Panguna Mine Legacy Impact Assessment

Phase 1 Assessment Report
Chapter 7 – Conceptual Site Model

Panguna Legacy Assessment Company Limited

Reference: 754-MELEN305719_R03

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7. CONCEPTUAL SITE MODEL

This chapter provides a description of the conceptual site model for the Panguna Mine Legacy Impact Assessment, including sources, pathways and end points across each domain. The conceptual site model was developed based on the environmental, social and health data described in Chapter 5 and Chapter 6.

7.1 OVERVIEW

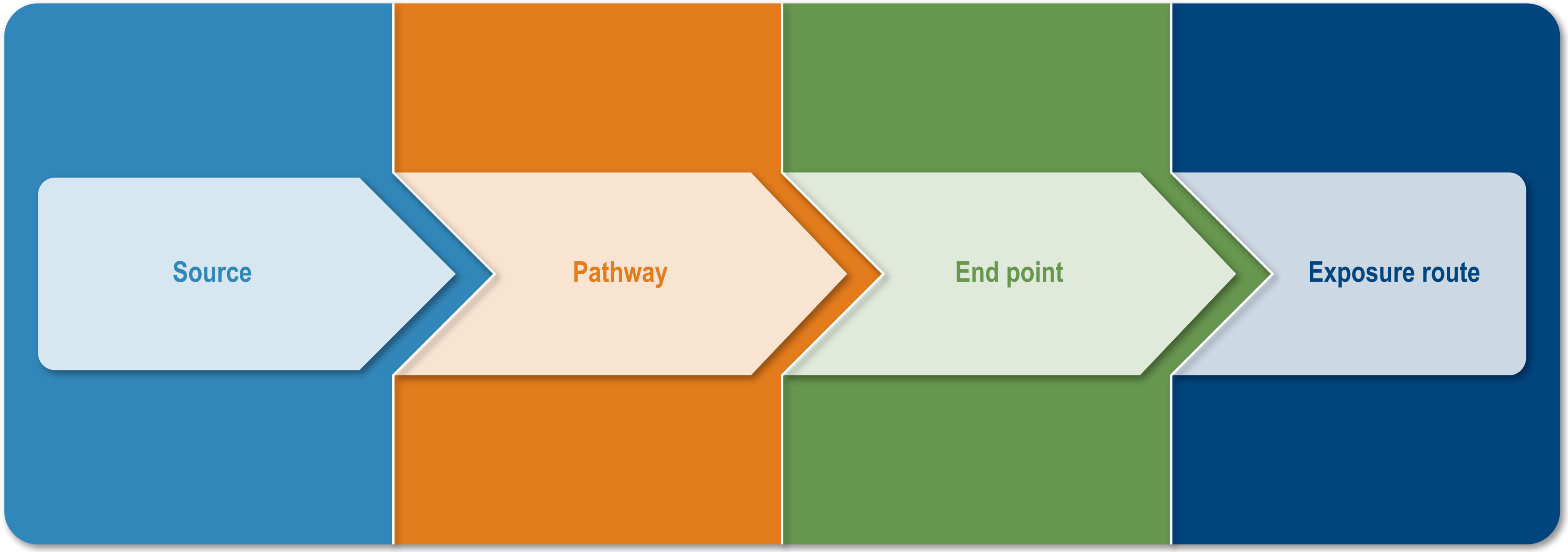
The conceptual site model has been developed to describe the possible pathways that mine-related contaminants or hazards (sources) may take to reach the receiving environment or community (end points) causing possible negative environmental, social, and human rights impacts. An individual source may have more than one pathway and/or end point.

As shown in Figure 7.1, the exposure pathway connects the source of contaminating activities or physical hazards to an end point where they may generate a negative interaction for the community and receiving environment. The exposure route is how a person or an ecological receptor may be exposed to hazard. Describing these exposure pathways helps to identify the places that contaminants and hazards may be found throughout the landscape that may be impacting communities. This conceptual site model has been developed based on the Primary Contractor Scope of Work for the Legacy Impact Assessment and therefore identifies and focuses on complete pathways for acute impacts, i.e., extreme, severe or very serious actual and potential impacts. To align with the required focus on acute impacts, only environmental risks of high or greater have been included in the conceptual site model for site contamination, and geotechnical and structural hazards.

All components of the conceptual site model (i.e., a source, a pathway, an end point and exposure route) must be present to indicate an actual or potential impact, referred to as a complete pathway. The information presented in the conceptual site model informs the impact assessment and helps to demonstrate the impacts' connection to the legacy of mining. Only those impacts with a complete pathway are carried through to the impact assessment. The conceptual site model is also a useful tool for stakeholder engagement to explain and visualise these connections.

The development of the conceptual site model has been an iterative process since mid-2022. An initial conceptual site model was prepared during scoping of the Legacy Impact Assessment. This was updated approximately halfway through Phase 1 based on field data collection, the results of laboratory testing of samples and evaluation and analysis from field campaign 1. This allowed for refinement of the subsequent field campaigns to focus sampling and surveys on the sources, pathways and end points identified in the conceptual site model most likely to be related to acute impacts. The conceptual site model presented in this chapter was further refined based on the data collected during field campaigns 2 and 3, and the completed environmental and social characterisation and evaluations presented in Chapter 5 and Chapter 6 of this report, respectively. The conceptual site model identifies areas that may pose an elevated risk to communities relative to other locations in the study area based on the exceedance of screening indicators (criteria) identified in the investigation reports. This chapter describes the conceptual site model and Table 7.1 in Section 7.7 presents it in tabular form.

Figure 7.2 presents an interactive PDF of the conceptual site model, where feature layers on the legend can be toggled on and off. For example, clicking 'Hide all layers' and then clicking on 'Source' will display only the source features; similarly, clicking on 'Pathway' will turn on and show pathway features along with source features. A visual representation of the conceptual site model has been developed in the project geographic information system, referred to as the digital conceptual site model. The digital conceptual site model is shown in Figure 7.3, Figure 7.4 and Figure 7.5, Figure 7.6 for the Mine Domain, River System Domain, Delta Domain and Port and Town Domain respectively.



SOURCE
Tetra Tech Coffey, 2024

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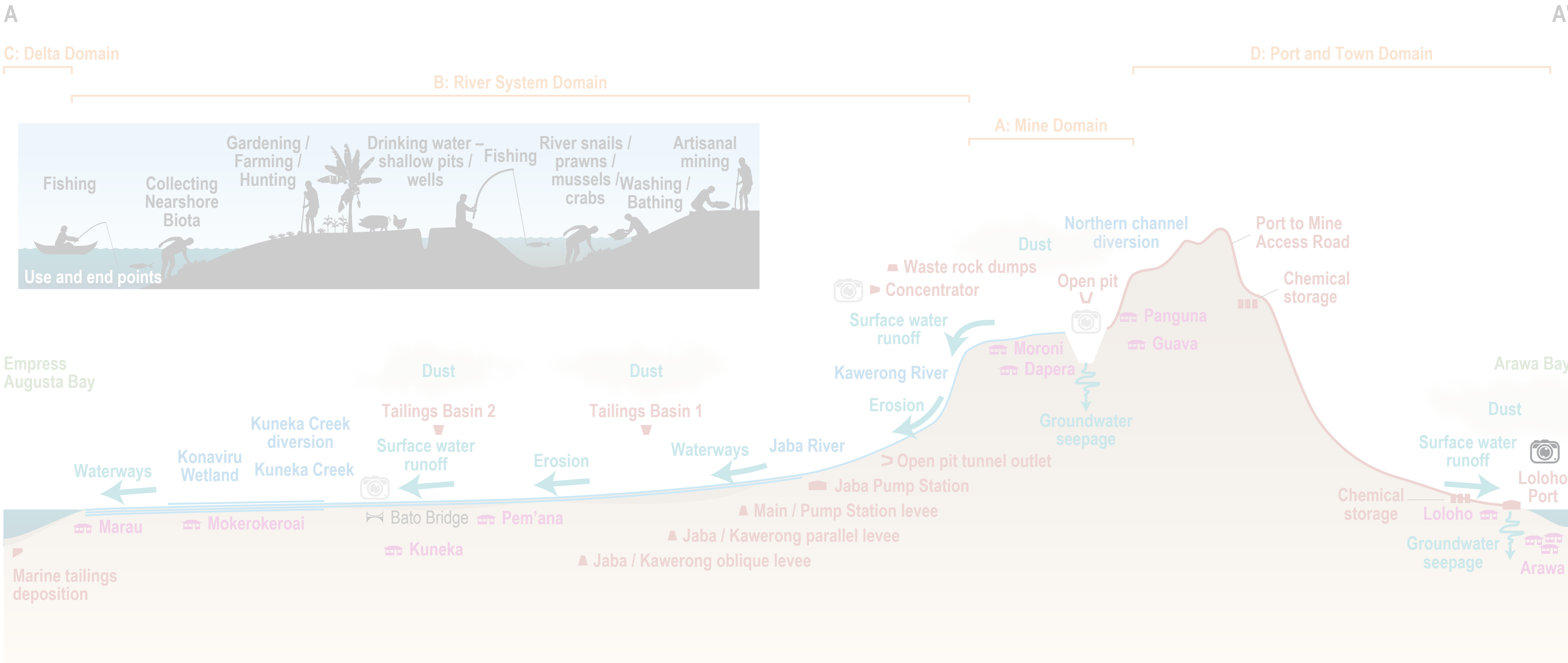
FIGURE 7.1

Conceptual site model - exposure pathway diagram

TETRA TECH COFFEY

DATE: 30.10.24 PROJECT: 754-MELEN305719 FILE: 305719_R03_F07.01_GRA

DOC REFERENCE: \\TT.LOCAL\COF\S772\S\GIS\305719_MELEN_PLAC_LEGACYIMPACTASSESSMENT\2_GRAPHICS\305719_R03_LIA\305719_R03_GRA087.AI_2 | SAVED BY: JO | 30.10.24



This is an interactive PDF, best viewed in Adobe Acrobat Reader.

Features on the legend can be toggled on and off.

Click to continue.

INTERACTIVE FUNCTIONALITY

If legend buttons or camera/photo symbol roll-over functionally stops working, please click off or away from the PDF page to restore.

SOURCE

Aerial image Google Earth

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FIGURE 7.2

Interactive visual conceptual site model

TETRA TECH COFFEY

DATE: 30.10.24 PROJECT: 754-MELEN305719 FILE: 305719_R03_F07.02_GRA_iPDF

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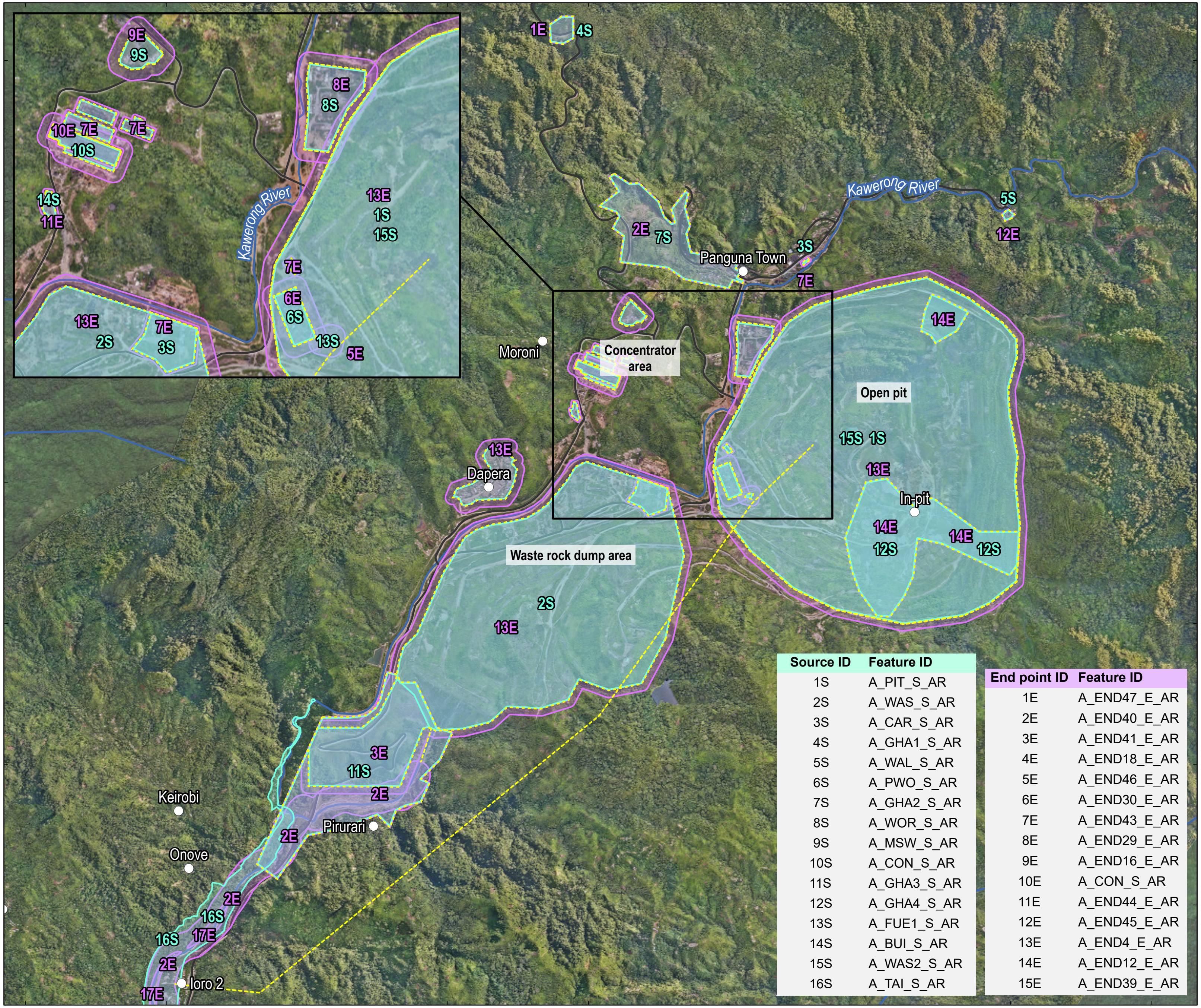

