted to gradually erode into the ISF reservoir over a period of approximately 20 years.

Due to the sequential nature of major construction activities in the mine area, continuous or high bed sediment loading of the aforementioned affected watercourses is expected to cause continuing significant impacts on streambed habitats through infilling and changes in the composition and particle sizing of watercourse bed substrata. These changes will reduce void (interstitial) spaces used by benthic macroinvertebrates for shelter and foraging habitat. Nesting habitat for fish and their eggs may also be smothered by sediment, reducing reproductive success.

The pattern of sediment deposition during flood recessions and scouring (eroding) during rising and flood flows will affect the nature and quality of streambed aquatic habitats. Stream bed reaches affected by elevated sedimentation rates anticipated during the construction period are expected to present a severe reduction in the quality of bottom habitat available to microflora, macroinvertebrates, fish and water-associated fauna. Consequential impacts on these aquatic biological communities are assessed in subsequent sections of this chapter.

The combined impact of these stressors is likely to give rise to major reductions in aquatic biological habitats in terms of structural diversity and aquatic species richness, diversity, density and productivity (i.e., the product of biomass and growth), resulting in permanent adverse changes to these habitats. In the context of the broader region, construction impacted stream reaches represent a small proportion of the overall unaffected aquatic habitats in first and second order streams within the Nena River, Ok Binai and Niar River catchments (and similar neighbouring catchments). While the spatial extent of the impact is limited to the FRCGP and FRHEP area, the magnitude of this impact was assessed to be **high** given there will be permanent major aquatic habitat damage. As a consequence the residual impact significance on aquatic habitats upstream of the ISF is assessed as **moderate**.

Aquatic Flora

Aquatic flora form an important food resource for herbivorous and omnivorous aquatic macroinvertebrates, fish and other water-associated fauna (e.g., tadpole life stages of tree frogs). As described above, the freshwater habitats of creeks, streams and rivers that drain the mine disturbance areas upstream of the ISF are predicted to have severe localised impacts. These include diversion and re-alignment (channelisation) of Ekwai, Ubai and Uba creeks, and substantial increases in bed sediment loads and high TSS concentrations in the Uba Creek, Ubai Creek and Nena River.

The impact of in-stream sedimentation and bed aggradation will be a smothering effect which will result in reductions in aquatic microflora biomass, densities and species richness and diversity. In-stream sedimentation will result in some infilling of the stony substrata of riffle reaches, with consequent reductions in the quality of stream-bottom habitats (e.g., reduced surface areas of stones and large woody debris) colonised by aquatic flora.

Increased TSS concentrations will also result in reductions in photosynthetic activity brought about by reductions in light penetration induced by turbidity in the water column. However, in reaches affected by heavy sedimentation, the contribution of this effect will be minimal with sedimentation being the primary stressor. Aquatic microflora in sediment-impacted reaches are expected to show a reduction in standing crops (biomass) and species richness and diversity, leading to reductions in primary productivity brought about by biomass reduction and depressed growth rates.

Construction activities in the Nena River catchment also have the potential to give rise to short-term increases in the concentrations of soluble nutrients in receiving streams. Such short-term pulses in soluble (i.e., readily available) nutrients will be available to benthic algae, diatoms and periphyton. However, the mobilisation of soluble nutrients is tempered by their adsorption onto soil particles and by their uptake by microorganisms that decompose stream detritus. Notwithstanding, the potential exists for stimulating algal growth and primary productivity in affected reaches of subcatchment streams and in the main channel of the Nena River.

The combined impact to aquatic flora consisting of benthic green algae, diatoms and periphyton in freshwater upland clear-water rivers and stream habitats on aquatic flora has been assessed as **moderate**. This assessment was based on the consideration that there will be severe reductions in aquatic flora in terms of diversity, richness and productivity in localised stream reaches during construction, translating to a **high** magnitude of impact. In the broader context, these impacts will be limited by the fact that autochthonous primary production in forest streams in the catchment upstream of the ISF embankment is very low compared to external inputs of allochthonous terrestrial organic matter, which forms a major base of the food web.

Aquatic Macroinvertebrates

During construction, significant increases in bed sediment loads and resulting sedimentation impacts are expected in Ubai and Uba creeks, and to a lesser degree in the Nena River with higher flow velocity which is expected to transport bed load downstream without significant bed aggradation (prior to ISF impoundment). Increased sediment loads and TSS concentrations are also anticipated to result from the development of the spoil dump adjacent to the limestone quarry and Ok Binai waste dump in Years -4 and -1, respectively.

During construction and prior to development of the Ok Binai waste dump, annual median TSS concentrations in the Ok Binai are estimated to range between 100 mg/L and 200 mg/L, compared to existing levels of around 60 mg/L. After the dump is developed in Year -1, annual median TSS concentrations are predicted to increase significantly and range from 700 mg/L to 1,500 mg/L throughout operations and post closure. Most of this suspended sediment generated from the eroding material is anticipated to be captured in the ISF reservoir, as only very fine suspended sediment particle sizes of approximately 8 μm diameter are predicted to pass through the ISF reservoir outflow. Sediment generated by the limestone quarry spoil dump, which will be developed approximately two years prior to impoundment of the ISF, will result in increased downstream sediment loads and TSS concentrations until ISF impoundment.

Due to the sequential nature of construction activities, continuous or intermittent high bed sediment loading of the watercourses upstream of the ISF is expected to cause direct impacts on benthic macroinvertebrate habitats through burial or suffocation and indirect impacts through reduction of macroinvertebrate food resources (e.g., benthic algae, diatoms and periphyton, and particulate organic matter). Within areas of in-stream sedimentation, there is expected to be an infilling of the stony substrata of riffle reaches.

Increased TSS concentrations and turbidity may further directly and indirectly impact the aquatic macroinvertebrate community. These effects include:

- Lethal effects (mortality of adult, larval or nymphal life stages).
- Sublethal effects (suppression of growth and productivity).
- Direct effects of high TSS concentrations including abrasion to body integuments, clogging of the gills and filtering or feeding apparatus of stream macroinvertebrates.

- Indirect effects of high TSS concentrations and attendant turbidity including:
  - Reduction of in-stream aquatic primary productivity which immediately reduces the organic carbon or energy available to enter the food web.
  - Displacement of macroinvertebrates by movement away from waters having continuously elevated suspended sediment concentrations (e.g., atyid prawns and the larger, more mobile macroinvertebrates) to clear-water side tributaries.
  - Downstream behaviour displacement through benthic macroinvertebrate drift (i.e., dispersal downstream passively or actively in the current to avoid areas of high TSS).

The principal impacts predicted in the aquatic macroinvertebrate communities within near-mine watercourses upstream of the ISF are:

- Loss (i.e., mortality or displacement) of suspended sediment-intolerant groups such as stonefly nymphs (Plecoptera), mayfly nymphs (Ephemeroptera) and caddisfly larvae (Trichoptera) that are sensitive to changes in water quality.
- Reductions in the abundance, diversity and standing stock (biomass) of suspended sediment-intolerant forms.
- Reductions in the abundance of river prawns.

Overall, the magnitude of combined stressors, primarily from in-stream sedimentation and elevated TSS concentrations, of benthic macroinvertebrate habitats and macroinvertebrates themselves at the local spatial scale (i.e., within Ubai and Uba creeks, Ok Binai and the Nena River) is assessed to be **high** during the construction period. As a consequence the residual impact significance is assessed as **moderate**.

On a regional scale, these construction impacts will be **negligible** given the widespread and abundance of macroinvertebrate communities and the localised nature of the impacts in the Frieda River catchment.

Fish Communities

During construction, Project-related impacts on fish will be due to stressors resulting from altered sediment transport regimes and habitat loss or degradation through in-stream sedimentation, as well as indirect impacts on fauna food resources such as microalgae, detritus and macroinvertebrates.

The potential impacts on fish from increased levels of TSS and sedimentation can be summarised as follows:

- Lethal effects on adult fish, eggs and larvae from increased levels of TSS (e.g., abrasion to body parts, especially the gills, and clogging or tissue damage).
- Burial of fish eggs attached to hard surfaces or fish eggs and larvae within stream bottom substrata.
- Filling of interstitial spaces between rocks on river beds, reducing the structural diversity of habitats by reducing voids and covering stone surfaces with sediment.
- Increased bed sediment transport and shifting stream bottom, reducing potential for benthic colonisation.

- Reduction in fish food resources (e.g., macroinvertebrates and macrophytes as discussed previously) with subsequent suppression of fish productivity through reductions in fish growth and biomass.
- Burial of terrestrially derived organic materials (e.g., vegetative and woody debris, leaves and detritus) by sediment, reducing benthic food resources available to fish.

During construction, the combined impact of changes in upland clear-water rivers and stream habitats on the fish community was assessed as a **high** magnitude impact based on the length of the construction period (the majority of infrastructure in the mine area will be constructed over a five-year period). There is likely to be severe reductions in fish abundance and diversity within impacted areas adjacent to, and downstream of, construction areas in the FRCGP and FRHEP area. In the context of the catchments upstream of the ISF embankment, however, these reductions are not considered to be high compared to the overall fish population in the broader catchment.

Most fish in the Sepik River catchment are known to tolerate extremely high TSS concentrations in the short term. Given that TSS concentration effects on fish are time-concentration dependent (NSR, 1986; Newcombe and MacDonald, 1991; Newcombe, 1994; DBA, 2005), intermittent exposure to such high concentrations of short duration is readily tolerated and inconsequential. For example, a total of 15 species of northern hemisphere freshwater fish tolerated and survived clay suspensions containing TSS concentrations of 100,000 mg/L for one week (Wallen, 1951; Alabaster and Lloyd, 1982). For southern hemisphere (PNG) fish, the red-striped rainbowfish (*Melanotaenia splendida*) survived five days in mine tailings having respective mean and peak concentrations of 13,030 mg/L and 44,645 mg/L, prior to the test being halted due to excess sedimentation (DBA and MFG, 2005). Furthermore, it is likely that some tolerant species are likely to persist, feeding upon allochthonous materials, such as terrestrial invertebrates, and material washed into the watercourses during periods of smothering as demonstrated by Roberts (1978).

The fish community within the catchments upstream of the ISF was assessed to be of **low** sensitivity. The fish community is common, widespread and of occasional subsistence importance from a resource use perspective. Given that the construction period is anticipated to last several years, the residual impact significance on fish communities during construction is assessed as **moderate**.

Construction: Downstream of the ISF Embankment (Frieda and Sepik Rivers)

This section assesses the residual impacts of the Project on aquatic habitats, flora and fauna of the Frieda and Sepik rivers and associated floodplain ORWBs.

Construction activities downstream of the ISF embankment (commencing in Year -7) include development of the Frieda River Port and access road, construction of the Link Road and upgrade of the Frieda River Airstrip site. Other than a section of the Link Road that is in steeper terrain, construction of these facilities will take place on relatively flat ground. With the implementation of erosion and sediment control measures, impacts associated with sedimentation and TSS generated by these activities are assessed to be low.

For a period of approximately five and a half years (from Years -7 to -2), construction-derived sediment impacts in the Frieda River will be associated primarily with activities in catchments upstream of the ISF embankment (discussed above) and the ISF embankment itself.

Prior to ISF impoundment in Year -2, median TSS concentrations in the Frieda River (AP6) are predicted to increase to about 250 mg/L to 300 mg/L in the first two years of construction (Year -7 to Year -5) and then increase to a peak of 750 mg/L in Year -4, which is approximately four times the average background concentration in the upper Frieda River of approximately 190 mg/L (AP6). During high flows (10% exceedance flow), TSS concentrations are predicted to reach up to approximately 2,500 mg/L. Median TSS concentrations downstream along the length of the Frieda River (down to AP11) are also elevated above median baseline concentrations for a period of two years. At AP11 in the lower Frieda River, median TSS concentrations reach approximately 500 mg/L during Year -4, which is approximately six times the median background TSS concentration. These elevated TSS concentrations in the Frieda River originate from the eroding spoil dump adjacent to the limestone quarry in the Ok Binai catchment to be developed in Year -4, two years prior to impoundment of the ISF.

TSS concentrations in the Frieda River downstream of the ISF embankment are predicted to reduce substantially to about 40 mg/L to 60 mg/L in Years -2 to -1 after the diversion tunnels (diverting flows around the embankment construction zone) are closed and the ISF commences filling.

Coarse-grained sediment generated in the catchments upstream of the ISF that reach the upper Frieda River will be transported downstream as either bed load or suspended load depending on flow velocities. Temporary areas of localised in-river sedimentation and river bed aggradation may occur; however, subsequent rising and flood flows will resuspend a portion of the deposited sediment. This material will be transported downstream as suspended load to the receiving lower Frieda River where they will resettle under reduced flows in this low-gradient river reach and form part of the river’s bed load and subsequently be transported downstream to the Sepik River.

Fine-grained sediments entering the natural drainage will be transported downstream as suspended load until they reach a lower energy hydrodynamic environment (e.g., pools, and lower-lying areas within the floodplain) where they will settle out of suspension. The very fine fraction of suspended sediment (e.g., <10 μm particle diameter) will be transported without settling as washload to the Sepik River.

Following ISF impoundment (Year -2), TSS and sedimentation impacts in the Frieda River will reduce substantially because of capture and retention of construction-derived sediments within the reservoir. Modelling has indicated that suspended sediment size fractions of less than 8 μm particle size diameter are predicted to pass through the ISF embankment as outflow.

During construction, annual median TSS concentrations in the Sepik River at Kubkain (AP13) are predicted to fluctuate between approximately 200 mg/L and 300 mg/L, which is a range comparable to the natural variability under existing conditions. Under natural conditions, the Frieda River catchment contributes approximately 8% of the combined sediment load of the Frieda River and upper Sepik River at their confluence. As such, the maximum mine-derived component of TSS contributing to sediment loads in the Sepik River during construction is estimated to be small. Furthermore, by the time flows from the upper and middle Frieda River reach the Sepik River (some 30 km downstream from the Nena/Niar river confluence), coarse- and fine-grained sediment will likely have been deposited in the lower Frieda River as bedload. This bedload will then eventually be carried to the Sepik River. Most of the TSS load reaching the Sepik River from the upper Frieda River is expected to comprise very fine slits (less than 30 μm) which will be transported as washload in the Sepik River to its mouth.

As indicated in Section 8.5.4, inflow TSS levels to floodplain ORWBs of the Frieda and Sepik rivers are expected to remain comparable to those estimated to occur under existing conditions. Therefore, no impacts on these ORWBs associated with construction activities are expected.

The residual construction-related impacts on freshwater values of watercourses downstream of the ISF embankment are discussed below with the significance ratings of the residual impacts summarised in Table 8.36.

Table 8.36 Residual impacts to freshwater ecology values in watercourses downstream of the ISF embankment impacted during construction

Impact Description	Residual Impact after Implementation of Management Measures		Significance Rating
	Magnitude	Sensitivity of Receptor	
Frieda River			
Loss or degradation of aquatic habitats due to physical disturbance (direct loss of habitat), and increased sedimentation, TSS and turbidity	High	Low	Moderate
Impacts on aquatic fauna due to loss of habitat, increased sedimentation, TSS and turbidity	High	Low	Moderate
Species of conservation significance			
Impacts on species of conservation significance in the Frieda River	High	Low	Moderate

Aquatic Habitats

During the first 5.5 years of the construction period, flows in the Frieda River will not be affected due to the installation of diversion tunnels that will continue to direct flows from upstream of the ISF embankment construction site to the upper Frieda River. During the initial 10-month filling period commencing in Year -2, flows in the Frieda River downstream of the ISF embankment will be maintained at 50 m^3/s to maintain the minimum environmental flows in the Frieda River. Therefore, aquatic habitats are not likely to be greatly impacted by changes in flow in the Frieda River, nor the receiving Sepik River.

Direct removal of aquatic habitat proposed in the upper Frieda River, which has a footprint of approximately 95 ha that includes approximately 3 ha of actual in-river bed habitat, is related primarily to the construction of the ISF embankment[13].

As discussed above, during construction, the main stressor with the potential to impact freshwater habitats in the Frieda River is increased in-stream sedimentation. During the first 5.5 years of construction, a sediment load of approximately 13 Mt is predicted at AP6 compared to a baseline of approximately 9 Mt. This increased load (by approximately 30%) is primarily related to the development of the spoil dump adjacent to the limestone quarry in Year -4, before ISF impoundment.

As a result of the increased sediment load and subsequent aggradation, the composition of the Frieda River bed substratum (i.e., boulders, cobbles and pebbles) is expected to be modified, with infilling of the interstitial spaces within watercourse stony substrata, reducing structural diversity and spaces for shelter and foraging habitat for aquatic macroinvertebrates. Nesting habitat for fish and their eggs may also be smothered by sediment, reducing reproductive success.

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[13] The river reaches to be inundated will be modified from a lotic (flowing) environment to a lentic (still) environment rather than directly lost.

To a lesser extent, the ISF embankment will result in temporary but localised in-stream sedimentation immediately downstream of the embankment construction site. However, flood flows discharged via the diversion tunnels will have sufficient kinetic energy to transport bed load downstream or resuspend previously settled solids and transport them downstream as suspended load.

The lower reach of the Frieda River may provide suitable nesting or foraging areas for crocodiles and turtles, where flow velocities are reduced in river bank vegetation and floodplain habitats. As discussed above and in Section 7.4, the habitats of the Sepik River (and the lower reaches of the Frieda River) have been significantly changed as a result of introduced non-native species. Based on the predicted effects of construction of the lower Frieda River and the Sepik River, impairment of habitat integrity for crocodiles and turtles is not expected. Furthermore, the proximity of the lower Frieda River to the Sepik River would offer alterative suitable habitat for these species.

Floodplain ORWBs, swamps and wetlands of the lower Frieda River are the least likely to be impacted by construction-derived sediments because water flows tend to be confined within the main channels and are too low for overbank inundation of the floodplain to transport suspended sediment loads to these depositional environments. However, under extreme high flows in the Frieda River, overbank inundation of its floodplain may occur from time to time but at low frequencies or return intervals. Reduced TSS concentrations and turbidity are typical of low-flowing or still water (lentic) surface waters within the floodplain swamps and wetlands compared to the Frieda River. Management measures proposed for the access roads make provision for installation of culverts to allow normal flow of water in low gradient sections in swamp and wetland terrain.

Habitats within the Frieda and Sepik rivers were assessed to be of **low** sensitivity as they are well represented regionally and in northern PNG and are moderately tolerant to changes in water quality, particularly the upper reaches that are characterised by higher flow conditions (particularly following high rainfall events) and attendant high TSS levels.

As annual predicted median TSS concentrations in the Sepik River are comparable to natural variability under existing conditions, a **negligible** magnitude of impact is predicted for the Sepik River aquatic habitats. Overall, the residual impact significance rating has been assessed as **negligible**.

For the Frieda River down to AP11 during construction, the residual impact significance rating for aquatic habitats has been assessed as **moderate** based on a **high** impact magnitude.

Aquatic Flora, Macroinvertebrates and Fish Communities

During construction, the primary stressors on aquatic biota (flora, macroinvertebrate and fish) will be increased sedimentation, TSS and turbidity. During development of the spoil dump adjacent to the limestone quarry in Year -4 and for a period of 2 years thereafter, median TSS concentrations in the Frieda River at AP7 are predicted to be approximately four times higher than median baseline TSS concentrations.

This prolonged increase in TSS concentrations during the 5.5-year construction period prior to ISF impoundment, and particularly during Years -4 to -2, will result in a reduction in the quality of bottom habitat available to microflora and some reduction in photosynthetic activity brought about by reductions in light levels induced by turbidity in the water column. These conditions are likely to favour sediment-tolerant aquatic flora. However, considering the limited flora present, this is not a significant impact.

Since the Frieda River is characterised by lower velocity flows compared to upland rivers and creeks, moderate to high TSS and low water transparency, macroinvertebrates and fish present in these habitats are somewhat tolerant to intermittent high TSS and sedimentation. Increased sediment concentrations in the Frieda River may favour macroinvertebrates, and to a lesser extent fish, that are tolerant of high TSS concentrations, such as the exotic species which are typically sediment-tolerant species that are highly adaptable to watercourses of variable turbidity. This may result in a macroinvertebrate community shift to avoid water quality changes, for example a higher proportion of species inhabiting the lower Frieda River, as a result of increased drift (e.g., Jones et al., 2012). There may also be some direct and indirect impacts from increased fine sediment, which can influence growth rates (e.g., Kent and Stelzer, 2008), and cause mortality of individuals and population growth rate (e.g., Broekhuizen et al., 2001).

As a result, these changes may be of sufficient duration, intensity or extent to result in a shift in the overall ecosystem structure within reaches of the Frieda River. A reduction in macroinvertebrate distribution and abundance may result in a reduction of food resources for fish, which may affect in turn affect fish community distribution and abundance.

Furthermore, when turbidity is consistently high, resulting from elevated TSS concentration, water clarity and visibility is reduced, which may affect fish species that are visual predators.

While there are relatively few tributary stream of the Frieda River, fish can take refuge in clear water side streams that are present, such as Kaugumi Creek, or may be displaced downstream during periods of high TSS and turbidity until conditions are more favourable. Food resources within these side streams are expected to be sufficient to sustain populations in the short-term (i.e., 2 years).

Freshwater turtles and crocodiles are unlikely to inhabit the swift-flowing reaches of the Frieda River in its upper and middle reaches. However, both crocodiles and freshwater turtles may occur in the lower Frieda River (and the Sepik River), which have been modified as a result of introduced non-native species. Significant impairment of habitat integrity for these species in the lower Frieda River is not anticipated, as described above, While increases in TSS concentrations and associated turbidity, as well as indirect impacts on food resources (e.g., aquatic microalgae, detritus, other organic matter inputs from forested catchments, prawns and fish), may affect any species present in the lower Frieda River, the survival of individuals or populations of turtles or crocodiles is not expected to be affected.

Prior to ISF impoundment, median TSS concentrations are predicted to be approximately four times higher than median baseline TSS concentrations in the Frieda River during the construction. As such, the magnitude of impacts on macroinvertebrates, fish communities are considered to be **high** and the residual impact significance rating has been assessed as **moderate**. Construction impacts on turtles and crocodiles, which may be present in the lower Frieda River are anticipated to be **low**, resulting in a **minor** impact significance rating.

In the Sepik River, construction-related impacts on aquatic macroinvertebrates, fish communities and other aquatic fauna species (turtles and crocodiles) are not expected given that predicted TSS concentrations are comparable with the natural background variability in TSS concentrations in the Sepik River. Therefore, residual impact significance rating has been assessed as **negligible**.

Species of Conservation Significance

Impacts on species of conservation significance, most of which are sediment tolerant, in the Frieda and Sepik rivers are the same as those on other species and therefore attract a **moderate** and **negligible** impact significance rating, respectively. Impacts on conservation significant species in the mid to lower Frieda River are assessed as **negligible**, consistent with other species in this river reach.

Construction: Infrastructure Corridor

Construction of the infrastructure corridor will result in short-term localised increases in sedimentation, TSS concentrations and turbidity. The new road section between the mine site and Green River is expected to generate more fugitive sediment, particularly in the steeper terrain of the Usake/May River catchment where sidecasting will be required. The existing section of road to be upgraded between Green River and Vanimo is expected to generate less fugitive sediment, as new road sections that have a higher propensity to generate sediment-laden runoff are not required.

Localised accumulations of coarse sediment will occur in the drainage lines downstream of the construction areas and where sidecasting along roads occurs, although the extent of the accumulation will be dependent on the effectiveness of the sediment control measures that are implemented. Where this accumulation occurs it is likely to be visible and could lead to some dieback.

Rainfall-based erosion and scour of construction disturbed or displaced soils at the approaches to, and banks of, the creeks at road crossings is predicted to cause temporary sedimentation of aquatic habitats immediately downstream of the crossing sites. However, successive rising and flood flows are expected to resuspend 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 intervention.

Increases in TSS concentrations where the infrastructure corridor is closely aligned along tributaries in the upper reaches of the May River, particularly where the infrastructure corridor crosses into and leaves the May River watershed are expected. These effects will, however, reduce closer to Hotmin given the larger natural upstream contributing areas of the May River and consequent higher discharges and natural sediment loads.

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

The magnitude of localised and short-term impacts on aquatic habitats and aquatic biota are assessed as **medium** during construction of the infrastructure corridor and the resulting residual impacts significance rating has been assessed as **minor**. Given that the impacts are anticipated to be greatly reduced within two years, no further assessment of the infrastructure corridor is undertaken for subsequent Project phases.

Operations: Upstream of the ISF Embankment

During FRCGP operations, mined ore and waste rock from the open-pits will be transported via conveyor for processing or stockpiling and subsequent disposal within the ISF reservoir. From Year 1, the ISF will be operating to generate hydroelectric power with a minimum operating level of approximately RL 199 m. The ISF will ultimately store approximately 1,500 Mt of tailings deposited at depth via a floating pipeline system, 1,450 Mt of waste rock and 66 Mt of sediment from the natural catchment over the life of the mine. This material will be stored below a predicted water cover of approximately 40 m within the ISF reservoir for the life of the FRCGP. After this time, the ISF reservoir will silt up as a result of natural sediment inputs and therefore the depth of the water cover over the sediments (tailings and waste rock plus natural sediments) will very gradually reduce over many hundreds of years.

Based on the acid-forming characteristics of the in-pit waste rock, open-pit runoff is expected to be acidic (low pH) and contain high concentrations of sulphate and dissolved metals and metalloids. It will be treated from Year 1 to limit potential poor water quality downstream. Water treatment will take place prior to release of the water into Ubai Creek, from where it will flow into the ISF reservoir and be further diluted. As discussed in Section 8.5.5, the main contaminants of environmental concern are dissolved aluminium and copper. While these metals concentrations meet the PNG Schedule 1 ambient water quality criteria, they are predicted to be elevated above ANZECC/ARMCANZ (2000) ambient water quality criteria, as well as background concentrations as discussed in Section 8.5.5.

Concentrations of aluminium, cadmium and copper were identified as being capable of bioaccumulating in the aquatic food chain. The predicted impacts on aquatic biota are discussed below.

Within the ISF reservoir at AP4 (representing a worst-case water quality scenario) during operations, labile (and potentially bioavailable) concentrations of aluminium (0.329 mg/L) and copper (0.0063 mg/L) are 6 and 4.5 times higher than their respective ANZECC/ARMCANZ (2000) guideline values. Water at AP5 within the Niar River arm of the reservoir is predicted to be of better quality than AP4. Waters flowing into the ISF reservoir from the headwaters and various tributaries of the Nena River and Niar River will retain good water qualities that will maintain aquatic biota.

After the ISF reservoir is at full capacity, the lower reaches of the Nena and Niar rivers and the Ok Binai will be inundated and change from a lotic (flowing) environment to a lentic (still or very slow flowing) environment. Concentrations of contaminants in the ISF reservoir are expected to be elevated above background concentrations and water quality guidelines given that the ISF has purposely been designed to be a repository for waste rock and tailings as well as a means of generating hydroelectric power, and this facility is considered a part of the physical FRCGP footprint. Therefore, while impacts within the ISF reservoir are described below, residual impacts have not been given a significance rating as they will form part of the mixing zone upstream of the Compliance Point proposed at AP7, which is discussed in Section 8.5.5. As such, impacts upstream of the ISF embankment are not further assessed.

Aquatic Habitats

The changes as a result of ISF impoundment and transformation from the existing riverine aquatic habitats to lacustrine aquatic habitats and their effects on aquatic biota are described below. Three main habitat types of the future ISF reservoir comprise bottom, littoral and open-water habitats.

The ISF reservoir submerged bed will receive both natural and mine-derived sediment deposits. The mine-derived deposits will comprise tailings and waste rock and the natural deposits will be derived from upstream bed load transport and the settling of natural TSS loads within the reservoir. Where upstream rivers and streams flow into the reservoir, coarse-grained deltaic sediments will form as inflow velocities decrease. As flow intrusion velocities decrease further downstream of river inflows, finer grained suspended sediments will progressively settle within the river arms of the reservoir, and finally, within the main body of the ISF reservoir. This pattern of longitudinal sedimentation will result in a bed sediment particle-size gradient ranging from coarse sediment to fine sediment bottom habitats available for colonisation and establishment of macroinvertebrates and benthic fish assemblages.

The structural diversity of bottom habitats in the ISF reservoir will tend to be generally homogeneous compared to the heterogeneous nature of the riverine bed sediments prior to impoundment. Under homogeneous bed sediments of the reservoir, the number of taxa capable of colonising these soft-bottom habitats will be reduced.

There will be an increase in littoral zones (i.e., areas adjacent to the reservoir banks to a depth of 7 m) due to the reservoir's dendritic form, compared to the limited linear littoral zones of the Niar and Nena rivers and their tributaries prior to inundation. Water-level fluctuations in the reservoir as a result of flow regulation for hydroelectric power generation may result in a large expanse of aquatic habitat in the littoral zone being exposed and subject to desiccation and then subsequent inundation. The long-term effects of drawdown and ISF reservoir refilling may also include shoreline erosion and sedimentation which can alter habitat quality in the littoral zone.

Formation of the ISF reservoir also creates a large expanse of open-water habitat, varying from pelagic through mid-water to profundal (deep) habitats. The anoxic hypolimnion will be the least likely to contain nekton; however, the oxygenated epilimnion will offer suitable open-water habitat for some taxa such as phytoplankton, zooplankton and open-water fish species.

In the areas within the ISF reservoir where deposition of waste rock and tailings is active, high concentrations of TSS and dissolved metals and metalloids are likely to render the majority of aquatic habitats within the affected area inhabitable for both benthic and water column aquatic biota. The littoral zone, covering approximately 8% of the ISF area adjacent to the ISF banks, is likely to contain elevated nutrient concentrations during early operations. These areas are likely to have short-term increases in pioneering aquatic biota taking advantage of the increased nutrient supply for at least a year or two.

Other areas of the ISF reservoir providing aquatic habitats include the areas of inflows unaffected by mining activities (i.e., Niar River main inflow and numerous tributaries to the south).

Aquatic Biota

During FRCGP operations, it is likely that some aquatic species will continue to maintain stable self-producing populations within the ISF, but primarily in areas unaffected by mining activities, while other species are not likely to survive upstream of the ISF embankment due to its barrier effect disrupting migratory species (e.g., river prawns and eels). Aquatic insects will continue to lay eggs in the littoral margins of the ISF reservoir and phytoplankton and zooplankton, which can be transported in via wind-blown dust particles, will continue to colonise suitable areas of the reservoir.

Based on the changes in aquatic habitat (from lotic to lentic) described above, macroinvertebrate communities are expected to change in terms of distribution and abundance. Species that prefer flowing water, such as Ephemoptera and Tricoptera, will be replaced by species that prefer still water, such as oligochaete worms and chironomid larvae. Benthic deposits of tailings, which are pH neutral, may be colonised by some benthic macroinvertebrate species. However, it is unlikely that the deposited waste rock, which is high in sulphides with elevated concentrations of trace metals and metalloids, will be colonised by benthic organisms.

On a local ISF catchment scale, the ISF embankment will form a barrier to longitudinal movements of migratory macroinvertebrate species such as river prawns. River prawns, which are amphidromous (migration of juveniles from estuarine water in the lower Sepik River to upstream fresh waters), are likely to decline upstream of the ISF embankment within 3 to 4 years. In general, gravid female freshwater prawns of the family Palaemonidae migrate downstream into the Sepik River estuary where the eggs hatch as free-swimming larvae in brackish water. After metamorphosis, juveniles migrate back upstream to freshwater habitats. The ISF embankment will form a barrier to upstream migrating juvenile prawns as the embankment represents an insurmountable barrier. This may result in the eventual decline of freshwater prawns in the ISF reservoir and its catchment streams. However, it is possible that some species of prawns will survive if their eggs and juvenile stages can survive within the reservoir and do not depend on salinity for their development. On a regional scale, impacts on prawn species populations will be negligible as other upstream areas outside the FRCGP and FRHEP areas will be unaffected by the ISF embankment and will remain available for migration to and from the Sepik River.

The main fish species affected by the ISF embankment are two species of eels that are catadromous (migrating down rivers to the sea to spawn) and three species of fish (paoillate catfish, Emily's fish and Java carp) that are potamodromous (undertake longitudinal and lateral movements within the river system only). Eels can pass downstream via the turbine discharge or spillway outflows but cannot pass upstream. The three potamodromous fish species are expected to be capable of maintain self-reproducing and sustainable populations within the ISF reservoir. However, eels trapped upstream of the embankment will either die at the end of their lives or escape downstream via turbine discharges or spillway tunnel flows and not return, as the embankment is insurmountable. The embankment will also prevent juveniles migrating from the sea and repopulating the ISF.

Fish species are expected to persist in areas of the ISF reservoir that are unimpacted or less impacted by FRCGP activities, including the Niar River arm of the reservoir which is predicted to have better water quality than in more impacted Nena River arm. Fish will also likely tolerate short excursions and periods within the tailings and waste rock deposition zones, being exposed to increased TSS concentrations and elevated metals concentrations.

Non-native fish including the rubber mouth (*Prochilodus argenteus*) and the Red-bellied pacu (*Piaractus brachypomus*) are candidates as the predominant pioneering fish that will establish and maintain self-reproducing populations in the ISF reservoir and its arms as well as the tributaries. This is because these species are hardy and highly adaptable in different aquatic environments as demonstrated by their success of their introduction into the Sepik River. Most of the native fish species currently present in the watercourses upstream of the ISF embankment, such as the North New Guinea rainbowfish (*Melanotaenia affinis*), Silver rainbowfish (*Chilatherina crassispinosa*), Koragu tank goby (Glossogobius koragensis), Gellerup's mouth almighty (Glossamia gjellerupi) and Coates' goby (*Glossogobius coatesi),* are also expected to persist mainly in river inflows and flow intrusions within arms of the reservoir and littoral zone.

Bioaccumulation

As described in Appendix 7b, macrophytes and terrestrial vegetarian similar to what is currently observed along the rivers in the region are expected to rapidly colonise the littoral zones of the ISF. This zone is also expected to be fairly rapidly colonised by various algae (periphyton and phytoplankton), zooplankton, benthic invertebrates and fish. For the purposes of the study, it was assumed that the pioneering fish species likely to colonise the ISF and inhabit the littoral zone include: the red-bellied pacu (*Piaractus brachypomus*); the papillate catfish (*Neoarius velutinus*); and the rubber mouth (*Prochilodus argenteus*). All three of these species are omnivores that consume detritus, plants, invertebrates, and to some extent bait fish. Contaminant concentrations in the littoral zone will be reduced compared to the pelagic zone given that waste rock and tailings deposition will occur at least 400 m from the banks of the ISF.

Figure 8.9 shows a conceptual model of metals transport in the ISF reservoir during Year 10 of FRCGP operations (as well as 50 years' post closure).

In the littoral zone, metals can be absorbed by plants and algae which are then consumed by invertebrates and by fish species (which also consume plants directly). All of the fish species considered to be present in the ISF are omnivorous and obtain their energy and nutrition from plants, algae and invertebrates to varying extents.

Compared to the littoral zone, the pelagic zone is anticipated to have a more simplified food web, in which the only bioaccumulation pathways to fish are via direct contact with the water column, or through consuming phytoplankton and zooplankton. The benthic substrate (around 90 m below the surface at this time; see Figure 8.4) in the pelagic zone will consist of coarse rock and tailings with little or no detritus or other food source for upper trophic levels. As a result, benthic invertebrates and benthic-feeding fish species, such as the papillate catfish are not likely to be present within the pelagic zone (and therefore there is no bioaccumulation pathway associated with benthic organisms in this zone); however, the red-bellied pacu and the rubber mouth could inhabit the pelagic zone, as well as the littoral zone.

In the pelagic zone, fish diets were assumed to comprise only plankton as any metals from lower layers of the ISF are not likely to be mobilised to the upper layers of the reservoir, and plants are not expected to be a source of metal uptake in the pelagic zone.

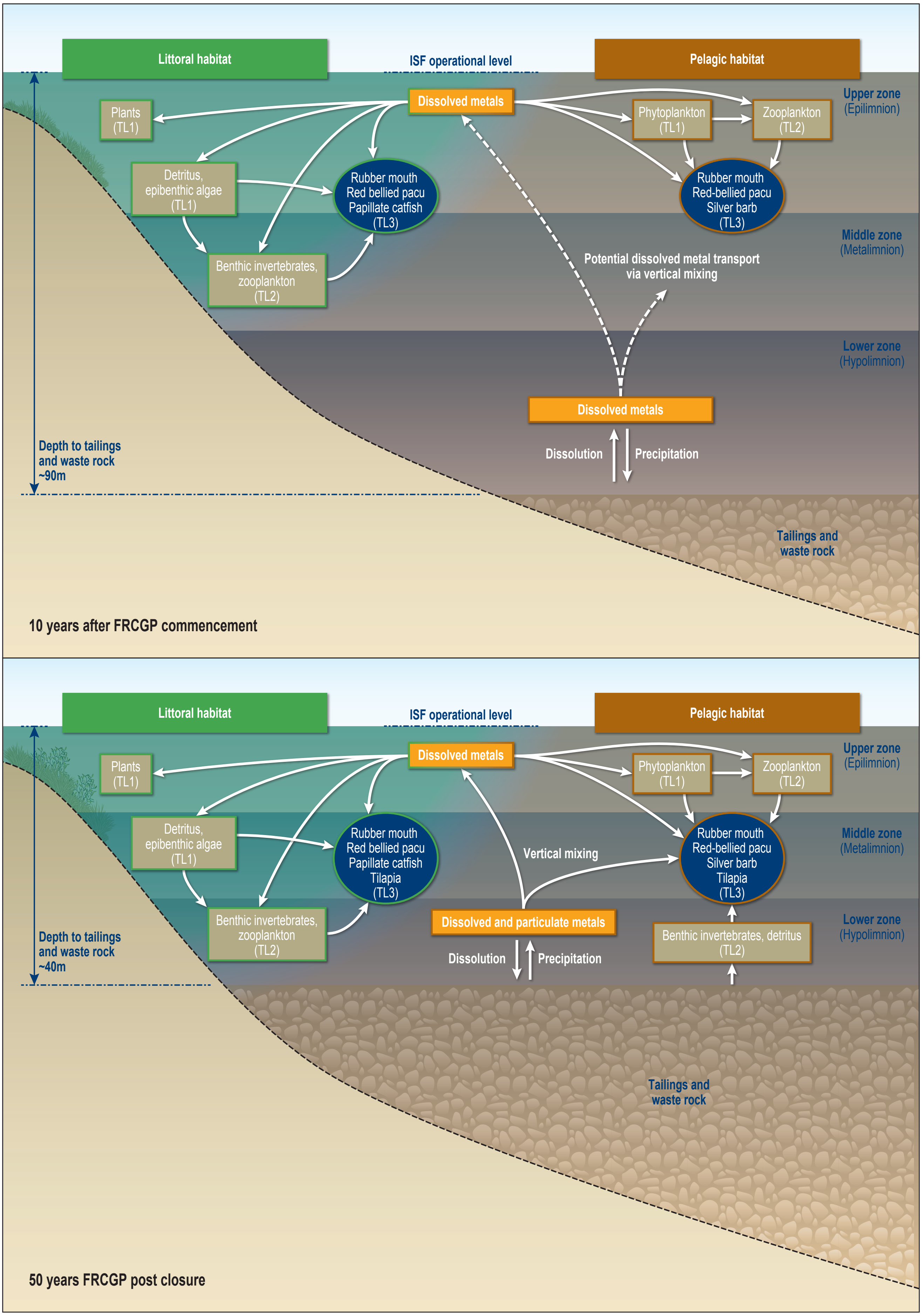
The baseline and predicted aluminium, cadmium and copper concentrations in fish tissue during operations for the littoral and pelagic zones are shown in Table 8.37, along with concentration increase factors for each scenario under average flows. During operations, under average flows, the modelling indicated that compared to calculated fish tissue baseline metals concentrations, fish tissue concentrations of:

- Aluminium are predicted to increase by a factor of 2 to 4 in the littoral zone, and by more than 6 times in the pelagic zone, due to the elevated aluminium concentrations in the water column as a result of waste rock dumping.
- Cadmium are predicted to increase by a factor of 2 to 2.5 in the littoral zone, and by a factor of 2.5 in the pelagic zone.
- Copper are predicted to increase by a factor of 0.6 to 1.2 in the littoral zone. In the pelagic zone, concentrations of copper are predicted to decreased by a factor of 0.6.

