PORGERA
JOINT VENTURE

CARE AND MAINTENANCE

ENVIRONMENT REPORT

2022

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Barrick Niugini Limited - Porgera Joint Venture

February 2023

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PO Box 484, Mt Hagen, Western Highlands Province

PAPUA NEW GUINEA

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Cover Photo: Lower Strickland River upstream of SG4 Gauging Station

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CSIRO

James Versluis
Manager, Environment
Porgera Joint Venture
P.O Box 484, Mount Hagen WHP
Papua New Guinea

2 March 2023

Dear James,

Re: Porgera Joint Venture Care and Maintenance Environment Report 2022

Dr Simon Apte and Dr Brad Angel reviewed a draft of the 2022 Porgera Joint Venture Care and Maintenance Environment Report (AER) and provided detailed comments for consideration. Overall, the draft report was found to be technically sound and of good quality. However, as might be expected with a report of this size, a number of minor errors were identified and some general recommendations were made for improvement of various sections. Porgera Joint Venture responded positively to the review team's recommendations and the report was satisfactorily revised in the light of the comments made.

We commend your Department on their considerable efforts in producing this extensive technical report.

Sincerely

BAngel

Dr Simon Apte
Senior Principal Research Scientist

Dr Brad Angel
Research Scientist

EXECUTIVE SUMMARY

The Porgera Gold Mine is located in the Porgera Valley of Enga Province in the Papua New Guinea (PNG) highlands, approximately 630 km NW of Port Moresby.

The operation consists of an open cut and an underground mine, waste rock dumps, processing facility, gas-fired power station, a water-supply dam, limestone quarry and lime plant and ancillary infrastructure. Production commenced in 1990 and is expected to continue until at least 2039, with an annual production of approximately 500 koz of gold.

In April 2020, the operation was placed into care and maintenance (C&M) after the PNG Government announced that it would not be approving Barrick Niugini Limited’s (BNL) request for extension of the Porgera Special Mining Lease. As of February 2023, negotiations between BNL, the PNG Government and other stakeholders continue with the aim of restarting the mine and returning to normal operations.

Porgera Mine has a number of unique economic, social and environmental aspects. The environmental aspects are managed through implementation of an Environmental Management System (EMS). The objectives of the EMS are to ensure methodical, consistent and effective control of the mine’s environmental aspects so as to achieve compliance with legal and other requirements, to mitigate potential environmental risks and to continually improve environmental performance. The EMS has been continuously certified to the ISO14001 international standard since December 2012, including during the C&M period.

A fundamental element of the Porgera EMS is the environmental monitoring and reporting program. The program provides feedback on the effectiveness of the EMS in achieving the stated objectives, it allows the operation to confirm which management techniques are working well and to identify opportunities for improvement. The scope of C&M activities is outlined in the Porgera Environmental Security Health Safety Plan - Care and Maintenance, which was reviewed and approved by the PNG Government. The Porgera EMS and the environmental monitoring program continued throughout the care and maintenance period, although the scope and frequency of the monitoring program was reduced. Environmental management and monitoring activities during care and maintenance were conducted in accordance with the Porgera Environmental Security Health Safety Plan - Care and Maintenance, which was reviewed and approved by the PNG Government.

The objectives of this C&M Environment Report are to provide an assessment of the overall environmental performance of the operation throughout the care and maintenance period and to assess historical trends in performance between the operational phase and care and maintenance period. The objectives of this report are aligned with those of the EMS and are to assess:

1. Compliance with legal and other requirements during care and maintenance;
2. The level of potential and actual environmental impact during care and maintenance; and
3. The environmental performance of the operation during care and maintenance

The first section of the report describes background environmental conditions by quantifying the natural, non-mine related conditions and changes within the environment. Next, the operation’s environmental aspects (activities which interact with the environment) are identified and quantified. Then, assessments are made of compliance, mine-related risk, impact and performance, followed by a discussion of the findings, and finally, recommendations for improving the environmental management system and the monitoring and reporting program.