LEGEND

- Village
- Road
- Watercourse
- Pathway
- Source
- End point

Source ID	Feature ID
1S	A_PIT_S_AR
2S	A_WAS_S_AR
3S	A_CAR_S_AR
4S	A_GHA1_S_AR
5S	A_WAL_S_AR
6S	A_PWO_S_AR
7S	A_GHA2_S_AR
8S	A_WOR_S_AR
9S	A_MSW_S_AR
10S	A_CON_S_AR
11S	A_GHA3_S_AR
12S	A_GHA4_S_AR
13S	A_FUE1_S_AR
14S	A_BUI_S_AR
15S	A_WAS2_S_AR
16S	A_TAI_S_AR

End point ID	Feature ID
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2E	A_END40_E_AR
3E	A_END41_E_AR
4E	A_END18_E_AR
5E	A_END46_E_AR
6E	A_END30_E_AR
7E	A_END43_E_AR
8E	A_END29_E_AR
9E	A_END16_E_AR
10E	A_CON_S_AR
11E	A_END44_E_AR
12E	A_END45_E_AR
13E	A_END4_E_AR
14E	A_END12_E_AR
15E	A_END39_E_AR

SOURCE
CSM, villages, roads and watercourses from Tetra Tech Coffey.
Imagery and LiDAR from Woolpert (2023) and ArcGIS Online.

0 250 500 m
SCALE 1:40,000
PAGE SIZE: A4
PROJECTION: WGS 1984 UTM Zone 56S

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FIGURE 7.3

Digital conceptual site model – Mine Domain

TETRA TECH COFFEY

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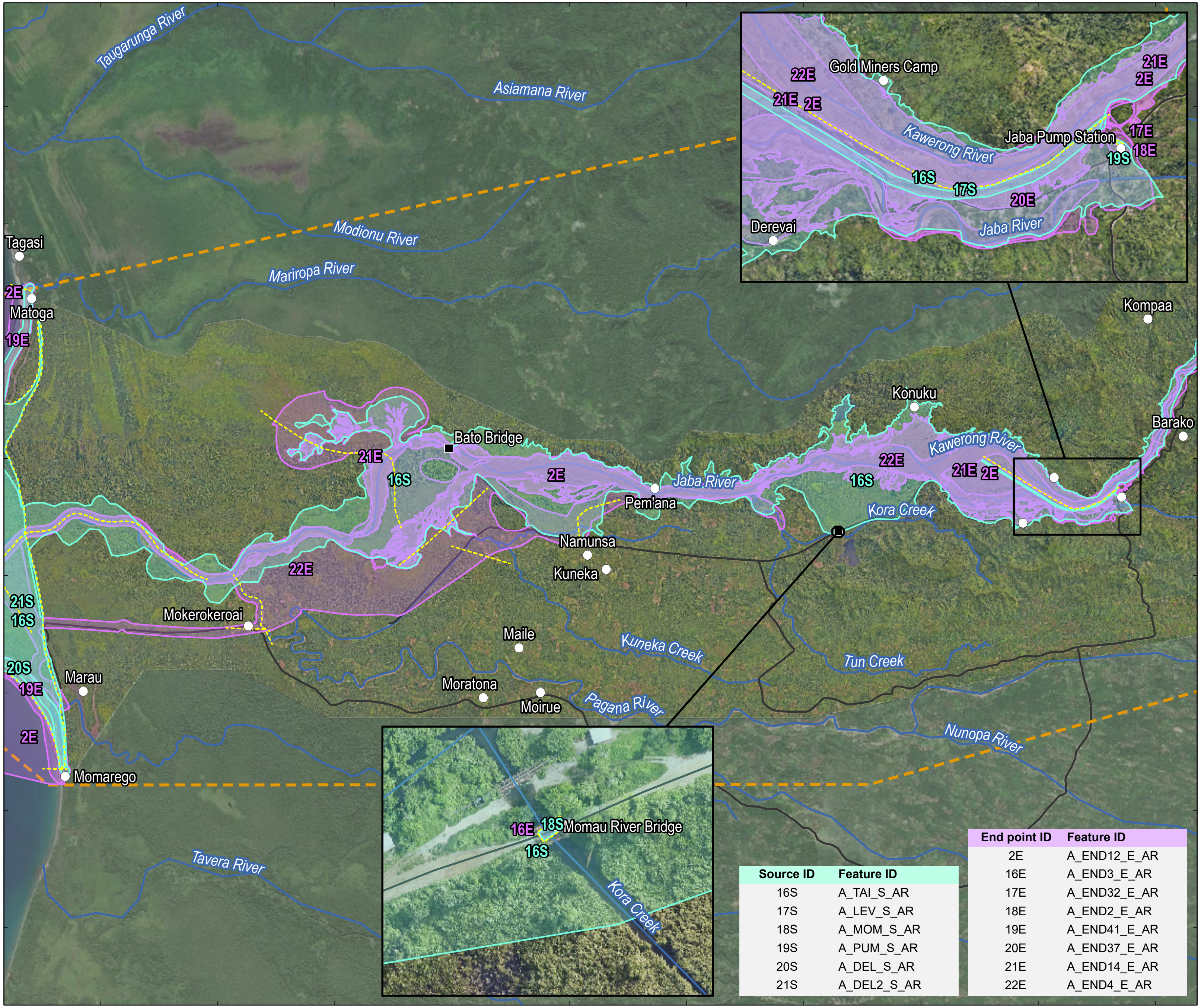

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18S	A_MOM_S_AR
19S	A_PUM_S_AR
20S	A_DEL_S_AR
21S	A_DEL2_S_AR

End point ID	Feature ID
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16E	A_END3_E_AR
17E	A_END32_E_AR
18E	A_END2_E_AR
19E	A_END41_E_AR
20E	A_END37_E_AR
21E	A_END14_E_AR
22E	A_END4_E_AR

LEGEND

- Village
- Point of interest
- Road
- Watercourse
- Pathway
- Source
- End point
- Phase 1 study area

SOURCE
CSM, villages, roads and watercourses from Tetra Tech Coffey.
Imagery and LiDAR from Woolpert (2023) and ArcGIS Online.

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SCALE 1:120,000
PAGE SIZE: A4
PROJECTION: WGS 1984 UTM Zone 56S

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FIGURE 7.4

Digital conceptual site model – River System Domain

TETRA TECH COFFEY

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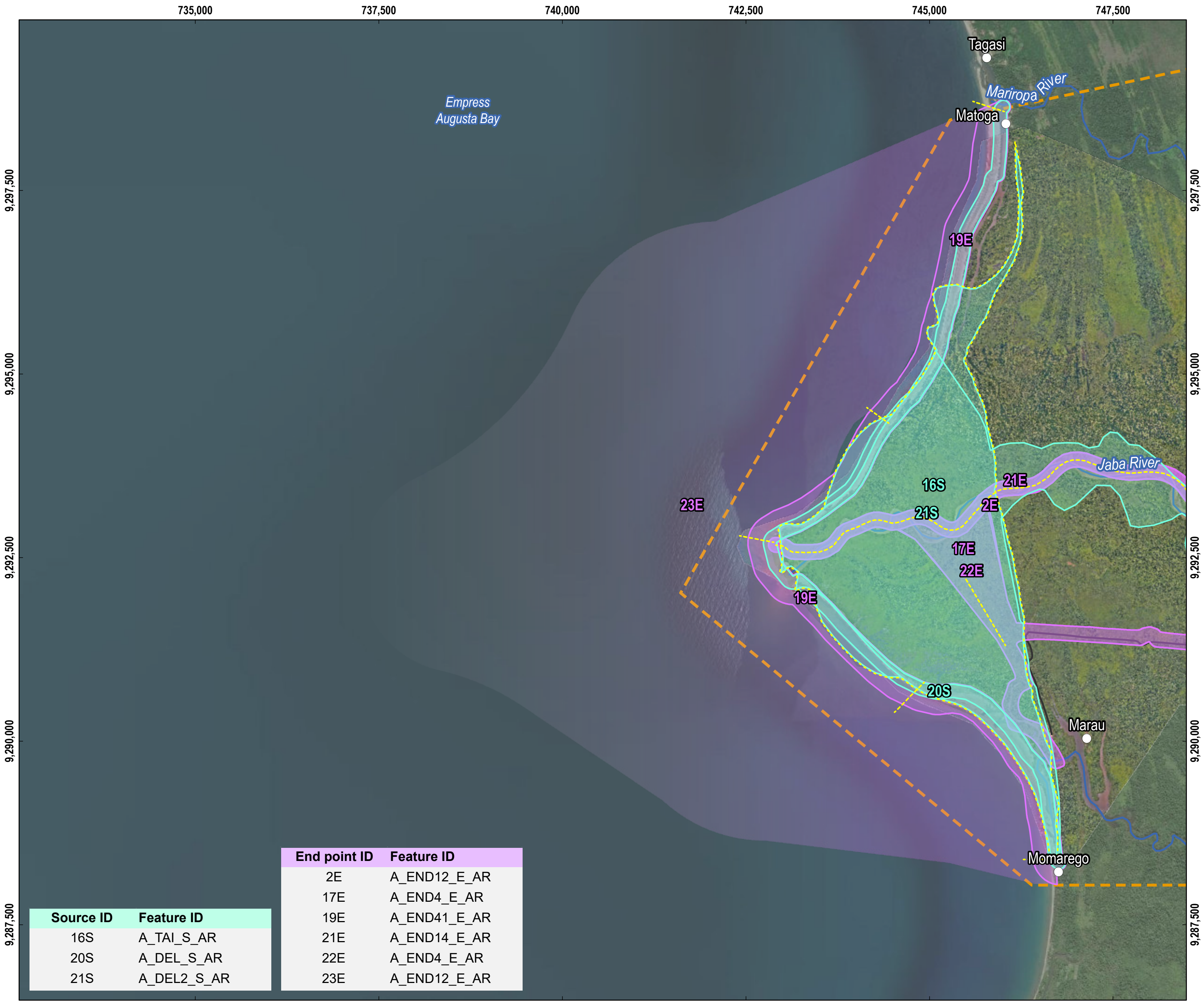

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20S	A_DEL_S_AR
21S	A_DEL2_S_AR

End point ID	Feature ID
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17E	A_END4_E_AR
19E	A_END41_E_AR
21E	A_END14_E_AR
22E	A_END4_E_AR
23E	A_END12_E_AR

LEGEND

- Village
- Road
- Watercourse
- Pathway
- Source
- End point
- Phase 1 study area

SOURCE
CSM, villages, roads and watercourses from Tetra Tech Coffey.
Imagery and LiDAR from Woolpert (2023) and ArcGIS Online.