The results are generally supported by examples in the literature, with aluminium bioaccumulating to the greatest degree, and cadmium and copper to a much lesser extent. Studies indicate that 59 to 93% of aluminium in water was accumulated by duckweed (Mo et al., 1988) and that signal crayfish accumulated approximately 78% of the aluminium from its prey (freshwater snails), which had accumulated aluminium from water (Walton et al., 2010). Handy (1993) found that bioavailability of aluminium from food sources to rainbow trout was low (< 1% uptake).

With regards to cadmium, Campenhout et al. (2009) evaluated sources of cadmium accumulation in carp and found that the majority of cadmium accumulation was primarily from food (20%) in comparison to water (0.11%). In addition, Kay (1984) indicated that cadmium does not generally biomagnify in freshwater systems.

For copper, tropical fish were reported to accumulate 55 to 73% copper from tubificid worms and that the bioaccumulation factor for fish was much lower than that for worms (Patrick and Loutit, 1978).



coffey A TETRA TECH COMPANY	Date: 17.09.2018 Project: 754-ENAUABTF11575 File Name: 11575_11_F08.09_GRA	Frieda River Limited Sepik Development Project	FRIEDA RIVER	Conceptual models of metals transport in the ISF reservoir during FRCGP operations (Year 10) and 50 years FRCGP post closure	Figure No: 8.9

AI Reference: 11575_11_GRA051.ai_5

While there are no standards or criteria for aquatic fish tissue for aquatic biota protection, none of the criteria for human health (i.e., food standards) are predicted to be exceeded. This is further described in Chapter 12.

Table 8.37 Predicted aluminium, cadmium and copper concentrations in fish tissue during FRCGP operations for average flows

Scenario	Metal	Red bellied Pacu tissue concentration (mg/kg)	Papillated catfish tissue concentration (mg/kg)*	Rubber mouth tissue concentration (mg/kg)	Tissue concentration increase factor compared to calculated baseline
Baseline†	Aluminium	1.88 (1.60)	1.75 (1.60)	2.19 (1.60)	-
	Cadmium	0.002 (0.01)	0.002 (0.01)	0.001 (0.01)	-
	Copper	0.16 (0.51)	0.23 (0.51)	0.04 (0.51)	-
Littoral zone	Aluminium	2.35	2.19	2.74	0.25 to 0.5
	Cadmium	0.006	0.007	0.005	2 to 2.5
	Copper	0.25	0.35	0.06	0.6 to 1.2
Pelagic zone	Aluminium	13.21	NA	13.21	6.0
	Cadmium	0.007		0.007	2.5
	Copper	0.066		0.066	-0.6

* NA, not applicable. The catfish is unlikely to be found in the pelagic zone due to its diet and therefore was not assessed for this zone.

† Calculated baseline results. Results in brackets represent 90th percentile measured omnivorous (TL3) fish tissue concentrations. For measured baseline data results below the limit of detection, the value of the detection limit has been assumed.

Operations: Downstream of the ISF Embankment (Frieda and Sepik Rivers)

The variability in flows in the Frieda River during operation of the FRCGP and FRHEP is reduced relative to existing conditions. While average flows downstream of the ISF embankment are predicted to be similar to those under existing conditions, low flows are predicted to be substantially increased and high flows are predicted to be substantially decreased.

The ISF will be the most prominent and effective engineering control limiting sedimentation of the Frieda River. It is estimated around 99% of the sediment inflow, along with tailings and waste rock placed into the ISF, will be retained within this storage and not transported further downstream. The sediment released over the ISF spillway and/or through the hydroelectric power intake will report to downstream watercourses and will consist predominantly of very fine material (approximately less than 8 μm). This is expected to be readily transported downstream rather than settling and causing streambed aggradation.

During FRCGP operations when waste rock and tailings deposition occurs in the ISF, TSS concentrations (all of which are fine particles, the majority being mine-derived) increase up to approximately 240 mg/L at AP6 over the first 14 years of operations after which concentrations begin to decrease. From Year 28, median TSS concentrations are predicted to reduce to about 30 to 40 mg/L which is much lower than the predicted median TSS concentrations at AP6 (about 190 mg/L) under existing conditions.

As described in Section 8.5.4, the proportion of particulate metals at AP7 in the upper Frieda River progressively increases downstream at AP13 in the Sepik River. While dissolved-phase metals (including labile forms) are the most bioavailable and potentially toxic (depending on concentration and duration of exposure) to aquatic biota, particulate associated metals may form the basis of metal bioaccumulation within those aquatic organisms that ingest sediments.

Predicted labile concentrations of aluminium (0.173 mg/L) and copper (0.0033 mg/L) during average flows in the Frieda River (AP7) are 3 and 2.3 times greater than their respective ANZECC/ARMCANZ (2000) trigger values. Based on the comparison of the US EPA (2017a; 2017b) calculated acute and chronic site-specific criteria (that consider the recent advancements in aluminium research and site-specific factors) acute or chronic aluminium-related toxicity is unlikely as the predicted labile aluminium concentrations are below these calculated criteria.

As described in Section 8.5.5, the predicted labile copper concentrations in the Frieda River approach the ANZECC/ARMCANZ 95% ecosystem trigger value during average flows. During low flows (i.e., 10% of the time (or approximately 36 days per year)) in the Frieda River, the labile copper concentration is predicted to be four times the ANZECC/ARMCANZ (2000) trigger value for copper. Therefore, there is the possibility of impacts to copper-sensitive microalgae and benthic invertebrates in the Frieda River but there is unlikely to be any significant changes in algal or invertebrate community biomass and abundance.

In addition to copper complexing capacity, the adsorption of copper by the substantial concentrations of natural suspended particulate matter will also act to reduce the concentrations of dissolved copper in the Frieda and Sepik rivers. This suggests that site-specific triggers for action in relation to copper concentrations can be justified for the Project and that bioavailable copper is likely to meet the ANZECC/ARMCANZ (2000) trigger value for copper.

Concentrations of TSS in the Sepik River reflect the dominance of the natural sediment load coming from the upper Sepik River catchment relative to inputs from the Frieda River. Project influences on TSS concentrations in the Sepik River are predicted to be comparable to the natural variability for existing conditions. Bed level changes as a result of the Project are also predicted to be negligible in the Sepik River. Labile concentrations of aluminium (0.029 mg/L) and copper (0.0002 mg/L) in the Sepik River (AP13) during average flows are predicted to be below ANZECC/ARMCANZ (2000) trigger values and background concentrations at AP13. During low flows however, the predicted concentration of aluminium (0.1072 mg/L) is above the ANZECC/ARMCANZ (2000) trigger value but is below the US EPA (2017 a and b) calculated acute and chronic site-specific criteria.

Given that these predictions indicate that hydrology, sedimentation and water quality impacts in the Sepik River as a result of FRCGP operations are **negligible**, no further impact assessment for the Sepik River during operations is undertaken below.

Aquatic Habitats

Given that average flows in the Frieda River below the ISF embankment are predicted to be similar to existing conditions, aquatic habitats are not likely to be greatly affected by changes in flow, with the exception of the initial 10-month ISF filling period. During this time, environmental flows of 50 m^3/s will be released downstream, equivalent to the lowest recorded flows in the Frieda River (recorded in 1997), and some aquatic habitats will likely be maintained especially within the continually wetted mid-channel zone. However, some aquatic habitats in other lateral and near-bank zones will be lost or degraded during the 10-month period. The upper Frieda River reach will be the most sensitive reach to changes to the natural flow regime and is more likely to have very shallow depths during the temporary low flow release. This is primarily due to the steep channel gradient and small contributing lateral catchments in the area downstream of the ISF embankment.

The upper Frieda River may be prone to disconnection, leading to isolated areas of pools or shallow, slow-flowing riffle reaches, which may impact upon the connectivity between some in-river aquatic habitats. In such cases, there may be a very small number of isolated areas of flowing-water (lotic) habitat that will be transformed into still-water (lentic) habitats and which may dry up. Such areas are likely to occur in the braided channel reach of the middle Frieda River. Overall, there will be a reduction in the areal extent of wetted river bottom habitat, which also occurs during natural low flow periods but for a shorter duration.

Aquatic habitats of the middle and lower Frieda River are less likely to be affected by reduced flows due to the ISF filling.

The greatest factor imposing long-term changes to aquatic habitats in the Frieda River will be the changed bed sediment load and composition of the suspended sediments entering its upper reaches. Due to the loss of bed load (trapped upstream in the ISF reservoir), reduced suspended sediment loads and reduced TSS particle size range (generally >8 µm diameter) reaching the Frieda River immediately downstream of the ISF embankment, streambed degradation is predicted with bed levels reducing by approximately 3 m (possibly down to bedrock) in the upper Frieda River (compared to approximately 1 m predicted under existing conditions). This streambed degradation is likely to cause a reduction in structural diversity of aquatic habitats. However, void spaces in the rocky and stony bed substratum will increase as the finer fractions of existing bed sediments are removed by flow and transported downstream without being replenished.

The magnitude of impact on aquatic habitats of the upper Frieda River is assessed as **medium** during the period when the greatest transformational changes to aquatic habitats downstream of the ISF embankment will occur. Therefore, the significance rating of residual impacts on aquatic habitats in the upper Frieda River has been assessed as **minor**. Impacts on aquatic habitats of the lower Frieda River are assessed as having a **negligible** impact magnitude, resulting in a **negligible** impact significance rating.

Aquatic Biota

The aquatic biological communities of the Frieda River are adapted to fluctuating flow regimes; therefore, the altered flow regimes imposed by hydroelectric facility operation is not expected to cause substantial impacts on the downstream aquatic flora or fauna. An exception occurs within the 10-month filling period where there may be a reduction in the width and areal extent of riverbed substratum which normally forms bottom habitat available to benthic or spawning fish species. Given their higher mobility, fish are expected to move away from areas of receding waters and exposed river bottom towards the mid-channel zone where adequate water depths will be maintained during the environmental low flow releases from the ISF. Therefore, diverse and abundant main channel fish assemblages will be maintained in the Frieda River.

Because the Frieda River is wide and shallow, extensive areas of bottom habitat will be exposed to air and less mobile benthic macroinvertebrates and hyporheic invertebrates will be exposed to desiccation. This may result in a reduction of benthic macroinvertebrate species abundance and biomass, but they are likely to persist in wetted areas of the Frieda River main channel. The larger, more mobile decapod crustaceans can readily move away from exposed riverbed and are likely to be the least impacted of the aquatic macroinvertebrate fauna.

For most of the FRCGP operational period, predicted median TSS concentrations in the Frieda River are within the range of natural variability with an increase up to approximately 240 mg/L (compared to a median baseline of approximately 190 mg/L). However, towards the end of operations as mine waste deposition reduces, median TSS concentrations are predicted to reduce to much lower levels than under existing conditions. Given that aquatic biota of the Frieda River are sediment tolerant species and that TSS concentrations are predicted to be similar to the natural conditions, TSS and turbidity-related impacts to aquatic biota are not expected.

Particulate associated metals may form the basis of metal bioaccumulation within those aquatic organisms that ingest sediments and result in a number of effects on these organisms. However, given the predicted predominance of very fine TSS (<8 µm particle size diameter) discharged in the ISF outflows or spillway, most of the fine TSS load will be transported as washload in and through the Frieda River without settling. Therefore, exposure of benthic organisms to particulate associated metals in bed sediments is anticipated to be low. The principal trace metal exposure route to aquatic biota will be via dissolved metals present in the water column, which are more bioavailable, and especially the labile forms of the trace metals (see below).

Given that predicted labile concentration of aluminium (0.173 mg/L) at AP7 meets the US EPA (2017 a and b) calculated acute and chronic site-specific criteria, acute or chronic aluminium-related toxicity is unlikely as the predicted labile aluminium concentration is below these calculated criteria.

Concentrations of labile copper predicted to occur in the Frieda River (sites AP7 through AP11) during low and average flow conditions may result in some impacts to copper-sensitive species of microalgae and to benthic invertebrates. However, bioavailable copper concentrations in the Frieda River at AP7 (reduced through complexing with organic matter and adsorbing to suspended particulate matter) are likely to meet the ANZECC/ARMCANZ (2000) guideline value for dissolved copper. As such, impacts on aquatic biota from labile aluminium and copper concentrations are not anticipated.

The magnitude of impact on aquatic flora, macroinvertebrates, fish communities and other aquatic species (turtles and crocodiles) conservation significant species of the Frieda River is assessed as **medium**. Therefore, the significance of impacts on aquatic flora and macroinvertebrates is assessed as **minor**.

Post Closure: Upstream of the ISF Embankment

Open-pit mining will cease at the end of FRCGP operations, as will deposition of tailings and waste rock into the ISF. The diversions allowing water flows to be directed around the open-pit during operations will be removed and the open-pit will be allowed to flood, which is expected to take approximately three years. During this filling period, treatment of pit water will not be required and there will be no discharge to Ubai Creek. Once the open-pit has filled to RL 440 m, approximately 9 m below the spill point on the eastern side of the open-pit, pit water treatment will resume and the treated open-pit water will be discharged to Ubai Creek which flows into the ISF.

The ISF will remain in place and flows through the ISF may continue to be regulated for power generation. Following an additional approximate 70-year operation of the hydroelectric power facility, the spillway gates will be removed. Surface waters will continue to flow into the ISF reservoir via direct rainfall and inflows from the upstream catchment, and excess water will pass over the ungated spillway while will operate as a flow-through facility.

During the FRCGP operational period, sediment control measures downstream of mine infrastructure will limit coarse-grained fugitive sediments reaching the ISF reservoir and by the commencement of FRCGP post closure, exposed areas and slopes (other than the open-pits which would be internally draining) will have stabilised through natural or assisted revegetation.

Given that tailings and waste rock deposition will no longer be occurring, both TSS concentrations and dissolved and total metals and metalloids concentrations within the ISF reservoir are predicted to reduce considerably. For the modelled FRCGP post closure period (18 years) and assuming pit water is treated prior to discharge, all dissolved metals concentrations, with the exception of aluminium, chromium and copper in the ISF reservoir, will reduce to below ANZECC/ARMCANZ (2000) guidelines during average flows. Predicted concentrations of aluminium were below the US EPA (2017a and b) site-specific acute and chronic calculated criteria for aluminium. Labile (bioavailable) concentrations of chromium and copper are predicted to be reduced by the natural complexing capacity in the ISF reservoir as well as adsorption to suspended particulate matter to meet ANZECC/ARMCANZ (2000) guidelines. Open-pit water will continue to be treated prior to discharge until FRCGP water quality closure criteria are met, estimated to be for a period of approximately 50 years. IFC effluent discharge guidelines for metals will be met at the ISF discharge.

The predicted bioaccumulation impacts in relation to aluminium, cadmium and copper during FRCGP post closure are discussed below.

After the waste rock and tailings have been placed in the ISF, the remaining capacity of the reservoir (to RL 160 m) is approximately 1,173 Mm^3. Based on a predicted sedimentation rate in the ISF of approximately 1.4 million m^3 per year (Mm^3/year), it is estimated that the reservoir will take many hundreds of years before the power intake is affected.

As for the operational period, impacts for the watercourses upstream of the embankment are described below for the post closure period but have not been given a significance rating given that the ISF is considered a part of the FRCGP and FRHEP infrastructure footprint.

Aquatic Habitats

Impacts to aquatic habitats within the ISF and upstream are similar to those predicted for the FRCGP operational period. However, as TSS concentrations and total and dissolved metals concentrations reduce, additional areas of the ISF reservoir, primarily within the bottom and open-water habitats, may become available for colonisation. Natural bed load and suspended sediments from the upstream catchments will continue to enter the ISF reservoir and eventually cover the mine waste rock and tailings deposits. Over time, an approximate 5 to 10 cm layer of natural sediments will cover the mine waste to provide habitat suitable for benthic macroinvertebrate colonisation. Given the limited bioturbation depth of around 5 cm by burrowing macroinvertebrate species (e.g., oligochaete worms and chironomid larvae), exposure to the underlying waste rock and tailings deposit contaminants is not anticipated.

It is difficult to predict the duration for the deposited mine waste to be covered by a 10 cm layer of natural sediments based on sedimentation rates predicted to be variable across the reservoir, although it is likely to take several hundred years. The tailings and waste rock, however, does not cover the entire base of the reservoir and therefore there will be additional areas of habitat in the reservoir available for colonisation by aquatic biota.

Aquatic Biota

During post closure, aquatic species that continue to survive and maintain self-reproducing populations in the ISF reservoir during operations (described in the section above Operations: Upstream of the ISF Embankment) are expected to move into areas of the ISF reservoir that become suitable for recolonisation, including bottom and open-water habitats where respective bed sediment and water quality improve following cessation of waste rock and tailings deposition.

Benthic invertebrates will likely colonise areas of ISF reservoir bottom habitats in areas of waste rock and tailings deposits as natural sediments cover these deposits, as well as other areas of the reservoir unaffected by deposited mine waste.

Bioaccumulation

Bioaccumulation modelling assumptions and methods for the FRCGP post closure phase were largely similar to that completed for the operations phase, with the following exceptions (see Figure 8.9):

- In the littoral zone, it was assumed that there will be greater vegetation and macrophyte density for biota consumption during the post closure scenario than during the operations scenario.
- In the pelagic zone, while the water cover over the waste will be greater than approximately 40 m at the end of operations, it was conservatively assumed that there might still be a complete bioaccumulation pathway between sediment, benthic invertebrates and metal bioaccumulation in fish.

In the littoral zone, fish tissue concentrations of metals are predicted to be nearly the same for the FRCGP operations and the post closure scenarios, which is directly related to the slight difference in predicted metal concentrations based on modelling in the littoral zone between the two phases (Table 8.38).

In the pelagic zone, there is a substantial decrease in predicted fish tissue aluminium concentrations between the operations and the post closure scenarios due to the predicted decrease in metal concentrations in the upper layers of the ISF reservoir post closure once deposition of tailings and waste rock ceases at the end of mining.

The baseline and predicted aluminium, cadmium and copper concentrations in fish tissue for 50 years' FRCGP post closure for the littoral and pelagic zones are shown in Table 8.38, along with concentration increase factors for each scenario under average flows.

Aluminium and copper fish tissue concentrations are predicted to approach calculated baseline tissue concentrations FRCGP post closure. While predicted cadmium concentrations in fish tissue are reduced compared to operations, the concentrations in both the littoral and pelagic zones are approximately 1.5 to 3 times higher than the calculated baseline cadmium tissue concentration.

Table 8.38 Predicted aluminium, cadmium and copper concentrations in fish tissue FRCGP post closure for average flows

Scenario	Metal	Tissue concentration (mg/kg)					Tissue concentration increase factor compared to baseline
		Red bellied Pacu	Rubber mouth	Papillate catfish*	Silver barb	Tilapia	
Baseline†	Al	1.88 (1.60)	2.19 (1.60)	1.75 (1.60)	NA	NA	-
	Cd	0.002 (0.01)	0.001 (0.01)	0.002 (0.01)			-
	Cu	0.16 (0.51)	0.04 (0.51)	0.23 (0.51)			-
Littoral zone	Al	2.4	2.8	2.24	NA	2.24	0.2 to 0.5
	Cd	0.007	0.005	0.008		0.008	1.5 to 3
	Cu	0.25	0.06	0.36		0.36	-0.6 to 1.25
Pelagic zone	Al	1.98	2.47	NA	1.98	1.98	0.05 to 0.3
	Cd	0.008	0.005		0.008	0.008	1.5 to 3

Table 8.38 Predicted aluminium, cadmium and copper concentrations in fish tissue FRCGP post closure for average flows (cont'd)

Scenario	Metal	Red bellied Pacu	Rubber mouth	Papillate catfish*	Silver barb	Tilapia	Tissue concentration increase factor compared to baseline
Pelagic zone (cont'd)	Cu	0.29	0.05	NA	0.29	0.29	-0.7 to 0.8

* NA, not applicable. The catfish is unlikely to be found in the pelagic zone due to its diet and therefore was not assessed for this zone.

† Calculated baseline results. Results in brackets represent 90th percentile measured omnivorous (TL3) measured fish tissue concentrations. For measured baseline data results below the limit of detection, the value of the detection limit has been assumed.

Post Closure: Downstream of the ISF Embankment (Frieda and Sepik Rivers)

As indicated in the sections above, the high sediment trapping efficiency of the ISF results in a decrease of TSS concentrations (approximately 30 mg/L) in the ISF discharge to the upper Frieda River. This essentially changes the upper Frieda River from a moderately turbid river to a low turbidity, clear-water river.

Reductions in bed levels in the Frieda River up to around 3 m in the vicinity of AP6 and AP7 are predicted over 60 years compared to a reduction of less than 1 m under existing conditions. Longer-term (100 years) predictions of bed levels in the Frieda River indicated that bed levels at AP6 stabilise around Year 30 of FRCGP operations with a final minimum channel elevation some 3 m below the existing bed level, and at AP7 the bed levels stabilise around 37 years FRCGP post closure with a final minimum channel elevation of around 1 m below the existing bed level. Long-term bed level changes further downstream (at AP8 and AP9) are predicted to be comparable to the predicted natural reduction of the bed levels in the Frieda River.

During post closure, assuming open-pit water outflows are treated, water quality parameters in the Frieda River at AP7 down to AP13 in the Sepik River are predicted to meet ANZECC/ARMCANZ (2000) guideline values for most total dissolved metals, with the exception of total dissolved copper which marginally exceeds the guideline value for copper of 0.0014 mg/L. In the Frieda River at AP7, approximately 78% of the total dissolved copper concentration (0.0021 mg/L) is anticipated to be complexed with organic matter, reducing bioavailable concentrations to approximately 0.0004 mg/L which is below the ANZECC/ARMCANZ (2000) guideline value. Given that TSS concentrations will be reduced, less particulate surface area will be available for adsorption. However, the complexing capacity alone is expected to reduce labile concentrations to levels commensurate with aquatic ecosystem protection.

Similar to the construction and operations periods, TSS concentrations in the Sepik River reflect the dominance of the natural suspended sediment load coming from the upper Sepik River catchment relative to inputs from the Frieda River. During post closure, Project influences on TSS concentrations in the Sepik River are predicted to be well within the natural TSS concentration variability for existing conditions. Bed level changes are also predicted to be negligible in the Sepik River. During FRCGP post closure, labile concentrations of aluminium and copper (based on attenuation of copper concentrations as a result of copper complexing capacity and adsorption to suspended particulate matter) in the Sepik River (AP13) during average flows are predicted to be below their respective ANZECC/ARMCANZ (2000) guideline values and background concentrations at AP13.

Given that previous predictions indicate that impacts in the Sepik River as a result of FRCGP operations are negligible, no further impact assessment for the Sepik River during post closure is undertaken below.

Once FRCGP closure criteria related to downstream water quality have been met and treatment of pit water prior to discharge to Ubai Creek ceases (estimated to be around 50 years FRCGP post closure), water quality impacts within the Frieda and Sepik rivers are not anticipated.

Aquatic Habitats

During post closure, as the upper Frieda River transforms from a moderately turbid river to a low turbidity and clear-water river, there are predicted to be consequential benefits to the prevailing composition of existing or slightly modified (due to residual construction impacts) aquatic biological communities in this river reach. The reduction in TSS concentrations and water turbidity is predicted to result in improved water quality and a concomitant increase in water clarity which is conducive to colonisation of the river substratum by diatoms, periphyton and benthic algae.

The bed material (gravels and sands) in the upper Frieda River will gradually be washed away (commencing in early operations, representing a highly transformational period for aquatic habitats) and will not be replenished by coarse-grained sediments coming from upstream, owing to entrapment and retention upstream of the ISF embankment. As a result, once the aquatic habitats have stabilised following the transformational period during operations, there is expected to be an increase in the interstitial spaces and surface areas as river flows and high velocities winnow out the finer settled sediments which will be transported downstream without being replenished. Eventually the river bed below the embankment will be reduced to bedrock and large bounders and rocks. This process will result in additional river bed structural diversity and new habitats available for colonisation by aquatic biota.

The post closure residual impact significance rating for aquatic habitats of the Frieda River has been assessed as **negligible**. However, improved water quality and river bed structural diversity represent beneficial changes to the upper reaches of the Frieda River which may give rise to a more diverse aquatic biological community than under pre-Project natural conditions (see below).

Aquatic Biota

Based on reductions in TSS concentration and turbidity, as well as the increased structural diversity of the river bed, the additional aquatic habitats are expected to be colonised by aquatic microphytes such as diatoms, benthic algae and periphyton. This provides a new food resource that can be exploited by herbivorous and omnivorous macroinvertebrates and fish.

In the medium to long term, fish species diversity and richness may be expected to increase as sediment-intolerant fish move into the clear waters of the Frieda River. Fish assemblages are expected to change towards a new equilibrium condition. The likely nature of the fish assemblages that will develop, or their relative biomass compared to pre-Project natural conditions, is difficult to predict but environmental monitoring will allow a record of changes that take place.

Overall, post closure impacts in the Frieda River on aquatic biota, including native fish, turtles and crocodiles and species of conservation significance, are assessed as having a **negligible** significance of impact. This assessment is due to the changes being beneficial to the upper reaches of the river as both sediment-tolerant and sediment-intolerant fish assemblages may colonise the river main channel and not just the former.

Summary of Residual Impacts on Freshwater Ecology Values

Combined impacts as a result of construction and operation of the Project on freshwater ecology values are presented in figures 8.10 and 8.11. An analogous figure for post closure is not presented given that impacts on freshwater ecology values downstream of the ISF reservoir are predicted to be **negligible**.

During construction, the residual impacts on aquatic ecology will primarily arise from mobilisation of fugitive coarse and fine sediments to watercourses upstream and downstream of the ISF embankment, mainly as a consequence of rainfall-based erosion and scour of construction-disturbed or displaced soils. From the late construction period (Year -2), the ISF will act as a sediment trap to reduce sedimentation and TSS concentrations downstream of the ISF embankment.

Residual impacts on freshwater ecology in the Frieda River as a result of construction-related stressors are assessed as having a **high** magnitude of impact, resulting in a **moderate** impact significance.

Construction-related impacts on aquatic ecology of the Sepik River are assessed as having a **negligible** impact significance rating due to the significant separation distance from construction activities, as well as the Sepik River being a turbid river with naturally high TSS concentrations.

Once FRCGP operations commence, the main impacts on aquatic ecology will result from the discharge of treated open-pit water to Ubai Creek, as well as the deposition of tailings and waste rock into the ISF reservoir, which are expected to result in increased dissolved metals and metalloid concentrations within the ISF reservoir and downstream of the ISF embankment. Concentrations of metals and metalloids within the ISF reservoir are elevated, as expected, given that it is an engineered structure designed for storage of waste rock and tailings.

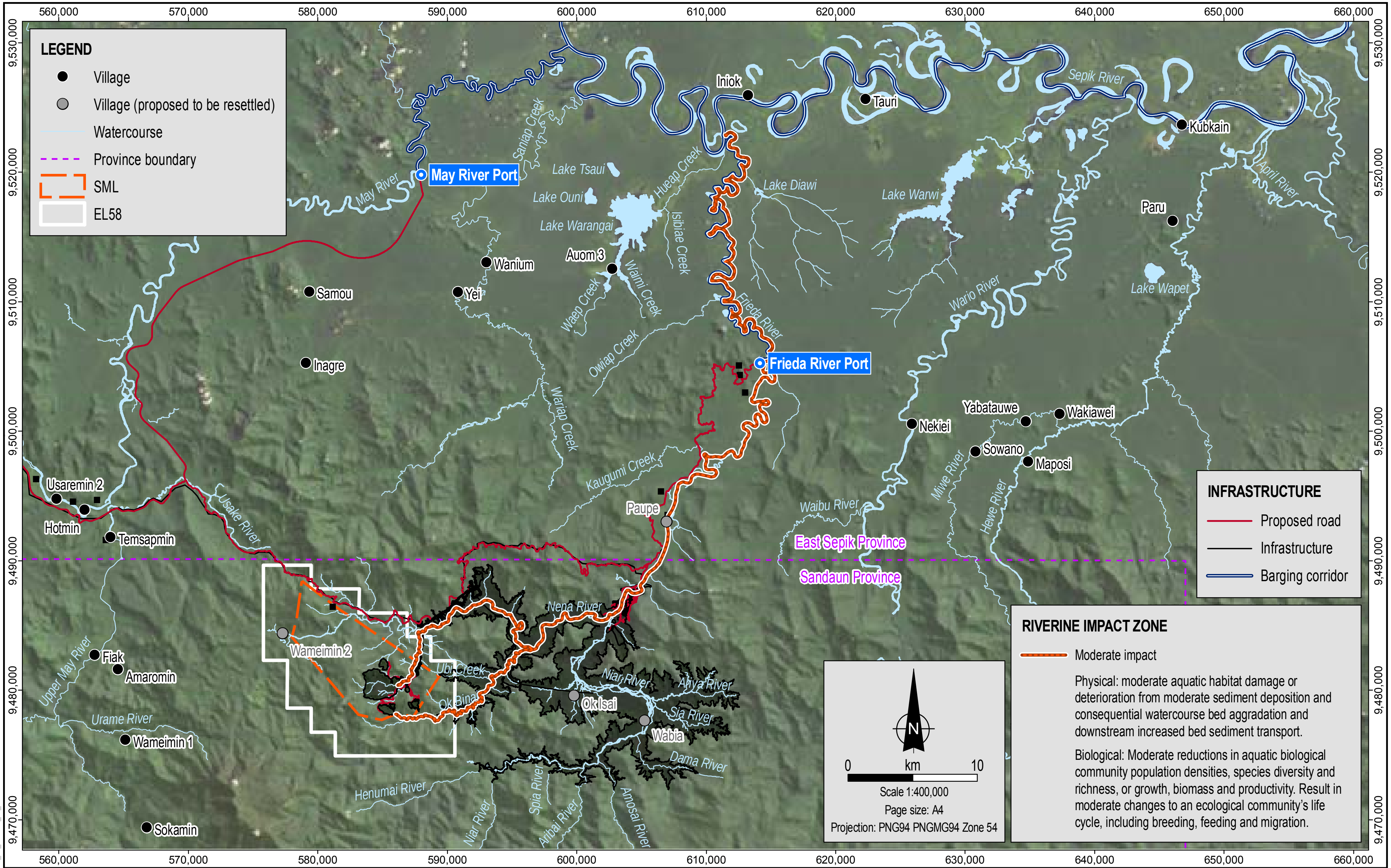
Concentrations of labile copper predicted to occur in the Frieda River (sites AP7 through AP11) during low and average flow conditions may result in some impacts to copper-sensitive species of microalgae and to benthic invertebrates. However, bioavailable copper concentrations in the Frieda River at AP7 (reduced through complexing with organic matter and adsorbing to suspended particulate matter) are likely to meet the ANZECC/ARMCANZ (2000) guideline value for dissolved copper. As such, impacts on aquatic biota from labile aluminium and copper concentrations are not anticipated in the upper and mid to lower Frieda River.

Impacts on aquatic habitats in the upper Frieda River during FRCGP operations are assessed as having a medium magnitude of impact due to the transformation of the habitats (from a reduced sediment load) below the ISF embankment, resulting in a **minor** impact significance. Operational impacts on aquatic habitats in the mid to lower Frieda River are anticipated to be **negligible**.

No operational impacts on the aquatic ecology of the Sepik River are expected based on the predictions that hydrological, sediment transport and water quality impacts in the Sepik River are **negligible**.

During the post closure period, Project-related impacts on aquatic habitats and biota within and downstream of the ISF in the Frieda and Sepik Rivers are not expected.

The assessment of these impacts assumes the implementation of the management measures as described in Section 8.5.2 and in the FRCGP, FRHEP and the SIP (Road) EMMPs.



MXD Reference: 11575B_11_GIS036_v0_6

Source:
Impact zones from Coffey.
Infrastructure, roads and tenements from FRL.
Villages, topographic features, watercourses and water bodies from FRL and Coffey.
Provinces from NMB.
Landsat satellite imagery from FRL (capture date unknown). Hillshade DEM from SRTM.

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Date: 24.10.2018
Project: 754-ENAUABTF11575B
File Name: 11575_11_F08.10_GIS

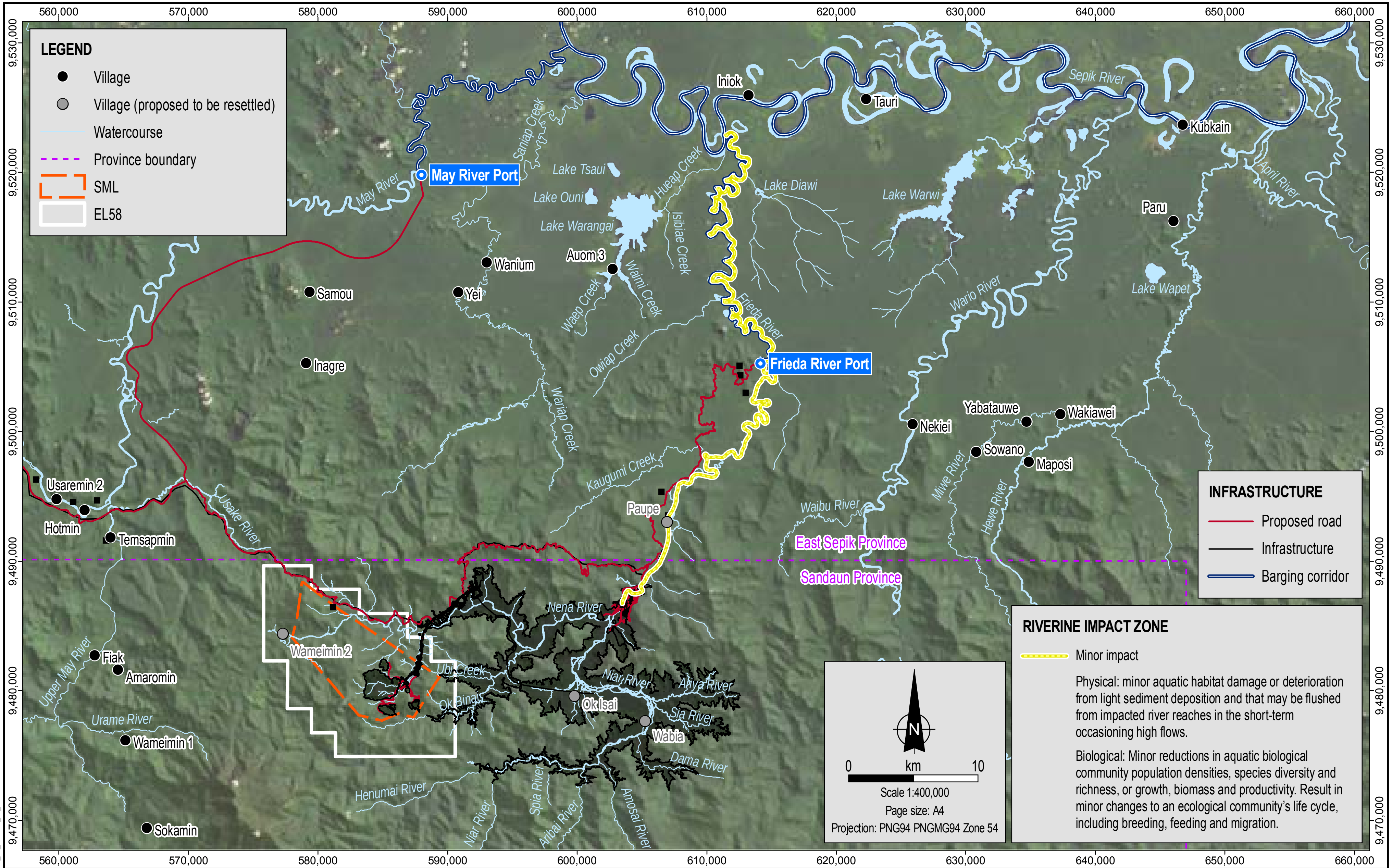
Frieda River Limited

Sepik Development Project

FRIEDA RIVER

Riverine impact zones during construction

Figure No: 8.10



MXD Reference: 11575B_11_GIS038_v0_4

Source:
Impact zones from Coffey.
Infrastructure, roads and tenements from FRL.
Villages, topographic features, watercourses and water bodies from FRL and Coffey.
Provinces from NMB.
Landsat satellite imagery from FRL (capture date unknown). Hillshade DEM from SRTM.

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Date: 14.09.2018
Project: 754-ENAUABTF11575B
File Name: 11575_11_F08.11_GIS

Frieda River Limited

Sepik Development Project

FRIEDA RIVER

Riverine impact zones during operations

Figure No: 8.11

8.6 Terrestrial Biodiversity

This section summarises the values with regards to terrestrial biodiversity, as characterised in Sections 7.1.5 to 7.1.7, and presents the assessment of the predicted Project-related impacts to these values. The discussion is based on the findings from the terrestrial biodiversity assessment for the Project presented in Appendix 8c. Material is sourced from this assessment unless otherwise referenced.

8.6.1 Approach to Impact Assessment

The impact assessment method and criteria described in Section 8.1 have been further defined for the assessment of impacts on terrestrial biodiversity, considering:

- Potential scales of impact are required that apply specifically to the terrestrial biological environment.
- Assigning sensitivity to environmental values requires the assessment of value (or importance), formal status, vulnerability and resilience. This assessment draws primarily on information provided in Appendix 8c and on other sources of literature that describe the existing terrestrial biodiversity in the region.

Where feasible, engineering design measures have been included to avoid impacts. However, where impacts are unavoidable, management measures are proposed to limit each impact as far as is practicable. The residual impact is then assessed assuming that avoidance and management measures are successful.

Identifying Impacts

A range of potential direct and indirect sources of impact may affect terrestrial biodiversity values. These typically act in an interactive manner on flora and fauna populations and their habitats and may have multiple interrelating sources. Therefore, the approach for the terrestrial biodiversity impact assessment was to consider these holistically to determine the overall magnitude of impacts on each value. The rationale for adopting this approach, based on over 30 years' experience assessing impacts of resource development projects in PNG, recognises that the causes of impacts on biological values are often:

- Complex and generally occur concurrently, and as a consequence it is difficult to determine specific contributions for each activity or source of impact.
- Interrelated, and in many cases cumulative, such that examining each contributing source of impact in isolation may lead to a misleading assessment.

Sources of impact to terrestrial biodiversity values can either be directly or indirectly related to the Project. More specifically:

- **Direct sources of impact** – arise from physical loss or removal of habitat from Project activities and subsequent changes to resources as a result of the location of the Project's facilities (e.g., barriers to fauna).
- **Indirect sources of impact** – arise from Project activities but with a degree of separation in time or space, i.e., they are at least one step removed from Project activities in terms of cause-and-effect links. For example, an indirect impact could occur from increased hunting pressure if the Project leads to an increase in population density through in-migration.

As a nation building project, the intent of the Project is to facilitate future development across northern and western PNG. As such, any facilitated development would also have impacts upon terrestrial biodiversity; however, it is difficult to predict the spatial, temporal or physical nature of such undetermined development at this time. Consideration of cumulative impacts as a result of credible currently proposed or existing developments is presented in Chapter 10.

Terrestrial biodiversity values were recognised and impacts assessed at four scales for the purposes of the impact assessment: landscape, ecosystem, habitat and population.

At the broadest scale, impacts were assessed at the landscape level. The landscape value of the terrestrial biodiversity study area (described in Section 7.1.6) incorporated multiple aspects including:

- Extensive intact habitats.
- High biodiversity.
- Species new to science.
- Endemic species.
- Concentrations of migratory and/or congregatory species.
- Habitat and biodiversity of cultural significance.