CARE & MAINTENANCE ACTIVTIES

The significant environmental aspects of the operation during the operational phase of the mine were riverine tailings disposal, riverine waste rock disposal, on-land waste rock placement, water extraction and discharge, the transport, storage and use of chemicals and waste management.

During care and maintenance tailings discharge, erodible waste rock placement to the Anjolek dump, on-land waste rock placement and the transport and use of large volumes of chemicals ceased altogether. As a result, the quantities of mine derived water and sediment being discharged to the environment was significantly reduced during care and maintenance, when compared to the operational phase.

Throughout the care and maintenance phase, the operation continued to place relatively small volumes of erodible waste rock to the Anawe erodible dump, which consisted of mudstone which was removed from the bottom of the pit to allow water to continue to drain through the underground mine. Water extraction, water discharge and waste generation volumes were also reduced significantly.

Environmental monitoring during care and maintenance was compliant with the requirements of the Porgera Environmental Security Health Safety Plan - Care and Maintenance, which was reviewed and approved by the PNG Government

CARE & MAINTENANCE ENVIRONMENT REPORT

Monitoring

The Porgera Valley and downstream catchments experienced average annual rainfall during C&M in 2021 and 2022 and slightly above average river flows throughout the upper river within the highlands and the lower river along the Strickland floodplain providing average rates of dilution of mine-related inputs within the receiving aquatic ecosystem compared with previous years.

Background conditions for environmental indicators of water quality, sediment quality, metals in the tissue of fish and prawns (tissue metals) and ecosystem health have been established using data collected from test sites prior to the commencement of mining operations (baseline data), and since operations began from sites that are not influenced by the operation (reference sites).

Although concentrations of physical and chemical parameters at the upper river reference sites were generally lower than the baseline data from the upper river test sites, the reference sites did exhibit moderate TSS concentrations and higher concentrations of dissolved selenium compared to baseline data. This indicates that tributaries to the Lagaip-Strickland system have the potential to contribute non-mine-derived (natural) TSS and some metals to the system. The trend for pH at Lake Murray reference sites and trends of dissolved zinc at upper and lower river reference sites and Lake Murray reference sites displayed statistically significant increases over the past decade. Reference sites are not influenced by mining activities and any variation in indicators at these sites are attributable to natural causes.

Compliance

Legal and other requirements are imposed predominantly by the two environmental permits issued to the mine by the Papua New Guinea Conservation and Environmental Protection Authority (CEPA). The operation complied with 100% of legal and other obligations throughout the C&M phase, including water quality at compliance point at SG3 on the Strickland River.

Environmental Assessment

Methodology

The methodology for risk and impact assessment developed by BNL is based on international guidelines (ANZG 2018) and advice received during consultation with external technical experts.

The risk and impact assessments are based on the comparison of physical, chemical and biological environmental indicators at sites potentially impacted by the mine (test sites) against a range of trigger values (TVs). TVs are derived from a combination of baseline data, collected from test sites before development of the mine, reference site data, collected from sites within the region that are not potentially influenced by the mine's activities, and international guidelines. The TVs act as benchmarks for determining whether risk or impact has occurred at a test site.

Tests of statistical significance were performed to provide a statistical basis for determining whether risk or impact may exist at a particular test site.

Conclusions

Due to the mine being in care and maintenance, this has resulted in reduced activities and considerably lower inputs from the mine, especially the cessation of tailings discharge and significantly reduced placement of erodible waste rock. Although the AERs during operations demonstrated continued compliance and expected influence as per the Environmental Impact Assessment (NSR 1990), the monitoring during care and maintenance expectedly demonstrated that the overall condition of the receiving environment has improved and, in some instances, returned to background conditions.