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SCALE 1:75,000
PAGE SIZE: A4
PROJECTION: WGS 1984 UTM Zone 56S

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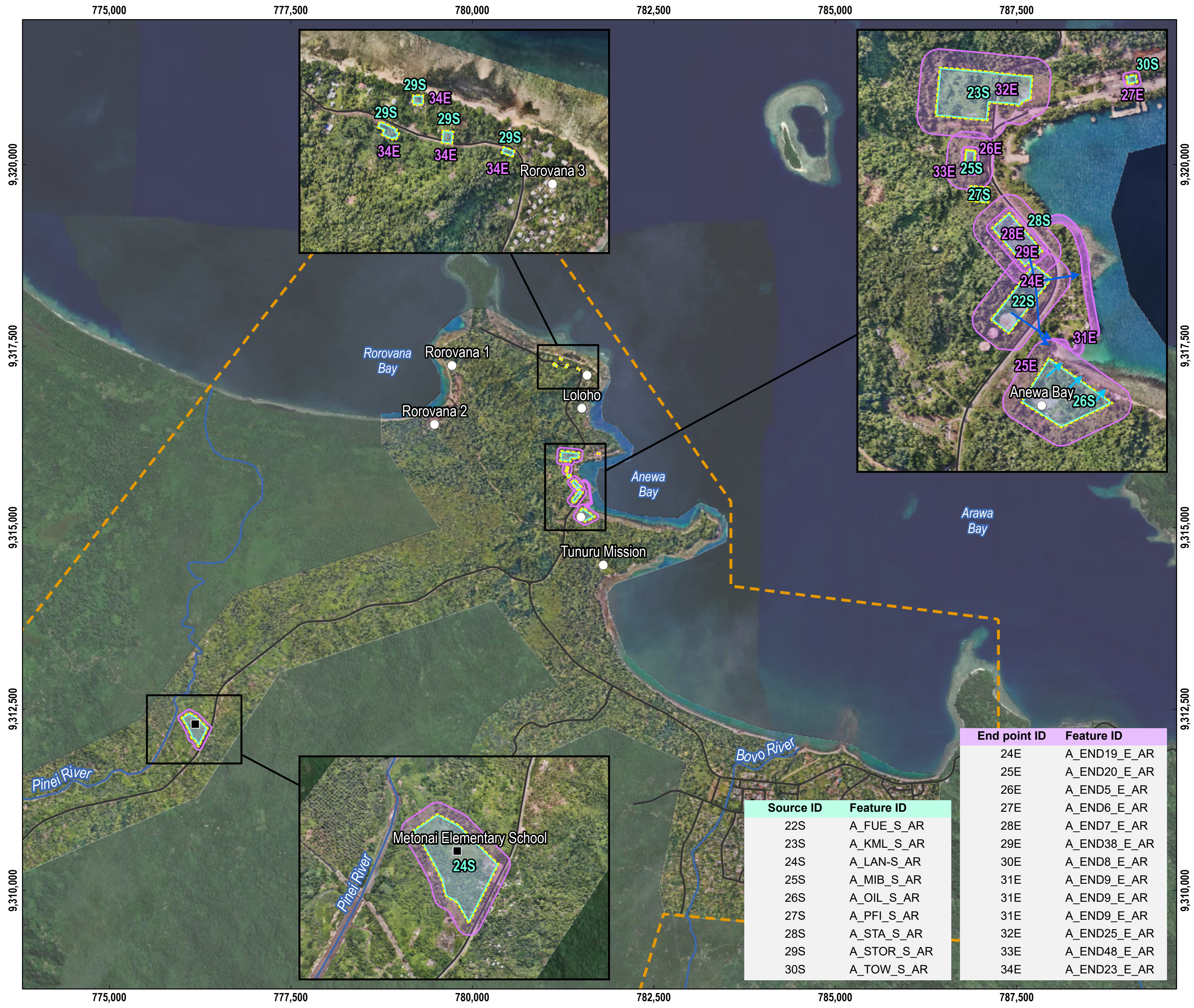
FIGURE 7.5

Digital conceptual site model – Delta Domain

TETRA TECH COFFEY

DATE: 30.10.24 PROJECT: 754-MELEN305719 FILE: 305719_R03_F07.05_GIS



Source ID	Feature ID
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23S	A_KML_S_AR
24S	A_LAN-S_AR
25S	A_MIB_S_AR
26S	A_OIL_S_AR
27S	A_PFI_S_AR
28S	A_STA_S_AR
29S	A_STOR_S_AR
30S	A_TOW_S_AR

End point ID	Feature ID
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25E	A_END20_E_AR
26E	A_END5_E_AR
27E	A_END6_E_AR
28E	A_END7_E_AR
29E	A_END38_E_AR
30E	A_END8_E_AR
31E	A_END9_E_AR
31E	A_END9_E_AR
31E	A_END9_E_AR
32E	A_END25_E_AR
33E	A_END48_E_AR
34E	A_END23_E_AR

LEGEND

- Village
- Point of interest
- Road
- Watercourse
- Groundwater migration
- Stormwater run-off
- Pathway
- Source
- End point
- Phase 1 study area

SOURCE
CSM, villages, roads and watercourses from Tetra Tech Coffey.
Imagery and LiDAR from Woolpert (2023) and ArcGIS Online.

N

0 1 2 km

SCALE 1:75,000
PAGE SIZE: A4
PROJECTION: WGS 1984 UTM Zone 56S

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FIGURE 7.6

Digital conceptual site model – Port and Town Domain

TETRA TECH COFFEY

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7.2 SOURCES

Contamination or hazard sources identified during the Preparatory Phase of the Legacy Impact Assessment have been further refined based on the data collected during Phase 1. This process included evaluation of whether the source is due to activities related to the Panguna Mine, and only these mine-related sources have been included in the conceptual site model. The mine-related contaminant or hazard sources identified have been separated by domain including:

- Mine Domain
- River System Domain
- Delta Domain
- Port and Town Domain.

Source types within each domain were broadly categorised as:

- **Contamination source**. Mine feature (for example, open pit, waste rock dump, tailings or structure) where mineralisation, chemicals or other hazardous materials are present that may affect human health or the environment.
- **Physical source.** The physical presence of tailings and waste rock, as well as sedimentation from natural or mine-related sources, that may influence the flow of water, and result in changes to hydrology and sediment transport.
- **Structural hazards.** Mine infrastructure that may result in structural failure based on estimated load scenarios and consequence from observed use of infrastructure and assessment of safety factors.
- **Geotechnical hazards.** Source of instability of landform features such as open pit walls and levee embankments.

Table 7.1 presents sources that have been identified and sections 7.2.1 to 7.2.4 describe key mine-related sources. Table 7.1 also provides a summary of key areas of uncertainty associated with the available data, level of assumptions and confidence in the accuracy of the inputs to the conceptual site model. Source type subheadings within each domain section are only used where sources were identified in those categories, i.e., if there is no source type subheading in a domain section then Phase 1 investigations have not found evidence of a credible mine-related source for that aspect. By way of example, the Mine Domain section describes source types for mineralised and non-mineralised contamination and structural and geotechnical hazards; for comparison, the Port and Town Domain describes source types for non-mineralised contamination and structural hazards as no mineralised contamination or geotechnical hazard sources have been identified in that domain.

7.2.1 Mine Domain

This section describes mineralised and non-mineralised contamination sources and structural and geotechnical hazards identified in the Mine Domain (see Figure 7.3).

7.2.1.1 Contamination sources – mineralised contamination

The key mineralised contamination sources in the Mine Domain that may contribute to poor water quality downstream include the waste rock dump, tailings and open pit and dewatering tunnel (see Figure 7.3). Each of the key mineralised contamination sources is described in further detail below. These mineralised sources contain sulfidic material, which when exposed to atmospheric conditions (i.e., air and water) can oxidise, leading to generation of acidic drainage that can solubilise metals and may impact downstream receiving aquatic ecosystems and human health where communities may be exposed.

Waste rock

Waste rock from the Panguna Mine was mainly deposited in the waste rock dump in the upper Kawerong River Valley. Some waste rock was also used for construction purposes including the construction of the road to the Jaba Pump Station, levelling of surfaces for buildings, roads and sports fields, and filling a valley for the relocation of Dapera village. Metals concentrations in waste rock were elevated above background soil with maximum concentrations of copper, arsenic and molybdenum exceeding agricultural human health criteria and maximum concentrations of copper, zinc, arsenic, molybdenum and selenium exceeding agricultural environmental health criteria. Ecological (residential/open space, industrial and agricultural) criteria were exceeded, mainly due to copper concentrations.

Approximately 395 Mt of waste rock is stored in the waste rock dump and is a primary source of acid and metals in the Mine Domain. The laboratory results of samples of the drainage from the waste rock dump, called waste rock leachate, collected from the base and downstream of the dump indicates that:

- Drainage from the waste rock dump is mildly acidic and contains elevated (with respect to screening criteria) conductivity (i.e., salts) and concentrations of sulfate and metals including copper and manganese.
- There is a degree of neutralising capacity in the waste rock dump, whereby carbonates in the rock counteract the formation of acid as indicated by the elevated conductivity attributed to release of salts during carbonate neutralisation and mildly acidic pH.
- The copper load discharging from the waste rock dump has been decreasing over time and is currently approximately 10% of the copper load recorded during mining.
- Based on preliminary estimates, the waste rock dump contributes approximately 94% of the cadmium load, 61% of the copper load, 39% of the zinc load and about 30% of the manganese and sulfate load to the downriver system.
- Within approximately 400 m downstream of the base of the waste rock dump, dissolved copper concentrations rapidly reduce as the copper precipitates (forms a solid) as particulate copper. This form of copper is less bioavailable in the aquatic environment than dissolved copper. Bioavailable refers to the portion of a substance easily taken up and used by living organisms.
- High-level calculations of the amount of copper-containing rock stored in the waste rock dump compared with the estimated copper that has been released over time from the dump suggest that there is a significant amount of copper remaining in the waste rock dump. However, the current measured concentrations of copper in the leachate from the waste rock dump are significantly lower than concentrations measured previously during mining. This is likely due to the consolidation (settlement and compaction) of the waste rock over time and the flushing of fine-grained rock into the spaces in between the waste rock, reducing the amount of air that is able to enter the waste rock dump. The reduced air infiltration then reduces the generation of acidic and metal-rich drainage. This reduction in copper concentrations is expected to continue into the foreseeable future.
- The waste rock material is producing acidic conditions, but carbonate materials are currently neutralising the acidic drainage to maintain pH at a mildly acidic pH (known as the lag phase in geochemical terms). Sulfide oxidation is expected to continue once the available carbonate materials have been consumed, after which highly acidic and metal-rich drainage could occur. However, the waste rock contains a high proportion of plagioclase (10.3 wt% to 58.7 wt%), which is a silicate mineral which also contributes to neutralisation of acidic drainage, although at a slower rate than carbonates. The lag time could be extended if plagioclase is confirmed to be effective in acid neutralisation.

Open pit

In order of expected level of contribution, the mineralised contamination sources in the open pit relate to broken eroded rock material on the open pit benches (called talus), exposed wall rock, and reactive sulfide bearing tailings from artisanal hard rock mining activity that are also being disposed in the base of the open pit.

Dewatering of the open pit created a cone of depression in the groundwater table which desaturated the rock surrounding the open pit. Exposing this rock to oxygen contributes to mobilising sulfate and metals into groundwater which subsequently discharges into the open pit as groundwater seepage. This seepage then flows, along with surface water runoff from the waste rock and talus, into the pit lake.

The quality of water in the open pit lake is weakly alkaline and some metals concentrations were elevated above ecological and drinking water criteria, such as copper. Water from the open pit lake flows through the dewatering tunnel to the Kawerong River where the contribution of metal concentrations (albeit at lower concentrations compared to the upper Kawerong River receiving waste rock dump leachate), were identified in water samples collected from the dewatering tunnel outlet. Water coming from the dewatering tunnel outlet is circumneutral (approximately pH 7 to 8), which is similar to pH of the Kawerong-Jaba River system. It is expected that the geochemistry of the surrounding rock within the 6-km-long dewatering tunnel that connects the open pit lake to the upper Kawerong River contributes salinity, acidity and metals via groundwater to the tunnel outlet.