Impacts on these values are those that would operate at a systemic, landscape level (e.g., large-scale clearing, major changes to hydrology or other ecological processes or extensive habitat modification as a result of invasions by exotic species). The bulk of the proposed management measures are focused at this scale with the aim of simultaneously reducing systemic and widespread impacts to ecosystems, habitats and species.

Ecologically significant ecosystems values (intermediate scale) were identified as discrete functional systems of particular ecological sensitivity, rarity and/or unusual flora and fauna requiring specific management controls. These consisted of:

- Peat forest.
- Nena karst.
- Off-river waterbodies.
- Montane forest above 1,000 m.
- North coastal ranges.

Habitat and populations of significant species value were identified as those having particular sensitivity or importance. Focal habitat values were identified as those disproportionately important to local and/or regional biodiversity and requiring special management. Identified focal habitats were:

- Riparian and gallery forests.
- Hilltops.
- Upland streams.
- Caves.

Populations of species of conservation significance, or with elevated sensitivity or importance, were also assessed individually in the context of the terrestrial biodiversity study area.

An assessment of the likely timing of each source of potential impact was also completed. This process assessed the likely emergence or presentation of the impact with regards to Project phases. This allows for targeted management measures to be developed effectively. For example, impacts associated with weeds and pests could occur during construction, operation or during closure of the Project, while vegetation clearing would be largely restricted to construction. The period during which the impact is likely to persist is considered as part of the residual impact assessment and summarised in Section 8.6.2.

Significance

The concept of significance is an assessment of the sensitivity of the environmental value and the magnitude of change to the environmental value arising from the Project. Predicting impact significance is partly objective and partly subjective.

Sensitivity of Environmental Values

For terrestrial biodiversity, the value or sensitivity of a receptor can be determined by considering factors such as:

- Conservation status under the IUCN or national legislation.
- Contribution to the integrity of local ecosystems (e.g., caves, vegetation communities).
- Importance as a component in local subsistence or commercial economy (e.g., essential, frequent or minor).

Sensitivity combines the inherent susceptibility of the receptor to change including its capacity to adapt to, or accommodate, the kinds of changes that the Project may bring about, the societal or ecological value of the receptor such as its conservation status, or its iconic or symbolic importance to culture, society or the community. These sensitivities are captured in Table 8.39 where an environmental value's sensitivity is classified if it meets one or more of the definitions in each row.

Table 8.39 Criteria for sensitivity of the terrestrial biodiversity value

Sensitivity	Definition		
	Status, Value or Importance	Vulnerability	Resilience
High	A critical national or international recognised site or value. An IUCN Critically Endangered or Endangered species. Iconic or symbolic importance to cultural value systems.	Restricted distribution.	Limited or no capacity to adapt to change.
Medium	A regional or provincial recognised site or value. An IUCN Vulnerable species and/or classified as Protected under the PNG *Fauna (Protection and Control) Act 1996.*	Abundance and distribution are limited.	Some resilience to change.
Low	Low or only local value or recognition.	Abundant, widespread, numerous representative examples occur.	Easily adaptable to change or no change required.

Magnitude of Impact

The magnitude of an impact considers the severity (or intensity), geographical extent and duration of an impact that could potentially occur. Magnitude ratings were developed using a matrix of geographical extent of the impact combined with the severity of the impact expressed as deviation from natural variability as shown in Table 8.40.

Table 8.40 Criteria for magnitude of the impact

Detectability with respect to natural variability	Extent of effect		
	Confined in the Project disturbance area or a small, isolated locale outside	**Extend beyond the disturbance area to the surrounding area but contained within the general area**	**Widespread and long-term (i.e., greater than ten years); changes unable to be practically or significantly rehabilitated or alleviated**
Effect likely to be very large.	Medium	High	High
Effect will be readily detectable but not severe.	Low	Low	Medium
Effect barely detectable.	Negligible	Negligible	Negligible

Assessment of Significance

The significance of an impact to an environmental value is determined by the sensitivity of the value itself and the magnitude of the expected change (Table 8.41). Where the magnitude of impact is negligible, the overall significance of impact is also negligible regardless of sensitivity.

Table 8.41 Matrix of significance

Magnitude of Impact	Sensitivity of Receptor		
	High	**Medium**	**Low**
High	Extreme	Major	Moderate
Medium	Major	Moderate	Minor
Low	Moderate	Minor	Negligible
Negligible	Negligible	Negligible	Negligible

The detailed terrestrial biodiversity impact assessment separates direct and indirect impacts on the basis that management of the latter is not entirely within the Project's control. Indirect impacts to values are assessed as being additive to direct impacts in recognition that direct and indirect impacts will not be discrete. As discussed in Section 8.6.2, the Project will impact four local villages that will require resettlement elsewhere. This has the potential to increase the magnitude of indirect impacts on terrestrial biodiversity values.

The assessment of impact significance in regards to terrestrial biodiversity values summarises all impacts (both direct and indirect) but presents a summary of sensitivity and magnitude ratings for those impacts for which the significance is predicted to be moderate or greater. Appendix 8c provides a comprehensive assessment for all terrestrial biodiversity values that are defined.

8.6.2 Potential Impacts

Potential impacts on terrestrial biodiversity values may be caused by a variety of direct or indirect processes. Impacts can be grouped into three broad types, which may occur at each scale, including:

- Habitat loss from vegetation clearance and earthworks, ISF inundation, altered hydrology and forest fire. These impacts can be exacerbated indirectly by increased human populations (through in-migration and improved accessibility to Project areas).

- Habitat degradation resulting from colonisation by invasive species or the introduction of exotic pathogens, edge effects, barrier effects, deposition of eroded sediments or from contamination caused by accidental spills of hazardous materials. Degradation may also occur indirectly as a result of increased use of natural resources as a result of increased populations (through in-migration and improved accessibility to Project areas).
- Reduced abundance and/or diversity of flora and fauna populations as a consequence of:
  - Changes to available habitat (including food sources, shelter and nesting or roosting sites) due to habitat loss and degradation (described above).
  - Injury, death or displacement of flora and fauna from vegetation clearing and earthworks, collision with vehicles, predation by exotic species, infection by introduced diseases or increased hunting in previously inaccessible areas or increased hunting pressure from increased human populations (through in-migration and improved accessibility to Project areas).
  - Increased disturbance (through Project-related activity such as noise and lighting) disrupting the behaviour of fauna and potentially reducing reproductive success.

The following section summarises sources of impact that may occur as either a direct or indirect result of the Project. It then describes the potential impacts on landscape, ecologically significant ecosystems[14], focal habitats and species terrestrial biodiversity values in the terrestrial biodiversity study area. Further detail is provided in Appendix 8c.

Direct Sources of Impact

Physical Disturbance

Habitat loss from vegetation clearance and earthworks will result in:

- Decreased area of intact vegetation and communities within the region.
- Loss of rare or unique habitat features such as large trees (particularly figs), bird-of-paradise display trees and megapode mounds.

Fauna that occur outside the direct area of disturbance may also be impacted by the clearing of areas previously used for foraging or breeding. The impact of linear clearings for roads, tracks, pipelines, conveyors and powerlines on terrestrial biodiversity is likely to be lower than the clearing of similar areas for non-linear infrastructure. In areas allowed to regenerate, biodiversity will recolonise as succession progresses but it will take some time for forest specialists to colonise cleared areas.

The Project will create new forest edges with consequent ‘edge effects’ by clearing intact habitats. These occur where two dissimilar habitats, in this case forest and cleared area, abut each other; each influences the other along the boundary and physiological and ecological effects can propagate from the edge to several hundred metres into the forest. This can produce continued degradation of forest adjacent to the edge and possible retreat of the forest edge.

Edge effects are most pronounced for the following situations:

- Wide cleared areas that allow the full wind exposure to the forest face.

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[14] Described as priority ecosystems in Appendix 8c.

- Large clearings maintained for long periods.
- Higher altitudes, where edge effects last longer.
- High-altitude steep slopes exposed to the wind above cuttings.
- Formation of small forest blocks surrounded by multiple roads and other linear clearings, which allow edge effects to penetrate from more than one side.
- Hairpin road sections of bends.

Edge effects in primary tropical forest are influenced by a number of factors. These include direct sunlight and wind, which combine to dry the forest edge, increase wind throw of trees close to the edge and cause changes to the forest microclimate away from the edge. The ground layer is known to desiccate making the forest edge more susceptible to fire under these conditions.

Exotic flora and fauna adapted to drier habitats and secondary forest can penetrate the forest along these edges and primary forest specialist fauna generally retreat from the forest edge as it dries and light levels increase.

The Project will create gaps within the terrestrial biodiversity study area by clearing intact habitats and constructing infrastructure, which will result in ‘barrier effects’. Barrier effects are related to edge effects and occur where a strip of non-forest habitat acts as a barrier to movement of forest pollen, seeds and fauna. Natural features, like rivers and large forest gaps (e.g., landslides), can create similar barriers to many forest animals, particularly specialist primary forest species. The important issue is whether the barrier effect splits the population into subpopulations, each with a reduced chance of survival.

Barrier effects have been demonstrated for a wide range of animals. Animals with a particular aversion to crossing linear gaps, such as roads, include specialist terrestrial and arboreal marsupials and primary forest birds as well as several reptiles and amphibians. The barrier effect reduces the number of fauna movements across the barrier from a combination of disturbance and avoidance effects, creation of physical obstacles and, potentially, traffic mortality. For most non-flying terrestrial animals, infrastructure imposes movement barriers that restrict the animals’ range, make habitats inaccessible and potentially lead to an isolation of populations.

The Project has the potential to act as a significant and continuous barrier for some species across the terrestrial biodiversity study area from the upper limits of the hill zone to the Sepik River; only the montane zone would be unaffected. In the hill zone, the major barriers created by the Project will be the large open spaces produced by the open-pit, mine infrastructure area, process plant, ISF and accommodation area. The narrower roads and linear infrastructure such as the access roads will be a lesser barrier; however, these may still act as a barrier for some specialist species. In the lowland zone, the public road, transmission line and concentrate pipeline will be up to 70 m in width. This will present a barrier that will affect many species.

Disturbance and Mortality of Fauna

Disturbance and mortality of fauna may be caused by a variety of Project activities and sources. These include:

- Mortality of fauna (e.g., mostly reptiles, frogs, small mammals and flightless birds) by falling into trenches during construction.
- Increased noise, a particular issue for birds and bats which communicate acoustically. This is likely to be most acute during construction, causing fauna to retreat from construction sites, but fauna is likely to return if not hunted or harassed.
- Traffic collisions and fauna deaths from traffic movements along access roads.

- Collisions with transmission lines leading to deaths of birds and bats, particularly waterbirds, flying foxes and fruit pigeons.
- Dust generation, particularly along access roads. The most sensitive group is butterflies where the physical effects of dust are manifested through the leaf-eating larvae which are highly sensitive to dust accumulation on leaves.
- Increased lighting around facilities can affect the behaviour of fauna, particularly nocturnal birds and bats, which may forage on the increased abundance of insects attracted to the lights.

Further discussion on each of these impacts is provided in Appendix 8c.

Inundation and Altered Hydrology

The ISF is the largest areal component of the Project and the biggest contributor to terrestrial habitat loss. Construction of this reservoir may also impact terrestrial biodiversity by altering downstream hydrology and therefore floodplain vegetation dynamics. The ISF has been designed as a 'flow-through' system with inflow water discharged to the Frieda River downstream of the ISF embankment. The modelled effects of the ISF on flows in the Nena and Frieda rivers are that:

- Construction of the embankment will modify downstream flows in the Frieda River; however, an environmental flow of 50 m^3/s will be maintained during the initial 10-month impoundment filling period.
- The variability in flows in the Frieda River during operation of the FRHEP is reduced relative to existing conditions. While average flows downstream of the ISF embankment are similar to those under existing conditions, it was predicted that low flows will be substantially increased and high flows will be substantially decreased. The ISF will maintain a minimum 50 m^3/s environmental flow discharge during the operating life of the facility.
- Operation of the hydroelectric power facility will result in the regulation of maximum flows immediately downstream of the ISF embankment and this is expected to result in a reduction of overbank flows along the upper reaches of the Frieda River, but current flooding regimes in the Sepik River are not expected to change. The Project is likely to have minimal impact on the current sediment deposition regime during overbank flooding along the lower Frieda River and Sepik Rivers.
- Post closure, the ISF will remain as a flow-through system.

Other highly localised hydrological changes will occur in the mine area. For example, flows in Uba Creek will increase during operations due to the introduction of clean water diverted around the Koki open-pit. Flows in the Ubai Creek and Nena River will increase to a lesser extent.

Suspended sediment will increase significantly during construction and operations in a number of watercourses, particularly Uba and Ubai creeks. This will result in bed aggradation in these areas, but there will be no bank overtopping due to the steeply incised nature of the watercourses. Flows from all watercourses containing key mine infrastructure (Ubai Creek, Uba Creek, Ok Binai, Niar River and Nena River) will report to the ISF reservoir.

The ISF will reduce allochthonous input (i.e., material that originated elsewhere before being transported and deposited) into the Frieda River as silt and larger organic fragments and debris will be sequestered in the reservoir sediments.

Erosion and Sedimentation

The effects of habitat loss, edge and barrier effects can be exacerbated by erosion, sidecasting and dumping of spoil. Cuts for roads, particularly in steep areas, will result in sidecast material impacting more forest. Erosion can transport sediment some distance from the area of disturbance potentially affecting vegetation and habitat beyond the extent of vegetation clearance. Erosion of soils is likely to be highest on sedimentary and volcanic soils on steeper slopes. Smothering understory vegetation and lower parts of tree stems has the potential to reduce tree root aeration leading to tree death and causing habitat loss.

Hydrological changes, brought about by excavated sidecast or cuttings, causeways or roads damming areas or promoting poor drainage of others, may impact some terrestrial habitats. For example, dryland forests can become stressed if flooded more frequently, and swamp forest complexes and swamp woodland complexes may become stressed if the dynamics of flooding and drying are altered.

Further discussion regarding the impacts of erosion and sedimentation is provided in Section 8.5.4.

Contamination and Pollution

The Project will use and generate a wide range of gaseous, liquid and solid contaminants. These include industrial and domestic wastes, domestic, process and agricultural chemicals, fuels and hydrocarbons, AMD, mine waste rock, fine sediments from erosion and spoil, tailings, industrial chemicals, sewage and biocides. If not appropriately managed, these may impact biodiversity through direct mortality, reductions in reproductive output and reduced survival.

Contaminants can impact at different points in a food web depending upon the contaminant and species involved and may impact via several processes. For example, bioavailable copper can impact the physiology of flora and fauna at relatively low concentrations. Fauna are at risk from directly consuming contaminants if they have prolonged exposure to wastes, chemicals and hydrocarbons.

Contamination of waterways is a potential path whereby contaminants can impact biodiversity in the terrestrial biodiversity study area. The fauna most directly threatened are frogs, odonates, waterbirds, kingfishers and a small number of species of forest birds and mammals that depend on the consumption of aquatic fauna. Silt and suspended solids in streams, caused by runoff and erosion, may also impact biodiversity by directly causing mortality of sensitive semiaquatic species or by smothering stream microhabitats. This may also manifest as impacts on other species, dependent upon aquatic food webs, and could alter streamside vegetation by silt deposition. For example, the generation of fine sediments has been linked to declines in amphibian communities.

A key design feature of the Project was to limit fugitive sediment emissions from the mine site and the potential for AMD by storing mine waste rock and process tailings subaqueously in the ISF.

Emissions including those from rock crushers and diesel powered plant and dust from vehicle movements could adversely affect the health of surrounding vegetation and fauna. For example, dust deposition from the Project may impact roadside vegetation (as mentioned above) while gaseous emissions such as SO_2 can be detrimental to plant growth. However, these are predicted to be localised around emission sources (see Section 8.8) at concentrations below those likely to cause impacts to plants and therefore are not considered further here.

Pests, Weeds and Diseases

The Project traverses a large area of north-western PNG and accesses previously undeveloped areas. This introduces the potential for the spread of pests, weeds and diseases than can cause landscape-wide effects, unlike direct habitat loss which generally acts at a local level.

The terrestrial habitats of the terrestrial biodiversity study area are largely free of invasive species, weeds and pests, with the exception of small areas of human influence such as around villages or areas of mineral exploration. The introduced species documented during the biodiversity surveys were benign weeds of low invasive capacities that are not regarded as conservation threats. Similarly, no invasive or pest vertebrate or invertebrate species were documented apart from the house sparrow, feral pigs and black rats.

Given the large volumes of traffic and long supply lines to other parts of PNG and international destinations that will be associated with the Project, the introduction of noxious plants, animals and diseases is a potential impact to biodiversity in the terrestrial biodiversity study area.

Accidentally or deliberately introduced invasive animals can be serious environmental and agricultural pests and can have far reaching landscape impacts. Species such as small Indian mongoose (*Herpestes javanicus),* rosy wolfsnail (*Euglandina rosea*), slider turtle (*Trachemys scripta elegans*), crazy ant (*Anoplolepis gracilipes*) and cane toad (*Bufo marinus*) have caused major impact in other tropical areas.

Exotic weeds present serious environmental problems worldwide, with some weeds capable of altering entire forest habitats. Such species are not yet present in the terrestrial biodiversity study area. Intact tropical forests tend to be resistant to invasion; weeds as a problem are usually associated with the opening of forests by roads and clearing, thereby allowing weeds and other exotics to enter and establish.

Introduction (and spread) of pathogen-caused dieback poses a serious risk to vegetation, particularly along the roadways. Dieback is a disease caused by a range of root-rotting pathogens that can kill a variety of plants and manifests under a range of environmental conditions.

A range of other exotic diseases can be found within PNG; these have not yet been recorded in the terrestrial biodiversity study area.

Indirect Sources of Impact

Fire

Uncontrolled fires could result from the Project during construction and operation, primarily as a result of accidental industrial fires but also indirectly through the expansion of local populations. While fire in wet tropical areas is uncommon based on historical patterns, it has had marked impacts on environments, particularly habitat integrity, throughout New Guinea. Repeated burning practices have converted much forested land to ‘permanent’ grasslands and this is particularly evident in the Lae–Wau–Bulolo Valley and the Markham Valley, and is widespread in Western Highlands Province.

The most sensitive forests to fire are montane forest on high ridges, heath and swampy forest in the lowland zone developed on peat substrates, and those forests affected negatively by edge effects. Peat forests are particularly sensitive as they cannot regenerate on the mineral substrate.

In-migration, Resettlement and Changes to Existing Land Uses

The history of development projects in PNG has shown that the migration of people who are seeking work or economic opportunities into more prospective areas is almost inevitable. Increased population density in the terrestrial biodiversity study area, indirectly caused by the Project, could create issues such as overhunting, forest clearing and degradation, which may extend beyond the Project disturbance area itself, thereby reducing habitat integrity.

Increased human movements could also exacerbate issues of quarantine and spread of invasive species, greatly increase the potential for impacts from fire, and overwhelm the Project’s environmental management of these issues.

As discussed in Chapter 9, most in-migrants are expected to come from the Telefomin district. The Sepik River area (particularly the Middle Sepik/Wosera-Gawi) will also be a significant source of in-migrants along with Min people who have moved to Tabubil due to the Ok Tedi mine operation. Habitats most vulnerable to effects from in-migration are hill and montane forests with swamp forest and temporarily flooded lowland forest less likely to be affected. In-migration also has the potential to severely reduce populations of the montane mammals as a result of increased hunting pressure (see Section 8.6.4).

Four villages (Ok Isai, Wabia, Paupe and Wameimin 2) will require resettlement as a result of the Project as described in Section 5.3. Resettlement will entail further clearing for villages and the construction of roads to those sites. Further clearance for subsistence gardening purposes and hunting is expected once new villages are established. This could make areas of intact forest previously distant from the present villages more accessible. The resettled villages are also likely to become focal points for migrants and thus forest degradation around these areas is likely to occur. Other issues relating to in-migration are discussed at length in Chapter 9.

Indirectly, intact habitats may be impacted by changes to the existing land use by the local population. These impacts are more difficult to quantify and depend on a number of interrelated factors that may include:

- Increased forest clearing for building and gardening if the local population density were to increase as a result of the Project.
- Shifts to cash cropping and small-scale agriculture as a result of increased access to markets including establishing businesses to sell fresh produce to the Project.
- Increased land clearing and small-scale logging as a result of increased access and markets.
- Indirect impacts to water and food resources as a result of construction activities.

These changes could result in additional clearing of existing vegetation and are further discussed in Chapter 9.

The Project is designed to stimulate development expansion and may therefore facilitate or incentivise more intense development along the infrastructure corridor including commercial forestry and agroforestry with a consequent large area of disturbance. The provision of power through the SPGP may also stimulate industrial growth in the Vanimo-Jayapura border corridor. Such development and expansion of population would be expected to have impacts on terrestrial biodiversity. The cumulative impacts of the Project and other credible currently-proposed projects in the Sandaun and East Sepik provinces are considered in Chapter 10.

Hunting

Hunting is a major contributor to rarity and decline of larger mammals and birds in New Guinea. The Project may indirectly influence the level of hunting in the terrestrial biodiversity study area by improving access (e.g., creation of roads), introducing hunting by the workforce and increasing the use of firearms as a hunting method, indirectly caused by greater wealth.

Hunting is a traditional local activity and interviews conducted in villages within and around the terrestrial biodiversity study area revealed that all households consume bush-meat at least occasionally, with some eating bush-meat once or twice a week. As such, virtually all fauna in the terrestrial biodiversity study area are potential prey, with the larger or more spectacular species particularly vulnerable. However, in general, the hill zone experiences very low levels of hunting except within a few kilometers of villages and along walking tracks that link villages and existing Project infrastructure. The level of hunting in the montane zone is unknown.

Increased hunting activity will impact larger fauna, particularly echidnas, tree kangaroos, wallabies and cuscus, contributing to potential local extinction and the wider regional and national decline of these species.

Summary of Direct and Indirect Sources of Impact

Table 8.42 presents a summary of processes that may affect terrestrial biodiversity values during construction, operation and closure of the Project.

Table 8.42 Summary of the sources of impact and their timing

Threatening Processes	Phase			Comment
	Construction	Operation	Closure	
Vegetation clearing.	✓			Primarily limited to Project construction.
Inundation of the ISF.	✓			Primarily limited to Project construction.
Creation of barriers within habitats.	✓	✓	✓	Barriers created during construction (e.g., open-pit, ISF).
Creation of new edges of habitats.	✓	✓	✓	Forest edges created during construction (e.g., open-pit, ISF).
Erosion and changes to hydrology.	✓	✓		Primarily limited to Project construction with impacts extending into operation.
Contamination and pollution of terrestrial ecosystems.	✓	✓	✓	Most likely to occur during construction and operation (e.g., in the form of spills or erosion of disturbed areas).
Disturbance and mortality of fauna.	✓	✓	✓	Initially this impact would occur during construction through disturbance (e.g., increased noise) but would continue through to closure with the risk of mortality from traffic interaction and permanent infrastructure features.
Introduced pests, weeds and diseases.	✓	✓		Most likely to occur during construction but could also be occur at any time during operation.
Fire.	✓	✓	✓	Could occur throughout construction and operation particularly during dry periods (i.e., El Niño events). Greatest likelihood would be during construction due to the number of ignition sources, but this would need to coincide with dry weather conditions.
Influencing changes to the existing land uses of the local population.	✓	✓		During construction the development of small-scale forestry is likely to increase. More permanent changes may eventuate with increased access facilitated by the Project.
Attracting migrants to the area i.e., in-migration.	✓	✓		Would likely commence prior to and during construction but would mainly be an impact during the operational phase of the Project.
Increased levels of hunting.	✓	✓		Will depend largely upon management of Project staff and accessibility to the terrestrial biodiversity study area.

Potential Impacts on Large Scale Terrestrial Biodiversity Values

Terrestrial biodiversity values on the large, landscape scale were identified based on importance in a regional context and include:

- Extensive intact habitats.
- High biodiversity.
- Species new to science.
- Endemic species.
- Migratory and congregatory species.
- Habitats and biodiversity of cultural significance.

Potential impacts on these values at the landscape scale are discussed in the following section.

Extensive Intact Habitats

The terrestrial biodiversity study area south of the Sepik River is characterised by extensive intact habitats that show little anthropogenic disturbance or modification. In the northern portion of the terrestrial biodiversity study area, the area has been extensively cleared by logging and creation of palm oil plantations. In total, it is estimated that 16,257 ha will be cleared, inundated or degraded for the Project. Of this area, 41% is undisturbed mature forest and 36% is lightly disturbed forest.

The terrestrial biodiversity study area comprises a mosaic of primarily intact vegetated areas. Hill forest occurs across an elevation range between 30 and 1,000 m ASL and forms a continuous area of habitat. Small areas of lower montane forests occur at higher elevations (i.e., greater than 1,000 m). At low elevations (i.e., below 100 m), lowland open forest, swamp woodland and mixed swamp forest, herbaceous swamps and peat forest also occur with riverine mixed successions flanking braided river channels.

These extensive intact habitats are of high sensitivity because of their role in maintaining the biodiversity and ecological integrity of the terrestrial biodiversity study area, as well as housing numerous species of conservation significance and ecologically important ecosystems and habitats.

Reduction in habitat integrity as a direct result of the Project could result from:

- Vegetation clearing.
- Inundation of the ISF.
- Creation of barriers within habitats.
- Erosion and changes to hydrology.
- Pests, weeds and diseases.
- Creation of new edges of habitats.
- Fire.

Reduction in habitat integrity as an indirect effect of the Project could result from:

- Influencing changes to the existing land uses of the local population.
- Attracting migrants to the area.
- Facilitating large-scale logging and agroforestry developments through the provision of infrastructure.

High Biodiversity

The Project is situated in an area of high biodiversity, i.e., a diverse variety of genes, individuals, species and communities, and the ecosystems they comprise. More than 1,354 species of vascular plants, 81 mammals, 220 birds, 58 frogs, 41 reptiles, 107 odonates and 359 butterflies were identified during the terrestrial biodiversity surveys undertaken for the Project. In addition, 59 mammal species and 195 bird species have the potential to occur in the Project disturbance area.

In terms of biogeographic assessments of biodiversity, the hill and montane zones have higher diversity and more specialised flora and fauna (i.e., plants, odonates, mammals, frogs) than the lowland zone. All zones are considered to be of high value since the lowland zone was important to some bird, reptile and butterfly species (Sections 7.1.7 and 7.1.8).

The biodiversity of the terrestrial biodiversity study area is high sensitivity. This is based on the biodiversity being considered of national or international value and the intact biodiversity being a rare natural resource.

Given the general ecological pattern that species diversity positively correlates to the size of available habitat, it is reasonable to predict that species diversity may be reduced in areas that experience large-scale clearing or loss of vegetation.

Reduction in biodiversity as a direct result of the Project could result from:

- Vegetation clearing.
- Inundation of the ISF.
- Introduced pests, weeds and diseases.
- Contamination and pollution.
- Fire.
- Disturbance and mortality of fauna.

Reduction in biodiversity as an indirect result of the Project could result from:

- Influencing changes to the existing land uses of the local population.
- Increasing levels of hunting.
- Facilitating large-scale logging and agroforestry developments through the provision of infrastructure.

Species New to Science and Endemic Species

The surveys reported in Appendices 8a and 8b discovered many species new to science. Since then the status (new or not) has been resolved for most of these species and some have been named. The surveys found 26 new plants, two new mammals, 26 new frogs, five new reptiles, 17 new odonates and nine new butterflies. Twenty-nine species have now been named or had their status clarified (Appendix 8c). Species new to science have been included for assessment since there is limited knowledge of their distribution and ecology. As most of these species are not formally recognised and have not been assessed by the IUCN, assessments of their sensitivity are based on expert opinion and past experience of such discoveries in similar environments.

The potential impact on species new to science across the terrestrial biodiversity study area depends upon the extent to which they are restricted within the terrestrial biodiversity study area. Where species new to science are found on isolated mountaintops, mountain ranges, islands or restricted habitats they may be expected to be restricted in distribution. Nonetheless, with so many new species, it is possible that some are restricted or have a significant part of their population within the terrestrial biodiversity study area.

Similarly, endemic species typically have more restricted distributions and therefore could be disproportionately affected within the overall biodiversity of the terrestrial biodiversity study area. A high number of species endemic to the island of New Guinea were recorded in the terrestrial biodiversity study area. Mammal species in particular exhibited a high level of endemism with approximately two-thirds of mammal species being endemic to mainland New Guinea.

The abundance of species new to science or endemic species could be directly or indirectly impacted as a result of the Project by the same processes that could impact high biodiversity listed previously.

Migratory and Congregatory Species

A range of species recorded in the terrestrial biodiversity study area congregate in groups at times. Parrots and pigeons congregate at food sources such as fruiting trees and some birds-of-paradise congregate at communal leks to mate. Similarly, some butterflies congregate on hilltops to mate while some species of odonates are also migratory. However, there is no evidence that any of these occur in unusually large congregations in the area. Similarly, while a range of migratory land birds from Australasia and Eurasia occur within the area, these are not congregatory except on migration and, again, there is no evidence that any of these occur in unusually large numbers.

While many species migrate to or congregate within the terrestrial biodiversity study area, the area is only significant for waterbirds, congregatory flying foxes (from the *Pteropus* genus) and cave-roosting and -breeding species (bats and swiftlets). Each has been considered separately given the differences between the groups.

Seventy-nine waterbird species have been recorded or are thought to occur along the Sepik River. Most are congregatory, some are breeding residents, many are nomadic within New Guinea and many are migrants from overseas and subject to treaty obligations under the Bonn Convention.

While only small groups of three migratory wader species were recorded in the terrestrial biodiversity study area, another 26 species could occur. The lowlands of the study area, particularly the off-river waterbodies, represent high value habitat for migratory and congregatory waterbirds. Therefore the waterbirds were considered to be of high sensitivity.

Flying foxes or fruit bats belonging to the Megachiroptera suborder (and *Pteropus* genus) often form large, dense congregations (known as 'camps') of varying size, that roost during the day then leave to forage at night. A main maternity camp of the great flying fox (*Pteropus neohibernicus*) of approximately 100,000 individuals was located near Wogamush Site in the terrestrial biodiversity study area, approximately 30 km northeast from the Frieda River Port (see Figure 7.14). A subsequent flyover indicated the camp had moved, but it is not known if this was a seasonal, temporary movement or if this was permanent.

Additional information from villagers indicated that other camps also occur in the region. While this species is widespread in Melanesia, no known major congregations of this species are recorded outside the Sepik Basin. The maternity camp near Wogamush Site could represent a significant portion of regionally occurring breeding females and, therefore, an ecologically important breeding area for this species in New Guinea. Therefore, the maternity flying fox camp near the Wogamush Site is considered to be of high sensitivity.

Numerous bat species and at least three species of swiftlet congregate and breed in karst caves in the hill and montane zones of the terrestrial biodiversity study area. Caves are considered a focal habitat and potential impacts on cave-roosting and -breeding species are considered below.

Reduction in population size of migratory or congregatory species as a direct result of the Project could result from:

- Increased hunting of congregatory species by the Project workforce.
- Contamination of waterways impacting migratory or congregatory waterbirds.
- Relocation of flying fox camps due to increased noise and air traffic.

Reduction in population size of species of conservation concern as an indirect result of the Project could result from:

- Increased siltation and suspended solids loads (for example created during construction activities) impacting riparian habitats, since migratory or congregatory waterbirds depend on these aquatic food webs.
- Indirect hunting pressure from the surrounding population as a result of in-migration.

Habitats and Biodiversity of Cultural Significance

The terrestrial biodiversity study area is sparsely populated. The primary linkage between communities and biodiversity is through subsistence use and cultural connection to the land. Local communities rely on the forests and rivers for the provision of ecosystem services and as sources of food and materials. Species likely to be hunted include pigs, cassowaries, wallabies, bandicoots, megapodes, rats, flying foxes, possums, tree kangaroos, monitor lizards, frogs, snakes, bats, crocodiles, turtles, lizards, insects and birds. Several hundred species of plants and animals are likely to be used for food, building, decoration, medicine and spiritual purposes.

Potential impacts on habitats and biodiversity of cultural significance are most likely to occur through impacts on the other identified values at different scales.

Potential Impacts on Ecologically Significant Ecosystems

Ecologically significant ecosystems are defined as geographically constrained ecosystems that play a disproportionate role in maintaining high, unique or rare terrestrial biodiversity and therefore a high sensitivity rating has been applied to each. These are termed priority ecosystems in the terrestrial biodiversity impact assessment Appendix 8c. While these features play a similar role in the ecology of the area (i.e., they all provide important unique habitats and services to flora and fauna), issues that impact these values and therefore management measures required to limit these impacts differ to some degree.

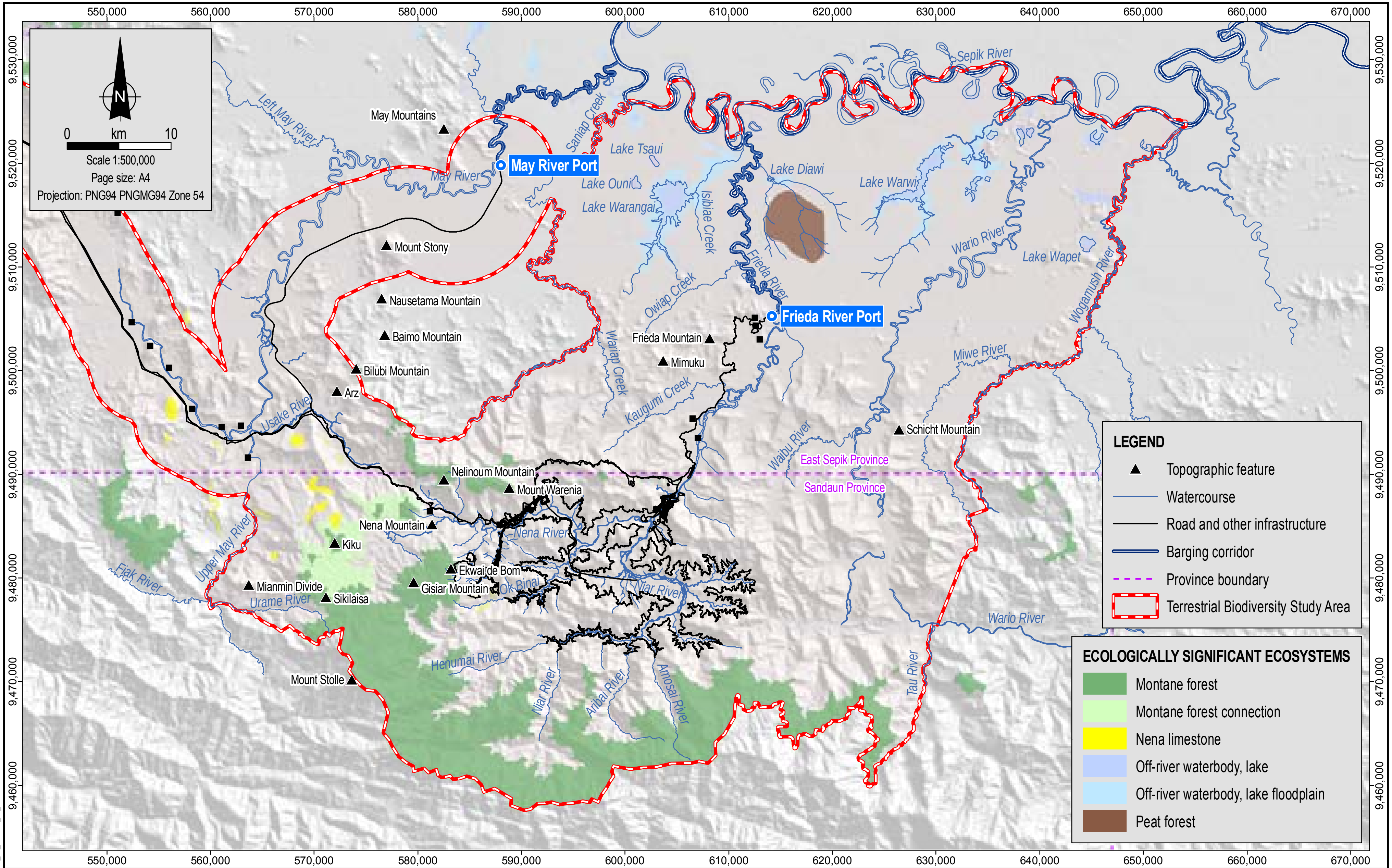
Ecologically significant ecosystems and habitats defined as occurring in the terrestrial biodiversity study area and shown in Figures 8.12 and 8.13 include:

- Peat forest.
- Nena karst.
- Off-river waterbodies.
- Montane forest.
- North Coastal Range.

Peat Forest

Peat forests are widespread in the Malay Peninsula, Borneo and Sumatra and occur in Indonesian New Guinea. On the island of New Guinea, peat substrates support various vegetation types from alpine bogs and shrublands to peat swamp forest. Regions of the island of New Guinea that have lowland peatlands include large areas of the Memberamo River and the Sepik basin, although no ground truthing has established the extent of these peatlands (Haantjens et al., 1968; Ono et al., 2015).

Similar peat forest on a well-developed dome had not been documented in the country until the current biodiversity surveys for the Project. Since then peat forests very similar to those recorded in the terrestrial biodiversity study area, but with different species composition, have been located on the Fly River drainage (Coffey Environments, 2016) and near Kraimbit village near the Black Lakes on the Sepik River (Ono et al., 2015). The latter consisted of peat between two to three metres deep containing sago and grass remnants.