In summary, monitoring of the environmental conditions within the Lagaip River, Strickland River and Lake Murray during the maintenance period has shown that:

- Water quality condition throughout the Lagaip River, Strickland River and Lake Murray continued to comply with the environmental permit limits and was assessed as 'low risk' (Table E-1).
- Sediment quality condition throughout the most of the Lagaip River, Strickland River and Lake Murray was assessed as 'low risk' (Table E-1). The exception was at monitoring site SG2 which is the first downstream monitoring site located on Lagaip River, where the concentration of weak-acid extractable (WAE) lead in sediments remained elevated resulting in a 'potential risk' rating (Table E-1). Lead concentrations did however show a reduction compared with the operational phase.
- Macroinvertebrate populations within the Lagaip River and Upper Strickland River showed no sign of mine-related impacts, aligned to reference conditions during care and maintenance as a result of improved water and sediment quality.
- Fish and prawn populations within the Lagaip River and Upper Strickland River, within the permitted mixing zone, did show signs of mine-related impact which were observed during and attributable to the operational phase of the mine.

  Although water and sediment quality and macroinvertebrate populations have recovered during care and maintenance, fish and prawn populations are expected to take longer to recover due to the slower rate of population growth through reproduction and migration for these species compared to macroinvertebrates.
- Fish populations downstream of the mixing zone within the Lower Strickland River and Lake Murray showed no mine-related impacts, which is consistent with the conditions observed at these sites during the operational phase of the mine.
- Although impact was observed in fish and prawn populations in the Lagaip River and Upper Strickland River, the concentrations of metals in fish flesh and prawn abdomen were below international food standards, indicating that they are safe for human consumption.
- The degree of impact detected is consistent with the predictions made prior to mining operations commencing in 1990 and compensation for environmental impact is paid to landowners living along the river within the permitted mixing zone, in accordance with the 1996 Ministerial Determination.

A summary of compliance, human health risk and environmental impact at each test site in C&M is presented in Table E-1. The compliance assessment showed that from January 2021 – May 2022 the site remained in full compliance with the conditions of its environmental permits. The human health risk assessment showed that the risk to human health posed by the operation of the Porgera Mine between

November 2021 and May 2022, downstream of SG1, was low which is consistent with the results during the operational phase.

Table E-1Summary of Compliance, Human Health Risk and Environmental Impact at test sites in 2021 - 2022

Region	Site	Distance From the Mine (km)	Compliance	Human Health	Environmental			
					Water	Sediment	Macro-invertebrates	Fish & Prawns
Upper River	SG2	42	Compliant	Low Risk	Low Risk	Potential Risk	NA	NA
	Wasiba	96	Compliant	Low Risk	Low Risk	Low Risk	No Impact	Moderate Impact
	Wankipe	116	Compliant	Low Risk	Low Risk	Low Risk	No Impact	Moderate Impact
	SG3*	164	Compliant	Low Risk	Low Risk	Low Risk	No Impact	NA
Lower River	Bebelubi	310	Compliant	Low Risk	Low Risk	Low Risk	NA	No Impact
	SG4	360						No Impact
	SG5	550						NA
ORWBs	Kuku-fionga	510	Compliant	Low Risk	Low Risk	Low Risk	NA	NA
	Zonga-mange	560						
	Avu	575						
	Levame	600						
Lake Murray	SG6	570	Compliant	Low Risk	Low Risk	Low Risk	NA	NA
	Miwa	590						No Impact
	Pangoa	600						No Impact

SG3* Located at the end of the permitted and compensated mixing zone boundary

WAE = Weak acid extractable

Recommendations for Improvement

The recommendations are intended to improve the assessment methodology, communication of the findings to stakeholders and with a view towards continued environmental performance (including further reduction of environmental risk and impact).

Note that a number of the recommendations from the most recent AER under operations, the 2019 Annual Environment Report are still in progress and appear in the list below in addition to new recommendations raised from this C&M Environment Report.