Based on preliminary estimates, it is predicted that the open pit and dewatering tunnel contribute approximately 3% of the total copper load, approximately 30% of the molybdenum load, 16% of the sulfate load and 6% of the cadmium load to the downriver system.

7.2.1.2 Contamination sources – non-mineralised contamination

The site contamination assessment, including site inspection and analysis of the samples collected during field campaigns, confirmed suspected contamination present within this domain at locations of mine-related infrastructure. The sites where non-mineralised contamination were identified at concentrations above health screening criteria with a risk rating of high or major are (see Figure 7.3):

- **Concentrator and transformer yard.** The former site where crushed ore was stockpiled, milled and concentrated through a flotation process. Residual soils and sediment were found to have PCBs and metals at concentrations above health screening levels. PCBs were detected in water draining from the site but were not detected in the Kawerong River.
- **Mine switchyard.** The mine switchyard is in an elevated position approximately 250 m north of the concentrator on the mine access road. During operation, the switchyard received high-voltage electricity from the Loloho power station and used a range of electrical infrastructure including transformers to adjust voltage levels and distribute power across the Mine Domain. PCBs, which were common additives to transformer oils prior to their phase out during the 1970s and 1980s, were detected in soil at the switchyard at concentrations above health screening levels.
- **Fuel storage area.** The above ground tanks from the bulk fuel storage area have been removed and underground petroleum fuel storage tanks may remain at the site, although there were no visual signs of their presence. Lead and hydrocarbons were detected in soil at concentrations above health screening levels. The hydrocarbons also exceed Management Limits which might indicate a fire hazard. The fuel storage area is not currently used by local communities and exposure would be associated with public access as local residents and workers pass through the site.
- **Central workshop and central warehouse.** Antimony, lead, molybdenum, nickel, zinc, petroleum hydrocarbons and PCBs were detected in soil and/or the sump sediment at the central workshop and central warehouse at concentrations above health screening levels.

- **Pit workshop.** Antimony, cadmium, iron, lead and zinc were detected in soil and/or drain sediment at the pit workshop at concentrations above health screening levels.

7.2.1.3 Structural hazards

Structural hazards identified in the Mine Domain (see Figure 7.3) were associated with the mine process plant and related facilities. This included structures such as crushing and screening plant, workshops, warehouses, conveyors, stockpiles, concentrators, tanks, pump station, substation, tailings pipeline and residential buildings. Ten structural hazards were identified with a risk level of high or greater:

- **Primary crusher, secondary crusher, fine ore crushing plant, screening plant, fine ore stockpile, substation, milling building and integrated mess**. These structures were in poor to critical condition with much of the materials being previously salvaged.
- **Unidentified building (identified as milling area workshop and storage).** The building is in critical condition with much of the materials being previously salvaged. The soil beneath one edge of the concrete slab has mostly been removed through erosion and ASM activity.
- **Panguna Town concrete walls**. These structures near the potable water treatment plant have been salvaged leaving only the concrete masonry walls, which are in critical condition and could collapse during high winds or seismic loading.

The milling area workshop and storage, and Panguna Town concrete walls were assessed as potential Imminent Severe Risks and were escalated to the Secretariat under the Imminent Severe Risk process in September 2023.

7.2.1.4 Geotechnical hazards

Geotechnical hazards identified in the Mine Domain (see Figure 7.3) were associated with the open pit, waste rock dump, roads, building foundations, stockpiles, dams, channels and slopes. Five geotechnical hazard areas were identified with a risk level of high or greater:

- **Open pit south wall (Area 6.1)**. This area encompasses the open pit south wall where there is historic slope instability and signs of deformation, rock fall and erosion. Multiple hazards were identified for this pit wall including the potential for slope failure, erosion, debris flow and rockfall. The in-pit village is located in the area that may be affected if failure was to occur.
- **Open pit east pit slope (Area 6.2 and Area 6.5)**. Area 6.2 is located in the southeast corner of the open pit and Area 6.5 is located in the northeast corner of the open pit, both showing signs of deterioration and previous slope failure. Water runoff on the slopes is causing ongoing erosion. There is potential for slope failure and rock fall to occur in these areas. Dwellings and artisanal miners along the east pit slope may be affected if failure was to occur.
- **Port to Mine Access Road (Area 9.1)**. This section of the Port to Mine Access Road is located approximately 100 m within the northern boundary of the SML. There is potential that a landslide may occur based on indicators suggesting instability such as slope deformation, pavement deterioration, and tension cracks.
- **Port to Mine Access Road (Area 9.4 and Area 9.5)**. This section of the Port to Mine Access Road is located on the northern outskirt of Panguna Town. The slope in Area 9.4 is showing signs of potential landslide development including deformation and is experiencing artisanal mining disturbance. More than ten houses are located in the primary area that may be affected if failure was to occur, and this section of the access road would be lost. Area 9.5 is adjacent to Area 9.4 and also shows signs of possible deformation including deterioration of the pavement.

- **Access road above Pirurari (Area 5.2)**. This area includes the cut and filled slopes above the village of Pirurari. The slopes are steep and include fine grained materials that show indications of sensitivity to pore pressures, hence there is a potential for slope failure to occur that may affect the village of Pirurari, the nearby bridge and the Kawerong River.

The Port to Mine Access Road (Area 9.4) was assessed as a potential Imminent Severe Risk and was escalated to the Secretariat under the Imminent Severe Risk process in January 2024.

7.2.2 River System Domain

This section describes mineralised and non-mineralised contamination sources, physical sources, and structural and geotechnical hazards identified in the River System Domain (see Figure 7.4).

7.2.2.1 Contamination sources – mineralised contamination

The main source of mineralised contamination in the River System Domain is the presence of tailings in the Kawerong-Jaba River system.

Metals concentrations in tailings were elevated above those in background soil with maximum concentrations of copper, arsenic and molybdenum exceeding agricultural human health criteria and maximum concentrations of copper, zinc, arsenic, lead and molybdenum exceeding agricultural environmental health criteria. Ecological (residential/open space, industrial and agricultural) criteria for copper and molybdenum were exceeded.

Of the 500 to 600 Mt of tailings that were discharged to the Kawerong River during operations, an estimated 200 to 240 Mt of tailings remain on land in the river system and delta, partially exposed to air (called subaerial), and the remainder (300 to 360 Mt) were deposited underwater in Empress Augusta Bay. Of the tailings that are on land, it is estimated that approximately 70% (140 to 170 Mt) are in Tailings Basin 1 and 10% (20 to 24 Mt) are in Tailings Basin 2. Most of the remaining on land tailings are part of the large delta at the mouth of the Jaba River. Tailings that are exposed to air are likely to be already fully or partially oxidised and therefore have a reduced capacity to generate future acidic conditions and associated downstream mobilisation of metals contamination. The tailings that are under water are expected to be unoxidised and stable while under water but have the potential to result in future mine-related water quality impacts if they become exposed to air. Tailings and levee sediments (that were constructed using tailings material) are slowly becoming exposed to air due to ongoing river channel erosion and ASM activity and therefore are expected to continue to increase inputs of sulfate and metals to the Kawerong-Jaba River system.

The contribution of copper being leached from tailings as a mineralised contamination source downstream of the Jaba Pump Station is clear in the Kawerong-Jaba River system, as evidenced by an increase in dissolved copper concentrations between Tailings Basin 1 and Tailings Basin 2. The dissolved copper rapidly forms solids immediately downstream of the tailings sources due to near-neutral pH, indicated by an increase in total copper concentrations. Particulate copper is less harmful to the environment than dissolved copper, so this is an important process that reduces copper toxicity downstream of the tailings. However, based on the small particulate size, the precipitated metal-rich solids can be carried downstream into Empress Augusta Bay and possibly offshore by river flows and wave action. These fine particles containing high concentrations of copper and other metals could affect biological processes and ecosystem function in the marine environment.

7.2.2.2 Contamination sources – non-mineralised contamination

One non-mineralised contamination source was identified in the River System Domain at the Jaba Pump Station where remnants of water pumping infrastructure and supporting electrical infrastructure were present (see Figure 7.4). Cadmium, lead and PCBs were detected in soil and drain sediment at concentrations above the health screening criteria. The local community has repurposed the pump housing building as a church with the entrance passing between the large transformers.

7.2.2.3 Physical sources

Between approximately 500 and 600 Mt of tailings was discharged into the Kawerong River over the mine life. The physical presence of tailings can influence the flow of water, and result in changes to hydrology, including modification of the direction and rates of flows and changes to flooding regimes, and changes to sediment transport, including aggradation and degradation of river channels. The key physical source in the River System Domain is the widespread presence of tailings in the lower floodplain area of the Kawerong-Jaba River system. This has caused flooding in lower-lying areas of the broader floodplain area on both sides of the potion of the lower Jaba River main channel, and in Kuneka Creek and the lower reach of the Pagana River.

7.2.2.4 Structural hazards

Structural hazards in the River System Domain (see Figure 7.4) comprised two bridges and two pump stations. The pump stations were both associated with the mine; it is unknown if the mine was responsible for construction of the bridges. Two structures were identified with a risk level of high or greater:

- **Jaba Pump Station structure.** This structure is in critical condition and may collapse in the event of an earthquake or strong winds. The collapse of the structure would typically affect an area twice the height of the structure. Although no one lives within this area of impact, the former pump station building was observed to have been used as a church and this was confirmed by local residents.
- **Momau River Bridge. T**he Momau River Bridge is in critical condition and may collapse during a significant event (high wind, earthquake, flooding) or from use by a heavily loaded vehicle. The bridge connects the lower tailings communities to the upper and mid tailings and mine areas, and this road is the primary thoroughfare for these communities to access services in Arawa. However, in terms of connectivity an alternate route can be used (i.e., a river crossing) when river levels are safe to do so.

Each of these structures were assessed as potential Imminent Severe Risks and were escalated to the Secretariat under the Imminent Severe Risk process in July 2023.

7.2.2.5 Geotechnical hazards

Geotechnical hazards identified in the River System Domain (see Figure 7.4) were associated with the levee, tailings and Bato Bridge. Four geotechnical hazard areas were identified with a risk level of high or greater, all of which were sections Main/Pump Station Levee:

- **Main/Pump Station Levee Section 1 (Area 8.1).** This section of the levee is located above the Jaba Pump Station and is experiencing significant erosion, both due to scouring and ASM which is undercutting the slopes on the downstream side of the levee. As more of the slope is removed the risk of a large-scale collapse becomes more likely. If this section of the levee were to collapse it could affect the artisanal miners on the levee slopes and Jaba Pump Station village.
- **Main/Pump Station Levee Section 2 (Area 8.2).** This section of the levee has the potential to become unstable based on observations of crest settlement, over-steepened slopes, historic liquefaction and ASM disturbance. There are dwellings located close to the levee that would likely be affected if the levee failed at this location.

- **Main/Pump Station Levee Section 4 (Area 8.4).** This section of the levee has experienced significant erosion and oversteepening and in one area is only two to three metres wide. An extreme rain event or seismic activity could cause the levee to fail, and it is also vulnerable to further erosion, including by ASM activity. This is consistent with the levee stability assessment that was completed by Tetra Tech Coffey for the Autonomous Bougainville Government in 2022. The levee assessment identified that it is almost certain that the Main/Pump Station Levee will fail in Section 4 near the narrow part of the levee that is experiencing levee erosion on both sides. Levee failure at this location may affect ASM workers and structures located close to the levee.
- **Main/Pump Station Levee Section 5 (Area 8.5).** This section of the levee is located at the end of the levee and shows signs of erosion and oversteepening of the banks. There is potential for localised failure of the levee at this location and the tailings are highly susceptible to liquefaction. No dwellings were observed at this location and there appeared to be minimal ASM or intermittent human exposure.

Sections 1, 2 and 4 of the levee were assessed as potential Imminent Severe Risks and were escalated to the Secretariat under the Imminent Severe Risk process in January 2024.

7.2.3 Delta

This section describes mineralised contamination sources identified in the Delta Domain (see Figure 7.5).

7.2.3.1 Contamination sources – mineralised contamination

Tailings material that has migrated down the river system and has deposited in coastal (i.e., beach) sediments along the coast of Empress Augusta Bay has been identified, extending from the Jaba River delta at least as far north as the mouth of the Mariropa River (about 7 km north of the mouth of the Jaba River) and as far as 5 km south of the mouth of the Jaba River near the Tuju River mouth. Tailings material in coastal areas is subjected to wetting and drying cycles as tidal processes, wave action and erosion and rainfall can introduce air and water into the sediment, generating AMD. Copper concentrations in the tailings-affected sediment samples collected for Phase 1 ranged from 525 mg/kg to 588 mg/kg, exceeding the ecological sediment screening criterion (GV-High value) for copper.