MXD Reference: 11575B_11_GIS025_v0_4

Source:
Ecosystems and study area from Francis Crome and Coffey.
Infrastructure, roads and tenements from FRL.
Topographic features, watercourses and water bodies from FRL and Coffey.
Provinces from NMB.
Hillshade DEM from SRTM.

coffey
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Date:	14.09.2018
Project:	754-ENAUABTF11575B
File Name:	11575_11_F08.12_GIS

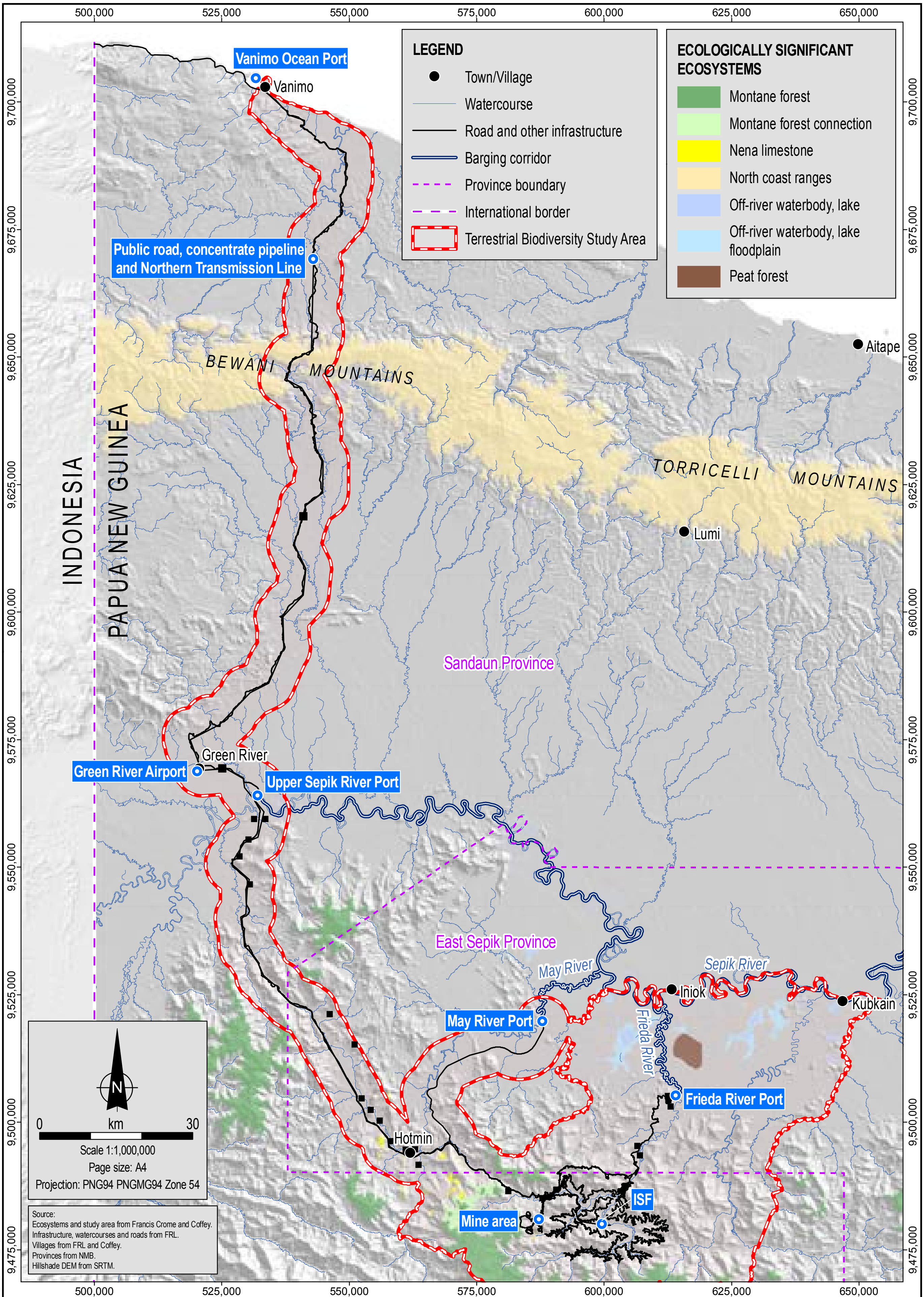
Frieda River Limited

Sepik Development Project

FRIEDA RIVER

Ecologically significant ecosystems in the terrestrial biodiversity study area - Greater Frieda Area

Figure No: 8.12



MXD Reference: 11575B_11_GIS027_v0_4

coffey A TETRA TECH COMPANY

Date: 14.09.2018
Project: 754-ENAUABTF11575B
File Name: 11575_11_F08.13_GIS

Frieda River Limited

Sepik Development Project

FRIEDA RIVER

Ecologically significant ecosystems in the terrestrial biodiversity study area - infrastructure corridor

Figure No: 8.13

Peat forests generally develop on a thick dome-shaped peat lens. In terms of vegetation, their canopy is stunted with poor crown development, and is flat and uniform; there are no emergents and there is a lack of palm species within the vegetation community (Plate 8.4). Substrates are highly oligotrophic (infertile) and acidic (pH less than four) and the watertable (usually close to the surface) is situated above the watertable of the surrounding landscape. While the development process of the peat forests is unclear, it may occur as relictual formations developed from organic deposits in brackish estuarine environments when the Sepik basin was a shallow inland sea.

The ecosystem is characterised by low biodiversity and endemism. While the flora diversity of the peat ecosystem is low, it contains the West Malesian peat specialist tree *Tetramerista glabra (*discovered for the first time in Papuasia) and has a peculiar vine association of *Timonius caudatu* and *Schradera novoguineensis*. Several pteropodid species appear to be absent and microchiropteran bat diversity is low. Bird species composition is distinct, richness and abundance are low and there are no peat specialist birds. The depauperate flora also means that the butterfly fauna is accordingly species poor, with the peat forest being dominated by common and widespread odonate fauna.

Potential impacts that could affect the peat forest ecologically significant ecosystem are wildfire, introduction of an invasive species or altered hydrology; such effects are likely to be limited due to the distance of peat from Project infrastructure.

Nena Karst

The karst habitats in the terrestrial biodiversity study area stand out as being of high biodiversity value. The largest block, the Nena Limestone Plateau (Plate 8.5 and Figure 8.12), contains large-scale karst features including at least two large sinkholes that are said to contain large colonies of cave-roosting megachiropteran bats but possibly also the IUCN critically endangered Bulmer’s fruit bat (*Aproteles bulmerae*). Smaller areas of polygonal karst have also been mapped along the infrastructure corridor (see Figure 7.8).

Karst outcrops were found to support several high montane plants occurring at low elevation and possess a unique herpetofauna fauna including two undescribed species of frogs and one undescribed gecko species. Karst also provides habitat of the karst specialist bird greater melampitta.

Potential impacts that could affect the karst ecologically significant ecosystem are uncontrolled fires, the introduction of exotic invasive species, and potentially in-migration resulting in habitat degradation.

Off-river Waterbodies

Off-river waterbodies along the Sepik River provide important nesting and refuge sites for two crocodile species, two freshwater turtles and the common frogs *Litoria infrafrenata* and *Rana papua*. The structure of aquatic vegetation in these waterbodies, and particularly of floating mats of vegetation, is critical for the nesting success of crocodiles. This is discussed further in Sections 7.2.4 to 7.2.6.

Potential impacts that could affect off-river water bodies include the introduction of exotic invasive species and in-migration resulting in increased habitat degradation. Potential impacts from an aquatic ecology perspective are discussed in Section 8.5.6.

Montane Forest

High elevation peaks and ridges that occur along the southern boundary of the terrestrial biodiversity study area and also in the North Coastal Range (Plate 8.6 and Figure 8.12) support a montane mammal community with a restricted distribution in New Guinea. The ecosystem is known to include two species of tree kangaroos (*Dendrolagus* spp.), a long-beaked echidna (*Zaglossus* species), a small dorcopsis (*Dorcopsulus* sp.), a striped bandicoot

(*Microperoryctes* sp.), several species of montane cuscus (*Phalanger* spp.) and at least one giant montane rat. It also supports a range of high elevation birds.

The montane mammal community is significant because these species have suffered a decline through the greater part of their distribution along the Central Cordilleran ranges of PNG due to overhunting and habitat modification.

Potential impacts that could affect the montane forest ecologically significant ecosystem include the introduction of exotic invasive species and increased hunting pressure either directly from the Project's workforce or indirectly from in-migrants; the latter process could also result in general habitat degradation.

North Coastal Ranges

The North Coastal Ranges include isolated northern ranges of New Guinea including the Van Rees, Foya, Cyclops, Denake, Bewani, Torricelli and Prince Alexander mountains. These ranges support a high diversity of endemic species, particularly mammals and frogs. Of relevance to the terrestrial biodiversity study area are the Bewani Mountains which form part of the North Coastal Ranges.

The eastern Bewani Mountains have been identified as a major 'Unknown Area' and a major 'Wilderness Area' with Mount Menawa in the Bewani Mountains nominated as a 'Biologically Important Area' for reptiles and amphibians by the Papua New Guinea Conservation Needs Assessment (CNA) (Allison, 1993). Since the CNA assessment, surveys in the eastern Bewani Mountains have documented a number of new frog species (Allison and Kraus, 2003; Kraus and Allison, 2006b).

The terrestrial biodiversity impact assessment (Appendix 8c) identifies a number of species endemic to the North Coastal Ranges. These include the Critically Endangered northern glider (*Petaurus abidi*), tenkile (*Dendrolagus scottae*) and Endangered northern water rat (*Paraleptomys rufilatus*). It is this diversity of endemic species that qualifies the North Coastal Ranges as an ecologically significant ecosystem.

The North Coastal Ranges in proximity to the infrastructure corridor have experienced extensive commercial forestry operations and forest conversion to palm oil plantations (Appendix 9).

Potential impacts that could affect the North Coastal Ranges ecologically significant ecosystem are limited to the introduction of exotic invasive species and potential disturbance for the transmission line.

Potential Impacts on Focal Habitats

A range of focal habitats was recorded in the terrestrial biodiversity study area. Focal habitats are defined as habitats that are often restricted and play an important role in maintaining the biodiversity of the area. The four focal habitats are outlined below.

Riparian and Gallery Forests

Forest along riverbanks is an important landscape component providing specialised habitats for a range of fauna. Riverine forest is most important in the lowlands where it supports a variety of large fruiting trees. Consequently, lowland riverine forests are particularly rich in pigeons and parrots, although no species is restricted to this habitat. Many birds will move into these habitats in the drier parts of the year and at hot times of the day, particularly in the lowlands. At such times the riverine forests act as refuges.

Reduction of riparian and gallery forests focal habitats as a direct result of the Project could result from erosion and siltation downstream of construction areas that alter the existing flooding

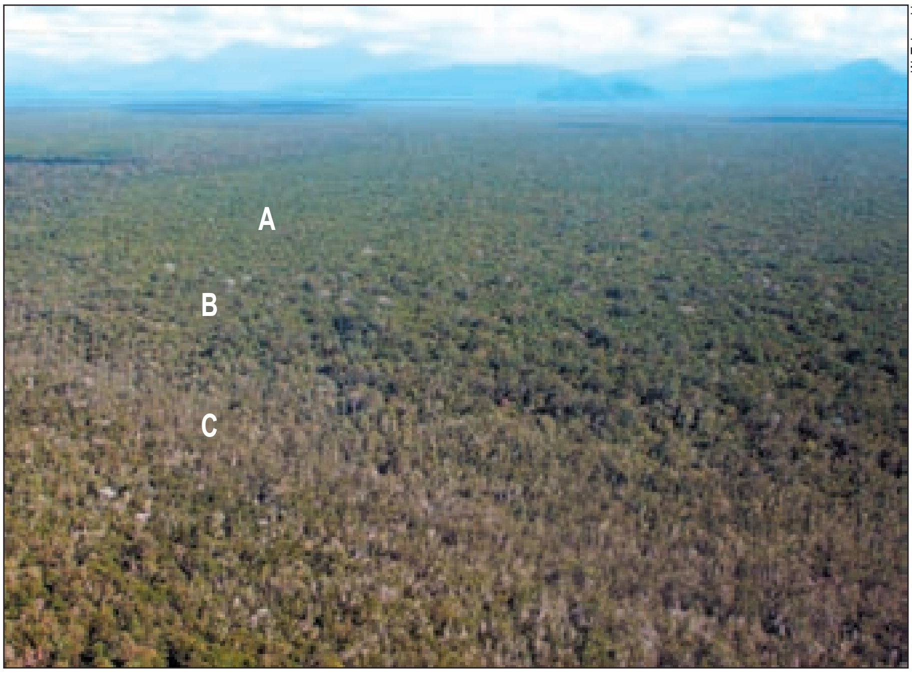


Plate 8.4
Peat forest in the terrestrial biodiversity study area documented for the first time in PNG. A, peat dome; B, transitional forest, probably a successional community to the peat formation; C, dieback zone in alluvial wooded swamp, visible as a light-colored circumferential arc.

Plate 8.5
Nena karst limestone

Plate 8.6
Lower montane forest

regimes with consequent impacts on riparian and gallery forest immediately downstream of the silt sources. Degradation of riparian and gallery forests could indirectly be impacted as result of increased in-migration and increased population densities.

Hilltops

The tops of steep, forested hills below approximately 900 m ASL are a specialised habitat for butterflies. The males of many species establish territories on hills, where they seek females to mate with, which are particularly important for species that are rare or sparsely distributed. Butterflies will use disturbed hilltops although in such situations they use the remaining forested areas. Butterflies prefer isolated, steep, pointy hills as opposed to long subtle ridgelines.

Reduction in hilltop focal habitats as a direct result of the Project could result from the introduction of invasive species. Degradation of hilltops could be impacted as an indirect result of the Project from increased in-migration and subsequent land clearance, introduction of invasive species and ignition of fires.

Upland Streams

Stream condition in upland torrential streams and upland low-gradient streams is important for maintaining populations of torrent-dwelling frogs, butterflies, odonates, semi-aquatic rodents and birds such as Salvadori's teal, torrent-lark and torrent robin. These streams are characterised by natural rapid changes in volume following intense rainfall events with an associated sediment load increase during these events. The torrent-dwelling frogs and odonates, in particular, require fast-flowing, clear rocky streams with intact riparian vegetation. They are especially important as areas in which butterflies mate. The structure and density of riparian vegetation associated with these streams is a crucial factor in determining the species that are able to persist along them. Different assemblages of odonates and frogs occur in different types of streamside vegetation. Some prefer dense overhanging riparian vegetation, some open sections of stream, others smaller shaded streams with complex understorey riparian vegetation, and some frequent streams with open understoreys and canopy gaps that allow large sun patches to penetrate to the creek bed.

Reduction in availability and or quality of upland stream focal habitats as a result of the Project could result from erosion and siltation of upland streams downstream of construction areas reducing their capacity to maintain diversity of specialist amphibious species, and uncontrolled fires and the introduction of exotic invasive species reducing surrounding vegetation and habitat quality. Degradation of upland streams could be impacted as an indirect result of the Project from increased in-migration and subsequent land clearance and degradation.

Caves

Caves are critical for survival of a number of bat species and swiftlets (birds). While caves will be most abundant in karst and other limestone areas, rock shelters and cavities in other geologies also provide potential roost and maternity sites. Bat species vary greatly in their degree of specificity in choice of roosting sites – some have broad requirements while others have very narrow tolerances that limit them to a small subset of all available caves. For these species, the value of particular roosting caves may be regionally or even globally significant.

Six of the seven microchiropteran bats listed as data deficient by IUCN are likely to roost in caves or clefts in cliffs. All but one of these, the small Melanesian bent-winged bat, are known from very few locality records in PNG and discovery of a large cave-roosting colony of any one of them in the terrestrial biodiversity study area would be significant.

Potential impacts to caves and the fauna they support as a direct result of the Project could result from direct disturbance or damage to caves or increased hunting of cave fauna by Project workforce or from in-migrants as an indirect result of the Project.

Potential Impacts on Species of Conservation Concern and Cultural Significance

Eighty-five species of conservation concern or cultural significance were assessed as either occurring, likely to occur (e.g., reliable record from local hunter) or possibly present (based on known distribution and ecology) in the terrestrial biodiversity study area (Appendix 8c). This included nine species listed as Critically Endangered by IUCN (2011), seven as Endangered, 15 as Vulnerable and 28 as Near Threatened. Of these, 14 were also listed as protected under the *Fauna (Protection and Control) Act 1966* (Fauna Act) and a further 23 were solely listed as protected under the Act. Two species not listed as Threatened or Near Threatened by the IUCN or protected by the Fauna Act were assessed based on their cultural significance. Descriptions for each of these species, including their conservation status, distribution and habitat requirements, evidence for occurrence in the terrestrial biodiversity study area, habitat availability in the area, and threatening processes, are presented in Appendix 8c.

Reduction in population size of species of conservation concern as a direct result of the Project could result from:

- Vegetation clearance and habitat disturbance resulting in the loss or disturbance of individuals and populations, particularly breeding sites (e.g., lek trees where males of particular bird species gather for the purposes of competitive mating display), nesting and roosting places for bats (e.g., caves), changes to stream ecology (e.g., contamination or siltation), generation of dust impacting butterfly food plants, fire and the creation of habitat barriers. For fauna, those that are large bodied generally have larger home ranges and lower population densities than smaller species.
- Hunting of specific fauna species for food (e.g., cassowaries and larger mammals) and for ornaments (e.g., feathers).
- Introduction and/or spread of weeds, pests and diseases that can impact on all species.

Reduction in population size of species of conservation concern as an indirect result of the Project could result from:

- Logging and over-harvesting including targeting tree species of conservation concern for their commercial value.
- Habitat loss through vegetation clearance and conversion to agricultural land.
- Indirect hunting pressure surrounding employment centres for the Project.
- Increased harvesting of the two species of crocodiles.

Specific processes effecting individual species are discussed at length in Appendix 8c.

8.6.3 Management Measures

Avoidance Measures

During the design of the Project, a number of options were evaluated with respect to several criteria including avoiding or limiting the total area of vegetation to be cleared. The major design options relevant to avoidance of potential impacts on terrestrial biodiversity included options for the location of an export route for concentrate, locations for mine waste rock and tailings disposal, location of an airport and locations of transport access routes to the mine. Alternative locations and layouts of Project components were subject to multiple account analysis and are discussed in Chapter 6.

Management Measures

Management measures that will limit the level of impact from activities on large scale terrestrial biodiversity values (i.e., extensive intact habitats, high biodiversity, species new to science and endemic species) in the terrestrial biodiversity study area are summarised in Table 8.43.

Table 8.43 Management measures for large scale terrestrial biodiversity values

No.	Management Measure
Vegetation clearing	
MM027	Mark the extent of vegetation to be cleared on technical drawings and mark in the field. Do not clear beyond design limits.
MM038	In areas that will be rehabilitated, use land clearing techniques that preserve the rootstock of removed vegetation in the ground, where practicable.
MM057	Locate quarries, and temporary infrastructure in cleared areas, secondary and/or degraded forest as far as practicable.
MM058	Retain and manage vegetation between Project components, where practicable.
MM059	Spread excavated soil, mulch and discarded vegetation debris (including natural seed stock) on reclaimed or rehabilitated disturbed land surfaces to facilitate natural revegetation, where practicable.
MM060	Retain bird-of-paradise display tree and megapode mounds as far as practicable.
MM061	Retain large trees (including fig trees) likely to have hollows and other roosting sites for fauna at sites for temporary facilities such as vehicle parks, lay down areas, storage sites, bulk fuel storage, dumps and temporary camp where practicable and safe to do so.
MM063	Complete targeted pre-construction surveys of proposed transmission line tower and access track locations within intact primary forest to identify ecological values to be considered as part of the detailed design of the transmission line.
Measures aimed at reducing forest loss, edge and barrier effects	
MM064	Ensure linear infrastructure in swampy lowland habitats is designed and constructed so as to maintain the original drainage patterns of the habitat as far as practicable.
MM065	Minimise the width of clearing required for linear infrastructure as far as practicable.
MM066	Retain trees along the edges of roads and pipeline routes so that the canopy gap is reduced where practicable and safe to do so.
MM067	Install fauna ‘underpasses’ and /or ‘overpasses’ at strategic locations along the infrastructure corridor to reduce vehicular fauna strike.
Pests, weeds and diseases	
MM068	Develop pest and weed quarantine procedures (including for inbound foreign freight), a weeds management plan to limit the introduction of invasive weed or pest species, monitoring susceptible areas to detect new alien incursions, and protocols for reporting sightings of weed or pest infestations, and establish inspection and treatment standards and procedures for all freight types, including imported bulk materials. It will cover both Company and Contractors.
MM069	Prohibit transportation of live plants or seeds to Project sites unless part of an approved rehabilitation plan or approved community development program.
MM070	Establish and implement procedures to ensure soil and weed seeds are cleaned from plant and machinery brought into the Project area from overseas, logging areas or agricultural areas elsewhere in PNG prior to reaching the Project site (applies to Company and Contractors).
MM071	Establish procedures to prohibit Project workers/contractors from establishing gardens or introducing plants, seeds or animals, including fish species, within the Project area.
MM014	Carry out pre-construction survey of work sites for weeds, exotic fauna and dieback using a risk-based approach to identify areas susceptible to invasion of exotic species. If dieback is recorded, testing for Phytophthora will be completed and if present, procedures for managing the spread of dieback will be developed.

Table 8.43 Management measures for large scale terrestrial biodiversity values (cont'd)

No.	Management Measure
Pests, weeds and diseases (cont'd)	
MM072	Control infestations of high priority weeds prior to commencement of construction.
MM073	Establish permanent chemical wash down point(s) to prevent weeds and pathogens being transported to work sites, where appropriate.
Contamination and pollution	
MM050	Store, handle and transport hazardous substances in accordance with Australian Standards AS1940:2017 and AS3780:2008, and the PNG Environmental Code of Practice for Vehicle/Machinery Workshops and Petroleum Storage/Resale/Usage Sites.
Fire	
MM074	Develop and implement fire management procedures for the construction and operations phases of the Project aimed at reducing the likelihood of wildfires starting in surrounding undisturbed vegetation. The plan will include banning the burning of cleared vegetation and other fires during drought years, particularly in the hill environment.
In-migration	
MM075	Maintain the mine access road (south of Hotmin), link road and FRHEP access road as private roads.
MM076	Make Project roads and other linear infrastructure impassable to vehicles at closure where these are not required for ongoing environmental management and monitoring, or where third party agreement is reached to transfer roads at FRCGP closure.
Fauna	
MM077	Prohibit hunting, collecting, or harassing of wildlife, keeping wildlife as pets and/or the possession and/or transport of wildlife products by Project employees and contractors at Project sites.
MM078	Implement appropriate inductions and education to ensure staff comply with hunting and collecting regulations.
MM079	Include training in the recognition of endangered fauna in inductions of all staff and contractors. Encourage a precautionary approach "If in doubt - report it".
MM080	Enforce speed limits on Project roads, tracks, pipeline rights-of-way and transmission line corridors.
MM081	Prohibit the procurement or consumption of bush meat in Project sites including fly camps and exploration camps.
MM082	Prohibit non-security related Project employees and contractors from possessing firearms and/or bows and arrows while engaged in Project activities.
MM083	Prohibit keeping or temporary housing of pets or wild fauna at Project facilities other than trained animals under the control of a handler.
MM084	Maintain a 500 m buffer (prohibiting clearance and blasting) to any large flying fox camp (>1,000) animals and a 200 m buffer (prohibiting clearance and blasting) at camps having 500 to 1,000 animals.
MM085	Install markers visible to birds on the transmission line to reduce the likelihood of bird and bat strikes at high risk locations including near waterbodies.
MM086	Maintain unsealed mine and FRHEP access roads in a damp and compacted condition (when required and safe) to control dust.
MM087	Direct lights at facilities and camps to minimise shine into surrounding forest where practicable.

In addition to the general management measures listed in Table 8.43, specific management measures are proposed to limit the level of impact from Project activities with respect to ecologically significant ecosystems and focal habitats as summarised in Table 8.44.

Table 8.44 Management measures for ecologically significant ecosystems and focal habitats

No.	Management Measure
Ecologically significant ecosystems	
Montane forest	
MM088	Limit disturbance in montane forest as far as practicable and do not place any temporary infrastructure in this habitat.
Peat forest	
MM089	Do not place any temporary infrastructure in the peat forest or in areas that may affect its drainage.
Nena limestone karst	
MM090	Avoid, where practicable, placement of infrastructure in the Nena limestone karst area, and minimise disturbance to other karst areas.
Off-river waterbodies	
MM028	Do not place any infrastructure, permanent or temporary, in off-river waterbodies.
MM029	Do not use ORWBs for waste disposal, including for domestic and industrial waste, or for discharge of treated or untreated waste waters.
MM030	Locate, design and construct linear infrastructure to avoid impacts on the hydrology of ORWBs.
North Coastal Ranges	
MM091	As far as practicable, place transmission line pylons in already cleared or degraded areas.
Focal habitats	
Riparian and gallery forests	
MM092	For roads required within riparian vegetation, utilise areas of disturbed riparian vegetation as far as practicable. Keep road alignment approaches to watercourses as close to right angles as practicable to limit disturbances to the banks of watercourses.
MM093	Preserve riparian vegetation to the greatest extent practical and create a buffer of natural vegetation between watercourses and construction areas, where practicable.
MM094	Stabilise cleared banks to facilitate regeneration of riparian vegetation.
MM095	Use local species, wherever practicable, where watercourse crossings are to be revegetated.
MM096	Conduct washing, servicing and refuelling of equipment, vehicles or machinery at designated, appropriately designed facilities, away from watercourses.
Hilltops	
MM097	Minimise disturbance to forest on or close to the summit if facilities must be placed on hilltops.
Upland streams	
MM098	Place suitable erosion control devices between tracks and upland torrential streams, where practicable.
MM099	Reduce sediment loading by reducing sidecasting above watercourses where practicable.
MM044	Where practicable, locate valley-bottom access alignments so as to provide a buffer strip of natural vegetation between the access ways and watercourses.
MM100	Prohibit disposal of domestic and industrial waste outside of designated waste storage and disposal areas.
MM101	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.
Cave management	
MM102	Ensure that any limestone karst areas situated above 500 m ASL and located within 2 km of Project components is surveyed for the presence of roosting populations of Bulmer's fruit bat (*Aproteles bulmerae)* prior to the development.

Table 8.44 Management measures for ecologically significant ecosystems and focal habitats (cont'd)

No.	Management Measure
Cave management (cont'd)	
MM103	If Bulmer's fruit bat (*Aproteles bulmerae*) is located, develop a management plan that includes: 1) avoidance of direct disturbance and encroachment by Project activities; 2) avoiding construction that would increase access to the roosting site; 3) monitor the population; 4) implement a local cultural awareness program with the objective of a local moratorium on hunting of cave roosting flying foxes.
MM104	Conduct a pre-clearance survey of infrastructure, including quarries, to determine presence of caves with bat colonies and where colonies are located within 100 m of infrastructure, establish procedures to reduce disturbance, where practicable. Procedures will include: • Limiting or controlling where practical, blasting within 150 m of known colonies of cave bats. • Avoiding quarry sites within 150 m of caves with protected bat species, as far as practicable.
MM105	Establish cave management protocols for worker and contractor inductions, to prohibit unnecessary disturbance of bat colonies by Project workers.

Management measures that will limit the level of impact from Project activities to species of conservation concern in the terrestrial biodiversity study area are summarised in Table 8.45.

Table 8.45 Management measures for species of conservation concern

No.	Management Measure
MM106	Establish a conservation program for fauna at risk of being overhunted to manage direct impacts and indirect impacts of in-migration.
MM107	Develop a fauna relocation program for species of conservation concern to be implemented during clearing of relevant habitat.
MM108	Project workers or contractors to report sightings of the following species to the Project environment team: long-beaked echidna (*Zaglossus* spp.), Telefomin cuscus (*Phalanger matanim*), black-spotted cuscus (*Spilocuscus rufoniger*) and tree kangaroos.
MM109	Attempt to cultivate species of plants that are new to science and use them in revegetation where practicable.
MM110	Establish a project to identify the food plants of the new butterfly species so as to cultivate these plants and use them in revegetation.
MM111	Include threatened plant species, the food plants of listed butterfly species and fruiting plants that attract frugivores in revegetation plans where practicable.

8.6.4 Residual Impact Assessment

The residual impact assessment must be considered in the context of the Project which, by its nature and aims, is a regional and national development project. Major impacts to terrestrial biodiversity values as a result of the Project are largely predicted to occur from the development opportunities provided by road access and electrification in north-western PNG and the growth of its population. Commercial forestry operations have been operating in Sandaun Province for many years and are predicted to expand southwards, regardless of the development of the Project (refer Appendix 9). Nonetheless, with improved road access, the development and expansion of forestry, agroforestry and agriculture in the western Sepik River floodplain may be aided. These combined land use changes would inevitably result in the loss of large forest areas and consequential impacts to its biodiversity. Such impacts are likely to be greater in scale and severity than the direct forest loss caused by the development of FRCGP and FRHEP. Cumulative impacts associated with forestry and agroforestry are discussed in Chapter 10.

As described in Section 8.6.2, four villages (Ok Isai, Wabia, Paupe and Wameimin 2) have been identified for resettlement as a result of the Project. Resettlement will entail vegetation clearing for villages and the construction of roads to those sites. Further clearance for subsistence gardening purposes and hunting is expected after new villages are established. The resettled villages are also likely to become focal points for migrants and thus forest degradation around these areas is likely to occur. At present, the potential locations of these villages are subject to ongoing consultation with landowners and the exact nature of impacts cannot be predicted until the locations are agreed. However, the magnitude of residual indirect impacts (above what is predicted below) can reasonably be expected to increase but will depend on the final locations as to what values will be affected. If resettled villages and roads to access them are above 1,000 m ASL then impacts to the montane ecologically significant ecosystem and a range of conservation significant species are likely to be increased.

Landscape Scale (Large)

Impacts have to be considered in a regional context at the broadest, landscape scale. A summary of the direct and indirect residual impacts (assessed in Appendix 8c) are provided in Table 8.46 and summarised in the following sections. The sensitivity of the value remains the same irrespective of whether it is a direct or indirect impact.

Table 8.46 Residual impact on landscape scale terrestrial biodiversity values

Impact Description	Sensitivity	Direct Residual Impact		Indirect Residual Impact	
		Magnitude	Significance	Magnitude	Significance
Reduction of extensive intact habitats as a direct result of clearing and inundation; or indirectly increased land use due to in-migration and associated effects.	High	Medium	Major	Medium	Major
Reduction of biodiversity as a direct result of clearing and inundation; or indirectly increased land use due to in-migration and associated clearing and hunting.	High	Negligible	Negligible	Low	Moderate
Reduced abundance of species that are new to science primarily as a result of direct habitat loss, introduction of invasive species and indirect habitat loss due to increased land use or wildfire.	High	Negligible	Negligible	Low	Moderate
Impact on the congregatory flying foxes as a result of increased hunting.	High	Negligible	Negligible	Low	Moderate
Direct and indirect impact on habitats and biodiversity of cultural significance as a result of Project clearing, inundation, introduction of pests, weeds and diseases, fire and clearing and hunting resulting from in-migration.	High	Low	Moderate	Low	Moderate

Extensive Intact Habitats

The area cleared and inundated during the construction phase of the Project will be up to 16,257 ha within the terrestrial biodiversity study area (Table 8.47). This area is greater than the Project footprint described in Chapter 5 because it conservatively includes assumed loss of habitat between closely located pieces of Project infrastructure. Small stands of forest in these fragments may remain following construction in these areas; however, these are likely to be degraded and fragmented and have therefore been assumed as cleared. Of this area, 68% is hill forest and 20% is tall lowland forest. Negligible vegetation losses will occur in the lower montane zone. Approximately 41% of the clearing will be in undisturbed forest and a further 36% will be in lightly disturbed forests. An estimated 91% of the vegetation cleared will be permanently lost, largely due to the open-pit and ISF developments, with some 1,240 ha (or 9% of the Project disturbance area) likely to be available for rehabilitation. Of this area, 10 to 30% is likely to be available immediately after construction and the remainder after decommissioning.

Table 8.47 Estimated clearing of vegetation (type and condition) due to Project development

Vegetation Type	Condition Category				Total (ha)	Percentage
	Intact (ha)	Lightly disturbed (ha)	Moderately disturbed (ha)	Heavily disturbed (ha)		
Montane forest	3	-	-	-	3	<0.1%
Hill forest	5,281	5,484	-	328	11,093	68.2%
Lowland forest	1,254	339	10	1,693	3,284	20.2%
Swamp forest	123	33	-	-	156	
River or cleared areas	-	-	-	-	1,721	10.6%
Total	**6,661**	**5,856**	**10**	**2,021**	**16,257**	**100%**
Percentage of vegetation clearance	**41.0%**	**36.0%**	**<0.1%**	**12.4%**	**100%**	

Source: Appendix 8c.

Forest disturbance per se does not necessarily have a major impact since tropical forest dynamics depend upon disturbance of some sort (Section 7.1.6). In general, tropical forests of New Guinea tolerate disturbances, such as those caused by natural tree falls and landslides. If clearing mimics these dynamics, permanent change to forest landscape and overall habitat integrity would not be compromised. Permanent deforestation arises when substrates are irreversibly altered or when disturbance regimes produce continuous and expanding loss of habitat. Management measures have therefore focused on restricting vegetation clearance within the area required for Project construction by avoiding unnecessary clearing.

In the hill and montane zones, gap phase dynamics is the major driver of forest composition. Gaps form constantly from natural tree deaths of one or a few trees and produce continuous low-level disturbance. The amount of mineral soil is important in determining how a gap is filled. In a gap produced by a tree fall, the forest substrate remains more-or-less intact and the major change is the product of increased sunlight in the gap. As the gap size increases by, for example, landslides, logging or mechanical clearing, the area of soil exposed to sunlight or exposed to mineral soil increases thereby allowing colonisation by pioneer and early secondary species. Such large disturbances can produce dynamics whereby an entire area regenerates through successional processes from pioneer through secondary stages to intact forest.

While gap phase dynamics also operate in all the forests of the lowland zone, hydrology is the major driver that determines the community composition and structure of floodplain forest. Floodplain community composition is complex and is driven by flooding periodicity, depth and length (see Appendix 8c for discussion). Floodplain vegetation within the terrestrial biodiversity study area can be summarised as follows. Lowland open forest and small crowned forest mostly occurs in areas free of flooding but can tolerate flooding for some time. In shallow swamps where the watertable is at or near the surface for part of the year, mixed swamp forest and swamp woodland occur with forest transitioning to woodland as water depth and flood duration increases. Riverine mixed successions are predominant features where high energy river flows occur for longer periods, such as along the Sepik River. As water depth increases it merges into herbaceous swamp, to flooded grasslands and eventually to open lakes. Sago occurs throughout these formations and its occurrence can vary from scattered palms in the understory to dense stands. Peat forest occurs on raised peat lenses where the watertable is stilted and is maintained by a degree of isolation from normal overbank flows of nutrient rich river water. Changes to the duration, depth and periodicity could have effects on these lowland habitats. These effects are further considered in Section 8.5.3.

Forest loss is likely to have a considerable local impact, although the loss will not be large in the regional context. The majority of the permanent losses will be in the terrestrial biodiversity study area hill zone which will lose 8% of its estimated 170,000 ha of forest within the terrestrial biodiversity study area. Some barrier effects are likely to be produced by the Project considering its scale and linear components. None of the direct impacts are expected to be system-wide nor extensive enough to affect the overall integrity of this value so the residual magnitude of direct impacts to extensive intact habitats is assessed as **medium**. As a result, the residual impact significance is **major** because of the high sensitivity of this value.

Indirect impacts on the terrestrial biodiversity study area landscape (and the upper Sepik River basin) could arise, primarily through indirect effects from further forest loss from wildfires, invasion of exotic species and the barrier effect produced by the Project. These impacts may be more widespread and could lead to changes at a broader scale that continue over a longer time frame. For example, the impact on habitat integrity from expansion or construction of new gardens or houses, and the development of small-scale forestry in the terrestrial biodiversity study area, is likely to indirectly increase the area of habitat cleared as a result of the Project with the consequence of decreased habitat integrity in the area.

Implementation of in-migration management measures will reduce the likelihood of wildfires starting at the Project disturbance area and reduce the probability of introducing weeds, pests and diseases. However, the Project's ability to directly control in-migration beyond the lease areas is likely to be limited (Section 9.2.8). Therefore, forest loss and degradation through harvesting of non-timber forest products and possibly small-scale logging can reasonably be expected around existing villages and new village locations for displaced villages. As a result, the magnitude of the residual indirect impact on extensive intact habitat is assessed as **medium** as the impact will be readily detectable with respect to natural variability but not severe in the context of the wider region. The significance of the residual indirect impact of the Project on extensive intact habitats in the terrestrial biodiversity study area was assessed as **major**.

High Biodiversity

Most flora and fauna will be lost from areas cleared for Project development. The extent to which it can recolonise will depend upon the extent to which various areas will regenerate. Areas that regenerate only to grass or shrublands will develop a low diversity of widespread secondary and grassland species, while areas that regenerate back to forest will build up species rapidly. In the case of the Project, however, the majority of forest losses will be permanent in that they will be converted to a permanent waterbody (i.e., the ISF) which, while available for aquatic species, will only provide habitat for waterbirds and a few species of generalist frogs and reptiles, not forest species as a whole.

Beyond the Project disturbance area, it is unlikely that the loss of habitat within the terrestrial biodiversity study area will cause any local extinctions of flora or fauna. Therefore, reductions in biodiversity are unlikely, unless there are species entirely restricted to the Project disturbance area. With management measures listed above limiting habitat loss and fire, reducing habitat degradation and hunting, and reducing the likelihood of introducing noxious pests and weeds, the magnitude of the residual direct impact to terrestrial biodiversity in the terrestrial biodiversity study area was assessed as **negligible**, resulting in a **negligible** impact significance rating.

The indirect impact on biological diversity as a result of in-migration and associated effects is more difficult to predict. The Project has limited direct influence on in-migrant settlement and behaviour beyond the lease areas. Therefore, increased forest conversion to gardens, harvesting of non-timber forest products and possibly small scale logging are likely to increase the loss of intact habitats and biodiversity. Furthermore, should in-migrants introduce exotic species, impacts could be even greater; the Project has no ability to control this. As a consequence, and acknowledging the uncertainty relating to this impact, the magnitude of such an impact was assessed to be **low** resulting in **moderate** impact significance.

Impacts to habitats and biodiversity of cultural significance from a resource use, subsistence or cultural heritage perspective are assessed within Chapter 9.

Species New to Science and Endemic Species

Biodiversity surveys in such a remote and inaccessible part of the tropics that has not been biologically explored before, particularly one as comprehensive as that conducted for the Project, is likely to find species new to science. At least 85 species were discovered during field surveys for this Project, some of which have now been formally named. The majority of these species were from less well-known groups of plants, herpetofauna and invertebrates. Known distributions of these species may be a reflection of the limited scientific research focus on these taxa, rather than the actual distribution of these species.

Nonetheless, with new species it is possible that some are restricted or have a significant part of their population within the terrestrial biodiversity study area. The residual impact on these species depends upon the extent to which they are restricted in range. A major impact would occur if their ranges were so small that they wholly or mostly overlapped with the Project footprint and thus would be subjected to severe range reduction. Where species new to science are found on isolated mountaintops, mountain ranges, islands or restricted habitats they may be expected to be restricted in distribution. The only species likely to be so restricted is the butterfly *Mycalesis* sp. nov. 1 found only in the peat forest. All other species are in habitat that is continuous along the north slope of the Central Cordillera or on the continuous Sepik River lowlands and thus are unlikely to have very narrow distributions.

Of the species potentially new to science, five species (one plant, one mammal, one reptile, and two odonates), were found only at a survey site within the Project disturbance area; the rest occurred outside, or both inside and outside, the Project disturbance area. However, experience suggests that continued ecological investigation generally continues to increase the known range of species previously thought to be narrowly restricted. The large number of range extensions resulting from the Project surveys demonstrates this. It is extremely unlikely that any of the new species, including those only found so far in the Project footprint, are entirely restricted to the terrestrial biodiversity study area as all but *Mycalesis sp. nov.* 1 were in widespread habitats.

With management measures limiting habitat loss and fire, reducing habitat degradation and limiting the introduction of noxious pests and weeds, the residual direct impact to species new to science is assessed as being **negligible**.

In assessing indirect effects on species new to science, it is noted that none of the species would be of any interest to hunters or subsistence gatherers and so would not be targeted by in-migrants. Clearing of vegetation by in-migrants or the accidental introduction of exotic pests and pathogens are greater potential indirect impacts. The residual indirect impact to species new to science is predicted to increase to **moderate** significance.

The endemic species recorded during the field surveys for the Project do not appear to be concentrated in particular ecological niches nor particular locations within the terrestrial biodiversity study area overall. The Project is therefore highly unlikely to alter the levels of endemism in the biota. The magnitude of residual direct and indirect impact to endemic species is thus predicted to be **negligible**.

Migratory and Congregatory Species

The prime waterbird habitat in the terrestrial biodiversity study area is located in ORWBs in the lowland zone. Other habitats such as riversides may support waterbirds but not in the numbers required to be classed as congregations. Given that the Project will not directly impact off-river waterbodies, and measures will be implemented to limit in-migration and hunting, the magnitude of impacts to waterbird populations in the terrestrial biodiversity study area is considered to be **negligible** as any effect will be barely detectable above natural variation.

The ISF may provide new habitat for amphibious fauna such as waterbirds, crocodiles and frogs, although the ISF lake will be too deep to provide habitat for most waterbirds except the diving piscivorous species such as cormorants.

There is extensive habitat that could serve as sites for flying fox camps and the retention of the Wogamush camp is dependent upon reducing disturbance to the animals. The possibility remains that loss of the forest due to Project activities could reduce foraging habitat and resources for this colony. In addition, camps could be put under pressure by in-migration and increased hunting primarily as a result of indirect in-migrant hunters. Flying foxes are attractive to hunters because their congregatory nature allows large numbers to be hunted in a single event. Large camps are most likely in the lowland zone where the known camp at Wogamush site was recorded. However, the Wogamush site is not located in an area where in-migrants are expected to settle (Chapter 9). While some hunting of flying foxes would be expected, the magnitude is predicted to be **low** and the residual impact significance as an indirect effect of the Project is **moderate**.