Assessment Methodology and Communication of Findings

1. Review the frequency of TSS sampling in the upper and lower river, Lake Murray and ORWB reference and test sites.
2. Deliver a summary presentation of the report methodology and findings to the Conservation and Environmental Protection Authority to support delivery of the C&M Environment Report.
3. Develop a Porgera Mine Environment Report Card to present a summary of the findings of the report and make the report card available in hard copy and via the PJV website.
4. Undertake a study to update the particle size information for the erodible dumps, used in the sediment mass balance calculations.
5. Conduct a critical review to investigate the major ions present in the system, which contribute to elevated EC, and their impacts on aquatic life. This work should also investigate options for development of a site-specific EC trigger value.
6. Review the analytical procedure used for the determination of WAE metals. The CSIRO 2019 ultratrace study reported much lower WAE metal concentrations in benthic sediments from the main river than typically reported by BNL. It may be appropriate to adopt the CSIRO procedure for routine analysis.
7. Engage CSIRO to visit Porgera and review of the BNL environmental monitoring program. As a minimum, the review shall include training and competency, sample collection, sample handling and dispatch, laboratory analytical methods, data management and internal quality assurance and quality control systems. The review shall also include the collection and analysis of water, sediment and tissue metal samples by CSIRO for comparison against BNL results.
8. Undertake a specific investigation into the behaviour of mine derived sediment and contaminants of concern in the Lower Strickland floodplain.

Reduce Environmental Risk and Impact and Improve Performance

9. Continue to investigate options for reducing the concentrations of bioavailable metals and mass loads of metals in mine discharges.
10. Investigate the metal uptake pathway by which prawns and fish are accumulating mine derived metals to understand the influence of particulate metals and metals bound to organic matter.

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ANSTO: Australian Nuclear Science and Technology Organisation.

ANZECC/ARMCANZ: Australian and New Zealand Environment and Conservation Council and the Agricultural and Resource Management Council of Australia and New Zealand.

ANZFA: Australia New Zealand Food Authority.

Baseline data: Also called pre-operational data (studies); collected (undertaken) before development begins (ANZG 2018). Note that alluvial and small- scale mining had been conducted in the Porgera Valley prior to collection of PJV baseline data, however, the data were collected prior to beginning construction and operation of the PJV project.

BOD_5: 5-day Biological Oxygen Demand.

CIL: Carbon-in-leach.

CIP: Carbon-in-pulp.

CN: Cyanide.

C&M: Care & Maintenance

CO_2-e: Carbon dioxide equivalents.

Competent waste rock: Hard and durable rock with high shear strength, capable of supporting terrestrial waste rock dump construction.

CV-AAS: Cold vapour atomic absorption spectrometry.

Dissolved metals: Operationally defined as passing a very fine (0.45 µm) membrane filter, contains a bioavailable fraction capable of being metabolised by organisms.

EL: Exploration Lease.

EMS: Environmental Management System.

ENSO: El Niño Southern Oscillation.

Environmental aspect: Activities that have the potential to interact with the environment (ISO 14001).

Environmental impact: A statistically significant adverse change in the ecosystem health of the receiving environment as a result of the operation’s environmental aspects.

Environmental risk: The potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases, energy use, or the depletion of natural resources. (U.S. Environmental Protection Agency definition).

Erodible/incompetent waste rock: Waste rock with low shear strength, not capable of supporting terrestrial waste rock dump construction.

Erodible waste rock dump: Designed to temporarily store incompetent waste rock in a river valley while allowing the dump to gradually and progressively fail and some material to be eroded and transported downstream by the river system.

FT07: Flow through drain #7, Kogai Waste Rock Dump

GELs: Generally Expected Levels.

ICP-MS: Inductively coupled plasma mass spectrometry.

ISO14001: International Organisation for Standardisation Environmental Standard for Management Systems.

KPI: Key Performance Indicator.

LMP: Lease for Mining Purposes.

LOM: Life of Mine.

LOR: Limit of Reporting.

ME: Mining Easement.

NMI: National Measurement Institute.

NOEC: No Observable Effects Concentration.

NR: Not reported.

ORWBs: Off-river Water Bodies.