Tailings material underwater in Empress Augusta Bay is also likely to be a source of contamination of the marine environment although no samples were collected for this as marine investigations were outside the Scope of Work for Phase 1.

7.2.3.2 Physical sources

A new area of land was created by tailings at the mouth of the Jaba River as a result of tailings discharge during the mine's operation. By 1989, the area of the subaerial portion of the delta was about 975 ha, which increased to about 1,056 ha between 1989 and 2020 (based on satellite imagery). This land has now revegetated and stabilised; however, there is the potential for the land formed by tailings to be subject to liquefaction (the process that generates a liquid from a solid) due to the delta being located within a zone of high to very high earthquake risk. In 1975, an earthquake caused subsidence of the delta area due to seismically induced tailings liquefaction and associated tsunamis and little of the subaerial portion of the delta was above sea level at this time.

7.2.4 Port and Town Domain

This section describes non-mineralised contamination sources and structural hazards identified in the Port and Town Domain (see Figure 7.6).

7.2.4.1 Contamination sources – non-mineralised contamination

Non-mineralised contamination in the Port and Town Domain was primarily associated with mine-related infrastructure at the Loloho Port including former power generation and distribution facilities, fuel and chemical storage facilities and the fire station. The sites where non-mineralised contamination was identified at concentrations above health screening criteria with a risk rating of high or major are (see Figure 7.6):

- **Loloho fire station**. PFAS was a common component of firefighting foams globally until the 2000s, at which point they started to be phased out as their adverse health effect became known. Firefighting foams would have been stored, used and possibly released via spills or training exercises in the vicinity of the fire station. PFAS was detected in soil at concentrations exceeding the health screening criteria. PFAS was not detected in marine water at the closest sampling location in Anewa Bay.
- **Bulk fuel storage tanks.** A hydrocarbon fuel spill has occurred within the earthen bund surrounding the storage tanks and petroleum hydrocarbons were detected in soil at a concentration exceeding heath screening criteria. The presence of free-phase hydrocarbons has the potential to impair the quality and uses of both land and water, the aesthetic values of the environment, it can impact terrestrial and aquatic ecosystems, and soil processes such as water retention and nutrient cycling (CCME 2008). The presence of the hydrocarbon spill surrounding the above ground tanks may present a fire and explosion risk, particularly to the residents in proximity to the former mine infrastructure and those who frequently pass by these structures.

  PFAS was detected in soil at a concentration exceeding heath screening criteria at a location where the local community is growing food on the fuel storage bund. The presence of PFAS in the vicinity of the bulk fuel store may be associated with a foam-based fire suppression system, which are commonly installed at large fuel storage facilities due to their high fire risk. PFAS-based foams were preferred globally until their phase-out for their effectiveness in forming a stable film over the fuel surface and smothering the fire.
- **Shell oil fuel storage area**. Large areas of the ground surface at the former Shell oil fuel storage terminal were observed to be impacted by hydrocarbons, spilled from the former above ground tanks that have since been removed from the site. Refuelling points were observed on a concrete slab which may indicate the presence of an underground petroleum storage tank. There was no other evidence to confirm its presence. The site is being used by a local family that occupies the former administration building and produces fruit and vegetables in areas of land visibly impacted by residual hydrocarbons. Lead and petroleum hydrocarbons were detected in garden soils at concentrations exceeding health criteria.
- **Power generation and distribution facilities**: The former Loloho power station is extensively damaged and safe access within the building footprint was limited. PCBs were detected in soil at the rear of the power station at concentrations exceeding health criteria; however, given the location, direct contact with contaminated soil by the local community is likely to be minimal. A sample collected from the cooling water discharge point to Anewa Bay identified the presence of PCBs, PFAS and elevated metals (copper, manganese, nickel and zinc) indicating the possibility for these contaminants to be present in soils beneath the power station that may be discharging via the cooling water infrastructure to Anewa Bay. PFAS was detected in a marine water sample collected approximately 250 m from the cooling water discharge point at concentrations exceeding ecological criteria. PCBs, copper, manganese, nickel and zinc were not detected above the limit of reporting.
- **Reagent storage areas**. Polyacrylamide monomer (PAM) reagents were observed within shipping containers located at both Area 1 and Area 3. PAM is generally of low toxicity to aquatic ecosystems and human health. However, acrylamide is a biodegradation byproduct of PAM and has a noted effect of causing local skin irritation characterised by blistering and loss of skin and of the hands and feet (DCCEEW, 2024). This is consistent with reports provided by a local port worker who had stood in the spilled PAM, which might suggest the degradation of PAM to the more toxic acrylamide is occurring.

- **MIBC storage tanks.** Five MIBC storage tanks are located within an earthen bund. It is unknown if the tanks still contain MIBC. Lead, PCBs and hydrocarbons were detected in soil at concentrations exceeding health criteria. MIBC was confirmed to be present in soil through tentatively identified compound laboratory analysis; there are no published health criteria for MIBC. The bund is not currently occupied or developed by the local community but it is crossed by people using paths that connect to other communities, productive gardens, and water supply points.
- **Former Camp 11 chemical storage warehouse.** Raw materials including xanthate-based reagents and chlorine gas cylinders are likely to remain in the collapsed main warehouse building, although were unable be observed. Shipping containers were observed to contain corroded drums with their contents remaining exposed in damaged plastic bags. Two locations of buried drums of unknown contents were also identified in this area and there is the possibility that chlorine gas cylinders may also remain at the former sewage treatment plant.
- **Former Itakaya waste disposal site (Metonai Elementary School).** The school is located on a mine waste disposal site in an area of formerly swampy land west of Metonai village approximately 250 m from the Pinei River. In addition to solid inert waste such as scrap metal, plastic and glass, visible signs of soil contamination were identified during the inspection, including hydrocarbon staining and the presence of industrial waste products such as slag (a by-product of metal smelting and other metallurgical processes). Soil samples identified arsenic, lead and nickel above agricultural human health criteria.

7.2.4.2 Structural hazards

Structural hazards identified in the Port and Town Domain (see Figure 7.6) were associated with the mine port facilities. This included structures such as buildings, tanks, towers, fuel storage areas, the concentrate thicker, and a power station. Three structural hazards were identified with a risk level of high or greater:

- **Weighing tower.** The weighing tower is comprised of beams and slab of the tower that are in poor condition and could collapse.
- **Power station.** The power station has a series of steel structures that are heavily corroded and may collapse.
- **Port reagent storage tanks.** The tanks are in fair condition and may collapse. It is unknown if the tanks still contain reagents.

7.3 PATHWAYS

Pathways (also known as transport pathways) identify the way that a source or hazard is likely to migrate through the environment to an end point where a person or an ecological receptor may be exposed. The transport pathway for a specific exposure pathway may be made up of more than one type of transport pathway. For example, water induced surface erosion from a storm event can mobilise contaminated soil which can be transported in stormwater runoff into surface water where the contaminants may bioaccumulate in aquatic resources.

Pathways were determined to be active (connecting a source to an end point) where the criteria identified in the specialist study was met. For example, if a contaminant was detected above the adopted screening criteria, then the pathway was deemed active.

Key pathways in the conceptual site model from a source to an end point include:

- **Erosion.** Surface erosion caused by wind or water can mobilise contaminated soils or tailings.

- **Air.** Airborne particulates (dust) generated by wind or other types of disturbance, from waste rock or tailings materials, which can contain contaminants. Vapour emitted from raw materials that are still present in the Port and Town Domain. Dust sampling did not identify transport of mine-related contaminants; however, only limited sampling has been conducted and hence this pathway has been conservatively retained for transport of contaminants within the Mine, River System and Port and Town domains.
- **Runoff.** Contaminated soil, tailings or soluble contaminants may be transported in stormwater runoff, typically into surface water.
- **Surface water.** This includes drainage lines, rivers, creeks and floodplain swamps and wetlands, and Anewa, Arawa and Empress Augusta bays. These features are expected to be the primary pathway for dissolved and particulate contaminants reaching end points (or communities) downstream.
    - Surface water is also a key pathway for transportation of physical sources, e.g., tailings and flood waters. Tailings in the Kawerong-Jaba River system may be transported further throughout this system and into Konaviru Wetland, Kuneka Creek and possibly the lower reaches of the Pagana River.
    - When dissolved copper (and possibly other metals) originating from the waste rock dump and from the tailings transforms to particulate copper (or particulate metals), it is expected to be comprised of fine material, which may be carried down the river system to the delta. The copper and other metals released from the mine wastes carried down the river are likely accumulating beyond the mouth of the Jaba River and offshore in slow moving water, possibly beyond Empress Augusta Bay.
- **Groundwater.** Soluble contaminants in soil may leach into groundwater and be transported hydraulically downgradient to locations where the groundwater discharges to surface water, or to seeps or wells. Phase 1 did not include intrusive sampling, hence samples were not collected from groundwater aquifers, only discharge points such as seeps or existing community wells. Due to this lack of data, a groundwater pathway has been assumed to be present where contaminant concentrations exceeded the relevant criteria at both a source and an end point, and where the connection between the two aligns with the expected groundwater transport behaviour, e.g., flow direction. Potential groundwater pathways have been identified where there is a credible future risk of a contaminant being transported through groundwater to an end point and resulting in an acute impact based on an understanding of the contaminant fate and behaviour and the expected groundwater transport behaviour.
- **Subsurface infrastructure.** Transport of water through underground pipelines in the Port and Town Domain.
- **Above ground infrastructure.** Transport of water through above ground pipelines in the open pit, installed by the In-pit community.
- **Fire and explosion risk.** Potential fire and explosion risks associated with raw materials still present in the Port and Town Domain.
- **Structural failure.** Collapse of a mine-related structure which may be caused by corrosion, earthquake, heavy winds or in the case of the bridge, a heavily loaded vehicle.
- **Geotechnical failure**. Mine-related landforms such as the open pit, diversions or levee may be subject to geotechnical failure due to earthquakes, wind or water erosion, as well as being influenced by ASM activity. Types of geotechnical failure that may occur include large-scale collapse of the open pit wall or the levee.
- **Soil.** Soil can be contaminated by leaks and spills of chemicals or other hazardous materials associated with mine-related infrastructure. Soil may also contain contaminants as a result of tailings discharge, dust deposition, irrigation using contaminated water, contaminants in shallow groundwater and flooding by sediment-laden water during the wet season. The contaminants can then be transported through the soil to the underlying groundwater, taken up by plants or ingested by animals or people. Soil has been identified as a pathway in all four domains.

7.4 END POINTS

End points in the conceptual site model include places and receiving environments (i.e., spatial areas) where people and/or ecological receptors may be exposed to contaminants or hazards, often referred to as exposure points. Sections 7.4.1 to 7.4.4 present the end points for each of the domains.

7.4.1 Mine Domain

End points located in the Mine Domain (see Figure 7.3) are:

- The Kawerong River downstream of its confluence with the waste rock dump drainage.
- Areas within the open pit.
- Areas in the immediate vicinity of unstable buildings or structures in the concentrator area, including the primary crusher, secondary crusher, fine ore crushing plant, screening plant, fine ore stockpile, substation, milling building and integrated mess and milling area workshop and storage.
- Areas in the immediate vicinity of the Panguna Town concrete walls.
- Areas where waste rock is present and is accessed by communities for residential, gardening, cropping and raising of livestock. This includes the waste rock dump, Dapera village and the open pit.
- Areas accessed by communities for residential, gardening, livestock raising, commercial or recreational use within the vicinity of the concentrator and mine switchyard. These sites were identified to have regular use by local communities such as through people living at the sites (in the case of the switchyard) and occupational use (artisanal miners in the concentrator area) and therefore the possibility for regular exposure to contaminants.
- Drinking water sources in the open pit.

7.4.2 River System Domain

End points located in the River System Domain (see Figure 7.4) are:

- Kawerong River, Jaba River, Konaviru Wetland, Kuneka Creek and lower Pagana River.
- Areas within the tailings footprint that are regularly used by communities for gardening, cropping and livestock raising.
- Areas within the immediate vicinity of the Jaba Pump Station.
- On and below the Momau River Bridge.