Habitats and Biodiversity of Cultural Significance

Potential impacts upon other values, such as individual species, could also result in impacts to habitats and biodiversity of cultural significance. While the terrestrial biodiversity study area is unlikely to decline greatly in value considering the extensive habitat that will remain, the predicted residual direct and indirect impacts on the most culturally significant large animals (e.g., cassowary species) tend to be moderate or higher. This prediction drives a residual direct and indirect impact to habitats and biodiversity of cultural significance of **moderate** significance.

Ecologically Significant Ecosystems (Medium Scale)

The residual impacts on ecologically significant ecosystems (the medium scale) are discussed below. Residual direct impacts to ecologically significant ecosystems are all expected to be **negligible**, with the exception of residual indirect impacts on montane forest, which were assessed as **major** (Table 8.48).

Table 8.48 Residual impacts montane forest

Impact Description	Sensitivity	Direct Residual Impact		Indirect Residual Impact	
		Magnitude	Significance	Magnitude	Significance
Impact on montane forest from habitat degradation as a result of habitat loss (as a direct effect of physical disturbance or indirect effect of in-migration, resettlement and increased land use intensity).	High	Negligible	Negligible	Medium	Major

Peat Forest

There will be no infrastructure or Project activities located on or near the peat forest hence there will be no direct impacts. Similarly, since the hydrology of the peat forest is dominated by the hydrology of the Sepik River, changes to the hydrology of the Frieda River are unlikely to impact the peat forest. Project infrastructure is unlikely to improve access for others to the peat forest as it is most easily accessed from the Sepik River or Frieda River. Therefore, any impact, if it was to occur, will be barely detectable with respect to natural variability. The overall magnitude of impact to peat forest by the Project was therefore assessed as **negligible**.

Nena Karst

No infrastructure or Project activities will be located on or near the main concentration of karst therefore direct impacts to karst ecosystems will not occur. A quarry for the Project is likely to use 17 ha of an eastern limestone outlier, without karstic features, located 1.5 km to the south-east of the open-pit. This is likely to result in the loss of caves that provide habitat for bats, but will not affect the Nena limestone plateau area where karst values are concentrated and where a colony of Bulmer's flying fox may be located. Considering that Project activities will not occur on or near the Nena limestone plateau, impacts to the ecosystem will be barely detectable with respect to natural variability.

With measures to limit in-migration, control hunting, manage fire and weeds, and implementation of a Biodiversity Management Sub-plan, the overall magnitude of impact to karst ecosystems from the Project was assessed as **negligible**.

Off-river Waterbodies

A number of ORWBs are located adjacent to the downstream reaches of the lower Frieda River and the Sepik River downstream of the Frieda-Sepik river junction. Lake Warangai and Lake Diawi are located adjacent to the Frieda River while there are a number of ORWBs adjacent to the Sepik River downstream of the Frieda River (e.g., Lake Warwi and Lake Mhowi). Lake Warangai and Lake Diawi are located on the floodplains west and east, respectively, of the Frieda River near its junction with the Sepik River. Lake Warangai is linked to both the Frieda and Sepik rivers by minor watercourses with water flowing either to or from the lake depending on river and lake water levels. Lake Diawi is linked only with the Frieda River.

There will be no Project infrastructure located on any ORWBs including oxbows. The only infrastructure that approaches ORWBs is the infrastructure corridor where it crosses the Sepik River and is 1.5 km from the nearest ORWB.

ORWBs in the terrestrial biodiversity study area are within the influence of the Sepik River. Overbank flooding occurs in the lower reaches of the Frieda River and across the Sepik River floodplain under existing conditions and a similar peak flooding regime is expected during construction, operation and closure. Likewise, TSS concentrations during overbank flooding will remain comparable to those under current conditions. Therefore, impacts of the Project on sediment inflows into Lake Warangai and Lake Diawi from the Frieda River are expected to be negligible. In addition, the sediment modelling indicates that the sediment concentrations in the Sepik River are predicted to remain comparable to those currently observed.

Any direct impacts will be barely detectable with respect to natural variability. Therefore, the overall direct magnitude of impact to ORWBs by the Project was assessed as **negligible**.

Measures will be put in place to address indirect impacts associated with in-migration such as the introduction of exotic invasive species. As a consequence, the magnitude for indirect impacts to ORWBs is likely to be negligible, resulting in **negligible** impact.

Montane Forest

There will be a limited direct impact of the Project in terms of vegetation clearing and disturbance above 1,000 m ASL. Less than 6 ha of intact vegetation above 1,000 m ASL will be disturbed by the upper rim of the HITEK open-pit.

The overall direct magnitude of impact to montane forest by the Project was assessed as **negligible** on the basis of management measures being implemented to prevent the introduction of exotic invasive species and fires.

The indirect impact that could erode the value of this ecologically significant ecosystem is in-migration and resultant increased effects relating to wildfires and the introduction of exotic invasive species. Since the Telefomin region is the most likely source of in-migrants, and these lower montane habitats are contiguous with the Telefomin, it is reasonable to predict that these forests will be most affected by in-migration. As a consequence, the indirect impacts on montane forests was conservatively assessed as **medium** resulting in a **major** impact significance rating. This will be exacerbated further if villages resettled by the Project are located at the higher elevations of the terrestrial biodiversity study area (above 1,000 m ASL).

North Coastal Ranges

Direct impacts on the North Coastal Ranges are likely to be **negligible**. The infrastructure corridor will follow the existing road corridor through the Bewani Ranges and will mainly involve clearing of degraded roadside vegetation which is also outside the known range of the important species within the North Coastal Ranges.

Indirect impacts on the North Coastal Ranges are also likely to be **negligible**. The area is already bisected by the existing road corridor, is characterised by the impacts of selective logging in accessible areas near the road and is unlikely to be a destination for in-migration.

Focal Habitats (Fine Scale)

The residual impacts on focal habitats (the fine scale) are discussed below with residual impacts on riparian forests, upland streams and caves summarised in Table 8.49.

Table 8.49 Residual impacts on focal habitats

Impact Description	Sensitivity	Direct Residual Impact		Indirect Residual Impact	
		Magnitude	Significance	Magnitude	Significance
Direct and indirect impacts to riparian forests as a result of inundation, altered flood regimes and in-migration and associated effects	High	Low	Moderate	Low	Moderate

Table 8.49 Residual impacts on focal habitats (cont'd)

Impact Description	Sensitivity	Direct Residual Impact		Indirect Residual Impact	
		Magnitude	Significance	Magnitude	Significance
Direct and indirect impacts on upland streams from habitat degradation (including fire, introduced species and in-migration) and erosion and siltation downstream of construction areas	High	Low	Moderate	Low	Moderate
Indirect impacts on caves from hunting and introduction of wildlife diseases resulting from in-migration	High	Negligible	Negligible	Low	Moderate

Riparian and Gallery Forests

Riparian and gallery forests were assessed as having a disproportionate role in maintaining the high terrestrial biodiversity values within the terrestrial biodiversity study area. Within the Project disturbance area most, if not all, riparian and gallery forests will be cleared or inundated. In addition, erosion and sediment deposition is likely to impact streams downstream of construction areas, particularly where the road route crosses rivers with riparian or gallery forest habitat. This may impact riparian and gallery forest by altering flooding regimes immediately downstream of construction areas. With management measures implemented to reduce impacts of river crossings, the magnitude of direct impacts was assessed to be **low** and the significance of the residual impact was assessed as **moderate.**

As riparian and gallery forests are mostly in the lowlands, they are unlikely to be a destination for in-migration nor part of the resettlement program. The residual indirect impact is predicted to remain **moderate**. Overall, the terrestrial biodiversity study area is unlikely to lose its overall capacity to maintain diversity in riparian and gallery forests.

Hilltops

Some hilltops suitable for butterfly congregations within the Project disturbance area are likely to be cleared or inundated. Hilltops outside the Project disturbance area are unlikely to be directly affected by the Project. The most likely source of impacts to hilltops outside the Project disturbance area are wildfires, the introduction of exotic invasive species and possible clearing resulting from in-migration that causes further forest degradation.

With management measures implemented to reduce the probability of direct impacts associated with the introduction of exotic invasive species and fire, the magnitude of impact to hilltops by the Project is considered to be **negligible**. Therefore, the significance of the residual impact was assessed to be **negligible**.

While hilltops are frequently cleared for gardens and these habitats are expected to be favoured by in-migrants, the very large number of suitable hilltops within the terrestrial biodiversity study area mean that the residual impact is predicted to remain **negligible**.

Upland Streams

Limited direct impacts from the Project are likely to occur on any upland streams above 1,000 m ASL. However, within the Project disturbance area, upland streams in the hill zone will be eliminated or severely degraded. Sediment and silt deposition is likely to impact most, if not all, streams immediately downstream of construction areas and reduce their capacity to maintain diversity of specialist amphibious species. Overall, this is likely to affect only a small proportion of upland streams within the broader terrestrial biodiversity study area and the area is unlikely to lose its overall capacity to maintain diversity of upland streams.

In the context of the terrestrial biodiversity study area, the effect on upland streams will be readily detectable but will be generally contained within the Project disturbance area. With a commitment to reduce damage at stream crossings and measures implemented to prevent introduction of exotic invasive species and fire, and to limit in-migration and hunting, the magnitude of direct and indirect impacts to upland streams by the Project was assessed as **low**, resulting in a **moderate** indirect impact significance rating.

Caves

Some caves are likely to occur in the area of the proposed limestone quarry and some in lithologies other than limestone will be damaged or lost during construction. However, there will be no direct impacts to caves outside the Project disturbance area where the majority of caves are likely to be located (i.e., in the Nena karst ecosystem). With management measures for caves and cave fauna implemented, damage to caves will be largely limited to within the Project disturbance area.

Considering that Project activities will not occur on or near the Nena limestone plateau (the location of the most important caves), any impact will be barely detectable with respect to natural variability. The magnitude of direct impacts by the Project was assessed as **negligible** after the implementation of management measures to limit disturbances to caves.

In-migration and resettlement have the potential to increase hunting pressure on cave fauna and to introduce wildlife diseases. There are not expected to be any physical damage to caves resulting from in-migration. The residual indirect impact is predicted to increase to **moderate** significance rating.

Species of Conservation Concern

The impacts on the terrestrial biodiversity study area landscape, ecologically significant ecosystems and focal habitats will affect flora and fauna species which inhabit these areas to varying degrees. This assessment of species population biodiversity values focuses on the dynamics of populations, how they interact with the environment and whether Project activities will influence these interactions over time and space. More detailed analysis is provided in Appendix 8c.

The impact assessment of flora and fauna populations includes species that are:

- Listed as threatened (Critically Endangered, Endangered and Vulnerable) or Near Threatened on the IUCN Red List.
- Listed as protected under the Fauna Act.
- Culturally important.

Overall, residual impacts (i.e., losses of individuals and populations within the terrestrial biodiversity study area) were assessed for 85 species. For direct Project impacts there were **moderate** impacts predicted for three species, **minor** impacts predicted for eight species and **negligible** impacts predicted for 75 species. Residual indirect impacts are likely to be higher due to the expected difficulty in controlling in-migration related effects. As a consequence, **major** impacts on eight species, **moderate** impacts on eight species, **minor** impacts on 24 species and **negligible** impacts on 45 species are predicted.

Impacts to species of conservation concern all take the form of reduced abundance and/or density of flora and fauna populations or reduction of their preferred and available habitat within the terrestrial biodiversity study area. As discussed in Section 8.6.2, these may be directly caused by the Project (e.g., by vegetation clearance) or indirectly caused by the Project (e.g., influencing human land use as a result of in-migration that occurs in response to the Project).

For discussion purposes, species have been grouped to reflect similar ecologies and sensitivities to threatening processes and, to a certain degree, the magnitude of potential impacts. A conservative approach was used by assuming species presence based on known habitats and distributions, rather than simply whether they were recorded during surveys. Residual direct and indirect impacts to species of conservation concerns that result in an impact significance of moderate and above are summarised in Table 8.50 and discussed in the following sections. Appendix 8c presents the assessment of all species of conservation concern including those with residual impact significance assessed as minor or negligible.

Table 8.50 Moderate or higher significance residual impacts to species of conservation concern

Species	Conservation Status (IUCN, Fauna Act)	Likelihood of Occurrence	Direct Impact Significance	Indirect Impact Significance
Sir David's long-beaked echidna (*Zaglossus attenboroughi)*	CE, P	Low	Moderate	Major
Eastern long-beaked echidna (*Zaglossus bartoni*)	VU, P	Recorded	Minor	Moderate
Telefomin cuscus (*Phalanger matanim)*	CE, P	Recorded	Negligible	Major
Black-spotted cuscus (*Spilocuscus rufoniger)*	CE	Recorded	Moderate	Major
Bulmer's fruit bat (*Aproteles bulmerae)*	CE	Low	Negligible	Major
Goodfellow's tree kangaroo (*Dendrolagus goodfellowi)*	EN, P	Recorded	Moderate	Major
Western montane tree kangaroo (*Dendrolagus notatus)*	EN, P	Recorded	Negligible	Major
Salvadori's teal (*Salvadorina waigiuensis)*	VU P	High	Negligible	Moderate
Pesquet's parrot (*Psittrichas fulgidus)*	VU	Recorded	Minor	Moderate
Papuan eagle (*Harpyopsis novaeguineae)*	VU P	Recorded	Minor	Moderate
Victoria crowned-pigeon (*Goura victoria)*	NT, P	Recorded	Negligible	Moderate
Northern cassowary (*Casuarius unappendiculatus)*	CUI	Recorded	Minor	Major
Dwarf cassowary (*Casuarius bennetti)*	CUI	Recorded	Minor	Major
Lesser bird-of-paradise (*Paradisaea minor)*	P	Recorded	Negligible	Moderate
Palm cockatoo (*Probosciger aterrimus)*	P	Recorded	Minor	Moderate

Table 8.50 Moderate or higher significance residual impacts to species of conservation concern (cont'd)

Species	Conservation Status (IUCN, Fauna Act)	Likelihood of Occurrence	Direct Impact Significance	Indirect Impact Significance
Blyth's hornbill (*Aceros plicatus)*	P	Recorded	Minor	Moderate

IUCN Categories: CE = Critically Endangered, E = Endangered, VU = Vulnerable, NT = Near threatened.
PNG Fauna Act: P = Protected.
Culturally important species = CUI.

Threatened Arboreal Mammals

Up to ten large threatened arboreal mammals may occur in the terrestrial biodiversity study area. These are primarily threatened by overhunting. Residual impacts to threatened arboreal mammals of conservation significance are discussed below and summarised in Table 8.50.

The Critically Endangered black-spotted cuscus (*Spilocuscus rufoniger*) is known from scattered localities within the Mamberamo, Sepik and Ramu drainages from sea level to 1,200 m ASL. Its presence in the terrestrial biodiversity study area is predicted based on distributional data, the occurrence of large areas of suitable habitat, trophy jaw photographed at Nekiei village and information obtained from villagers at Nekei, Paru and Kubkain. The smaller, but also Critically Endangered, Telefomin cuscus (*Phalanger matanim*) is known only from Telefomin and Urapmin, about 20 km south-south-west of the terrestrial biodiversity study area between 1,400 ASL and 2,600 m elevation. While not recorded in the terrestrial biodiversity study area, interviews with hunters suggest it could occur at higher elevations.

Five threatened arboreal mammals have the potential to occur within the northern portion of the terrestrial biodiversity study area. These include three additional tree kangaroos, Tenkile (*Dendrolagus scottae*) and Weimang (*Dendrolagus pulcherrimus*) both listed as Critically Endangered, the grizzled tree kangaroo (*Dendrolagus inustus*), and the smaller northern glider (*Petaurus abidi*) and D'Albertis's ringtail possum (*Pseudochirops albertisii*) listed as Critically Endangered and Near Threatened, respectively. Despite the known distributions of Tenkile, Weimang and northern glider potentially extending through portions of the northern terrestrial biodiversity study area, their discovery here would be a significant extension of range and would improve their conservation situation and as such their likelihood of occurring was conservatively assessed as low to moderate. Similarly, the Project area is not known to coincide with the known range of D'Albertis's ringtail possum although upper parts of the Bewani Mountains may provide suitable habitat above 1,000 m ASL. The grizzled tree kangaroo is a widely distributed species in the North Coastal Ranges and surrounding lowlands between 100 and 1,400 m ASL. As such, there is a higher likelihood of occurrence from the Sepik River northwards.

The two tree kangaroo species that occur in the Central Cordillera are more common. The Endangered Goodfellow's tree kangaroo (*Dendrolagus goodfellowi*) is a widespread New Guinea endemic occurring as different subspecies in what appears to be a naturally fragmented range. A hunting trophy from the Nena limestone area was recorded in Wameimin 2 and hunters from Wameimin 1 and 2 stated that this species, called '*Yema*', could be found on the peaks and ridges within the terrestrial biodiversity study area. The second tree kangaroo is clearly distinguished from the Goodfellow's tree kangaroo, with hunters describing it has having dark fur, which is consistent with western montane tree kangaroo (*D. notatus*). This species occurs from west of the Strickland River to near Lae between 900 and 3,100 m ASL. Finally, the plush-coated ringtail possum (*Pseudochirops corinnae*) is a small, folivorous possum endemic to New Guinea and widely distributed throughout the Central Cordillera and the Huon Peninsula between 900 and 2,900 m ASL.

Forest loss is a threat to all these species. Limited Project infrastructure is planned for the higher elevation parts of the terrestrial biodiversity study area. Therefore, only small areas of habitat of the Telefomin cuscus, western montane tree kangaroo, plush-coated ringtail, Tenkile, Weimang, northern glider D'Albertis's ringtail possum will be cleared. Some suitable habitat for the black spotted cuscus, Goodfellow’s tree kangaroo and grizzled tree kangaroo will be cleared and the access road may present a barrier to their movement. Minimising the Project disturbance area, initiating a conservation plan for hunted species and preventing wildfires in the Project disturbance area should reduce direct impacts. The significance of residual direct impact significance was assessed as **negligible** for the high montane species but **moderate** for black-spotted cuscus and Goodfellow’s tree kangaroo.

Hunting is the primary threat to all these species and is listed as a threatening process by the IUCN. Therefore, control of hunting by the workforce is a key mitigation measure to limit direct impacts on these species. Additional hunting pressure produced by in-migration is harder to mitigate and is likely to increase in the montane forests to the south-west, and possibly within the higher elevations of the terrestrial biodiversity study area as a result of migration from Telefomin.

The residual impacts for the remaining threatened arboreal mammals is predicted to be **high** with the exception of the species that have the potential to occur in the North Coastal Ranges, where indirect impacts in relation to the Project are not predicted and **negligible** residual impacts are predicted.

Residual indirect impacts for the Telefomin cuscus, black-spotted cuscus, Goodfellow’s tree kangaroo and the western montane tree kangaroo were predicted to be **major** primarily due of the uncertainties surrounding in-migration, particularly its effects around Telefomin. These impacts could be further exacerbated depending on the location of resettled villages. Indirect residual impacts for the grizzled tree kangaroo, D'Albertis's ringtail possum and the plush-coated ringtail possum were predicted to be **minor**.

Other Large Threatened Terrestrial Fauna

This group consists of terrestrial animals that are of conservation significance and primarily threatened from hunting. Residual impacts are discussed below and summarised in Table 8.50.

There are two long-beaked echidna (*Zaglossus* spp.) species that could occur in the terrestrial biodiversity study area. These are the Vulnerable eastern long-beaked echidna (*Z. bartoni*) and the Critically Endangered Sir David’s long-beaked echidna (*Z. attenboroughi*), both of which are also protected under the Fauna Act. The nearest records of the former are from the vicinity of Telefomin and Tifalmin, about 30 km south-south-west of the terrestrial biodiversity study area. The latter is known only from the Cyclops Mountains but recent fossil finds suggest the species may occur in the Sepik foothills. These echidnas are mostly nocturnal, weigh up to 10 kg and are culturally significant as they are favoured hunting prey.

Even more culturally significant are two species of cassowaries and the large Victoria crowned-pigeon (*Goura victoria*). Northern cassowary (*Casuarius unappendiculatus*) and dwarf cassowary (*C. bennetti*) both occur in the terrestrial biodiversity study area. Both are frugivores, solitary and territorial, with individual birds occupying a large home range that provides fruit all year round. The northern cassowary is endemic to northern New Guinea and inhabits rainforest and swampy forest to at least 500 m ASL, preferring forest on gentle terrain such as floodplains. The dwarf cassowary occurs throughout upland forests of New Guinea and New Britain, mostly in Hill Forest and Lower Montane Forest, but also locally in the lowlands. The Victoria crowned-pigeon is endemic to the northern lowlands and some offshore islands where it inhabits all forest types up to 600 m ASL. Suitable habitat for these species is widespread throughout the terrestrial biodiversity study area.

Other large threatened terrestrial fauna susceptible to hunting include:

- Two small wallabies: New Guinea pademelon (*Thylogale browni*), listed as Vulnerable, and a small mountain dorcopsis (*Dorcopsulus* sp., thought to be *D. vanheurni*, listed as Near Threatened) were confirmed during field surveys and through interviews with hunters.
- One smaller mammal: the New Guinean quoll (*Dasyurus albopunctatus*), listed as Near Threatened, which was recorded during field surveys.
- Boelen's python (*Morelia boeleni*) which is a large, heavy-bodied snake that occurs above 1,000 m ASL along the entire length of the Central Cordillera. It is protected under the Fauna Act. The species was not recorded but could occur in the higher parts of the terrestrial biodiversity study area.

The primary direct impact to these species was assessed to be habitat loss as a result of vegetation clearance. Since there is limited infrastructure planned for higher elevations, species favouring these altitudes such as the long-beaked echidnas, dwarf cassowary and Boelen's python are not likely to lose significant areas of habitat. However, considering the Critically Endangered status of the Sir David's long beaked echidna, the direct loss of habitat for the species combined with further edge and disturbance effects of the Project led to the residual direct impact being conservatively assessed as **moderate**. The residual direct impacts on the dwarf cassowary and Boelen's python were assessed as **minor** and **negligible**, respectively.

For species inhabiting lowland habitats there will be greater habitat loss but most of these threatened species have relatively broad distributions and are somewhat adaptable. As a result, the magnitude of residual direct impacts after measures to minimise the Project disturbance and prevent wildfires from starting are predicted to be **negligible**, with the exception of the northern cassowary for which the residual direct impact is predicted to be **minor**. Some species, such as the wallabies, may benefit from the grassy edges generated by the forest clearing.

Hunting remains the primary threatening process for all these species, although less significant for Boelen's python or New Guinean quoll. Control of the Project workforce is a key mitigation for all species but increased hunting pressure by in-migrants is difficult to control, particularly beyond any granted leases for the Project. Due to the uncertainties associated with the effects of in-migration, the significance of residual indirect impacts was assessed as: **major** for Sir David's long-beaked echidna and the two cassowary species; **moderate** for the eastern long-beaked echidna and the Victoria crowned-pigeon; and **minor** for the New Guinea pademelon, the small mountain dorcopsis, and the New Guinean quoll.

Cave Fauna

Many species of bats and swiftlets are dependent on caves for roosting and breeding. Residual impacts are discussed below and with full assessments provided in Appendix 8c.

The most significant species is the Critically Endangered Bulmer's fruit bat (*Aproteles bulmeri*). There is no direct evidence for the presence of Bulmer's fruit bat within the terrestrial biodiversity study area. However, one of the modern records of the species is from the Telefomin area, 30 km south-south-west of the terrestrial biodiversity study area. In addition, it is known to frequent large limestone sinkholes of the type found within the large limestone plateau in the area. As such, the species could occur in the terrestrial biodiversity study area. Other cave dwellers that could occur are five species of micro bats and swiftlets.

These species not only require forest for foraging but specifically caves for roosting and breeding, particularly for Bulmer's fruit bat and bent wing bats. There are no expected direct impacts on roosting or breeding caves since there is no Project infrastructure planned for the karst areas. Loss of habitat will reduce foraging areas for all species, but the areas of remaining habitat are extensive and mitigations to limit the Project disturbance area and prevent wildfires from starting due to Project activities were assessed to result in a **negligible** direct impact.

Increased hunting, particularly if there is in-migration from the Telefomin region, is the greatest potential threat to Bulmer's fruit bat, if it is present. In-migration and increased human movements around Telefomin could impact on the species if they hunt animals from a cave roost. The indirect impact on the Bulmer's fruit bat has conservatively been rated as **major** on the basis of its rarity, the uncertainty regarding in-migration and recent history of human caused local elimination of a roosting colony near Tabubil. This impact could be increased depending on the location of resettled villages. For other cave-dwelling species, such as the Vulnerable Hill's leaf-nosed bat (*Hipposideros edwardshilli*), the significance of any indirect impacts were assessed as **negligible** (Appendix 8c).

Birds-of-Paradise and Satinbirds

Eleven species of birds-of-paradise and satinbirds were recorded in the terrestrial biodiversity study area and seven others could occur. Residual impacts are summarised below and assessed in Appendix 8c.

All but two birds-of-paradise and satinbirds are endemic to New Guinea and protected under the *Fauna (Protection and Control) Act 1966*. The males are characterised by spectacular plumage while the females are duller plain brown. Most have communal display grounds (leks) where males compete for females. The lowland and hill birds-of-paradise are tolerant of forest disturbance to some extent. A mosaic of habitats provides a more plentiful and reliable source of fruit for the more frugivorous species. The higher elevation species are more dependent on primary forest but do use edge and secondary habitats. Only the yellow-breasted bird-of-paradise appears to be restricted to primary forest.

Upland species are highly unlikely to be directly impacted since limited infrastructure is planned for the higher elevations of the terrestrial biodiversity study area and only a small amount of edge habitat may affected. For lowland species, even though some habitat will be lost, all can occupy disturbed habitat mosaics so it is unlikely to significantly impact local populations. The significance of residual direct impacts are estimated to be **negligible** for all species.

Increased hunting pressure as an indirect result of the Project is likely the most significant threatening process for all except the duller species such as the manucodes. The significance of residual indirect impacts was assessed as **negligible** for the less valued species. Of the more valuable highly decorative species, the residual indirect impact was assessed as **moderate** for the conspicuous lesser bird-of-paradise and **minor** for the other decorative species (i.e., the black sicklebill, black-billed sicklebill, superb bird-of-paradise, Queen Carolina's parotia, twelve-wired bird-of-paradise, magnificent bird-of-paradise, king bird-of-paradise and magnificent riflebird).

Other Canopy Birds

This is a group of three frugivores and three raptors with particular habitat preferences. All require large areas of habitat and, for the frugivorous species, a supply of fruiting trees. All nest in tree hollows. These are:

- Pesquet's parrot (*Psittrichas fulgidus*): a large, black and red parrot, a nomadic, specialist frugivore patchily distributed throughout the island of New Guinea.
- Palm cockatoo (*Probosciger aterrimus*): a black cockatoo with a red face and large crest which occurs throughout the island of New Guinea lowlands and hills up to 1,300 m ASL in rainforest, secondary forest and tropical savanna.
- Blyth's hornbill (*Aceros plicatus*): one of the region's largest and most mobile frugivores and amongst the most widely recorded bird species during field surveys.

- Papuan eagle (*Harpyopsis novaeguineae*): occurs at low densities throughout the island of New Guinea in mostly undisturbed forests from sea-level to over 3,000 m ASL.
- Gurney's eagle (*Aquila gurneyi*): widespread though sparsely distributed in all forest habitats from sea level to about 1,300 m ASL.
- Doria's goshawk (*Megatriorchis doriae*): a smaller raptor that usually flies below the canopy and mainly preying on birds. It is a poorly known on the island of New Guinea, endemic and sparsely distributed from sea level up to at least 1,100 m ASL.

While some population losses would be expected, large areas of remaining habitat suggest that the direct habitat loss is unlikely to impact the species within the terrestrial biodiversity study area. The significance of residual direct impacts were assessed as **negligible** or **minor** after the implementation of mitigations to limit the Project disturbance area and prevent wildfires from starting.

The significance of residual indirect impacts as a result of increased hunting and the potential for accidental introduction of exotic diseases and pests caused from in-migration were predicted to be greater. Increased hunting pressure is a key threat to species that are commonly hunted such as Pesquet's parrot, the palm cockatoo, Blyth's hornbill and the New Guinea eagle. Therefore, residual indirect impacts were conservatively predicted to be **moderate** for these four species and **minor** for Gurney's eagle and Doria's goshawk.

Trees

Seventeen plants recorded in the terrestrial biodiversity study area are listed by IUCN. These include six valued timber trees, nine species of other trees, a cycad and a liverwort moss. Two species are listed as Critically Endangered – Saffronheart (*Halfordia papuana*) and the liverwort moss (*Schistochila undulatifolia*) – while one species is Endangered – Maple Silkwood (*Flindersia pimenteliana*). A further seven species are listed as vulnerable and the remaining seven listed as Near Threatened.

The significance of residual direct and indirect impacts is predicted to be **negligible** for all plant species. The liverwort moss has only been recorded at the Nena Base locality, which is outside the Project disturbance area. Saffronheart, maple silkwood and other tree species have wide natural distributions well beyond the Project disturbance area. Forest degradation by in-migration is less easily controlled but large-scale targeted felling of individual trees is unlikely.

Butterflies

Three large birdwing butterflies (genus *Ornithoptera*) were recorded in the terrestrial biodiversity study area: the Endangered ornithoptère méridional (*O. meridionalis*) and two Least Concern species, the butterfly of paradise (*O. paradisea*) and the goliath birdwing (*O. goliath*). A fourth species, the Near Threatened chimaera birdwing (*O. chimaera*), was not recorded but could easily occur. With the exception of *O. meridionalis*, all are protected under the *Fauna (Protection and Control) Act 1966*. Threats to these species include large-scale forest loss and invasive species replacing the *Aristolochia* foodplant. The significance of residual direct and indirect impacts are predicted to be **negligible** for these species.

Waterbirds

A range of waterbirds that may occur in the terrestrial biodiversity study area are protected under the *Fauna (Protection and Control) Act 1966* and/or listed as Vulnerable or Near Threatened by IUCN. These include the Vulnerable Salvadori's teal (*Salvadorina waigiuensis*), the Near Threatened forest bittern (*Zonerodius heliosylus*) and three species of egrets listed as Least Concern – the little egret (*Egretta garzetta*), eastern great egret (*Ardea modesta*) and the intermediate egret (*Mesophoyx intermedia*).

These species may be impacted by hydrological changes, waterway contamination and hunting. The significance of residual direct impacts on these species was assessed to be **negligible** after the implementation of management measures aimed at preventing contamination.

Indirect impacts are likely to be more significant for waterbirds. All are potential prey for hunters, particularly Salvadori's teal. In addition, degradation or loss of montane and hill habitats by in-migrants settling in the montane and hill forests would reduce habitats for Salvadori's teal and the forest bittern. There is unlikely to be large losses of lowland wetlands for the remaining species. The significance of residual indirect impacts were assessed as **moderate** for the Salvadori's teal, **minor** for the forest bittern and **negligible** for the egret species.

Shorebirds

A range of threatened migratory waders could potentially occur within the terrestrial biodiversity study area including the Endangered far eastern curlew (*Numenius madagascariensis*) and great knot (*Calidris tenuirostris*) and the Near Threatened black-tailed godwit (*Limosa limosa*), bar-tailed godwit (*L. lapponica*), red-necked stint (*Calidris ruficollis*), red knot (*Calidris canutus*), curlew sandpiper (*C. ferruginea*), Asian dowitcher (*Limnodromus semipalmatus*) and grey-tailed tattler (*Tringa brevipes*). These species generally have large breeding ranges in the northern hemisphere and migrate south to winter in Europe, Africa, the Middle East and Australasia. The vast majority that visit the island of New Guinea are en route to Australia via the East Asian-Australasian flyway. They frequent shallow freshwater and muddy marine habitats and, though predominantly coastal, can also occur in interior wetlands.

Few waders were recorded in the terrestrial biodiversity study area, but any can occur on soft muds and sands adjacent to any of the major waterways, open swamps and lakes in the lowland zone. Conservation issues concerning Palaearctic waders and their habitats are discussed in Appendix 8a. With the exception of the Vanimo Ocean Port that will be built in an already developed area, there will be no direct impacts to the coastal habitats of these species nor the ORWBs, which would be their primary inland foraging habitat when in PNG. The major potential impacts are contamination of waterways reaching these habitats and these are not predicted to occur. The significance of residual direct and indirect impacts are therefore predicted to be **negligible**.

Amphibious Species

This group contains species, including odonates and frogs, dependent on both aquatic and forest condition. The discovery of several of these species in the terrestrial biodiversity study area represents major range extensions. All are endemic to the island of New Guinea and some frog species are endemic to the North Coastal Ranges. However, the only listed threatened species is the Vulnerable dragonfly (*Bironides teuchestes),* which was recorded perched in sunlight in forest near torrential streams at Malia and Frieda Bend Sites, and appears rare. Local populations of *B. teuchestes* may be eliminated by clearing activities; however, the species is likely to persist if stream bank disturbance is minimised and buffers along waterways maintained. The potential effects of in-migration can be addressed through the management measures. The residual direct and indirect impacts are assessed to be **minor**.

Forest Bats and Birds

The island of New Guinea has many species of small forest bats that roost in forests, under leaves or in tree hollows.

The Near Threatened blue-black kingfisher (*Todiramphus nigrocyaneus*) was provisionally recorded during the surveys. Loss of lowland forest habitat as a result of the Project is expected; however, large areas of suitable habitat will remain and populations within the terrestrial biodiversity study area are unlikely to be significantly impacted. The residual direct impact significance is predicted to be **negligible** with implementation of measures to limit the disturbance area and prevent contamination. Deforestation resulting from in-migration may increase the threat to the species and the residual indirect impact significance is predicted to increase to **minor**.

Rodents of Conservation Concern

The Endangered northern water rat (*Paraleptomys rufilatus*) is known from montane forests in the Cyclops, Bewani and Prince Alexander Mountains between 1,200 and 1,700 m ASL. It is likely to occur in the upper parts of the Bewani Mountains section of the infrastructure corridor, but the route of the pipeline and transmission line are well below 1,200 m ASL. The residual direct and indirect impacts are predicted to be **negligible** as this part of the infrastructure corridor is not expected to attract migrants.

8.6.5 Offsets

The terrestrial biodiversity impact assessment has identified biodiversity values and, where avoidance was not feasible, proposed management measures to reduce the severity of impact and then assessed the likely residual impacts to these values. Within the mitigation hierarchy, offsets are then typically developed for direct impacts that cannot be avoided or mitigated.

Currently there is no legislative framework for biodiversity offsets in PNG, although there are plans to establish an offset system and/or fund. This means that offset mechanisms available in other jurisdictions, such as compensation funds and mitigation banks, are not currently available. Nonetheless, FRL is committed to developing and implementing a biodiversity offsets package and program consistent with the goals of CEPA.

The most practical way in which to offset residual impacts to terrestrial biodiversity is through conservation. FRL's biodiversity offset program will therefore consider as a first preference a focus on area-based conservation through the strengthening of existing protected areas and/or establishment of new protected areas. However, FRL recognises there are challenges to achieving such an outcome in PNG. These include: the few existing protected areas in the country; the limited organisational capacity to develop and manage protected areas; and recognition that customary land ownership in PNG creates challenges when controlling land for conservation purposes.

As a regional and national development project, the Project is designed to stimulate the expansion of agricultural and industrial development and therefore could influence (both directly and indirectly) terrestrial biodiversity in the region. Biodiversity loss as a result of regional development requires a coordinated regional approach and the production of conservation outcomes involving all stakeholders from village, local, provincial and national governments as well as private enterprise.

An effective response to regional scale biodiversity loss that may result as an indirect impact of the Project would be for FRL to expand activities of the existing consultative systems to include regional conservation planning, which may involve other private enterprise projects. Such a program has the potential to be an effective way to develop an offset system which is currently absent from PNG. This high level, integrated regional approach would establish active negotiated conservation developments that would not solely rely on FRL. Offsets for any project would then be a formal contribution to a planned conservation system by the particular project. This will be further discussed with CEPA during the EIS assessment and approval process.

8.7 Noise and Vibration

This section describes the noise and vibration impacts of the Project, based on the noise and vibration impact assessment conducted by SLR Consulting Australia Pty Ltd (SLR) and presented in Appendix 10.

8.7.1 Approach to Impact Assessment

This section describes the scenarios considered in the assessment and the Project guidelines applied to them.

Assessment Method

Noise

The noise assessment was performed using a mixture of quantitative and qualitative assessment techniques for a range of Project components and scenarios. The quantitative methods included three-dimensional (3D) computer modelling and calculation of offset distances. These methods took into account factors such as the noise source and location, distance attenuation, ground absorption, air absorption, shielding attenuation as well as adverse and neutral meteorological conditions, based primarily on wind effects. The qualitative method was comprised of a review of likely noise sources and the proximity to sensitive receptors. Table 8.51 shows the assessment method used for each scenario.

Table 8.51 Summary of noise assessment scenarios

Number	Project Component	Assessment	Scenario/Year
Construction			
1	Mine and FRHEP area*	3D computer modeling†	Worst case§
2	Vanimo Ocean Port	3D computer modeling†	Worst case§
3	Frieda River Port, Upper Sepik River Port and May River Port	Offset Distance Calculations**	Worst case§
4	Infrastructure corridor (concentrate pipeline, transmission line and main access route)	Offset distance calculations**	Worst case§
5	Barging (materials transport) along the Sepik, May and Frieda rivers	Offset distance calculations**	Worst case§
6	Frieda River airstrip and Green River Airport	Offset distance calculations**	Worst case§
7	Quarries	Offset distance calculations**	Worst case§
8	Sepik River bridge	Offset distance calculations**	Worst case§
9	Mine and FRHEP area*	3D computer modeling†	Year 5 (representative of peak mining rate and processing throughput) Year 12 (peak operation)
10	Infrastructure corridor (main access route – road traffic)	Offset distance calculations**	Typical operations‡
11	Frieda River airstrip and Green River Airport	Offset distance calculations**	Typical operations‡

Table 8.51 Summary of noise assessment scenarios (cont'd)

Number	Project Component	Assessment	Scenario/Year
Construction (cont'd)			
12	Vanimo Ocean Port	3D computer modeling†	Typical operations‡

* Open-pit, primary crushing facility, ROM pad, process plant, ISF embankment, waste rock barges and hydroelectric power facility.

† 3D computer modelling using SoundPLAN (Version 7.4) environmental computer model comprising digitised ground map.

§ The construction year with the most plant and equipment operating simultaneously.

** Assumes flat open ground between the noise source and the receiver.

‡ Typical operations – scenario representative of typical operations at the facility.

Vibration

The vibration study assessed two types of activities: blasting and non-blasting. Blasting activities include construction of the open-pit, ISF embankment, quarries, Vanimo to Hotmin public road and concentrate pipeline. Non-blasting activities include works associated with rock breaking, heavy vehicle movement and compaction (such as vibratory rollers) during construction and operation. Vibration pathways investigated include ground vibration for both blasting and non-blasting sources and airblast emissions from construction blasting sources. The emissions from blasting have been assessed based on spatial areas, while the non-blasting activities or ground vibrations have been assessed based on equipment sources. These are shown in Table 8.52.

Table 8.52 Summary of vibration sources of emissions

Activity	Source of Emission
Blasting – Ground vibration	Open-pit (operation) (such as explosives or blast area). ISF and quarries (construction) (such as explosives or blast area for the construction of the embankment, tunnels etc.). Concentrate pipeline and public road (construction) (such as explosives or blast area).
Blasting – Airblast overpressure	Open-pit (operation) (such as explosives or blast area). ISF and quarries (construction) (such as explosives or blast area). Concentrate pipeline and public road (construction) (such as explosives or blast area).
Non-blasting	Heavy vehicle movement, compaction activities (vibratory rollers), piling, earthwork activities (trenching, excavating and rock breaking) for the transmission line, and to build the foundations for bridges, substations and other infrastructure.