PDO: Pacific Decadal Oscillation.

PLOA: Porgera Land Owner Association.

PNG: Papua New Guinea.

QA&QC: Quality Assurance and Quality Control.

Reference site: Sites within an ecosystem that are similar to and in the vicinity of the test site ecosystem but are not influenced by the mine operations.

Risk: A statistical concept defined as the expected likelihood or probability of undesirable effects resulting from a specified exposure to known or potential environmental concentrations of a material. A material is considered safe if the risks associated with its exposure are judged to be acceptable.

Estimates of risk may be expressed in absolute or relative terms. Absolute risk is the excess risk due to exposure. Relative risk is the ratio of the risk in the exposed population to the risk in the unexposed population. (ANZG 2018)

SAG: Semi-autogenous Grinding.

SML: Special Mining Lease.

SOP: Standard Operating Procedure.

DGV: Sediment Quality Guideline Value

TARP: Trigger Action Response Plan.

TD: Total digest

Test site: Those sites at which the influence of the operations environmental aspects may occur.

Total metals: The concentration of metals determined from an unfiltered sample after vigorous digestion, or the sum of the concentrations of metals in the dissolved and suspended fractions. (APHA 2005).

TSM: Test Site Median.

TSS: Total Suspended Solids.

TV: Trigger Value.

UAV: Unmanned Aerial Vehicle

WAD-CN: Weak Acid Dissociable Cyanide.

WAE: Weak Acid Extractable.

WWCB: West Wall Cut-back.

WHO: World Health Organization.

1 INTRODUCTION

The Porgera Gold Mine is located in the Porgera Valley of Enga Province in the Papua New Guinea (PNG) highlands, approximately 630 km NW of Port Moresby (Figure 1-1).

The operation consists of an open cut and an underground mine, waste rock dumps, processing facility, gas-fired power station, a water-supply dam, limestone quarry and lime plant and ancillary infrastructure.

Production commenced in 1990 and is expected to continue until at least 2039 with an annual production of approximately 500 koz of gold.