7.4.3 Delta Domain

End points located in the Delta Domain (see Figure 7.5) are:

- Empress Augusta Bay and the Jaba River mouth.
- The area of the delta formed by tailings.
- Areas to the west of Marau from the end of the tailings pipeline to the Tuju River.

7.4.4 Port and Town Domain

End points located in the Port and Town Domain (see Figure 7.6) are:

- Areas of Anewa Bay.
- Areas within the immediate vicinity of the weighing tower, power station and port reagent tanks.

- Areas used by communities for residential, gardening, cropping, livestock raising, commercial and recreational use within the vicinity of former mine infrastructure including the Loloho fire station, bulk fuel storage tanks and Shell oil fuel storage area.
- Areas within the vicinity of the Itakaya waste disposal site (Metonai Elementary School) regularly used by the community for gardening, cropping and livestock raising.

7.5 EXPOSURE ROUTES

Plants and animals can be exposed to contaminants in soil, water, air and food at an end point. Key exposure routes for plants and animals include:

- **Plant uptake.** Plants grown in contaminated soils may uptake those contaminants and store them, e.g., in their roots or leaves. They may also be contaminated via the deposition of contaminants in dust. If these plants are a food source for local communities, then they can also be a transport pathway for contaminants.
- **Aquatic (water-based) animals.** Aquatic animals such as fish or crustaceans may uptake or ingest contaminants in marine or freshwater environments and associated sediments. If these animals are a food source for local communities, then they can also be a transport pathway for contaminants.
- **Terrestrial (land-based) animals.** Village livestock (including poultry) and wild animals may ingest contaminated soil, plants or soil invertebrates. If these animals are a food source for local communities, then they can also be a transport pathway for contaminants.

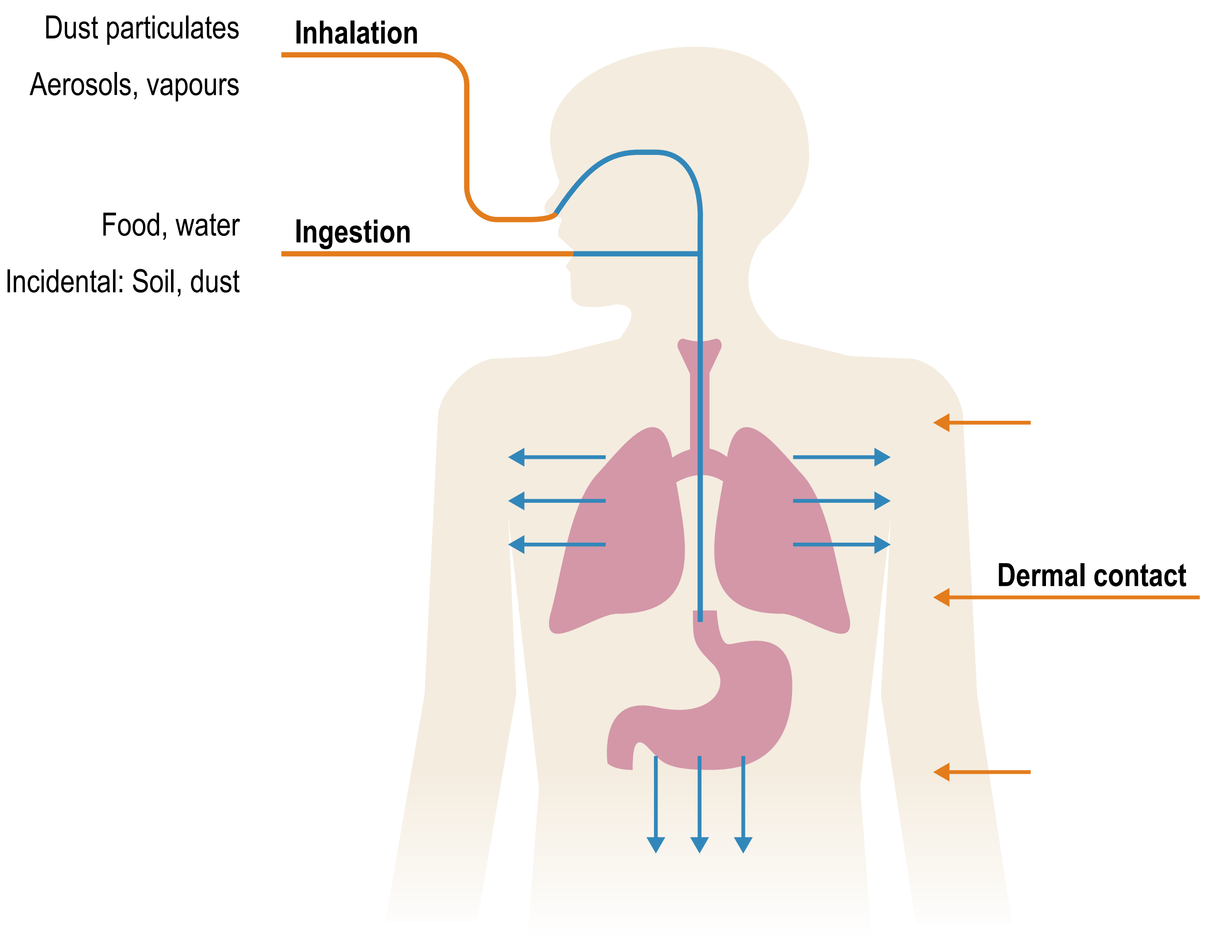
People can be exposed to contaminants in soil, water, air and food in three ways, referred to as exposure routes. Figure 7.7 presents these exposure routes for people which are:

- **Ingestion**. This may include:
  - Drinking contaminated water
  - Eating food grown or raised in, or caught from, contaminated water or soil
  - Incidental ingestion of contaminated water, e.g., swallowing small amounts of water when swimming
  - Incidental ingestion of contaminated soil, e.g., eating food with soiled hands or pica behaviour in children.
- **Inhalation.** This may include inhalation of contaminated dust or vapour from volatile contaminants.
- **Dermal contact.** This includes absorption of contaminants across the skin when coming into contact with contaminated soil or water.

7.6 CONCEPTUAL SITE MODEL UNCERTAINTY

Table 7.1 presents the uncertainty level associated with each complete exposure pathway in the conceptual site model. These levels are based on the characterisation uncertainty as outlined Chapter 5 and Chapter 6.

There were some exposure pathways that were determined to be incomplete based on the available data (i.e., no indicator exceedances were reported) but also had a high or major risk rating and a high level of uncertainty. Further investigation would be required to determine whether a complete exposure pathway exists. Specific high-risk sources associated with these incomplete pathways were identified for the Mine and Port and Town domains, but not the River System or Delta domains. These high-risk sources are discussed in this section.



PANGUNA LEGACY ASSESSMENT COMPANY

PANGUNA MINE LEGACY IMPACT ASSESSMENT
PHASE 1

FIGURE 7.7

Exposure routes for people

TETRA TECH COFFEY

SOURCE
Tetra Tech Coffey, 2024

DATE: 30.10.24 PROJECT: 754-MELEN305719 FILE: 305719_R03_F07.07_GRA

DOC REFERENCE: \\TT.LOCAL\COF\S772\S\GIS\305719_MELEN_PLAC_LEGACYIMPACTASSESSMENT\2_GRAPHICS\305719_R03_LIA\305719_R03_GRA093.AI_4 | SAVED BY: MG | 30.10.24

7.6.1 Mine Domain

High-risk sources associated with incomplete pathways in the Mine Domain are:

- **Fire station:** PFAS was detected in soil at the site of the former fire station, approximately 500 m southeast of the concentrator on the northern bank of the Kawerong River diversion. PFAS-based foaming agents were suspected to have been used for fire suppression at the Panguna Mine which was operational during the period that these firefighting foams were used and would have been preferred to manage hazards associated with bulk fuel and chemical storage.

  While PFAS concentrations in the two soil samples collected were below health screening criteria, the results confirm that PFAS-based foaming agents were stored and used at the site, and that contamination of the shallow soil has occurred at the site. Further investigation would be required to determine if higher concentrations of PFAS are present in soils at this location.

- **Mine switchyard, Panguna Town and central mine workshop:** Asbestos containing material (ACM) was confirmed to exist at two locations in the Mine Domain. This was associated with ACM vinyl floor tiles and fragments of bonded ACM sheeting from building materials within areas of both frequent public access (Panguna Town) and among the mine infrastructure and buildings (central mine workshop). The collected samples were of bonded ACM fragments that generally have lower risk of generating fibres unless they are crushed. The preliminary work completed cannot determine whether friable asbestos or asbestos fibres exist in the environment, which would pose an increased risk of inhalation and associated health impacts. However, due to the extensively degraded condition of the buildings and that crushing and weathering of ACM fragments may have occurred, the release of fibres cannot be discounted. Further assessment, such as asbestos air monitoring and asbestos in soil investigations would be required to determine this; this was not conducted as part of Phase 1.

  Asbestos may also be present in the mine switchyard due to asbestos' common historical use in components of electrical panels, wire insulation and shielding. Given the time the mine was constructed and operated, ACM is expected to be present elsewhere, possibly extensively within former mine buildings where it may have been used in building materials and in electrical infrastructure.

- **Substations:** At locations where transformers have been identified and nearby soil samples collected, PCBs have been detected, often at concentrations exceeding health screening criteria. Locations that exceeded health criteria have been included as complete pathways in the conceptual site model. It is possible that higher concentrations are present at other substations and transformers across the Panguna Mine where electrically-powered mine infrastructure were present. Further sampling would be required to determine this.

- **Herbicides:** Aerial spraying of Bush Killer 80, a phenoxyacetic acid herbicide, during vegetation clearance may have resulted in herbicide contamination to soils that were not removed during overburden stripping, such as in the undisturbed areas around the open pit. No detectable concentrations of penoxyacedic acid herbicides including the specific chemical components of Bush Killer (including 2,4,5-trichlorophenoxyacetic acid and 2,4-dichlorophenoxyacetic acid) were reported in the two samples collected from land surrounding Dapera village. The absence of herbicides from these two samples does not discount their presence elsewhere given the large areas where they were applied, and their potential to migrate through the catchment.

7.6.2 Port and Town Domain

High-risk sources associated with incomplete pathways in the Port and Town Domain are:

- **Former Itakaya waste disposal site (Metonai Elementary School) and Morgan Junction industrial area:** The site received a range of industrial waste from the mine, including asbestos waste which was wrapped in plastic and buried at the site (AGA, 1989). Waste oil and sludge from a sump at the Loloho Power station was also reportedly disposed to the surface of the landfill (AGA, 1989). The site has subsequently been disturbed during construction of the school when surface earthworks were undertaken to grade some of the residual surface waste towards Pinei River. A sample of a cement sheeting fragment was collected from the ground and submitted for laboratory analysis, which was confirmed not to contain asbestos. There remains uncertainty around the risk that may be posed particularly by asbestos waste that was reportedly historically placed in this area. The Morgan Junction industrial area is located to the south of the former Itakaya waste disposal site. Residents have reported that containers of chemicals were buried at the Morgan Junction industrial area during operation of the mine but this was unable to be confirmed within the scope of Phase 1.

  PFOS was detected in surface water in the tributary passing the Itakaya waste disposal site and the Morgan Junction industrial area, at concentrations that exceeded aquatic ecosystem criteria but were below health screening levels. The PFOS was detected both upstream and downstream of both sites, hence there is uncertainty regarding the source, although these chemicals are not commonly used outside of industrial applications. PFAS compounds were not detected in the Pinei River.
- **Camp 5 waste disposal site:** A waste disposal site was identified on the north side of the Port to Mine Access Road near the former Camp 5. The site was reportedly excavated, and waste materials disposed at the site, including drums and cylinders with unknown contents. The site inspection confirmed the presence of corroded drums and cylinders at surface, with other wastes reasonably expected to be present beneath the ground surface.
- **Power generation and distribution facilities:** Asbestos may be present in the switchyard and power station, and at other former electrical infrastructure sites such as transformers and substations due to asbestos' common historical use in components of electrical panels, wire insulation and shielding. Given the time the mine was constructed and operated, ACM is expected to be present elsewhere, possibly extensively within former mine buildings where it may have been used in building materials and in electrical infrastructure.
- **Marine sediments:** Assessment of the marine environment was excluded from the scope of Phase 1. Only two marine sediment samples were collected directly adjacent to shore to get a preliminary indication of any impacts from non-mineralised contamination sources.