Assessment Models

Noise

The noise modelling completed in SoundPlan used the CONCAWE noise propagation model and considered both neutral and adverse meteorological conditions to provide a conservative assessment. CALMET meteorological modelling was used to model wind and temperature fields that take the local topography and land uses into consideration.

Maximum aircraft flyover noise levels were determined using calculations from the relevant Australian Standard 2021:2000.

The offset calculations were based on prepared calculations that considered the source Sound Power and locations, distance attenuation, ground absorption, air absorption, flat open ground and neutral meteorological conditions.

Further detail about the noise assessment methods is provided in Appendix 10.

Vibration

Modelling of blasting emission levels was based on Australian Standard 2187-2:2006 and industry guides, incorporating the Project's typical blast design. Information for ground vibration was sourced from SLR's vibration source reference database.

Further detail about the vibration assessment method is provided in Appendix 10.

Project Guidelines

Noise

Adopted Project noise guidelines for construction and operation are summarised in Table 8.53. In the absence of PNG regulatory criteria for noise and vibration the noise and vibration assessment was undertaken in accordance with relevant international standards and guidelines.

Existing noise levels in the Project area have not been surveyed, although noise monitoring undertaken in similar environments elsewhere in PNG provides a basis for impact assessment. These existing noise levels ranged widely and therefore a conservative approach was adopted by applying the lower noise guideline values from WHO (1999) and IFC (2007a). Dwellings found in rural PNG differ to typical western houses and are generally constructed from lightweight materials with direct external openings, e.g., no glass windows to reduce noise. The WHO (1999) guidelines suggest that a correction of 15 decibels (dBA) is applied to typical western or European buildings to determine the difference between indoor and outdoor noise levels. A difference correction of 5 dBA was considered more appropriate for rural PNG given the typical dwelling construction.

Table 8.53 Adopted Project noise guidelines for construction and operation

Phase or Emission Source	Guidelines		
	Day (7:00 a.m. to 6:00 p.m.)	Evening (6:00 p.m. to 10:00 p.m.)	Night (10:00 p.m. to 7:00 a.m.)
Construction	55 dBA L_{Aeq}	50 dBA L_{Aeq}	35 dBA L_{Aeq}
Operation	40 dBA L_{Aeq}	40 dBA L_{Aeq}	35 dBA L_{Aeq}
Aircraft traffic	80 dBA L_{Amax}	80 dBA L_{Amax}	80 dBA L_{Amax}
Main access route – road traffic	65 dBA L_{Aeq}	65 dBA L_{Aeq}	50 dBA L_{Amax}
Barge traffic	65 dBA L_{Aeq}	65 dBA L_{Aeq}	50 dBA L_{Amax}

L_{Aeq} is the average sound level filtered for the sound frequencies corresponding to that of human hearing.

L_{Amax} noise level is the maximum A-weighted noise level associated with site activity.

Construction and operation activities will occur 24-hours-per-day, seven-days-per-week, for activities in the mine and FRHEP area, and 12-hours-per-day, seven-days-per-week for other operation activities including the river ports and roads. Given this, the most stringent noise guideline level (i.e., night levels of 35 dBA L_{Aeq}) has been used for the assessment for most scenarios. The exceptions are for construction of the public road and concentrate pipeline (55 dBA L_{Aeq}), road traffic on the public road (65 dBA L_{Aeq} with 50 dBA L_{Amax} for night levels), aircraft traffic (80 dBA L_{Amax}) and barge traffic (65 dBA L_{Aeq} with 50 dBA L_{Amax} for night levels).

Vibration

The vibration study has been divided into blasting and non-blasting activities. Blasting produces both ground vibration and airblast overpressure (i.e., the sound wave produced by the blast and transmitted through the air) while non-blasting activities only generates potential vibration impacts.

The vibration assessment was based on Australian and international standards. A daytime vibration goal of 5 millimetres per second (mm/s) peak component particle velocity for 95% of blasts (maximum of 10 mm/s) has been adopted for the Project, based on Appendix J4 of the Australian Standard 2187.2:2006. The airblast overpressure goals adopted for the Project allow 5% exceedance of a 115 dBL Peak and up to a ‘never to be exceeded’ maximum of 120 dBL Peak. This 120 dBL Peak corresponds to the WHOs limit to prevent hearing damage to children from sources such as blasting. Criteria for ground vibration for non-blasting activities were based on international criteria for human comfort and structural damage.

8.7.2 Potential Impacts

The main sources of noise and vibration during the construction and operation of the Project will comprise both fixed and mobile sources, including:

Fixed sources

- Hydroelectric power facility.
- Diesel generators.
- Process plant.
- Crushers and conveyors.
- Barge loading.
- Workshop and maintenance activities.

Mobile sources

- Machinery (e.g., drills, loaders, haul trucks, excavators and other ancillary equipment).
- Vehicles.
- Barges.
- Aircraft movement.
- Ship movement and other port activities.

The noise and vibration emitted from these sources has the potential to disturb the closest sensitive receptors. Noise and vibration nuisance is generally determined by the increment above background noise and vibration levels. Table 8.54 and Figure 8.14 show the sensitive receptors that are located within the vicinity of major Project infrastructure and 4 km of the infrastructure corridor. This will be refined during detailed design, and it is likely that these distances will increase where current information predicts very close separation distances (e.g., less than 100 m). As a consequence, the results presented for these aspects are highly conservative.

Table 8.54 Sensitive receptors located within the vicinity of Project components

Sensitive Receptor	Approximate Distance to the Open-Pit and ISF Embankment
Paupe	24 km north-east of the open-pit 6.5 km north-east of the ISF
Wameimin 2	7.5 km north-west of the open-pit
Ok Isai	Within ISF inundation area and not assessed due to proposed village relocation
	Approximate Distance to the Open-Pit and ISF Embankment
Wabia	Within ISF inundation area and not assessed due to proposed village relocation
	Approximate Distance to the Infrastructure Corridor
Temsapmin	900 m south-east

Table 8.54 Sensitive receptors located within the vicinity of Project components (cont'd)

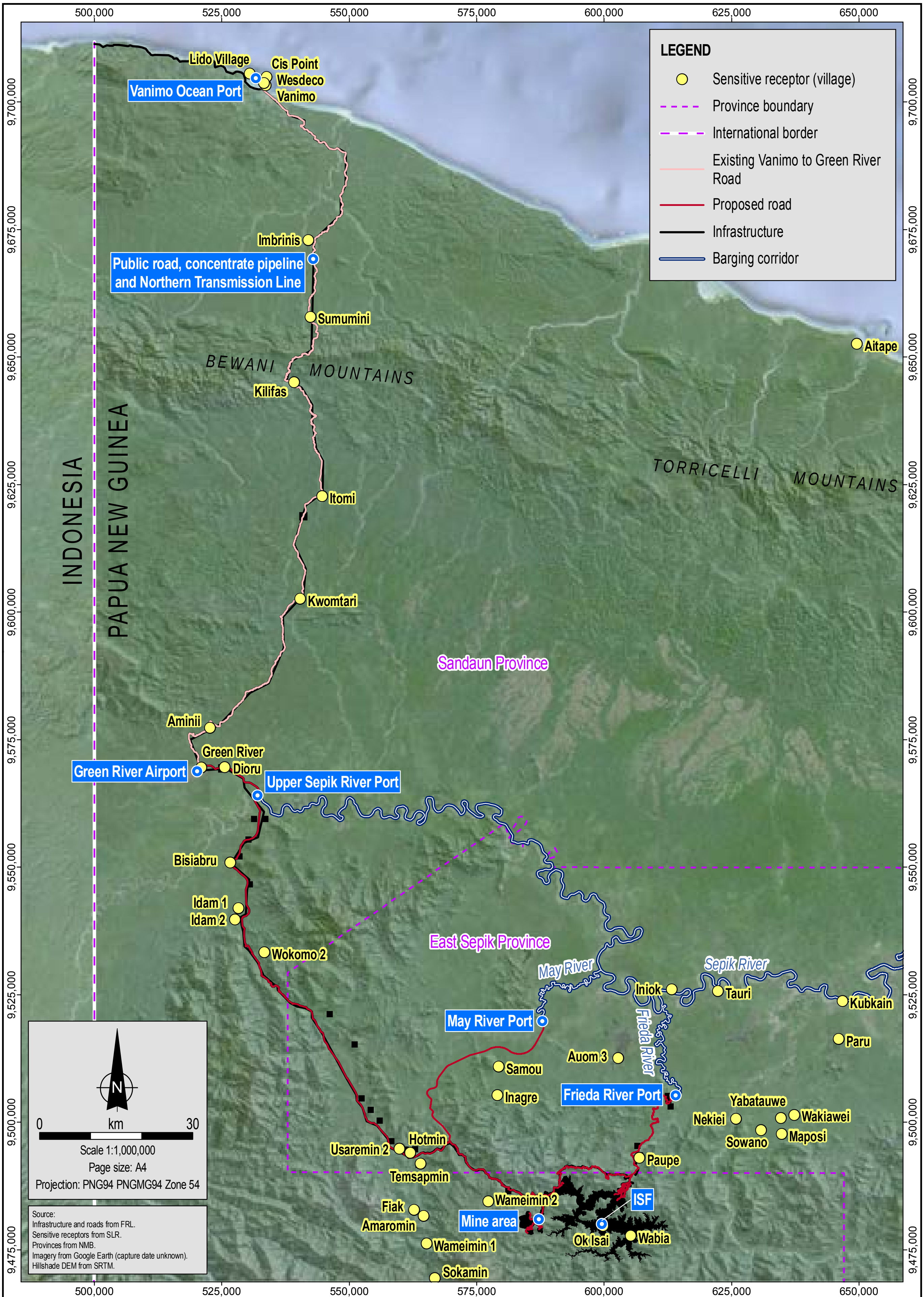
Sensitive Receptor	Approximate Distance to the Infrastructure Corridor (cont'd)
Hotmin	340 m north
Usaremin 2	550 m north-east
Wokomo 2	90 m south-west
Idam 1	1.5 km south-west
Idam 2	1.2 km west
Bisiabru	440 m west
Dioru	20 m south-west
Green River Station	30 m west
Aminii	10 m east
Kwomtari	300 m east
Itomi	140 m east
Kilifas	30 m east
Sumumini	20 m east and west
Imbrinis	25 m east and west
Vanimo	15 m on both sides of corridor
	Approximate Distance to Airstrips
Paupe	2.5 km north. Some receivers are located 1.9 km from the runway.
Green River Station	40 m north
	Approximate Distance to the Vanimo Ocean Port
Various residences in Vanimo	50 m (nearest receptors)
	Approximate Distance to River Ports
Dioru	8 km north-west of Upper Sepik River Port
Samou	11 km east of May River Port
Nekiei	12.8 km south-east of Frieda River Port

Project activities will generate noise and vibration, which can disturb roosting bat colonies. This potential impact is considered in Section 8.6.4 and is not discussed further in this section.

Table 8.55 describes the phases of the Project in which the potential impacts are predicted to be most applicable.

Table 8.55 Summary of potential impacts of noise and vibration emissions and relevance to Project phases

Potential Impact	Phase			Comment
	Construction	Operation	Closure	
Increased noise and blasting levels in proximity to sensitive receptors	✓	✓		Emissions will be from vehicles and equipment used for clearing, levelling, and surfacing, aircraft flyover, Green River Airport construction, barging, road and pipeline construction, road traffic, blasting, power generation, mine operations and Vanimo Ocean Port construction and operations.



MXD Reference: 11575B_11_GIS029_v0_4

coffey A TETRA TECH COMPANY	Date: 14.09.2018 Project: 754-ENAUABTF11575B File Name: 11575_11_F08.14_GIS	Frieda River Limited Sepik Development Project	FRIEDA RIVER	Sensitive receptors located in the vicinity of major Project infrastructure	Figure No: 8.14

8.7.3 Management Measures

Management measures to address noise and vibration emissions generated during construction and operations are detailed in Table 8.56.

Table 8.56 Noise and vibration management measures

No.	Management Measure
Stakeholder Engagement	
MM112	Sensitive receptors within 800 m of the infrastructure corridor will be made aware of the times and duration of construction activities.
SEM057	Provide access to an effective and transparent Grievance Management Procedure for communities, employees and contractors.
MM113	When a grievance has been received, investigate and conduct noise and/or vibration monitoring, if required.
MM114	Communicate the findings of a grievance investigation to construction site personnel.
MM115	Schedule construction works to avoid working in proximity of villages on religious and cultural holidays, where practicable.
Source Noise Control and Project Design Strategies	
MM1116	Equipment and vehicles will be maintained regularly in accordance with manufacturers' specifications.
MM117	Construct enclosures, bunds and noise barriers for operation of equipment and fixed infrastructure that may result in an exceedance of the adopted Project noise guidelines, where practicable.
MM118	The export facility at Vanimo Ocean Port and the public road and concentrate pipeline associated with the infrastructure corridor will consider noise impacts in the design layout.
Work Practice Control Strategies – Noise	
MM119	Train personnel and contractors, through site inductions, on potential noise and vibration impacts and appropriate management procedures (e.g., vehicle and truck drivers, earthwork machinery operators, dust suppression), including techniques to reduce noise emission.
MM120	Vehicle speed, the use of compression brakes and horn signals will be limited on roads close to villages.
MM121	Limit construction activities associated with the main access route, pipeline and Vanimo Ocean Port to daytime hours, or schedule significant noise generating activities during the daytime where possible. Should night-time works or noise generating activities be required in exceedance of the project noise limits, alternative arrangements would be made with relevant sensitive receptors. Schedule aircraft movements during the daytime period to minimise sleep disturbance and annoyance when practicable.
MM122	In quarry areas near villages, place large rocks in dump trucks rather than dropping them in.
MM123	Conduct a detailed noise assessment inclusive of background noise measurements of Vanimo Ocean Port area operations to confirm the extent of noise impacts from the site.
Work Practice Control Strategies – Ground vibration and airblast overpressure	
MM124	Determine if additional blasting management measures are required once blasting locations and design parameters are confirmed (if blasting is going to be conducted near villages).
MM125	Sensitive receptors located within 415 m of the public road and pipeline will be notified of scheduled blasting events that may affect them during construction of the public road.

8.7.4 Residual Impact Assessment

The primary objective of the noise and vibration assessment was to assess impacts on sensitive receptors who are people residing in locations such as residential dwellings, hospitals, churches, schools where people may often be present, typically in villages and recreational areas, and sensitive fauna such as roosting bat colonies, resulting from Project-related noise and vibration emissions. Excessive noise and vibration has the ability to cause nuisance, including sleep deprivation, stress and increased blood pressure, as well as other physical, physiological and psychological effects.

Noise

The potential for noise emissions to impact nearby sensitive receptors is dependent on:

- The level of noise generated.
- ‘At source’ management of the noise generating activities.
- The separation distance from activities to the receptors.
- The prevailing wind direction and strengths.
- Background noise levels.

The noise scenarios predicted to exceed the adopted Project noise guidelines are:

- Infrastructure corridor (inclusive of the concentrate pipeline, main access route and Northern Transmission Line) (construction): Wokomo 2, Dioru, Green River Station, Aminii, Kwomtari, Itomi, Kilifas, Sumumini, Imbrinis and Vanimo.
- Green River Airport (construction and operation): Green River Station.
- Vanimo Ocean Port (construction and operation): Vanimo and Wesdeco.

Maximum offset distances are based on the distance between a sensitive receptor and Project works required to achieve the adopted Project noise guidelines. The maximum offset distances for these scenarios are:

- 300 m for the construction of the concentrate pipeline and public road, and the Green River Airport.
- 1,900 m for Green River Airport during operation.
- 550 m during construction of the Vanimo Ocean Port.
- 2,500 m (night activity) and 1,900 m (day activity) during operation of the Vanimo Ocean Port. Background noise levels, such as existing logging activities, ship movement and associated port activities, and general urban noises may result in similar noise levels at sensitive receptors within Vanimo.

Barging along the Sepik River, Frieda River and May River is predicted to generate a maximum pass-by noise level of 55 to 60 dBA, which is less than the daytime Project noise guideline value of 65 dBA L_{Aeq}. There are no sensitive receptors along the riverbank between the confluence with the Sepik River and Frieda River Port. The Sepik and May rivers are at least 300 m wide for most of the barging corridor resulting in a relative distance of approximately 150 m between barges and sensitive receptors. Barging is only expected to occur during daylight hours with typically no more than two pass-by events per day.

With the implementation of the proposed management measures, the modelling predicts that other construction and operation of Project components will not exceed the adopted Project noise guidelines.

Vibration

Blasting

Two blasting scenarios are predicted to exceed the adopted Project noise guidelines during construction of the concentrate pipeline and public road:

- Ground vibration impacts may be experienced by sensitive receivers in Wokomo 2, Dioru, Green River Station, Aminii, Itomi, Kilifas, Sumumini, Imbrinis and Vanimo.
- Airblast overpressure impacts may be experienced by sensitive receivers in Hotmin, Wokomo 2, Dioru, Green River Station, Aminii, Kwomtari, Itomi, Kilifas, Sumumini, Imbrinis Temsapmin and Vanimo.

The relocation of Paupe means that the currently-predicted exceedances of airblast overpressure criteria will not eventuate, as the village will move from its current location.

Maximum offset distances required to achieve the blasting Project guidelines for airblast overpressure impacts range from a maximum of 1,300 m from the open-pit during operations to 540 m from the ISF embankment and quarries during construction, and 415 m from the concentrate pipeline and public road during construction. The maximum offset distances for ground vibration impacts are slightly less for each of these.

Specific blasting locations along the public road will be determined during construction. These villages will not be impacted if blasting remains outside the offset distances. If blasting is required adjacent to these receptors, then specific blast management measures may be required for the short duration that blasting will occur.

Ground Vibration (Non-blasting Activities)

Some non-blasting activities, such as compaction activities (heavy vibratory rollers), heavy rock breaking and heavy vehicle movements during construction of the concentrate pipeline, public road and Vanimo Ocean Port were predicted to exceed the adopted Project ground vibration guidelines. The offset distances (the distance between the ground vibration source and the sensitive receptor) required to achieve compliance with Project guidelines for these activities include:

- An offset distance of 55 m is required to achieve the human comfort guideline for sensitive receptors potentially impacted by heavy vibrator roller activities.
- An offset distance of 15 m is required to achieve the human comfort guidelines for sensitive receptors potentially impacted by heavy rock breaking and heavy vehicle movements.

Other non-blasting activities that generate ground vibration assessed include impact piling activities. Predicted vibration levels at sensitive receptors near the Vanimo Ocean Port did not exceed Project guidelines for ground vibration.

With the implementation of the proposed management measures, the modelling predicts that other construction and operation of Project components will not exceed the adopted Project vibration guidelines.

8.8 Air Quality

This section describes the air quality impacts arising from the Project, based on the air quality assessment conducted by SLR and presented in Appendix 11.

8.8.1 Approach to Impact Assessment

Assessment Method

The air quality impact assessment was performed using a mixture of quantitative and qualitative assessment techniques. Table 8.57 presents the scenarios assessed. Quantitative emissions estimation and dispersion modelling was undertaken for two construction and two operation scenarios. These scenarios were chosen based on the identification of key Project activities that have the greatest potential for impacts on local air quality.

The study area for this assessment was defined as the area within approximately 15 km of mine and FRHEP infrastructure, 2 km of the infrastructure corridor and 2 km of Vanimo Ocean Port. Sensitive receptors identified for this air quality assessment are shown on Figure 8.14 and listed in Table 8.57.

The modelling considered sources of the following emissions:

- Airborne particulate matter (total suspended particulates (TSP), particulate matter less than 10 µm in diameter (PM_{10}) and particulate matter less than 2.5 µm in diameter ($PM_{2.5}$)).
- Products of combustion including sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOC), organic micro-pollutants, PM_{10} and $PM_{2.5}$.
- Dispersion of heavy metals contained within TSP emissions due to their presence in the ore and waste rock.

These air quality indicators were used in the assessment due to their link to adverse impacts on human health and amenity.

Activities with a much lower potential for impacts on local air quality were assessed qualitatively by comparing the separation distances between Project activities and the nearest sensitive receptors based on relevant international guidelines published for specific types of activities. This will be refined during detailed design, and it is likely that these distances will increase where current information predicts very close separation distances (e.g., less than 100 m). As a consequence, the results presented for these aspects are highly conservative.

Table 8.57 Air quality modelling scenarios

Scenario	Site/Facilities	Method of Assessment	Activities Modelled	Nearest Sensitive Receptors and Approximate Distance from Project Infrastructure (Nearest Receptors)
Construction scenarios				
C1	Mine and FRHEP area (open-pits, mine infrastructure area, ISF embankment and barge loading construction)	3D CALPUFF modelling	Clearing, earthworks and construction	Wameimin 2: 7.5 km north-west of the open-pit Paupe: 7 km north-east of ISF embankment, 24 km north-east of the open-pit

Table 8.57 Air quality modelling scenarios (cont'd)

Scenario	Site/Facilities	Method of Assessment	Activities Modelled	Nearest Sensitive Receptors and Approximate Distance from Project Infrastructure (Nearest Receptors)
Construction scenarios (cont'd)				
C2	Concentrate pipeline and public road (clear and grade activities)	3D CALPUFF modelling	Excavators, dozers, hauling, soil handling, wind erosion, drilling and blasting	Tamsapmin: 900 m south-east Hotmin: 340 m north Usaremin 2: 550 m north-east Wokomo 2: 90 m south-west Idam 1: 1.5 km south-west Idam 2: 1.2 km west Bisiabru: 440 m west Dioru: 20 m south-west Green River Station: 30 m west Aminii: 10 m east Kwomtari: 300 m east Itomi: 140 m east Kilifas: 30 m east Sumumini: 20 m east and west Imbrinis: 25 m east and west Vanimo: 15 m both sides of the alignment
	Construction of the Northern Transmission Line	Qualitative	Clearing, earthworks	Temsapmin: 900 m south-east Hotmin: 340 m north Usaremin 2: 550 m north-east Wokomo 2: 90 m south-west Idam 1: 1.5 km south-west Idam 2: 1.2 km west Bisiabru: 440 m west Dioru: 20 m south-west Green River Station: 30 m west Aminii: 10 m east Kwomtari: 300 m east Itomi: 140 m east Kilifas: 30 m east Sumumini: 20 m east and west Imbrinis: 25 m east and west Vanimo: 15 m both sides of the alignment
	Construction of Vanimo Ocean Port	Qualitative	Fugitive dust emission, diesel combustion products	Various residences: 50 m
	Green River Airport	Qualitative	Clearing, earthworks	Green River Station: 40 m north
	Frieda River airstrip	Qualitative	Clearing, earthworks	Paupe: 2.5 km north

Table 8.57 Air quality modelling scenarios (cont'd)

Scenario	Site/Facilities	Method of Assessment	Activities Modelled	Nearest Sensitive Receptors and Approximate Distance from Project Infrastructure (Nearest Receptors)
Construction scenarios (cont'd)				
	River ports	Qualitative		Dioru: 8 km north-west of Upper Sepik River Port Samou: 11 km east of May River Port Nekiei: 13 km south-east of Frieda River Port
Operation scenarios				
O1	Mine area: Year 5 (HIT and Koki open-pit, primary crushing, ore and waste rock handling and quarries)	3D CALPUFF modelling	Mobile machinery, hauling, crushers, ROM and waste rock conveyors, wind erosion, drilling and blasting	Wameimin 2: 7.5 km north-west of the open-pit Paupe: 7 km north-east of ISF embankment, 24 km north-east of the open-pit
O2	Mine area: Year 12 (HIT open-pit, primary crushing, ore and waste rock handling, and quarries)	3D CALPUFF modelling		Wameimin 2: 7.5 km north-west of the open-pit Paupe: 7 km north-east of ISF embankment, 24 km north-east of the open-pit
	Operation of Vanimo Ocean Port	Qualitative	Dust emissions, exhaust emissions, products of fuel combustion	Various residences: 50 m

Note: Ok Isai and Wabia not assessed as current locations are within ISF reservoir area and these villages will be resettled.

The quantitative modelling used CALPUFF to determine ground level concentrations of several emitted gases and particulate matter and determined potential changes in air quality. The CALPUFF model has been adopted by the US EPA in its Guideline on Air Quality Models (2012) as the preferred model for assessing long range transport of pollutants and their impacts and near-field impacts in complex flow or dispersion situations. Meteorological modelling was performed using the Weather Research and Forecasting air pollution model and CALMET. CALMET is a meteorological model that takes into consideration factors including topography, differential heating and surface roughness associated with land use to develop wind and temperature fields. These models incorporate observed meteorological data to generate three-dimensional meteorological datasets for the areas surrounding the mine site and infrastructure corridor.

Project Guidelines

Table 8.58 presents the criteria adopted to assess the impacts to air quality due to air emissions from Project activities. These criteria are normally based on the results of epidemiological or other health-based studies. Compliance with these health-based criteria often means amenity values are also protected. In the absence of PNG regulatory criteria for air emissions, the WHO (2000; 2005), US EPA (2012) and Australian state-based air quality criteria (NSW EPA, 2016) have been adopted for Project-specific objectives, in that order of preference.

Table 8.58 Adopted Project ambient air quality assessment criteria

Pollutants	Averaging Period	Criteria (μg/m^3)	Source
NO_2	1-hour	200	WHO, 2005
	Annual	40	WHO, 2005
SO_2	10-Minutes	500	WHO, 2005
	24-hours	20	WHO, 2005
CO	15-minutes	100,000	WHO, 2000
	30-minutes	60,000	WHO, 2000
	1-hour	30,000	WHO, 2000
	8-hours	10,000	WHO, 2000
TSP	24-hours	150	US EPA, 2012
	Annual	75	US EPA, 2012
PM_{10}	24-hours	50	WHO, 2005
	Annual	20	WHO, 2005
$PM_{2.5}$	24-hours	25	WHO, 2005
	Annual	10	WHO, 2005
Dust deposition	Annual	2 g/m^2/month	NSW EPA, 2016
Arsenic	Annual	0.0066	WHO, 2000
Cadmium	Annual	0.005	WHO, 2000
Lead	Annual	0.5	WHO, 2000
Manganese	Annual	0.15	WHO, 2000
Mercury	Annual	1	WHO, 2000
Nickel	Annual	0.025	WHO, 2000

μg/m^3 = micrograms per cubic metre
g/m^2/month = grams per square metre per month

8.8.2 Potential Impacts

Construction

The main emissions to air from the construction phase of the Project are expected to include:

- Particulate matter from site preparation works, earthworks (including blasting) and wind erosion of open areas and stockpiles.
- Combustion products (NO_x, CO, CO_2, SO_2, VOCs and particulate matter) from construction equipment, diesel-powered generators and blasting.

Emissions from the construction of the road and concentrate pipeline and Northern Transmission Line will be transient in nature as the works progress and any localised impacts will be short-term. The other emission sources will be more static; however, the emission rates are likely to vary significantly with time depending on construction stage and associated activity levels.

In addition to these main emission sources during construction, other minor and/or transient emissions are expected to include:

- Combustion products (NO_x, CO, CO_2, SO_2, VOCs and particulates, metals and a range of organic micro-pollutants) from the transport of personnel (aircraft, passenger buses and light vehicles) and the oil-fired incinerator at the environmental waste management facility.
- VOCs from the storage and transfer of diesel.

- Hydrogen sulphide (H_2S) and odour from the sewage treatment plant, solid waste landfill and composting activities at the environmental waste management facility.
- Welding fumes, particularly associated with the pipeline construction.

Operation

Emissions to air from the operation phase of the Project are likely to include:

- Particulate matter from mining activities within the open-pit, crushing of ore and waste rock, other material handling activities (including the conveyor system), wind erosion of open areas and stockpiles, and vehicles travelling along unsealed roads.
- Combustion products (NO_x, CO, CO_2, SO_2, VOCs and particulates) from diesel-powered mining equipment and the transport of personnel (aircraft, passenger buses and light vehicles).
- Methane (CH_4) from decomposition of vegetation flooded by the ISF.

In addition to these main emission sources, other minor and/or transient emissions are likely to include:

- Combustion products (NO_x, CO, CO_2, SO_2, VOCs, particulate matter, metals and a range of organic micro-pollutants) from the oil-fired incinerator at the environmental waste management facility.
- Combustion products (NO_x, CO, CO_2, SO_2, VOCs and particulate matter) whenever back-up diesel-powered generators are used or tested.
- H_2S and odour from the sewage treatment plant and composting activities at the environmental waste management facility.
- Odour from flotation reagents.
- VOCs from the storage and transfer of diesel.

There will be no significant emissions to air from the ISF or hydroelectric power facility during the operation phase, aside from greenhouse gas (GHG) emissions, which are addressed in Section 8.9.

Project Phases

Table 8.59 describes the phases of the Project in which the potential for air quality impacts are predicted to be most applicable.

Table 8.59 Summary of potential air quality impacts and relevance to Project phases

Potential Impact	Phase			Comment
	Construction	Operation	Closure	
Increased particulate matter	✓	✓	✓	During construction and closure from site preparation works, earthworks and wind erosion of open areas and stockpiles.

Table 8.59 Summary of potential air quality impacts and relevance to Project phases (cont'd)

Potential Impact	Phase			Comment
	Construction	Operation	Closure	
Increased particulate matter (cont'd)	✓	✓	✓	During operation from the open-pit, crushing plant and material handling activities, wind erosion of open areas and stockpiles, and vehicles travelling along unsealed roads. At closure for as long as disturbed areas remain unvegetated.
Combustion products (NO_x, CO, CO_2, SO_2, VOCs and particulates, metals and a range of organic micro-pollutants)	✓	✓		During construction from construction equipment, diesel-powered generators and blasting, and other smaller producers of combustion products (which will also apply to a smaller extent to closure activities). During operation from diesel-powered mining equipment and the transport of personnel (which will also apply to a smaller extent to closure activities).
VOCs	✓	✓		From the storage and transfer of diesel.
H_2S and odour	✓	✓		From the sewage treatment plant, solid waste landfill and composting activities at the environmental waste management facility.
Welding fumes	✓			Particularly associated with pipeline construction.
Odour		✓		From flotation agents used during processing of ore.

8.8.3 Management Measures

Air emissions associated with construction and operation activities will be managed through compliance with the EMMPs (see Chapter 12). This will include implementation of procedures designed to meet air quality objectives adopted for the Project, based on the assessment criteria described above. Specific measures to be used to manage air emissions are summarised in Table 8.60.

Table 8.60 Air quality management measures

No.	Management Measure
MM126	During construction, nuisance dust will be managed using water sprays.
MM127	General measures will be applied to the construction works, including: • Limiting burning of vegetation or other waste materials on site. • Limiting dust generating activities in windy conditions where practicable. • Limiting the use of material stockpiles and minimising open stockpiles in areas prone to elevated wind erosion or close to sensitive receptors.
MM128	Dust and exhaust emissions from trucks and other vehicles will be controlled by: • Maintaining vehicles and machinery in accordance with the manufacturer's specifications. • Establishing vehicle speed limits. • Ensuring vehicles keep to marked trafficable areas.

Table 8.60 Air quality management measures (cont'd)

No.	Management Measure
MM128 (cont'd)	• Covering trucks carrying dusty or erodible materials offsite when travelling on public roads. • Covering the ROM stockpile at the mine and the product stockpile at the Vanimo Ocean Port.
MM129	Dust emissions from clearing and grading activities will be reduced by: • Limiting cleared areas as far as practicable and retaining existing vegetation where possible. • Stripping areas progressively and only where it is necessary for works to occur. • Retaining root stock in the ground where practicable to reduce erosion and to facilitate rapid rehabilitation, e.g., trimming and retaining trees rather than removing them, where practicable. • Employing stabilisation methods such as matting, grassing or mulch.
MM130	Additional measures for sensitive receptors located within 800 m from road and construction activities include: • Locate fixed and mobile equipment with consideration to potential impacts on local residents. • Postpone, limit or relocate dust-generating activities in close proximity to villages in dry and windy (e.g., >5 m/s) conditions, where practicable. • Ensure blasting is not conducted in windy (e.g., >5m/s) conditions when works are within the wind path of nearby villages.
MM131	Proceed with clean up and restoration as soon as is practicable after works are completed to minimise the duration of exposure of disturbed areas.
MM132	Consider discharge of emissions via appropriately designed stacks to limit downwash, wakes and eddy effects in the design of the waste incinerators and diesel generators.

The EMMPs (see Chapter 12) will incorporate stakeholder engagement strategies that will address the range of Project activities that will generate air quality emissions and provide further details on air quality management.

8.8.4 Residual Impact Assessment

Modelling Results – Construction

Scenario C1 – Mine Site

Predicted concentrations of particulate matter (TSP, PM_{10}, $PM_{2.5}$ and dust deposition) and trace metals from fugitive particulate emissions at Paupe and Wameimin 2 are predicted to be below relevant Project assessment criteria, as shown in Table 8.61.

Table 8.61 Predicted emission concentrations at sensitive receptors for Scenario C1

Emissions	Paupe	Wameimin 2	Criteria
TSP (µg/m^3)			
Maximum 24-hour	0.8	0.7	150
Annual average	0.2	0.2	75
PM_{10} (µg/m^3)			
Maximum 24-hour	0.7	0.5	50
Annual average	0.2	0.1	20

Table 8.61 Predicted emission concentrations at sensitive receptors for Scenario C1 (cont'd)

Emissions	Paupe	Wameimin 2	Criteria
$PM_{2.5}$ (µg/m^3)			
Maximum 24-hour	0.1	0.1	25
Annual average	0.02	0.02	10
Dust deposition rate (g/m^2/month)			
	<0.1	<0.1	2.0
Ambient heavy metals concentrations *(µg/m^3)*			
Arsenic	7.1 x 10-6	7.2 x 10^{-6}	0.0066
Cadmium	2.6 x 10^{-6}	2.6 x 10^{-6}	0.005
Lead	7.0 x 10^{-5}	7.1 x 10^{-5}	0.5
Manganese	4.4 x 10^{-4}	4.4 x 10^{-4}	0.15
Mercury	3.0 x 10^{-8}	3.0 x 10^{-8}	1
Nickel	1.8 x 10^{-5}	1.8 x 10^{-5}	0.025

Scenario C2 – Road and Pipeline

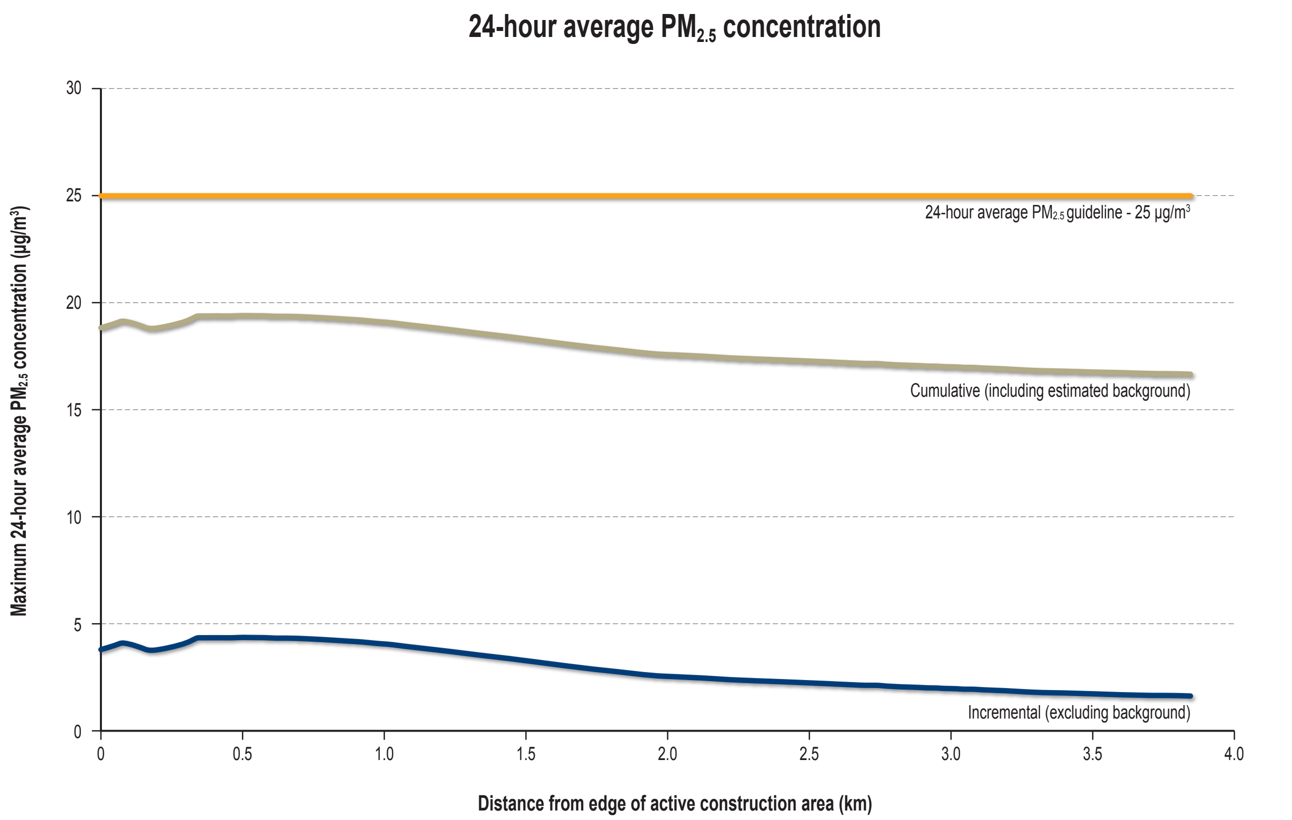
For the road and pipeline construction scenario, the dispersion modelling was performed based on a nominal 2 km length of the infrastructure corridor. Receptors were regularly spaced at fixed distances parallel to the sources for up to 4 km from the centre of the construction zone and the results of this modelling have been used to assess the offset distances for the road and pipeline construction activities at which elevated downwind pollutant concentrations may be expected to occur. When the works pass by sensitive receptors located within these offset distances, additional management measures may need to be applied to the construction activities to limit the impacts in these areas.