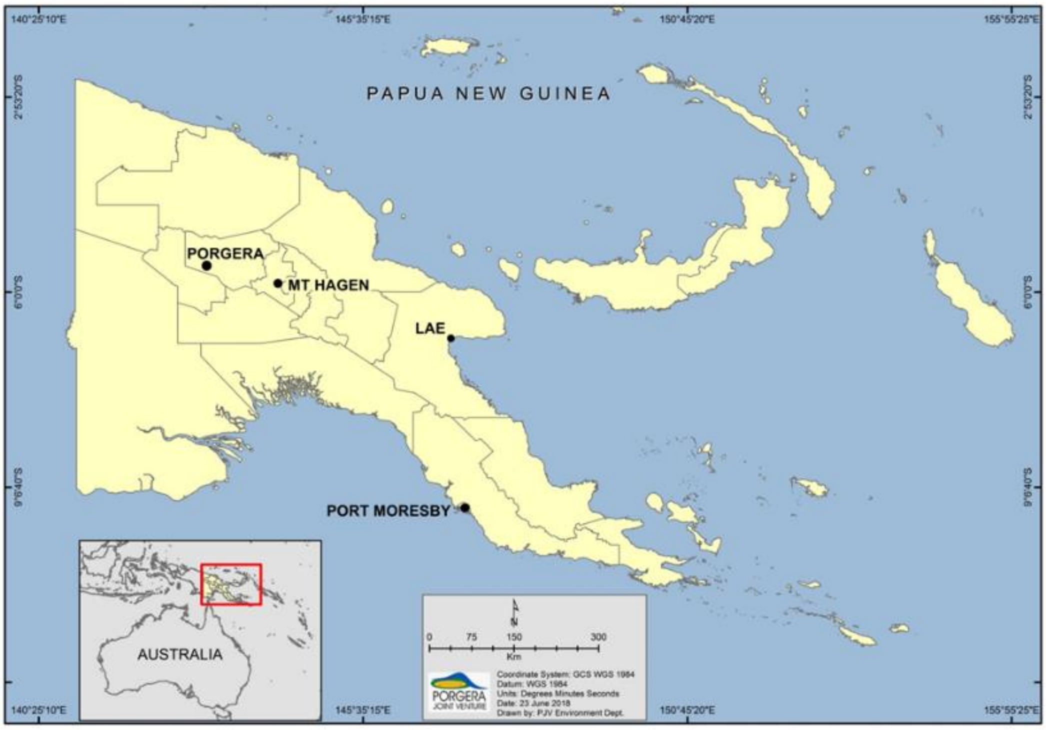


Figure 1-1 Location of Porgera operation

In April 2020, the operation was placed into care and maintenance after the PNG Government announced that it would not be approving Barrick Niugini Limited's (BNL) application to extend its Special Mining Lease (SML).

As of February 2023, the operation remains in care and maintenance, while negotiations between BNL, the PNG Government and other stakeholders continue with the aim of restarting the mine and returning to normal operations.

BNL has continued to manage the operation throughout the care and maintenance phase. Upon entering C&M, mining and processing was ceased, the number of employees significantly reduced and the scope of activities were limited to those required to maintain the site in a safe and stable condition. The scope of C&M activities is outlined in the Porgera Environmental Security Health Safety Plan - Care and Maintenance, which was reviewed and approved by the PNG Government.

During the operational phase, the Porgera mine has several unique economic, social and environmental aspects. The environmental aspects are managed in accordance with the site's Environmental Management System (EMS). The objective of the EMS is to effectively control the site's environmental aspects, and by doing so to ensure compliance, to mitigate potential environmental risks and to continually improve environmental performance.

BNL continued to implement the Porgera EMS throughout the C&M phase, and in accordance with EMS requirements, the EMS was adjusted to align with the change in operating conditions and ensure the EMS objectives continued to be met.

An important part of the EMS is the monitoring and reporting program. The program provides feedback on the effectiveness of the EMS for achieving the stated objectives and allows the operation to confirm which management techniques are working well, and more importantly, identify those which require attention to improve effectiveness. Since the EMS was adjusted to suit C&M activities, the Porgera environmental monitoring and reporting program was also adjusted to align with C&M activities.

The C&M monitoring program's objectives are to support C&M activities and to examine the receiving environment's response to the cessation of operational phase activities, especially the cessation of riverine tailings and erodible waste rock disposal.

This C&M environment report is based on the results of the EMS and C&M environmental monitoring program. The objectives of this report are to assess:

1. Compliance with legal and other requirements during the C&M phase;
2. The level of potential and actual environmental impact during C&M; and
3. The condition of the receiving environment in response to the cessation of operation phase activities.

The first section of this report describes background environmental conditions by quantifying the natural, non-mine related conditions and changes within the receiving environment. Next, the operation's environmental aspects during C&M (activities which interact with the environment) are identified and quantified. Then, assessments are made of compliance, mine-related risk, impact and performance and the condition of the receiving environment followed by a discussion of the findings and finally, recommendations for improving the environmental management system and the monitoring and reporting program.

Legal and other requirements during the C&M phase were outlined in the Porgera Environmental Security Health Safety Plan - Care and Maintenance, which was reviewed and approved by the PNG Government. BNL also continued to monitor compliance against the two environmental permits issued to BNL by the Papua New Guinea Conservation and Environmental Protection Authority (CEPA). Compliance assessment is performed by comparing monitoring data against the conditions of the permits.

The methodology for risk and impact assessment has been developed by PJV in accordance with international guidelines (ANZG 2018) and in consultation with external technical experts. The methodology is consistent with that applied by BNL to it's Annual Environment Reports, which have been submitted to CEPA throughout the operational phase of the mine.