  Impacts to the marine environment associated with mineralised contamination were not assessed as part of Phase 1, particularly possible contamination from concentrate thickening, storage and export.

  Copper concentrations in soil at the Loholo Port typically ranged from <5 mg/kg to 715 mg/kg, compared to background concentrations of 83 mg/kg to 86 mg/kg, indicating elevated copper concentrations in soil across the port area. One sample from adjacent to the concentrate thickener reported a copper concentration of 3,370 mg/kg but this was not representative of the broader area.

  While only two background samples were collected, this suggests possible contamination from copper handling and export at the port during mine operations due to fugitive copper concentrate in air and stormwater, as is common at many older copper export facilities. While ecosystem protection was not identified as a value on land at the Loloho Port, there may elevated copper concentrations in the marine sediments that have not been identified as part of Phase 1.

7.7 SUMMARY

Table 7.1 presents a summary of the sources, pathways and end points identified as complete pathways in the conceptual site model and notes the uncertainty associated with this. Exposure routes have also been identified for contaminant sources and these have been evaluated in the impact assessments. Table 7.2 presents a summary of the exposure pathways that were not found to be complete. Text in italics explains why the pathway was not found to be complete.

Table 7.1 Conceptual site model

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Exposure route	Uncertainty‡
Mine Domain					
Waste rock (1830.01; 1830.06; 1830.07)	Mineralised contamination: Elevated metals in waste rock (A_WAS2_S_AR)	Air transport of dust from waste rock Soil (A_PAT38_L)	Areas where waste rock is located, including the waste rock dump, open pit and Dapera village (A_END47_E_AR)	People: inhalation, dermal contact, ingestion of plants and animals	Low uncertainty
Waste rock dump (1830.01)	Mineralised contamination: Drainage from mine waste rock is mildly acidic and contains sulfate and metals (A_WAS_S_AR)	Surface water transport of acid and metal loads entering the Kawerong-Jaba River system Surface water transport of precipitated particulate metals in the Kawerong-Jaba River system (A_PAT19_P_L)	Downstream of the waste rock dump Kawerong and Jaba rivers Empress Augusta Bay (A_END12_E_AR)	People: incidental ingestion and dermal contact Ecological receptors: uptake and ingestion	The role of plagioclase in neutralising acid is not confirmed and hence whether this will delay or prevent the onset of acidic conditions once carbonates are used up Low uncertainty
Open pit (1120.01) and dewatering tunnel (1250.01)	Mineralised contamination: Open pit wall rock and eroded rock, and rock surrounding the dewatering tunnel (A_PIT_S_AR)	Groundwater (A_PAT1_P_L) Surface water transport of acid and metal loads entering the pit lake and the Kawerong-Jaba River system Surface water transport of precipitated particulate metals transported via the Kawerong-Jaba River system (A_PAT13_P_L)	Groundwater seepage from pit walls Pit lake (A_END31_E_AR) Areas downstream of the open pit along the Kawerong and Jaba rivers and Empress Augusta Bay (A_END14_E_AR)	People: ingestion and dermal contact Ecological receptors: uptake and ingestion	Low uncertainty
Mine switchyard (2860.03)	Contaminated site: PCB soil contamination (A_MSW_S_AR)	Air transport of dust from contaminated soil Soil (A_PAT14_P_L)	Areas within and surrounding the switchyard (A_END16_E_AR)	People: ingestion of plants, animals and soil, inhalation, dermal contact Ecological receptors: uptake and ingestion	Low sample density confirms PCB presence but may not represent maximum concentrations Medium uncertainty

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Exposure route	Uncertainty‡
Concentrator (2240.01) and transformer yard (2860.02)	Contaminated site: PCB soil and drain sediment contamination (A_CON_S_AR)	Air transport of dust from contaminated soil Soil (A_PAT15_P_L)	Areas within and surrounding the concentrator and transformer yard (A_END26_E_AR)	People: inhalation, ingestion and dermal contact Ecological receptors: uptake and ingestion	Low sample density confirms PCB presence but may not represent maximum concentrations Medium uncertainty
Central workshop (2920.01) and central warehouse (2930.01)	Contaminated site: Metals and PCBs in soil (A_WOR_S_AR)	Air transport of dust from contaminated soil Soil (A_PAT17_P_L)	Areas within and surrounding the workshop (A_END29_E_AR)	People: inhalation, ingestion and dermal contact	Limited sampling shows elevated metals and PCBs Medium uncertainty
Pit workshop (1921.01)	Contaminated site: Metals in soil and drain sediment (A_PWO_S_AR)	Air transport of dust from contaminated soil Soil (A_PAT18_P_L)	Areas within and surrounding the workshop (A_END30_E_AR)	People: inhalation, ingestion and dermal contact	Limited sampling shows some elevated metals Medium uncertainty
Fuel storage area (1969.01)	Contaminated site: Metals (lead) and hydrocarbons in soil (A_FUE1_S_AR)	Air transport of dust from contaminated soil Soil Fire risk (potential pathway) (A_PAT34_L)	Areas within and surrounding the fuel storage (A_END43_E_AR)	People: inhalation, ingestion and dermal contact	Limited sampling shows some elevated metals and hydrocarbons in soil Medium uncertainty
Primary crusher (2110.01), secondary crusher (2140.02), fine ore crushing plant (2120.01), screening plant (2130.01), fine ore stockpile (2140.01), substation (2860.01), milling building (2240.01) and integrated mess (5650.01).	Structural hazard: Unstable buildings in concentrator area (A_CAR_S_AR)	Structural failure due to high winds or earthquake (potential pathway) (A_PAT35_L)	Areas in immediate vicinity of buildings (A_END44_E_AR)	Not applicable	Low uncertainty
Unidentified building (milling area workshop and storage) (2970.02)	Structural hazard: Building and concrete slab unstable (A_BUI_S_AR)	Structural failure due to general loading (self weight) (potential pathway) (A_PAT36_L)	Area in immediate vicinity of building (A_END45_E_AR)	Not applicable	Low uncertainty

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Exposure route	Uncertainty‡
Panguna Town concrete walls (5681.03)	Structural hazard: Concrete masonry walls have no lateral support (A_WAL_S_AR)	Structural failure due to high winds or earthquake (potential pathway) (A_PAT37_L)	Area in immediate vicinity of walls (A_END46_E_AR)	Not applicable	Low uncertainty
Open pit (1120.01) (areas 6.1, 6.2 and 6.5)	Geotechnical hazard: Instability of open pit south wall and east pit slope (A_GHA4_S_AR)	Slope failure, erosion, debris flow and/or rock fall (potential pathway) (A_PAT33_L)	Areas below the open pit south wall and east pit slope including the in-pit village (A_END42_E_AR)	Not applicable	Moderate uncertainty of the failure mechanism and path. High uncertainty of the deformation rate
Port to Mine Access Road (5150.01) (Area 9.1)	Geotechnical hazard: Instability of slope that may be triggered by heavy rainfall or seismic activity (A_GHA1_S_AR)	Slope failure (potential pathway) (A_PAT30_L)	Section of the Port to Mine Access Road (A_END39_E_AR)	Not applicable	Moderate uncertainty, due to assumptions regarding seismic loading and absence of subsurface data
Port to Mine Access Road (5150.01) (areas 9.4 and 9.5)	Geotechnical hazard: Instability of slope due to ongoing degradation and erosion (natural processes and ASM activities) (A_GHA2_S_AR)	Slope failure (potential pathway) (A_PAT31_L)	Section of the Port to Mine Access Road Panguna Town (A_END40_E_AR)	Not applicable	Moderate uncertainty, particularly due to possibility of rapid change in conditions from ASM disturbance
Access road above Pirurari (1830.07) (Area 5.2)	Geotechnical hazard: Instability of slope due to build up of pore pressure (A_GHA3_S_AR)	Slope failure (potential pathway) (A_PAT32_L)	Section of the access road Kawerong River Bridge near Piruari Pirurari (A_END41_E_AR)	Not applicable	Moderate uncertainty, as material characteristics and other signs were difficult to observe due to vegetation
River System Domain					
Tailings – subaerial and subaqueous	Mineralised contamination: Tailings in the Kawerong-Jaba River system (A_TAI_S_AR)	Surface water transport of acid and metal loads entering the Kawerong-Jaba River system Surface water transport of precipitated particulate metals transported via the Kawerong-Jaba River system Sediment (A_PAT29_P_L)	Kawerong and Jaba rivers Empress Augusta Bay (A_END12_E_AR)	People: inhalation, ingestion and dermal contact Ecological receptors: uptake and ingestion	Medium uncertainty. Additional geochemical test work could clarify and refine behaviour of tailings materials

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Exposure route	Uncertainty‡
Tailings – subaerial and subaqueous	Physical: Physical presence of tailings in the Kawerong-Jaba River system (A_TAI_S_AR)	Transport of tailings downstream, including into Kuneka Creek and the Pagana River, via the Konaviru Wetland from Jaba River avulsion Presence of tailings causing flooding of both sides of the main Jaba River channel, upstream and downstream of the Kuneka Creek diversion structure and in the lower reaches of the Pagana River (A_PAT29_P_L; A_PAT3_P_L)	Main lower Jaba River channel (from Tailings Basin 2) Areas upstream and downstream of the Kuneka Creek diversion structure Lower Pagana River upstream of the confluence with the Jaba River (A_END4_E_AR)	Not applicable	Low uncertainty
Jaba Pump Station (2821.01)	Contaminated site: PCBs, cadmium and lead in soil (A_PUM_S_AR)	Air transport of dust from contaminated soil Soil (A_PAT2_P_L)	Areas within and surrounding the Jaba Pump Station (A_END2_E_AR)	People: inhalation, ingestion and dermal contact	Limited sampling shows elevated metals and PCBs Medium uncertainty
Jaba Pump Station: Steel building and masonry wall (2821.01)	Structural hazard: Steel structure is heavily corroded and unstable. No lateral support for masonry wall (A_PUM_S_AR)	Collapse during earthquake (potential pathway) (A_PAT2_P_L)	Area within and surrounding the Jaba Pump Station (A_END32_E_AR)	Not applicable	Low uncertainty
Momau River Bridge (5200.01)	Structural hazard: Some parts of the bridge are heavily corroded (A_MOM_S_AR)	Collapse due to high wind, earthquake, flooding or heavily loaded vehicle (potential pathway) (A_PAT20_P_L)	On and below Momau River Bridge (A_END3_E_PO)	Not applicable	Low uncertainty
Main/Pump Station Levee (2300.02)	Geotechnical hazard: Instability of levee embankments and tailings mass (A_LEV_S_AR)	Levee failure due to ongoing disturbance, heavy rainfall or seismic event (potential pathway) Surface water transport of acid and metal loads entering the Kawerong-Jaba River system if submerged tailings are exposed to air (potential pathway) (A_PAT28_P_L)	The levee and areas immediately below the point of failure of the levee, including Jaba Pump Station (A_END37_E_AR)	Not applicable	High uncertainty due to limited materials data and unmeasured rate of disturbance

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Exposure route	Uncertainty‡
Delta Domain					
Subaerial tailings in coastal sediments	Mineralised contamination: Tailings in coastal sediments at Empress Augusta Bay (A_DEL_S_AR)	Surface water transport of acid and metal loads leaching to Empress Augusta Bay Sediment (A_DEL_P_temp)	Empress Augusta Bay (A_END12_E_AR)	People: incidental ingestion and dermal contact Ecological receptors: uptake and ingestion	High uncertainty due to limited sampling of beach sediments and ocean water
Tailings – subaerial	Physical: Physical presence of tailings that form the delta landmass (A_DEL2_S_AR)	Earthquake induced liquefaction Additional land area (A_PAT40_L)	Jaba River delta Empress Augusta Bay (A_END41_E_AR)	Not applicable	Low uncertainty
Port and Town Domain					
Power station (4850.02)	Contaminated site: PCBs in soil PFAS (assumed present due to PFAS in pipeline and Anewa Bay, noting that sampling was not possible at source) (A_STA_S_AR)	Air transport of dust from contaminated soil Soil (A_PAT6_P_L) Subsurface infrastructure to Anewa Bay (cooling water pipeline) (A_RUN11_P_LA)	Areas within and surrounding power station (A_END7_E_AR) Anewa Bay (A_END9_E_AR)	People: inhalation, ingestion and dermal contact Ecological receptors: uptake and ingestion	Limited safe access to soil beneath power station within building footprint to conduct sampling. Presence of PFAS at source has been conservatively assumed based on detection along pathway and at end point. High uncertainty
Methyl isobutyl carbinol (MIBC) tanks and bund (4930.03)	Contaminated site: Lead, PCBs and hydrocarbons in soil MIBC tanks (A_MIB_S_AR)	Air transport of dust from contaminated soil Soil Fire and explosion risk (potential pathway) (A_PAT23_P_L)	Area within the tank bund (A_END5_E_AR)	People: inhalation, ingestion and dermal contact	Limited sampling shows elevated lead, PCBs and hydrocarbons Unknown if tanks still contain MIBC. Medium uncertainty