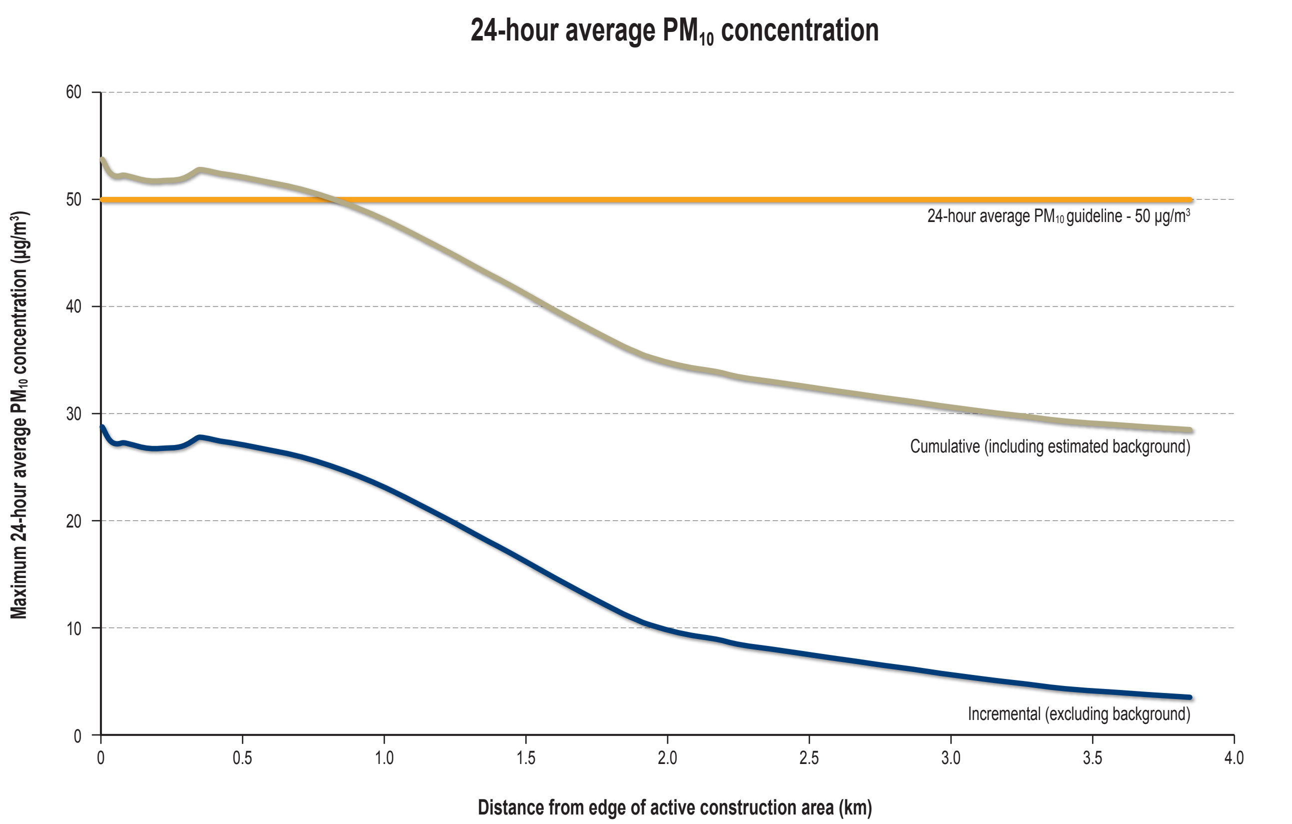
Modelling was performed for particulate matter, NO_x and SO_2 emissions. An assessment of potential downwind heavy metal concentrations has not been performed as the assessment criteria for deposition of trace metals from fugitive particulate emissions are based on annual average concentrations, and the construction of the road and pipeline will be transient in nature and will not affect any single receptor for extended periods of time.

The results indicated that the health-related 24-hour average guideline for $PM_{2.5}$ is unlikely to be exceeded even adjacent to the construction works; however, the maximum cumulative PM_{10} concentrations predicted exceed the relevant 24-hour average guidelines within the first 800 m downwind (Figure 8.15). If background levels are lower than assumed in the modelling, then no exceedances would be expected.

Other key conclusions regarding predicted air quality impacts during construction of the public road and concentrate pipeline include:

- No nuisance impacts due to elevated dust deposition rates are predicted to occur (Figure 8.16).
- Estimated SO_2 and NO_2 emissions predicted to result in worst-case downwind concentrations are below the relevant assessment criteria.





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SLR, 2018

AI Reference: 11575_11_GRA038.ai_3

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Date: 13.09.2018
Project: 754-ENAUABTF11575B
File Name: 11575_11_F08.15_GRA

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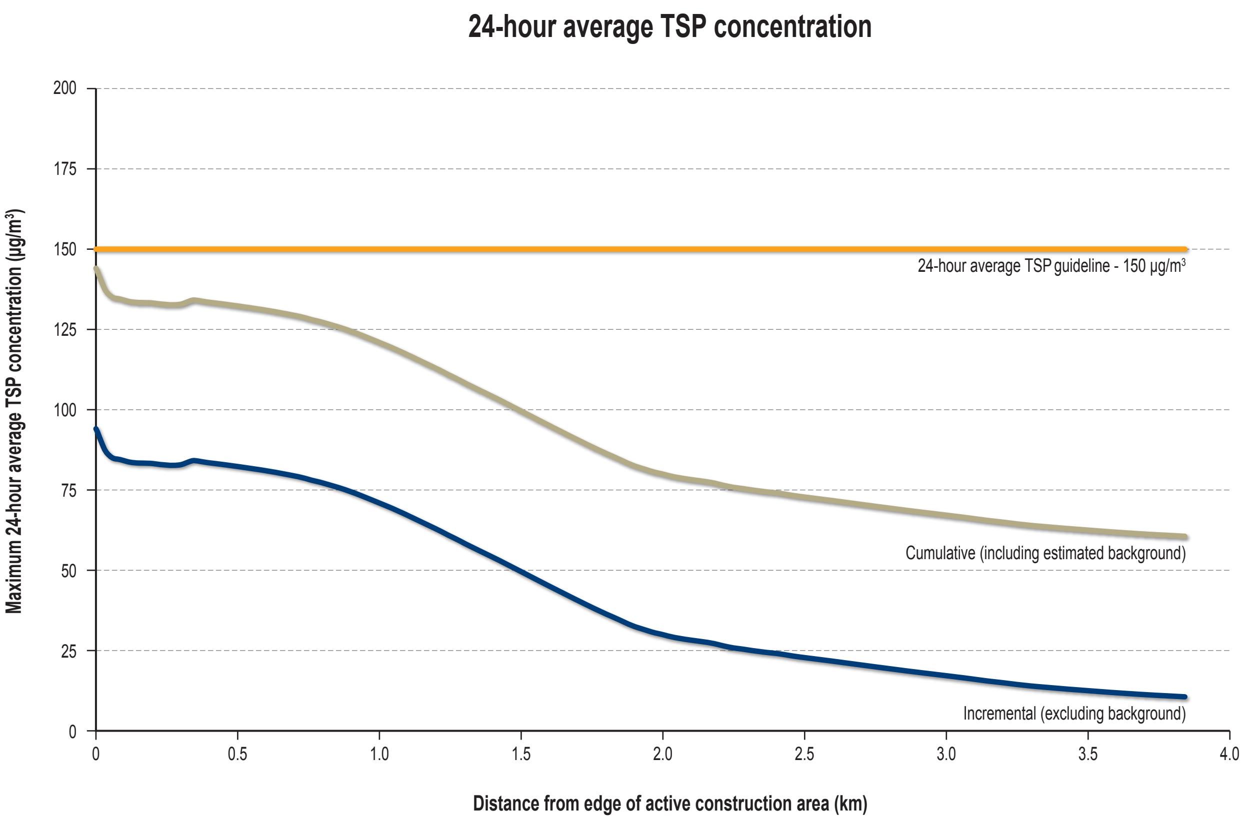
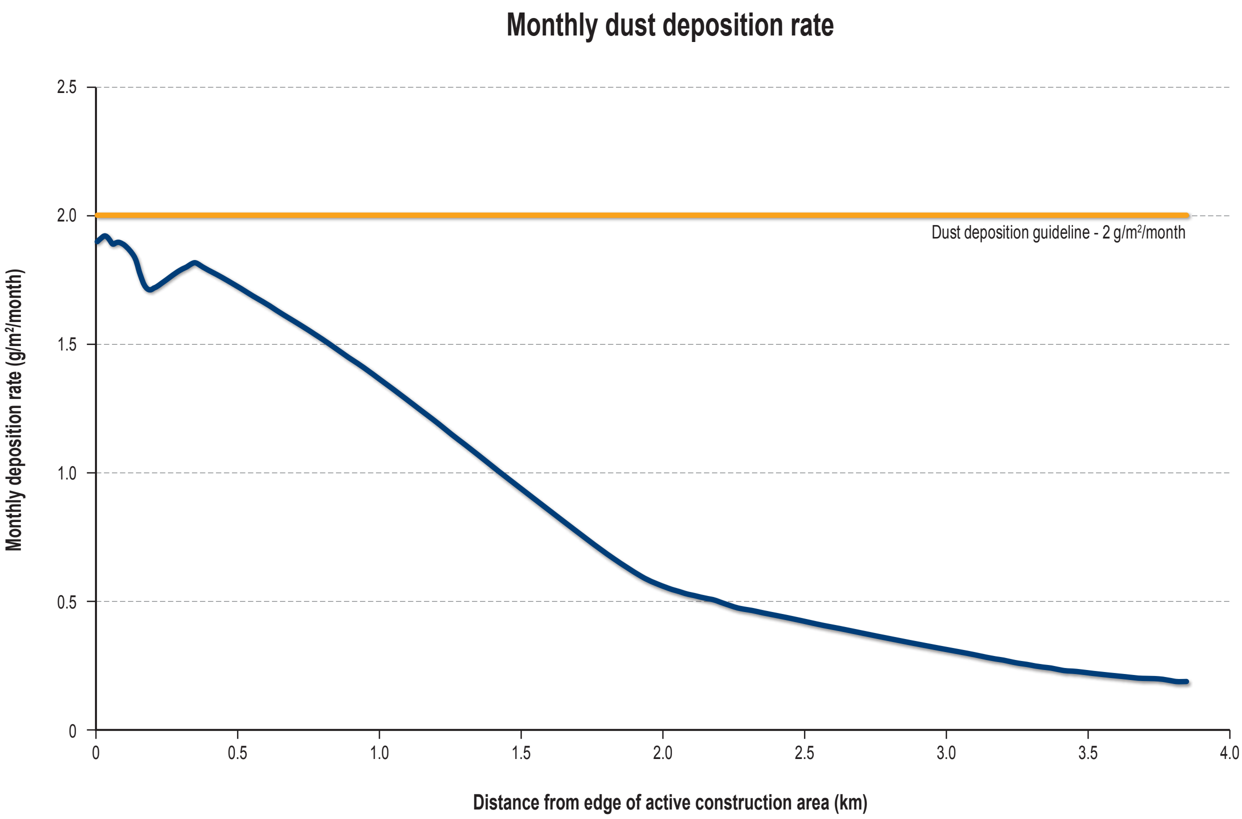
Sepik Development Project

FRIEDA RIVER

Maximum predicted 24-hour $PM_{2.5}$ and PM_{10} concentrations for Scenario C2

Figure No: 8.15





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Project: 754-ENAUABTF11575B
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Sepik Development Project

FRIEDA RIVER

Maximum predicted 24-hour TSP concentrations and dust deposition rates for Scenario C2

Figure No: 8.16

Qualitative Assessment

Other construction activities associated with the Project which could generate emissions and were assessed qualitatively include:

- Upgrade of the Vanimo Ocean Port.
- Upgrade of the Frieda River and Green River airstrips.
- Construction of the Northern Transmission Line.
- Transport of equipment and workers.
- Fuel storage.
- Solid waste management (operation of an oil-fired incinerator and odour from the solid waste landfill and composting activities at the environmental waste management facility).
- Sewage treatment.
- Welding fumes.

There is potential for fugitive emissions of dust and diesel combustion products during the upgrade of the Vanimo Ocean Port, including the construction of the concentrate storage shed and ship-loading facilities. There are anecdotal reports of fugitive dust emissions associated with the existing operations at the port, due to the storage and handling of logs, and wind erosion of the log storage areas. If these activities continue to operate during upgrade of the port, this could result in cumulative impacts. However, provided good management practices are implemented at the port, no significant increase in air quality impacts would be expected as a result of the Vanimo Ocean Port construction activities.

Given the localised and short-term nature of the activities, and appropriate distances from sensitive receptors in the case of solid waste management and sewage treatment, it was concluded that there will be no significant air quality impacts associated with the other construction phase activities.

Modelling Results – Operation

Scenario O1 - Mine Site Year 5

Predicted concentrations of particulate matter (TSP, PM_{10}, $PM_{2.5}$ and dust deposition), SO_2, NO_2 and trace metals from fugitive particulate emissions at mine area sensitive receptors were below the relevant Project assessment criteria for Scenario O1 (Table 8.62).

Table 8.62 Predicted emission concentrations at sensitive receptors for Scenario O1

Emissions	Paupe	Wameimin 2	Criteria
TSP ($\mu g/m^3$)			
Maximum 24-hour	0.3	0.7	150
Annual average	<0.1	0.2	75
PM_{10} ($\mu g/m^3$)			
Maximum 24-hour	0.2	0.5	50
Annual average	<0.1	0.1	20

Table 8.62 Predicted emission concentrations at sensitive receptors for Scenario O1 (cont'd)

Emissions	Paupe	Wameimin 2	Criteria
$PM_{2.5}$ (µg/m³)			
Maximum 24-hour	<0.1	0.1	25
Annual average	<0.1	0.02	10
Dust deposition rate (g/m²/month)			
Incremental annual average	<0.1	<0.1	2.0
SO_2 (µg/m³)			
Maximum 10-minute average	1	4	500
Maximum 24-hour average	0.2	0.4	20
NO_2 (µg/m³)			
Maximum 1-hour average	3	9	200
Annual average	0.1	0.4	40
Ambient heavy metals concentrations (µg/m³)			
Arsenic	9.5×10^{-7}	7.5×10^{-6}	0.0066
Cadmium	3.4×10^{-7}	2.7×10^{-6}	0.005
Lead	9.4×10^{-6}	7.5×10^{-5}	0.5
Manganese	5.9×10^{-5}	4.6×10^{-4}	0.15
Mercury	4.0×10^{-9}	3.1×10^{-8}	1
Nickel	2.3×10^{-6}	1.9×10^{-5}	0.025

Scenario O2 - Mine Site Year 12

Predicted concentrations of particulate matter (TSP, PM_{10}, $PM_{2.5}$ and dust deposition), SO_2, NO_2 and trace metals from fugitive particulate emissions at mine area sensitive receptors were below relevant Project assessment criteria for Scenario O2, as shown in Table 8.63 and Figures 8.17, 8.18 and 8.19.

Table 8.63 Predicted emission concentrations at sensitive receptors for Scenario O2

Emissions	Paupe	Wameimin 2	Criteria
TSP (µg/m³)			
Maximum 24-hour	0.6	1.1	150
Annual average	<0.1	0.3	75
PM_{10} (µg/m³)			
Maximum 24-hour	0.4	0.8	50
Annual average	<0.1	0.2	20
$PM_{2.5}$ (µg/m³)			
Maximum 24-hour	0.1	0.1	25
Annual average	0.01	0.03	10
Dust deposition rate (g/m²/month)			
Incremental annual average	<0.1	<0.1	2.0

Table 8.63 Predicted emission concentrations at sensitive receptors for Scenario O2 (cont'd)

Emissions	Paupe	Wameimin 2	Criteria
SO_2 (μg/m^3)			
Maximum 10-minute average	2	7	500
Maximum 24-hour average	0.4	0.7	20
NO_2 (μg/m^3)			
Maximum 1-hour average	5	17	200
Annual average	0.1	0.7	40
Ambient heavy metals concentrations *(μg/m^3)*			
Arsenic	1.5×10^{-6}	1.2×10^{-5}	0.0066
Cadmium	5.5×10^{-7}	4.3×10^{-6}	0.005
Lead	1.5×10^{-5}	1.2×10^{-4}	0.5
Manganese	9.4×10^{-5}	7.3×10^{-4}	0.15
Mercury	6.3×10^{-9}	4.9×10^{-8}	1
Nickel	3.8×10^{-6}	2.9×10^{-5}	0.025

Qualitative Assessment

Other activities conducted during Project operations which could generate emissions and were assessed qualitatively include:

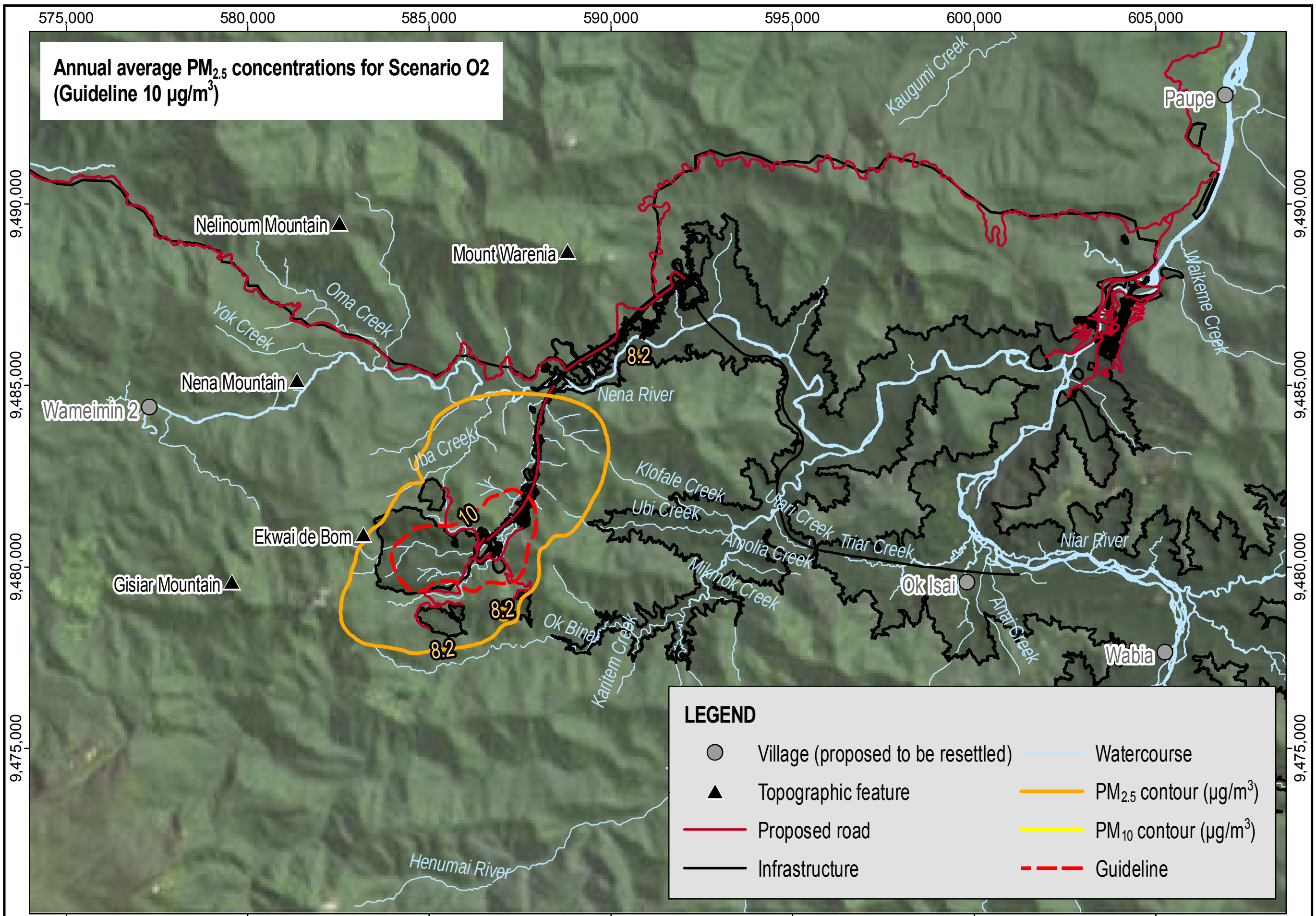
- Operation of Vanimo Ocean Port.
- Transport of workers (aircraft, passenger buses and light vehicles).
- Fuel storage.
- Solid waste management (emissions of products of combustion of the waste incinerator and odour from the solid waste landfill and composting activities at the environmental waste management facility).
- Sewage treatment.

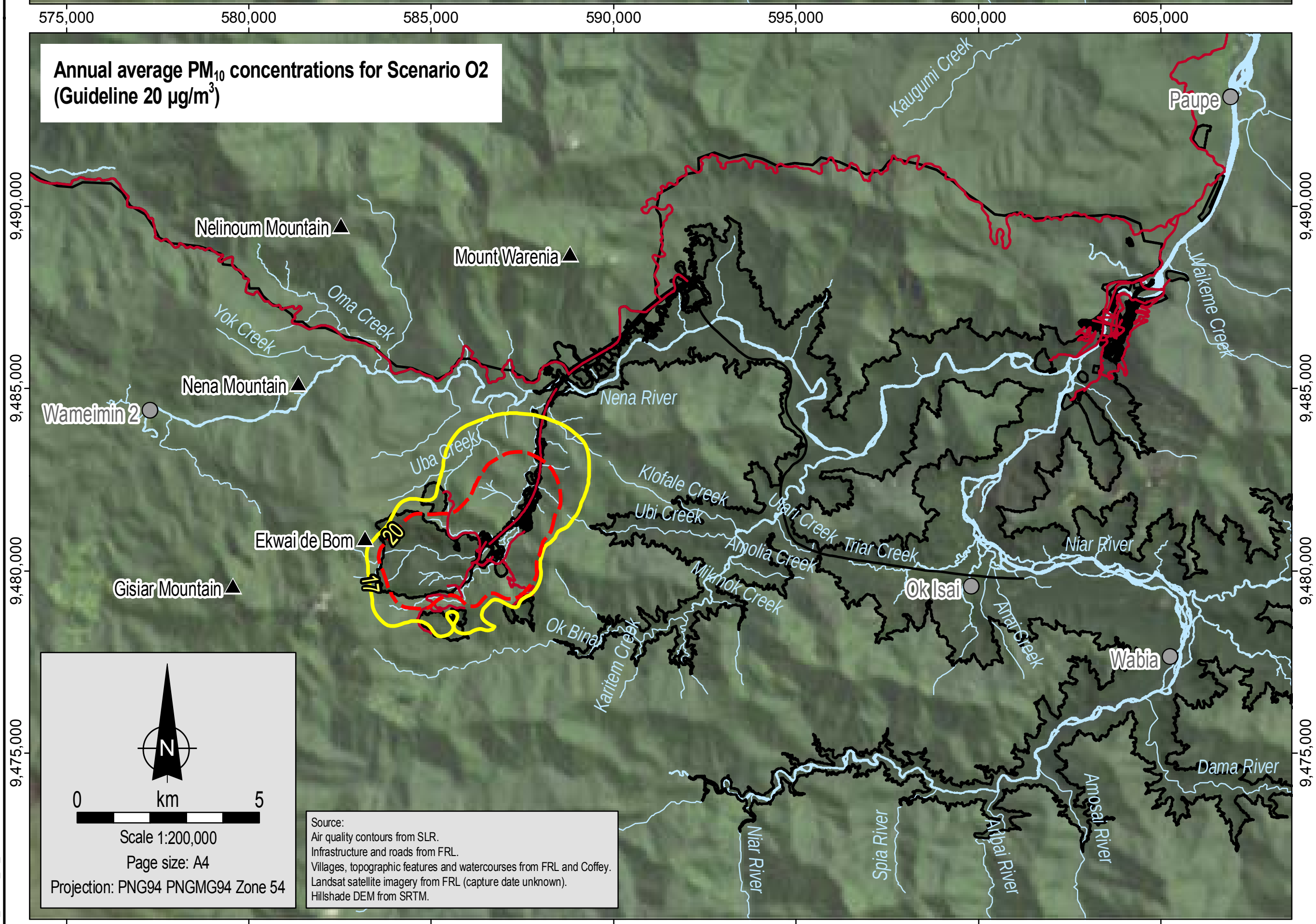
Provided good management practices are implemented at the site, no significant increase in air quality impacts would be expected as a result of the Project activities at the upgraded Vanimo Ocean Port.

As for the construction phase, given the nature of the activities and the separation distance to the nearest sensitive receptors (in the case of solid waste management and sewage treatment) it was concluded that there would be no significant air quality impacts associated with these activities.

Vegetation

High levels of dust deposition may cause damage to vegetation by blocking leaf stomata or inhibiting photosynthesis due to smothering of leaf surfaces. The high rainfall in the Project area will alleviate such impacts by frequently washing away dust deposited on leaves, and the low

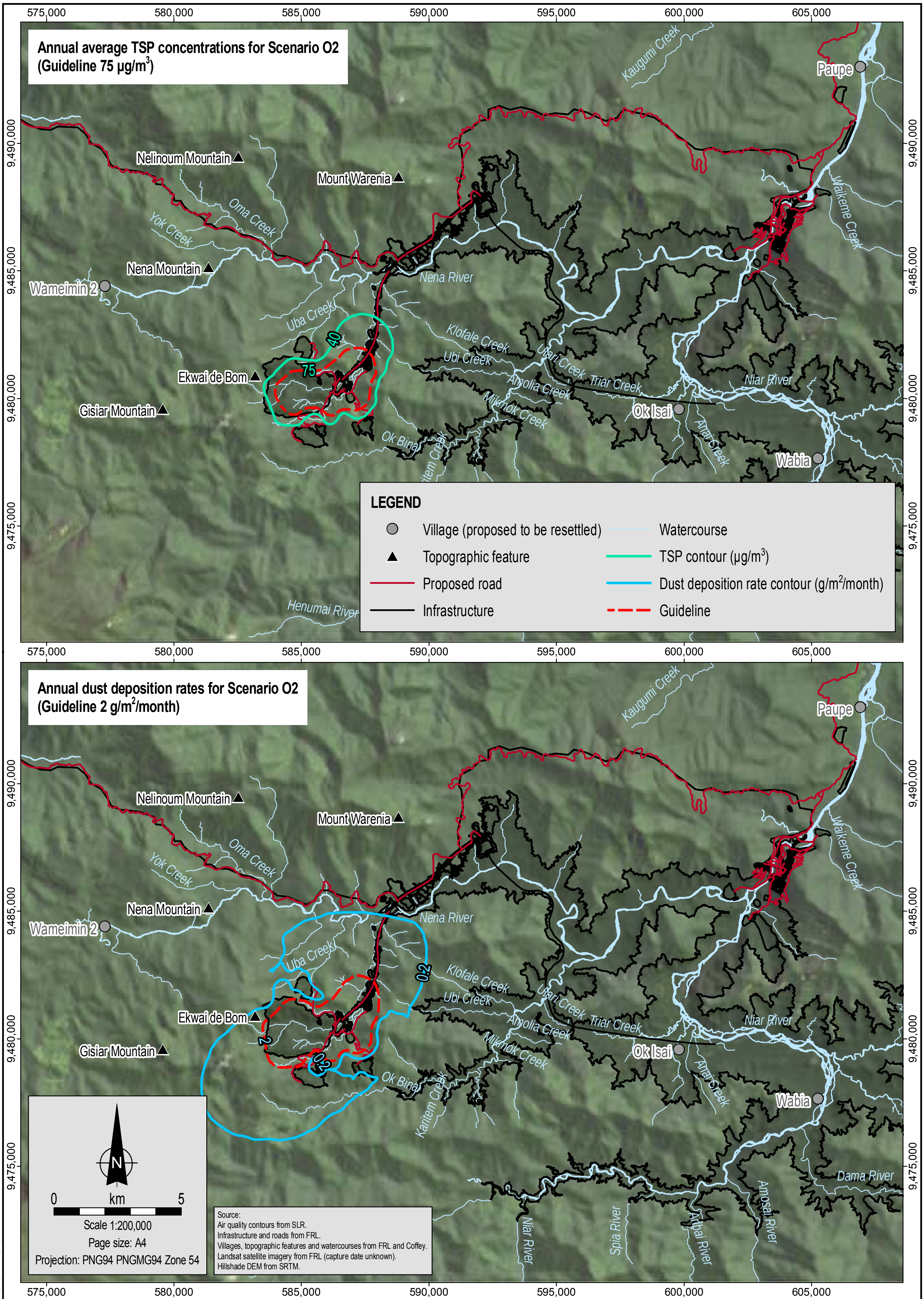




Source:
Air quality contours from SLR.
Infrastructure and roads from FRL.
Villages, topographic features and watercourses from FRL and Coffey.
Landsat satellite imagery from FRL (capture date unknown).
Hillshade DEM from SRTM.

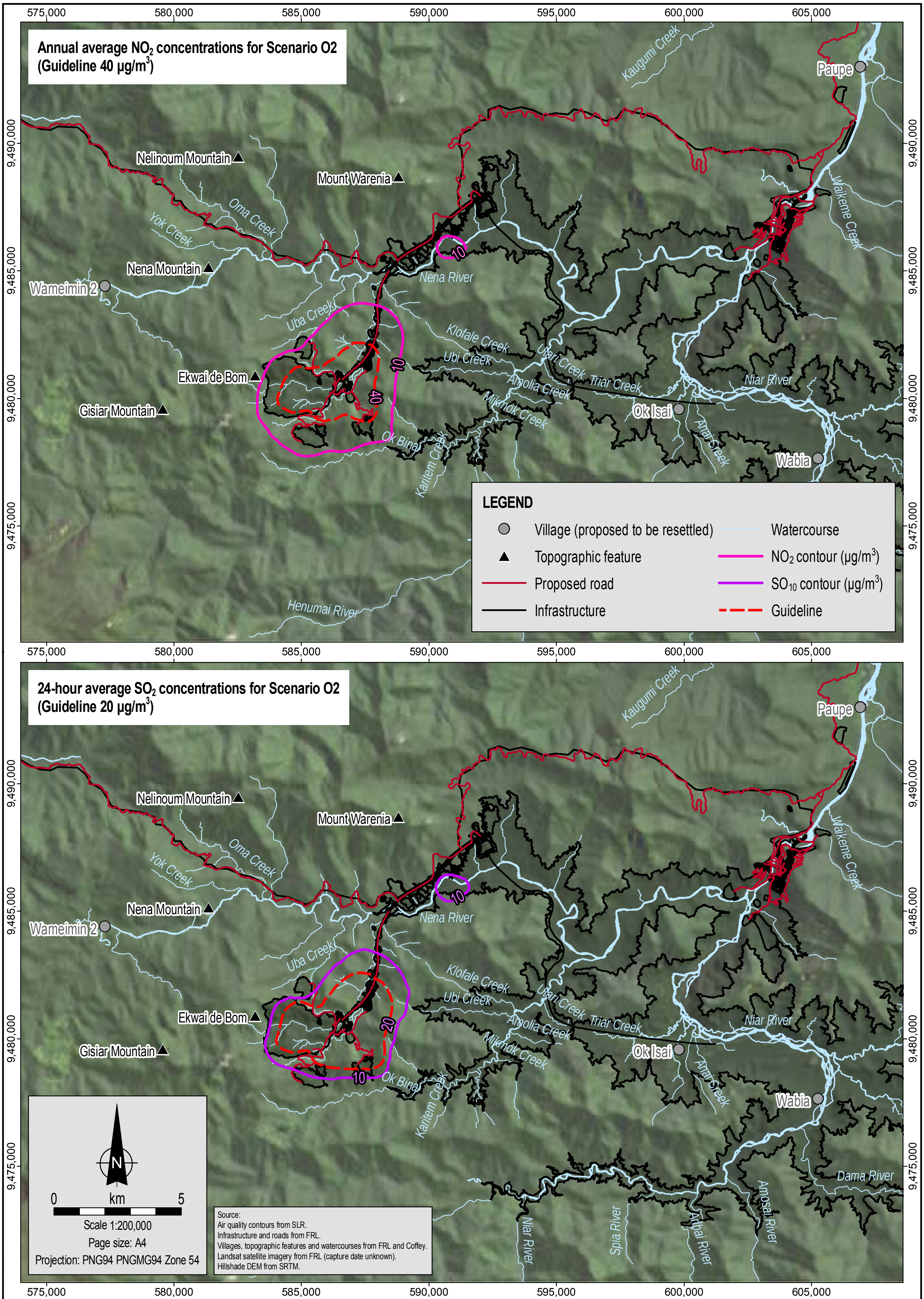
MXD Reference: 11575B_11_GIS030_v0_3

coffey A TETRA TECH COMPANY	Date: 14.09.2018 Project: 754-ENAUABTF11575B File Name: 11575_11_F08.17_GIS	Frieda River Limited Sepik Development Project	FRIEDA RIVER	Annual average $PM_{2.5}$ and PM_{10} concentrations for Scenario O2	Figure No: 8.17



MXD Reference: 11575B_11_GIS031_v0_4

coffey A TETRA TECH COMPANY	Date: 14.09.2018 Project: 754-ENAUABTF11575B File Name: 11575_11_F08.18_GIS	Frieda River Limited / Sepik Development Project	FRIEDA RIVER	Annual average TSP concentrations and dust deposition rates for Scenario O2	Figure No: 8.18



MXD Reference: 11575B_11_GIS032_v0_5

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Date: 14.09.2018
Project: 754-ENAUABTF11575B
File Name: 11575_11_F08.19_GIS

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Annual average NO_2 and 24-hour SO_2 concentrations for Scenario O2

Figure No: 8.19

local wind speeds will limit the area potentially affected as the majority of the particulates will not travel far before settling. As a result, any damage to vegetation due to dust emissions is expected to be localised and limited to less than 100 metres or so from the active work areas.

Impact Assessment

Construction of Project facilities is likely to result in localised emissions of particulate matter, NO_2, SO_2 and trace metals from fugitive particulates, although these emissions will typically be short-term. The modelling indicated that there are no predicted exceedances of Project air quality criteria expected during the Project operations phase. The lack of air quality impacts from these activities is primarily due to the remote location of the Project.

The construction activity with the greatest potential for air quality impacts at sensitive receptors (i.e., village locations) is construction of the road and concentrate pipeline, which has the potential to pass in close proximity to a number of villages. There is the potential for 24-hour average PM_{10} concentrations to exceed Project assessment criteria during road and concentrate pipeline construction where sensitive receptors lie within 800 m of the construction activities under worst-case meteorological conditions. This assessment has been based on a number of conservative assumptions and as a result it is expected that actual offsite particulate concentrations will be much lower. In addition, the construction works will only have short-term impacts at any given location for a limited period of time. Implementation of the management measures described in Table 8.60, including the use of water sprays and water trucks to suppress dust, postponing or limiting dust-generating activities in dry and windy conditions, when works are being performed within 800 m of villages along the road and concentrate pipeline route is expected to address this issue.

There are a number of existing sensitive receptors (residences) close to the existing Port of Vanimo operations; provided good management practices are implemented at the site, no significant increase in air quality impacts are expected as a result of the Vanimo Ocean Port construction activities or operational activities.

8.9 Greenhouse Gas Emissions

This section presents the GHG emissions predicted to arise from the Project based on the GHG assessment conducted by SLR and presented in Appendix 11.

8.9.1 Approach to Impact Assessment

Assessment Method

Project GHG emissions were calculated using Project-specific data for factors such as clearance rates and chemical usage, relevant emissions and formulae contained in the Intergovernmental Panel on Climate Change (IPCC) (2006) guidelines for national GHG inventories. The assessment included CO_2, CH_4, nitrous oxide (N_2O), sulphur hexafluoride (SF_6) and hydrofluorocarbons (HFC). Global warming potentials for these gases were sourced from IPCC (2007, 2013).

Emission factors relevant to each activity rate were sourced from IPCC (2006) or the Australian Government Department of Climate Change and Energy Efficiency National Greenhouse Account (NGA) Factors publications as the most comprehensive and up-to-date source of regionally representative emission factors. Emission factors for sources not included in the IPCC (2006) document, specifically emissions associated with explosive use and SF_6 leakage from switchgear, have been sourced from the NGA Factors (DoE, 2015). The scope of the assessment includes emissions associated with Project construction and operation, including associated mobile plant and equipment.

Detailed discussion and quantification of potential emission sources for each of the Project aspects is provided in Appendix 11.

Project Guidelines

The GHG assessment was undertaken with reference to the requirements of Principle 3 of the Equator Principles, the World Resources Institute/World Business Council for Sustainable Development GHG Protocol Initiative (WRI, 2004) and ISO 14064-1, 2 and 3 (GHG) guidelines, which are internationally accepted best practice.

PNG ratified the UNFCCC in 1993 and the Kyoto Protocol in 2002. In March 2008, PNG entered into a cooperative agreement with Australia to reduce GHG emissions from deforestation and forest degradation: the 'Papua New Guinea–Australia Forest Carbon Partnership'.

The PNG Office of Climate Change and Development (OCCD) published the National Climate Compatible Development Management Policy in August 2014 (OCCD, 2014) which aims to build a climate-resilient and carbon neutral pathway through sustainable economic development for PNG.

8.9.2 Potential Impacts

Direct Emissions (Scope 1)

Under the World Business Council for Sustainable Development (WRI, 2004) GHG protocol, direct GHG emissions are defined as emissions from sources that are owned or controlled by the reporting entity. These arise mainly from:

- Generation of electricity, heat and steam.
- Manufacturing processes.
- Transportation of materials, products, waste or people.
- Fugitive emissions, both intentional and unintentional.
- On-site waste management.

Within the Project-specific context, direct emissions will result from:

- Combustion of fuel in diesel generators during the construction phase.
- Combustion of diesel in mobile equipment, including on-road/off-road vehicles.
- On-site waste management activities through the decomposition, disposal and incineration of waste.
- Fugitive direct emissions of gases or vapours from pressurised equipment due to leaks and various other unintended or irregular releases of gases and operating processes, as well as fugitive gas release from soil as a result of land clearing activities.
- Decomposition of vegetation within the ISF that will be submerged as the ISF fills with water.

Major Scope 1 GHG emission sources for the Project are presented in Table 8.64.

Indirect Emissions (Scopes 2 and 3)

Indirect emissions are generated in the wider economy as a consequence of an organisation's activities and are physically produced by the activities of another organisation. The most common category of indirect emissions is from consumption of purchased electricity. Indirect emissions can also relate to upstream emissions generated through extraction and production of fossil fuels, and emissions from contracted or outsourced activities.

Scope 2 emissions have not been considered for the Project as almost all electricity consumption will be generated either by the FRHEP (during Project operation), or will be generated by diesel combustion (during Project construction). Therefore, all emissions will be covered under the Scope 1 emissions category, and Scope 2 emissions have not been considered further.

Assessment of Scope 3 emissions requires a full life-cycle analysis of Project activities and products, e.g., extraction and production of purchased materials and fuels, transport-related activities, and waste disposal by third parties, and therefore has not been included in this assessment.

Project Phases

Table 8.64 describes the phases of the Project in which the potential GHG sources are predicted to be most applicable.

Table 8.64 Potential GHG sources and relevance to Project phases

Activity/Source	Scope 1 GHG Emissions	Project Component			
		FRCGP	SIP	FRHEP	SPGP
Construction					
Land clearance / disturbance	Loss of carbon stock	✓	✓	✓	✓
Blasting	Combustion of explosives	✓	✓	✓	✓
Construction phase power generators	Consumption of diesel	✓	✓	✓	✓
Mobile construction equipment	Consumption of diesel	✓	✓	✓	✓
Road and river transport of equipment and workers	Consumption of diesel	✓	✓	✓	✓
Air transport of equipment and workers	Combustion of aviation fuel	✓	✓	✓	✓
Management of waste	Emissions from organic material decomposition			✓	
Use of refrigerants	Emissions from refrigerant leakage	✓	✓	✓	✓
Use of SF_6 in switchgear	Emissions from SF_6 leakage	✓		✓	✓
Operation					
Land clearance / disturbance	Loss of carbon stock	✓			
Blasting	Combustion of explosives	✓			
Mobile mining fleet	Consumption of diesel	✓			
Emergency generators, dewatering pumps	Consumption of diesel	✓			
Road transport of equipment and workers	Consumption of diesel	✓	✓	✓	✓
Air transport of equipment and workers	Combustion of aviation fuel	✓	✓	✓	✓
Management of waste	Emissions from organic material decomposition			✓	
Use of refrigerants	Emissions from refrigerant leakage	✓			

Table 8.64 Potential GHG sources and relevance to Project phases (cont'd)

Activity/Source	Scope 1 GHG Emissions	Project Component			
		FRCGP	SIP	FRHEP	SPGP
Operation (cont'd)					
Use of SF_6 in switchgear	Emissions from SF_6 leakage			✓	
ISF reservoir emissions	Decomposition of flooded vegetation			✓	

Note: Emissions over the closure period have not been included in the assessment given emissions during this period will be minimal when compared to the construction and operation phases.

8.9.3 Management Measures

Management measures to address GHG during construction and operation are detailed in Table 8.65.

Table 8.65 Greenhouse gases management measures

No.	Management Measure
Energy Efficiency Measures	
MM133	Limit the use of diesel fuel through the optimisation of on-site driving and measures such as: • Establishing speed limits on site. • Reducing gradients around site where possible.
Greenhouse Gas Management System and Target Setting	
MM134	Develop and implement a greenhouse gas management system that accurately quantifies emissions on a regular basis to allow major sources of emissions and the effectiveness of adopted measures to be continually identified, measured and indexed.

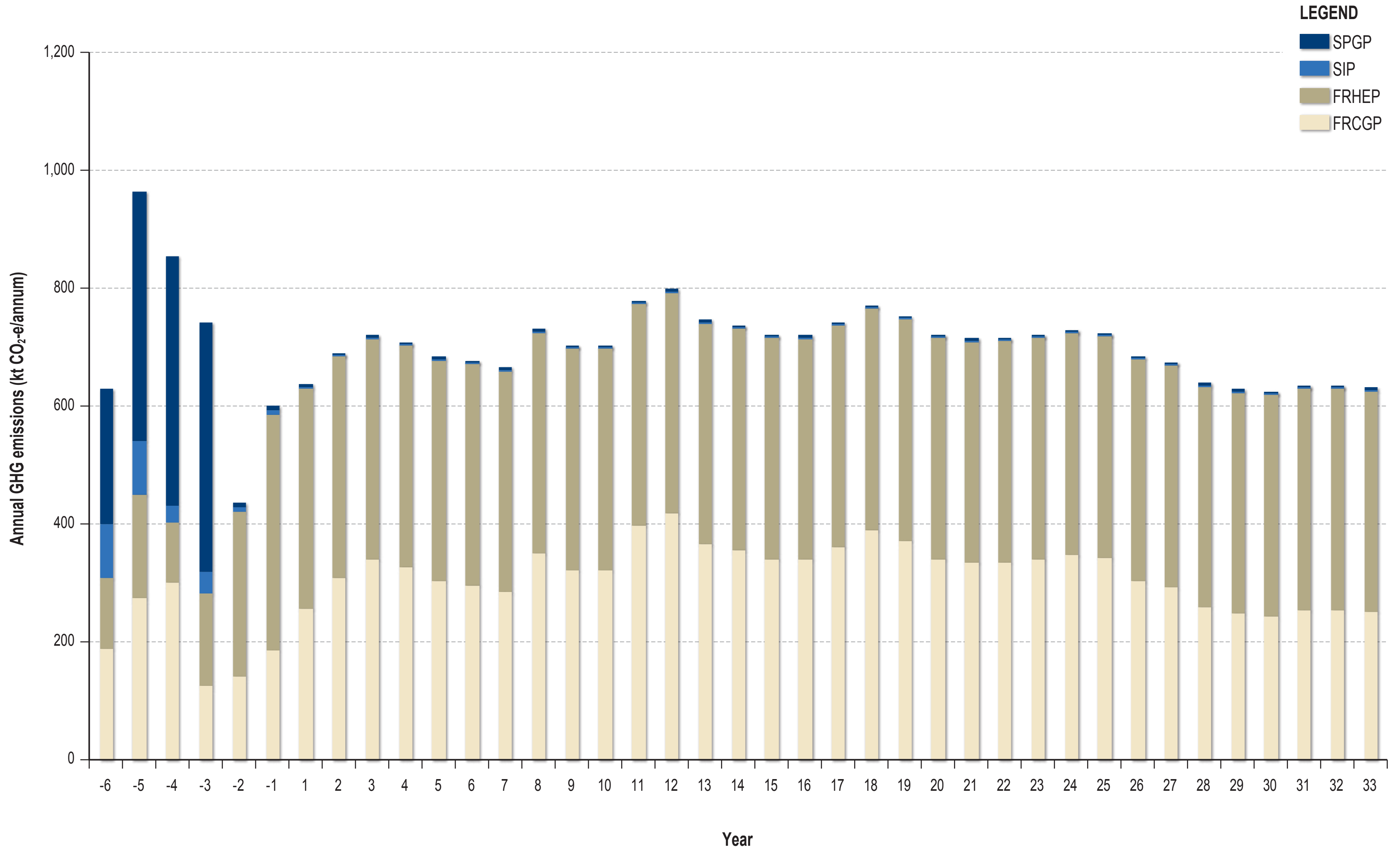
8.9.4 Residual Impact Assessment

Annual emissions of GHG (Scope 1 emissions) from Project construction and operation are estimated to be on average 639 kt CO_2-e per annum, generating a total of approximately 24,930 kt CO_2-e over the life of the Project.

The maximum calculated annual Scope 1 emissions of GHG associated with the Project are predicted to occur during construction (962.5 kt CO_2-e in Year -5). This is driven by the large area of land clearance in the construction of the transmission line and road. Figure 8.20 presents the predicted Scope 1 emissions by year for each of the Project components. The main sources of GHG emissions during the operation phase are:

- Diesel consumption.
- ISF reservoir emissions.
- The loss of carbon that would have otherwise been fixed annually in the land cleared or inundated as a result of the Project.

Figure 8.20 and Table 8.66 show the contribution of GHG emissions for each of the Project components across the life of the Project. Figure 8.21 shows the annual Scope 1 GHG emissions by activity category. Activity data and calculations are provided in Appendix 11.



Source:
SLR, 2018

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Date:	13.09.2018
Project:	754-ENAUABTF11575B
File Name:	11575_11_F08.20_GRA

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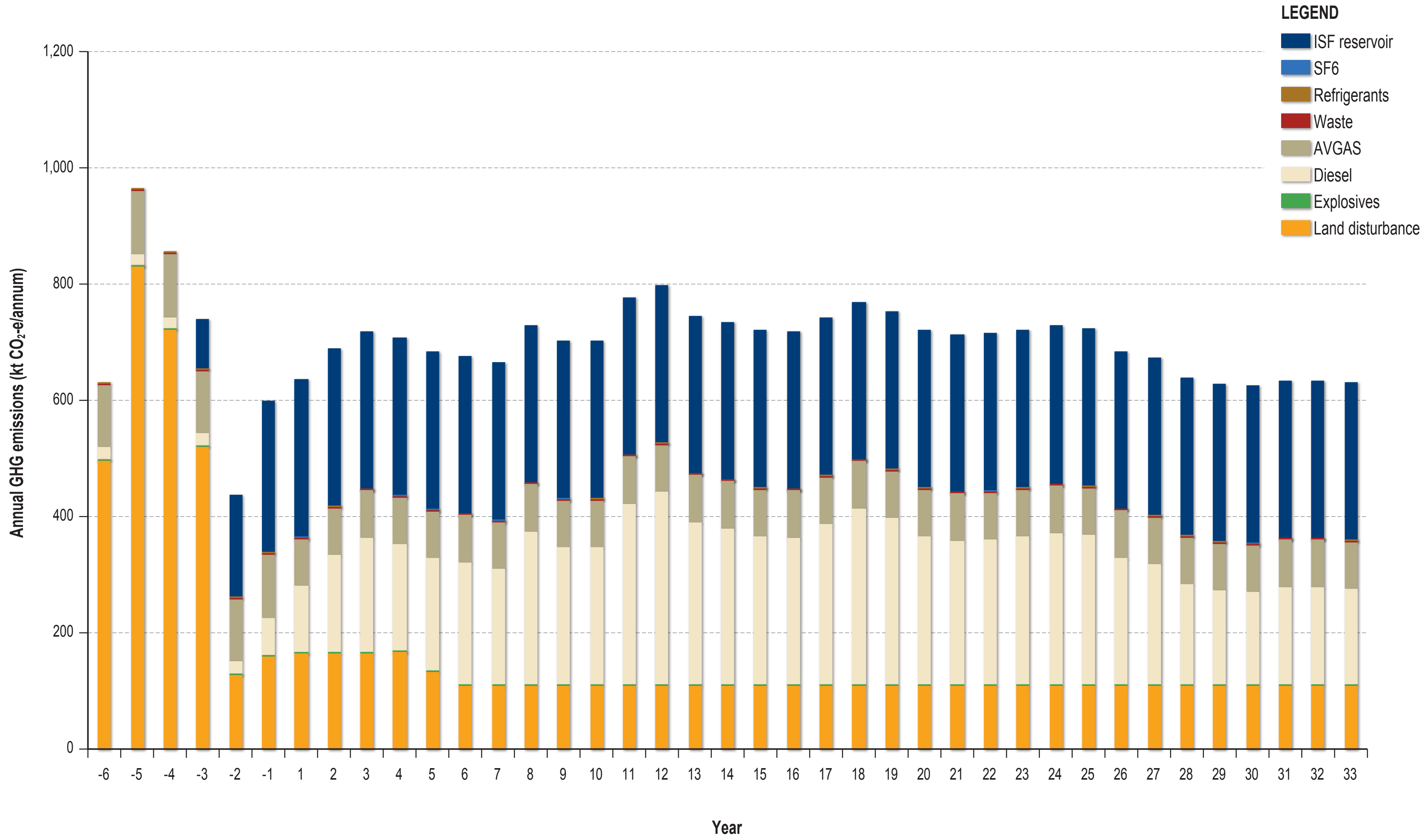
Annual Scope 1 GHG emissions (CO_2-e) by Project component

Figure No: 8.20



Source:
SLR, 2018

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Date: 13.09.2018
Project: 754-ENAUABTF11575B
File Name: 11575_11_F08.21_GRA

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Annual Scope 1 GHG emissions (CO_2-e) by activity category

Figure No: 8.21

AI Reference: 11575_11_GRA041.ai_3

Table 8.66 Summary of Project GHG emissions – per Project component

Project Component	Scope 1 (Direct) GHG Emissions								
	Construction Years (ktpa CO_2-e)						Operation Years (ktpa CO_2-e)		Project Life (kt CO_2-e)
	-6	-5	-4	-3	-2	-1	Maximum	Average	
FRCGP	186.5	274.1	299.2	124.0	141.1	185.6	416.7	320.2	11,017.6
FRHEP	120.5	174.8	103.9	157.5	277.8	398.0	375.2	375.2	13,213.8
SIP	91.2	91.2	28.6	37.0	8.1	7.9	1.4	1.4	97.9
SPGP	230.5	422.4	422.4	422.4	9.2	9.1	4.8	4.8	600.5
Total Project	**628.7**	**962.5**	**854.1**	**740.9**	**436.2**	**600.5**	**798.0**	**701.6**	**24,929.9**

Comparison of the annual average Project Scope 1 GHG emissions over the life of the Project with total national emissions (including land use change and forestry) reported by the FAO for 2013, the Project is expected to result in a relatively minor (1.1%) increase in the national emissions. Long-term operation of the FRHEP has the potential to provide a net-positive impact on PNG's GHG emission inventory based on the amount of electricity off-set, GHG efficiency and fuel types used in the displaced generation systems in comparison to existing and future fossil-fuel powered electricity generation.

8.10 Nearshore Marine

This section assesses the impacts of the Project on the nearshore marine environment. The assessment is based primarily on the information provided the nearshore marine characterisation study undertaken by BMT WBM and provided in Appendix 12a. The assessment is also based on dispersion modelling conducted by Tetra Tech (Appendix 12b) which describes the mixing zone boundary at which contaminants from discharge of the excess filtrate water from the concentrate thickener are predicted to meet PNG water quality standards.

The nearshore marine environment in this impact assessment is defined as the area of the sea and the seafloor adjacent to the shoreline, which is bound by and inclusive of the shoreline and beach, where one exists. The nearshore marine environment includes shallow waters to a depth of about 20 m, littoral habitats (between about 0 to 1.2 m given the local tidal range) and foreshore within the study area, which is shown in Figure 7.27 in Section 7.2.7.

8.10.1 Approach to Impact Assessment

This impact assessment uses two methods:

- The compliance method to assess impacts from the discharge of excess filtrate water from the concentrate thickener.
- The significance assessment method to assess impacts to environmental values.

These two methods are described below.

Compliance Assessment

The compliance method was used to assess the impact of discharge of excess filtrate water from the concentrate thickener into nearshore marine waters. The predicted water quality of the excess filtrate water from the concentrate thickener was compared to the PNG ambient marine water quality standards under Schedule 1 of the PNG Environment (Water Quality Criteria)

Regulation 2002. Hydrodynamic modelling was undertaken to predict the mixing zone boundary in the nearshore marine waters where the PNG standards will be met. The compliance assessment was done by numerically comparing the contaminant concentrations in the excess filtrate water from the concentrate thickener to the PNG ambient water quality standards. Dilutions required to meet the standards were calculated by dividing the contaminant concentrations by the relevant standards. These dilutions were hydrodynamically modelled to determine the extent of the mixing zone boundary.

Significance Assessment

The concept of significance is described in Section 8.1. Criteria for defining sensitivity and magnitude of impact that have been derived specifically for the nearshore marine environment are described below.

Sensitivity of Environmental Value

The sensitivity of an environmental value is its susceptibility to change, including its capacity to adapt to, or accommodate, the changes that the may be caused by the Project. It also considers the intrinsic importance of that environmental value within the nearshore marine environment.

In the nearshore marine environment, the sensitivity of an environmental value has been determined by the following criteria:

- A regionally, nationally or internationally recognised site or value of environment or conservation value.
- The level to which the value supports subsistence and/or commercial resource use.
- The existing condition of the environmental value.
- The distribution, extent or rareness of the environmental value.
- The capacity of the environmental value to adapt to change.

The definitions used for assigning sensitivities to environmental values are described in Table 8.67.

Table 8.67 Sensitivity of the environmental value

Sensitivity	Definition
High	• An environmental value that is listed as Critically Endangered or Endangered under the IUCN and/or recognised as such in PNG. • An environmental value of essential (local) subsistence/commercial requirement or importance in maintaining ecological integrity (even if not otherwise listed). • Environmental value is in very good condition. • Highly restricted distribution and/or rare environmental value. • No capacity of the environmental value to adapt to change.
Medium	• Environmental value is in moderate to good condition. • An environmental value that is listed as Vulnerable, Rare or Near Threatened under the IUCN and/or recognised as such in PNG. • An environmental value of common or frequent subsistence/commercial importance locally. • Limited distribution and abundance of environmental value. • Some capacity of the environmental value to adapt to change.

Table 8.67 Sensitivity of the environmental value (cont'd)

Sensitivity	Definition
Low	• Environmental value is in poor condition. • An environmental value that is common and is not listed under the IUCN and has no recognition in PNG. • An environmental value of occasional subsistence/commercial importance locally. • Environmental value is common and abundant and its distribution is widespread. • High capacity of the environmental value to adapt to change.

Magnitude of Impact

The magnitude of an impact considers the severity, geographical extent and duration of an impact that could potentially occur. Magnitude criteria for the nearshore marine impact assessment are described in Table 8.68.

Table 8.68 Magnitude of the impact

Magnitude	Definition
High	• Impact is very severe with respect to natural variability and significant effects to ecosystem function. • Impact is widespread and extends beyond the region (i.e., outside Sandaun Province). • Impact is permanent.
Medium	• Impact is of moderate severity with respect to natural variation and some effect to ecosystem function. • Impact extends outside of Dakriro Bay by up to 1 km. • Impact occurs during the period of concentrate handling at Vanimo Ocean Port (i.e., approximately 33 years).
Low	• Impact has a low severity with respect to natural variability. Little effect to ecosystem function. • Impact is restricted to within Dakriro Bay. • Impacts occur over the Vanimo Ocean Port construction period (i.e., approximately 3 years).
Negligible	• Impacts are barely detectable with respect to natural variability, regardless of the geographic extent or duration of the impact.

Assessment of Significance

The significance of a residual impact to an environmental value is determined by the sensitivity of the environmental value and the magnitude of the expected impact (Table 8.69). The sensitivity rating is fixed, whereas the magnitude can be reduced by implementation of mitigation measures. Where the magnitude of impact is reduced to negligible, as defined in Table 8.68, an overall significance of impact of negligible is applied regardless of sensitivity.

Table 8.69 Matrix of significance

	Sensitivity of the Environmental Value		
Magnitude of Impact	**High**	**Medium**	**Low**
High	Extreme	Major	Moderate
Medium	Major	Moderate	Minor
Low	Moderate	Minor	Minor
Negligible	Negligible	Negligible	Negligible

8.10.2 Potential Impacts

Potential impacts to the nearshore marine environment are outlined below. The impacts are assessed in the context of an existing port (with existing levels of environmental impact) being upgraded with additional port infrastructure. The existing location is adjacent to the Port of Vanimo, an existing logging port, and adjacent to an industrial area at Vanimo, the capital of Sandaun Province. As described in Section 7.2.7, there are a number of historic and ongoing impacts to the nearshore marine environment in Dakriro Bay and it is with regard to this context that the impacts herein are assessed.

Habitat Loss and Deterioration

Construction of the Vanimo Ocean Port will result in habitat loss due to land reclamation for the port and installation of pylons for the new shipping berths. This will include disturbance and loss of some reef and seagrass habitat and other areas of potential benthic habitat for infauna.

Movement of concentrate vessels, other vessels and tugboats to and from the Vanimo Ocean Port during construction may result in propeller wash disturbance of the seabed causing an increase in suspended sediments and turbidity. This could in turn result in suspended sediments depositing on benthic habitats.

The beaches in Dakriro Bay, where the Vanimo Ocean Port is located, are not sufficiently elevated above sea level to support sea turtle nesting (Appendix 12a). Sandy beaches in shallower areas above the fringing reefs are wide enough and high enough to support turtle nesting, but it is not known whether turtles use these beaches or whether egg harvesting occurs. It is likely that, based on the marine traffic, urban and industrial land uses, roads, discharges from culverts and rubbish along the coast in Dakriro Bay, that beaches are generally not used by turtles for nesting. Notwithstanding, these beach areas are more than 3 km from the Vanimo Ocean Port and are not expected to be impacted by the Project. Furthermore, the shoreline at the location of the Vanimo Ocean Port (and other surrounding locations where logs are shipped from) is highly modified due to the settlements at Wesdeco and Cis Point and the existing Port of Vanimo area and is not suitable for turtle nesting. Therefore, impacts to turtle nesting habitat as a result of land reclamation for the Vanimo Ocean Port are not expected and are not discussed further.

Disturbance of Nearshore Marine Fauna

During construction and operation of the Vanimo Ocean Port, vessel movements will result in noise emissions that may disturb nearshore marine fauna.

Commercial vessel movements are a major contributor to underwater noise, especially at low frequencies between 5 to 500 Hz (NRC, 2003; Richardson et. al., 1995). This activity has the potential to interfere with the behaviour of marine fauna, particularly marine mammals that communicate and navigate using sound (Richardson et. al., 1995). Project-related sources of underwater sound include propeller noise (e.g., cavitation, blade frequency, blade passage forces), main engines, other machinery and hydrodynamic hull flow. Pile driving of pylons for ocean port construction will also be a source of noise. These will add to background levels of noise that are derived from wind, waves and surf, and existing vessel movements and log export activity in the bay. In some cases, extremely high levels of sound can cause harm to air-breathing animals and fish with air-filled swim bladders. However, such impacts only occur when animals are close to sources such as powerful bow thrusters. Bow thrusters may be used by concentrate vessels, other large vessels during construction and operation, or tug boats but the noise emissions are expected to be typical of the existing activities at the Port of Vanimo.

Project-related vessels operating at night will be illuminated with artificial lights that can influence the movement and migration of marine fauna. As the Vanimo Ocean Port will be located within an existing port/industrial area, adjacent to Vanimo town, additional light emissions are not expected to result in credible significant impacts above the existing situation. This impact is therefore not discussed further.

Construction of the Vanimo Ocean Port, particularly during pile driving, may result in temporarily increased and localised suspended sediments in the water column when the seabed is disturbed. Increased suspended sediments could affect nearshore marine biota by physical smothering and blocking of gills and filter feeding mechanisms.

Introduction of Invasive Marine Species

Vessels servicing the Project have the potential to introduce invasive marine flora and fauna into nearshore marine waters.

The movement of vessels from other ports around the world can inadvertently introduce non-native marine flora and fauna into PNG waters, e.g., in discharged ballast water, on the hulls of vessels or via consumables. Marine pests introduced in this manner can cause problems to ecosystems through competition with existing native species for resources, alteration of localised gene pools and modification of physical environments, leading to a loss of diversity.

Waste Discharge and Spills

Activities at the Port of Vanimo have the potential to result in reduced water quality in nearshore marine water, primarily from the discharge of excess filtrate water from the concentrate thickener. A portion of the filtrate water will be reused for washdown with the excess being filtered prior to discharge at the location shown on Figure 8.22. The excess filtrate water will be a freshwater discharge containing residual metals and metalloids and residual ore processing reagents such as xanthates. The discharge will be located at an approximate depth of 13 m. The excess filtrate water will be discharged at a rate of 55 L/s for the life of concentrate handling.

Impacts to water quality could also be caused by accidental spills of diesel or concentrate at the Vanimo Ocean Port or during vessel loading. Accidental spillage of concentrate during loading could reduce water and sediment quality in the nearshore marine environment. During loading of the export vessels, if not adequately covered, wind may blow concentrate particles into nearshore marine waters or onto hardstand areas of the port which then drain to the ocean after rainfall, resulting in increased metals concentrations, particularly copper, and suspended solids in the waters.

The abovementioned sources of contamination have the potential to cause adverse physiological effects to nearshore marine fauna. These effects include clogging of gills with suspended solids, direct ingestion of contaminants including accumulation of copper or other metals in tissues of organisms at toxic concentrations and adsorption of contaminants to the surfaces of organisms.

Diesel spills may result in acute toxicity to nearshore marine fauna, particularly those that are less mobile to move from the area. This could involve accidental spillage of small volumes of diesel during handling or larger uncontained releases of diesel from a leak in the diesel pipeline or storage tanks.

8.10.3 Management Measures

The management measures to limit potential impacts relating to nearshore marine values are presented in Table 8.70.

Table 8.70 Nearshore marine management measures

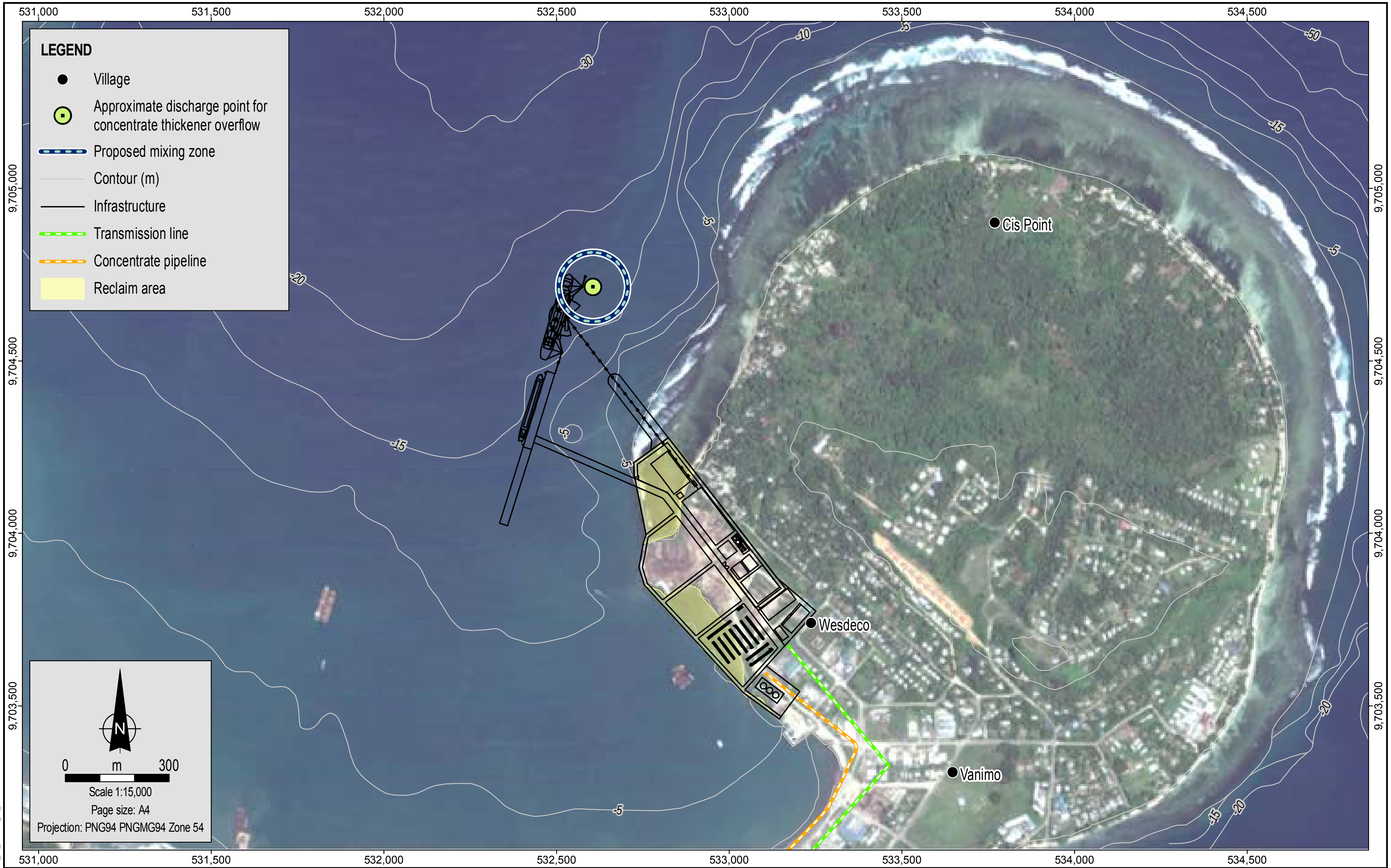
No.	Management Measure
Habitat loss and deterioration	
MM135	Limit, where practicable, disturbance of fringing reefs and seagrass during construction of the Vanimo Ocean Port.
Disturbance of nearshore marine fauna	
MM136	Minimise startling nearby marine fauna (e.g., larger fauna such as dolphins and turtles) by employing 'soft start' procedures (i.e., gradual increase from lower noise emissions to higher noise emissions) for pile driving during construction of the Vanimo Ocean Port.
MM137	Ad hoc marine fauna observation will be reported to the Vanimo Ocean Port environment team and subsequent avoidance actions (e.g., wait or reduce thruster power), as practicable, until large fauna have moved from the area.
Introduction of invasive marine species	
MM138	Implement a quarantine management plan which will include requirements for Project vessels to comply with PNG and relevant International Maritime Organization guidelines and standards including ballast discharge, hull cleaning and antifouling requirements.
MM139	Store on board any wastes produced by vessels that cannot be discharged under PNG and relevant International Maritime Organization guidelines and standards and transfer to an approved onshore facility for treatment, reuse, recycling or disposal.
Waste discharge and spills	
MM140	Implement a waste management plan (including hazardous and non-hazardous waste) as a component of the Sepik Infrastructure Project (Vanimo Ocean Port) EMMP.
MM141	An emergency response plan (as part of the Sepik Infrastructure Project (Vanimo Ocean Port) EMMP) will be developed and implemented that will: • Include a spill response plan for concentrate, oil and other hazardous substances. • Provide for training of staff during the induction process to facilitate awareness of their responsibilities, ensure that they are able to identify risks or sources of potential chemical and fuel spills, and can apply appropriate control measures.
MM142	Implement containment facilities at the concentrate handling system to minimise spillage of concentrate. This may include: • Windbreaks, water spray or mist systems. • Enclosed transfer points, conveyor belts and loading boom. • Telescopic loading chutes designed to limit spillage.
MM050	Store, handle and transport hazardous substances in accordance with Australian Standards AS1940:2017 and AS3780:2008, and the PNG Environmental Code of Practice for Vehicle/Machinery Workshops and Petroleum Storage/Resale/Usage Sites.

8.10.4 Residual Impact Assessment

This section assesses impacts after the assumed successful implementation of the management measures outlined in Section 8.10.3.

Habitat Loss and Deterioration

Construction of the Vanimo Ocean Port will involve reclamation of coastline adjacent to the settlement of Wesdeco. This will result in direct loss of adjacent reef and seagrass along a 500 m stretch of coastline. Land reclamation for the Vanimo Ocean Port will result in permanent loss of about 3.4 ha of fringing reef and seagrass adjacent to the existing port. This loss will be less than



Source:
Discharge locations and mixing zones from Coffey.
Villages from FRL and Coffey.
Port layout and reclaim areas from GHD. Contours from BMT WBM.
Transmission line and concentrate pipeline from FRL.
Imagery from Google Earth (DigitalGlobe captured 14 December 2014).

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Project: 754-ENAUABTF11575A
File Name: 11575_11_F08.22_GIS

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FRIEDA RIVER

Discharge location for the excess filtrate water from the concentrate thickener at Vanimo Ocean Port and proposed mixing zone boundary

Figure No: 8.22

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10% of reef and seagrass habitat within Dakriro Bay. While this impact will be permanent (high magnitude), the reefs in that area are in poor condition, being dominated by turfing algae and macroalgae and comprising low coral cover. Furthermore, rubbish (mostly plastics, cans and bottles) is prevalent in the intertidal zone contributing to the poor existing condition of habitat. There are sections of seagrass within the proposed ocean port area and these were found to be in good condition; larger seagrass meadows are to the north of Cis Point which is approximately 3 km from the area of proposed Project disturbance. Overall, the nearshore marine habitat is of **low** sensitivity. Given this and the high impact magnitude, the loss of habitat due to land reclamation for the Vanimo Ocean Port is predicted to be of **moderate** significance.

Construction of the new shipping berths will disturb the seabed and cause direct loss of small areas of seabed where pylons are installed. Additionally, the installation of the pylons via pile driving may cause increased suspended sediments and turbidity, resulting in sediment smothering of adjacent benthic habitat.

Installation of pylons for the berths at the Vanimo Ocean Port will result in long term but highly localised loss of benthic habitat at the location of each pylon. This is expected to be a negligible proportion of available benthic habitat in the bay (negligible magnitude). Given the generally poor condition of benthic habitat in the area (**low** sensitivity) and the **negligible** impact magnitude, this impact is predicted to be of **negligible** significance. The installation of pylons will likely result in new habitat for fish, corals and crustaceans. Fauna inhabiting such areas would be protected by a vessel safety exclusion zone around the ocean port, which will preclude fishing in these areas. This may be a positive impact in the long term.

Disturbance of the seabed due to propeller wash may occur during the period of vessel movements at the ocean port (i.e., over a long-term period). The new berths will be located where the water is at least 12 m deep with Project vessel draw ranging from 8.5 m to 12.5 m. The bathymetry at the ocean port ranges from more than 10 m deep to 20 m deep and the highest likelihood for propeller wash disturbance will be when vessels pass through the shallower waters. It is expected that disturbance will be localised to small sections of seabed and, although the disturbance will be frequent, it will cause only a short-term suspension of benthic sediments as the vessel passes through the area. This situation is likely to be similar to conditions near the existing port given this port is already used by a range of large vessels. Therefore, it is likely that propwash will result in little disturbance to, or smothering of, benthic habitat above the existing situation and the impact is predicted to be of **low** magnitude and **minor** significance.

Disturbance of Nearshore Marine Fauna

Noise levels that may interfere with marine fauna could occur in the event of extensive use of thrusters. Underwater noise from vessels during the construction of the ocean port and during the export of concentrate is likely to be similar to those types of vessels (e.g., large logging vessels) that already use the Port of Vanimo. Concentrate vessels will be in the range of 28,000 to 48,000 deadweight tonnes (dwt). Information on three cargo vessels known to use (or have used) Port of Vanimo, Bao Long (22,056 dwt; Marine Traffic, 2018b), Run FU 3 (32,115 dwt, Marine Traffic, 2018c) and BMC Carol (14,181 dwt, Marine Traffic, 2018d), shows that vessels that use Port of Vanimo are of a similar size to the proposed concentrate vessels.

The relatively shallow depth and soft sedimentary nearshore seafloor will partially attenuate underwater noise by reflection and absorption of sounds from engines and thrusters. Furthermore, there is a very low expected frequency of situations where marine fauna might suddenly be exposed to noise without prior detection to enable avoidance behaviour. With the application of management measures during pile driving, such as ‘soft start’ procedures where noise-causing activities are ramped up gradually, the residual effects of underwater noise on marine fauna are predicted to be of **low** magnitude and of **minor** significance.

Disturbance of the seabed could result in elevated concentrations of suspended sediments during construction of the Vanimo Ocean Port, which could clog gills of fish or smother benthic infauna. It is expected that increased suspended sediments will be short term (i.e., intermittently over the 3-year construction period of the export facility) during land reclamation activities and installation of the ocean port pylons. In the case of fish, it is likely that exposure to localised suspended sediments will be brief as fish are capable of avoiding plumes of increased sediment. Less mobile species such as sediment infauna will be more susceptible to being impacted by increased sediment. It is expected that fauna in Dakriro Bay have some resilience to fluctuations in suspended sediments given the delivery of terrigenous sediments from numerous open drains around Vanimo and from four watercourses that drain into the bay from the south delivering terrigenous sediments. Furthermore, the degraded nearshore reefs and seagrass areas and the paucity of observed fish in Dakriro Bay, indicate that the nearshore marine zone at the ocean port site is of **low** sensitivity. The disturbance of marine fauna due to increased suspended sediment from seabed disturbance is predicted to be of **low** magnitude and **minor** significance.

Introduction of Invasive Marine Species

The ability of an invasive marine species to become established in a different environment such as Dakriro Bay is difficult to predict because of the complex interaction between native and introduced exotic (i.e., non-native) species.

Potential quarantine-related impacts to the nearshore marine environment in Dakriro Bay need to be considered within the context of the existing and future vessel traffic to the Vanimo Ocean Port, including existing vessel movements unrelated to the Project, which may make attribution to a particular vessel or activity difficult. Approximately 10 vessel calls (i.e., arrivals and departures) occur at the Port of Vanimo each month (Marine Traffic, 2018a) which provides existing potential exposure to invasive species. According to Marine Traffic (2018a) these calls comprise mostly ‘Cargo’ and ‘Special Craft’ vessels.

The long-running use of the Port of Vanimo, and the fact that field observations did not identify invasive pest species, indicates that current quarantine practices are working and/or invasive species have not become established in the area.

With the implementation of Project-specific quarantine management measures and the requirements of international vessels arriving at the ocean port to comply with PNG customs and quarantine requirements, the significance of impacts related to introduction of invasive marine species are predicted to be of **low** significance.

Waste Discharge and Spills

Discharge of Excess Filtrate Water

Excess filtrate water from the concentrate thickener will be discharged into nearshore waters at a rate of approximately 55 L/s for the life of the FRCGP. Table 8.71 shows the predicted concentrations of potential stressors in the discharge such as pH and metals and metalloids. No predicted concentrations of residual mill reagents were available. However, one reagent that is likely to be used, sodium ethyl xanthate, an organosulphur compound used as a flotation agent, is likely to have the highest potential toxicity of the residual processing reagents to marine life. As a soluble salt, sodium ethyl xanthate will complex with the metallic ions contained in water and marine organisms and typically has a chemical half-life of 4.1 days (Boening, 1998 as reported in DCE, 2016). There are no PNG ambient marine water quality standards for xanthates. Given that sodium ethyl xanthate is biodegradable and has a short half-life, it is unlikely to bioaccumulate in marine organisms. In addition, NICNAS (1995) assessed that sodium ethyl xanthate is not expected to bioaccumulate in view of its ionic character. The remainder of this section therefore concentrates on residual metals and metalloids in the excess filtrate water from the thickener overflow discharge, which are likely to be the primary potential toxicants.

Table 8.71 also compares the predicted discharge concentrations to the PNG ambient marine water quality standards. Exceedances of the PNG ambient marine water quality standards are shown in bold and the dilutions required for compliance are also presented. Data is given for a discharge scenario based on filtrate water prepared from pilot scale tests. The discharge scenario assumes that although solids are filtered out, up to 50 mg/L TSS remains (a conservative maximum concentration) in the filtrate prior to discharge. The discharge scenario also assumes that metals/metalloids concentrations are total concentrations.

Table 8.71 Summary of excess filtrate water from the concentrate thickener discharge scenarios

		PNG criteria	Discharge contaminant concentrations	Dilutions required for compliance
pH (Field)	no units	no change	8.02	0
TSS	mg/L	-	50*	0
SO_4	mg/L	-	1,291	0
Aluminium	mg/L	-	0.079	0
Antimony	mg/L	-	0.0011	0
Arsenic	mg/L	0.05	<0.001	0
Cadmium	mg/L	0.001	0.00059	0
Chromium	mg/L	-	<0.005	0
Chromium VI	mg/L	0.01	<0.001	0
Cobalt	mg/L	LOD	**0.0027**	**3**
Copper	mg/L	0.03	**1.63**	**55**
Iron	mg/L	1	0.038	0
Lead	mg/L	0.004	0.00096	0
Manganese	mg/L	2	0.115	0
Molybdenum	mg/L	-	0.069	0
Nickel	mg/L	1	0.0058	0
Selenium	mg/L	0.01	**0.075**	**8**
Zinc	mg/L	5	<0.030	0

Concentrations that exceed PNG water quality criteria are shown in black bold.
Dilutions required for compliance have been given to the nearest and most conservative whole number.
* TSS concentration is given for the expected maximum (conservative) concentration. Typical TSS concentrations are expected to be much lower than these values most of the time.

Table 8.71 shows that 55 dilutions is the highest number of dilutions required for compliance with PNG ambient marine water quality standards, based on the concentration of copper. Based on this dilution factor, hydrodynamic modelling has predicted the mixing zone boundary at which the PNG ambient marine water quality standards for copper will be achieved.

The predicted maximum distance from the discharge point at which PNG ambient marine water quality standards will be met is 8.8 m (Appendix 12b).

The modelling assumed the discharge system comprises a horizontal diffuser with five ports, each port with a diameter of 5 cm and spaced from each other by 2 m. It was assumed that the total length of the diffuser is 10 m and it is located at 13 m depth. This diffuser configuration is likely to maximise rapid contaminant dilution after discharge.

Given that the predicted metals concentrations in the discharge are for total metals and the PNG ambient marine water quality standards are for dissolved metals, it can be conservatively predicted that the PNG ambient marine water quality standards will not be exceeded at 8.8 m from the discharge point during discharge of the excess filtrate water from the concentrate thickener. Monitoring such a mixing zone will not be practical given its location at an operational port. Therefore, a mixing zone with a (conservative) radius of 100 m from the discharge point is proposed to allow for natural variability and to allow safe access to the monitoring location. This proposed mixing zone is shown in Figure 8.22.

Spills

There will be a diesel import system at the berths and bulk storage of diesel at the port. There will be a pipeline transporting diesel to the bulk storage facility at the Vanimo Infrastructure Area. Given that the bulk diesel storage at the ocean port will be within a bunded area, it is expected that spills from the site will be localised in their extent and will be restricted to those times during diesel unloading. In the case of accidental spillage, it is likely that the spillage will be readily identified and contained after initiation of an emergency response plan. The impact to marine fauna due to diesel spillage is therefore predicted to be short-term and localised (**low** magnitude). Given the low diversity and abundance of fish and other fauna in the vicinity of the ocean port area, and the likelihood that most fauna, e.g., fish and mammals, will either pass through the area of spillage temporarily or be mobile enough to avoid or swim away from the area, the sensitivity of marine fauna to localised short term spillages is expected to be **low**. Therefore, the impact is predicted to be of **low** significance.

During handling and loading of copper concentrate, concentrate dust (notwithstanding its expected moisture content of 9.5%) could be transported by winds or spills into nearshore waters or onto hardstand areas of the port which then drain to the ocean after rainfall. It is unlikely that this will result in severe impacts to marine fauna because, with management measures to protect exposure of concentrate to wind and rain (i.e., by covering the concentrate loading facilities, and having enclosed transfer points), it is likely that amounts of concentrate spilled or transported by wind and rain will be low. The concentrate dust will likely quickly disperse and become diluted to very low concentrations in nearshore waters. Over time, copper concentrations in benthic sediments may gradually increase due to the frequent but small amounts of concentrate particles depositing on the seabed.

Overall, the impact to nearshore fauna due to spillage of concentrate is predicted to be of low magnitude and **low** significance.

Table 8.72 summarises the residual impacts on nearshore marine values, with significance ratings of moderate or higher.

Table 8.72 Residual impacts to nearshore marine values

Impact Description	Residual Impact after Implementation of Management Measures		Significance Rating
	Magnitude	Sensitivity of Receptor	
Loss of marine habitat due to land reclamation for the Vanimo Ocean Port	High	Low	Moderate