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Exposure route	Uncertainty‡
Bulk fuel storage tanks (4829.01) and spill (4829.05)	Contaminated site: Hydrocarbon fuel spill Above ground fuel storage tanks PFAS in soil (A_FUE_S_AR)	Air transport of dust from contaminated soil Soil Fire and explosion risk (potential pathway) (A_PAT8_P_L) Groundwater (potential pathway) (A_GRO19_P_ARW) Stormwater runoff to nearby creeks and marine environment (potential pathway) (A_RUN10_P_LA)	Areas within and surrounding the bulk fuel storage bund. (A_END19_E_AR) Anewa Bay (potential end point) (A_END9_E_AR)	People: ingestion of plants and soil, inhalation, dermal contact Ecological receptors: uptake and ingestion	Limited sampling shows elevated PFAS and hydrocarbons Unknown if tanks still contain fuel Medium uncertainty
Shell oil fuel storage (4829.04)	Contaminated site: Lead and hydrocarbons in soil (A_OIL_S_AR)	Air transport of dust from contaminated soil Soil (A_PAT9_P_L) Groundwater (potential pathway) (A_GRO20_P_ARW)	Areas within and surrounding former fuel storage area (A_END20_E_AR) Anewa Bay (potential end point) (A_END9_E_AR)	People: ingestion of plants, animals and soil, inhalation, dermal contact Ecological receptors: uptake and ingestion	Limited sampling shows elevated metals and hydrocarbons Medium uncertainty
Loloho fire station (4930.09)	Contaminated site: PFAS (A_PFI_S_AR)	Air transport of dust from contaminated soil Soil (A_PAT25_P_L)	Within and surrounding the fire station (A_END22_E_AR)	People: ingestion of plants, animals and soil, inhalation, dermal contact	Low sample density confirms PFAS presence at low concentrations but may not represent maximum values Medium uncertainty
Camp 11 chemical storage warehouse (5801.01), shipping container (5801.02), buried drums (5801.04 and 5801.05) and sewage treatment plant (5801.03).	Contaminated site: Xanthate-based reagent drums and chlorine gas cylinders (A_STOR_S_AR)	Vapour in air (potential pathway) Direct contact with raw material (A_PAT21_P_L)	Areas within the warehouse, shipping container, buried drums footprint or sewage treatment plant (A_END23_E_AR)	People: inhalation of, and direct contact with, raw material	Unconfirmed drum contents based on historical records and reported community information Medium uncertainty
Reagent storage areas, KMH areas 1 (4930.05) and 3 (4930.04)	Contaminated site: PAM (A_KML_S_AR)	Direct contact with raw material (A_PAT27_P_AR)	Shipping containers withing KMH area 1 and 3 (A_END25_E_AR)	People: direct contact with raw material	Limited access through vegetation regrowth to confirm remaining raw materials Medium uncertainty

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Exposure route	Uncertainty‡
Former Itakaya waste disposal site (5803.01)	Contaminated site: Lead, arsenic and nickel in soil (A_LAN_S_AR)	Air transport of dust from contaminated soil Soil (A_PAT7_P_L)	Areas within the vicinity of the former mine landfill (A_END8_E_AR)	People: ingestion of plants, animals and soil, inhalation, dermal contact	Limited access to inspect relocated waste areas (heavily vegetated) Medium uncertainty
Weighing tower (4550.01)	Structural hazard: Beams and slab of the tower are in poor condition (A_TOW_S_AR)	Collapse during earthquake (potential pathway) (A_PAT5_P_L)	Within and surrounding the weighing tower (A_END6_E_AR)	Not applicable	Low uncertainty
Power station (4850.02)	Structural hazard: Series of steel structures are heavily corroded (A_STA_S_AR)	Collapse during earthquake (potential pathway) (A_PAT6_P_L)	Within and surrounding the power station (A_END38_E_AR)	Not applicable	Moderate uncertainty
Port reagent storage tanks (4930.03)	Structural hazard: tanks in fair condition, contents not confirmed (A_MIB_S_AR)	Collapse during earthquake (potential pathway) (A_PAT39_L)	Surrounding and downgradient of the tanks (A_END48_E_AR)	Not applicable	It is unknown if the tanks still contain reagents Moderate uncertainty

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- High – further information is needed to adequately characterise the exposure pathway.
- Medium – there is some information available but additional information may be required to characterise the exposure pathway.
- Low – there is adequate information and evidence to characterise the exposure pathway

Table 7.2 Incomplete conceptual site model exposure pathways

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Uncertainty‡
Mine Domain				
General mine infrastructure	**Contaminated site:** PCB contamination in soil Asbestos material at surface	**Air** transport of dust from contaminated soil **Runoff** **Groundwater** *PCBs were not detected downgradient of sources.* *Presence of friable asbestos or asbestos fibres was not determined due to scope limitations.*	Areas within and surrounding the mine infrastructure *PCBs were not detected downgradient of sources. Presence of friable asbestos or asbestos fibres was not determined due to scope limitations.*	Medium uncertainty due to limited sampling conducted.
Mine fire station (2951.02)	**Contaminated site:** PFAS soil contamination *PFAS was not detected above the screening criteria at the source.*	-	-	Medium uncertainty due to limited sampling conducted.
Mine switchyard (2860.03)	Contaminated site: PCB soil contamination (A_MSW_S_AR)	**Runoff** to downgradient communities *PCBs were not detected downgradient of the source.*	Areas downgradient of the switchyard towards the concentrator *PCBs were not detected downgradient of the source.*	Medium uncertainty due to limited sampling conducted.
Concentrator (2240.01) and transformer yard (2860.02)	Contaminated site: PCB soil and drain sediment contamination (A_CON_S_AR)	**Runoff** to Kawerong River **Groundwater** discharge to Kawerong River *PCBs were not detected downgradient of the source.*	Kawerong River *PCBs were not detected in the Kawerong River.*	Medium uncertainty due to limited sampling conducted.
Central workshop (2920.01) and central warehouse (2930.01)	Contaminated site: Metals and PCBs in soil (A_WOR_S_AR)	**Runoff** to Kawerong River **Groundwater** discharge to open pit *PCBs were not detected downgradient of the source.*	Areas within and surrounding the workshop (A_END29_E_AR) *PCBs were not detected downgradient of the source.*	High uncertainty as no intrusive groundwater sampling has been conducted.

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Uncertainty‡
Pit workshop (1921.01)	Contaminated site: Metals in soil and drain sediment (A_PWO_S_AR)	**Groundwater** discharge to open pit *Groundwater not sampled downgradient of source due to scope limitations.*	Areas within and surrounding the workshop (A_END30_E_AR) *Groundwater not sampled downgradient of source due to scope limitations.*	High uncertainty as no intrusive groundwater sampling has been conducted.
Open pit (1120.01) (Area 6.3)	Geotechnical hazard: Instability of artisanal mining pit. *Not a mining related source.*	-	-	Low uncertainty
North Channel diversion (1130.06)	Physical hazard: Northern Diversion Channel to the west of the open pit.	Physical hazard: Potential overtopping in the Northern Diversion Channel due to sediment build up leading to flow of water from the Kawerong River into the open pit. *Determined to be very low probability.*	-	Low uncertainty as hydrology and geomorphology study found that the road between the North Diversion Channel and the open pit is elevated (~10 m), preventing overtopping into the pit.
-	Physical hazard: Diversion channels	Physical hazard: Flooding of the diversion channel. *Determined that there was no mine-related risk of flooding.*	Dapera and Pirurari	Low uncertainty
River System Domain				
Tailings – subaerial and subaqueous (2300.05 and 2300.06)	Mineralised contamination: Tailings in the Kawerong-Jaba River system (A_TAI_S_AR)	Surface water: Transport of tailings into the Pagana River. *Sediment delivery to the Pagana River is minor.*	-	Medium uncertainty. Mine-related sediment transport to the Pagana River has been limited by the capacity of the Kuneka Diversion Channel. Sediment delivered to the Pagana River via the diversion channel was observed to be depositing on the bank of the Pangana River with only a very minor volume of sediment reaching the Pagana River itself.

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Uncertainty‡
Tailings – subaerial and subaqueous	Physical: Physical presence of tailings in the Kawerong-Jaba River system (A_TAI_S_AR)	Presence of tailings causing flooding on the north side of the Kawerong-Jaba River. *Determined there has been no change in flooding extent for villages north of the Jaba River since 1989 associated with mine-related changes to the environment.*	Villages on the north side of the Kawerong-Jaba River.	Low uncertainty
Port and Town Domain				
Power station (4850.02)	Contaminated site: PFAS (assumed present due to PFAS in pipeline and Anewa Bay, noting that sampling was not possible at source) (A_STA_S_AR)	Groundwater migration to Anewa Bay *PFAS detected in Anewa Bay was also detected in surface water drainage from the site indicating surface water is likely the key transport pathway.*	Anewa Bay (A_END9_E_AR)	High uncertainty as no intrusive groundwater sampling has been conducted.
Loloho fire station (4930.09)	Contaminated site: PFAS (A_PFI_S_AR)	**Groundwater** migration to Anewa Bay Stormwater **runoff** *PFAS was not detected downgradient of the source.*	Anewa Bay *PFAS was not detected downgradient of the source.*	High uncertainty as no intrusive groundwater sampling has been conducted and limited marine sampling.
Switchyard (4850.04)	**Contaminated site:** PCB Asbestos (unconfirmed) *PCBs and asbestos not detected above the screening criteria at the source.*	-	-	Medium uncertainty due to limited sampling conducted.
Camp 11 chemical storage warehouse (5801.01), shipping container (5801.02) and buried drums (5801.04 and 5801.05).	Contaminated site: Xanthate-based reagent drums and chlorine gas cylinders (A_STOR_S_AR)	**Fire and** explosion **risk** **Groundwater** migration Stormwater **runoff** *Xanthates were not detected downgradient of the source.* *Not identified as a likely fire and* explosion *risk due to limited access*	Areas within the warehouse, shipping container and buried drums footprint (A_END23_E_AR) *Xanthates were not detected downgradient of the source.*	High uncertainty as no intrusive groundwater sampling has been conducted and limited surface water sampling.

Feature (WBS number*)	Source (source ID†)	Pathway (pathway ID†)	End point (end point ID†)	Uncertainty‡
Reagent storage areas, KMH areas 1 (4930.05) and 3 (4930.04)	Contaminated site: PAM (A_KML_S_AR)	**Fire and** explosion **risk** **Groundwater** migration Stormwater **runoff** *PAM was not detected downgradient of the source.* *Not identified as a fire and* explosion *risk*	Shipping containers withing KMH area 1 and 3 (A_END25_E_AR) Arawa Bay. *PAM was not detected downgradient of the source.*	High uncertainty as no intrusive groundwater sampling has been conducted and limited surface water sampling.
Chromic acid storage shed (4930.16)	**Contaminated site:** Chromium trioxide Hexavalent chromium *Chromium was not detected above the screening criteria at the source.*	**-**	-	Medium uncertainty due to limited sampling conducted.
Former Itakaya waste disposal site (5803.01)	**Contaminated site:** PFAS *PFAS was detected in water both upstream and downstream of the Itakaya waste disposal site and the source was not identified.* Suspected asbestos waste (unconfirmed) *Source not detected but high uncertainty as no intrusive investigations were conducted.*	**Groundwater** migration to Pinei River (**surface water**) *No exceedances of criteria were detected in the Pinei River samples from downstream of the Itakaya waste disposal site, hence a connecting pathway via groundwater was not identified.*	Pinei River *No exceedances of criteria were detected in the Pinei River samples from downstream of the Itakaya waste disposal site.*	High uncertainty as no intrusive sampling has been conducted and only one round of sampling of the Pinei River was conducted.

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