The risk assessment stage is based on the comparison of physical and chemical environmental indicators at those sites potentially impacted by the mine (test sites) against risk assessment criteria or trigger values (TVs) derived from baseline data, reference sites and/or international guidelines. This step provides an indication of which sites may be potentially impacted as a result of mine aspects.

The impact assessment stage is based on the comparison of biological indicators at test sites against biological indicator trigger values derived from reference sites or baseline data for test sites. When the performance of biological indicator values at the test site is below that of the trigger value, it indicates that environmental impact has occurred (i.e. species abundance at a test site is lower than baseline or reference) and warrants further investigation to determine whether mine-related factors are causing the impact. If the same performance of biological indicators is observed at both the test site and the reference site, then it indicates no impact is detected or there is a system-wide change that is not related to the mine. Additionally, long-term trends of biological indicators were assessed, where a significant declining trend is observed, it indicates that change is occurring over time and warrants further investigation to determine if there are mine-related factors driving the change.

1.1 Mine Operational History and Description

1.1.1 Staged development history of the mine

The Porgera operation was developed in four stages between 1989 and 1996 increasing the nominal processing capacity from 8,500 tonnes per day to 17,500 tonnes per day. The four stages of project development are described below and summarised in Table 1-1.

Stage 1 of construction of the mine commenced in July 1989 and comprised development of an underground mine, ore processing plant and associated infrastructure. The processing plant consisted of a crushing and grinding circuit, a concentrator to recover the gold-bearing sulfide portion of the ore and a cyanidation leach carbon-in-pulp (CIP) circuit. High-grade ore from the underground mine was fed to the mill at a rate of 1,500 tonnes per day (t/day). The sulfide flotation concentrate was direct leached in the CIP circuit, recovering approximately 60% of the contained gold, followed by refining into doré on site. The CIP tailings containing the remaining 40% of the gold were stored in a lined pond for later reclaim and processing through the pressure oxidation circuit. The barren flotation tailings were discharged into the river system. Stage 1 production commenced in September 1990.

Stage 2 of construction consisted of expanding the underground mine production and installation of the pressure oxidation circuit at the processing plant. The underground mine production was increased by addition of an ore crushing and hoisting system to convey the ore to the surface. In September 1991, commissioning was completed for the pressure oxidation autoclaves for processing the sulfide flotation concentrate and recovery of refractory gold. The sulfide flotation concentrate from the ore feed and the previously stockpiled Stage 1 CIP tailings were processed in the pressure oxidation circuit at 2,500 t/day. Gold liberated by pressure oxidation was recovered through the CIP cyanide leach circuit. The tailings neutralisation circuit was commissioned for combining the various processing waste streams (acid wash effluent, cyanidation tailing and flotation tailings) to detoxify and neutralise the tailings before discharge to the river system.

Stage 3 was commissioned in September 1992, with mill throughput increased to 4,500 t/day. The underground ore was supplemented with ore from the open pit mine.

Stage 4A of the project commenced in October 1993 and further expanded open pit mining operations and the mill facilities, increasing mill throughput to 8,500 t/day.

In 1993, a major review of the project recommended expansion to a nominal capacity of 17,500 t/day for optimisation of mining and ore processing rates. Following the granting of project approvals, this additional expansion, known as Stage 4B, was completed in the first quarter of 1996. Stage 4B involved addition of a second semi-autogenous grinding (SAG) mill and a large ball mill, a 350 t/day oxygen plant, a 150 t/day lime kiln and increased flotation and leaching capacity. Process water storage and the Hides power plant generation capacity, together with other infrastructure also were increased to support this expansion.

The open pit mining fleet capacity was expanded in 1997 from 150,000 to 210,000 t/day to provide for the increase in mill feed rates. Four Knelson concentrators were installed in the same year, to recover free gold ahead of the flotation circuit. In 1999, a further flotation expansion was installed to improve recoveries, and additional oxygen plant capacity was added to increase autoclave throughput.

In 2001, an Acacia reactor was commissioned to treat the Knelson gravity concentrate, and modifications were made to the grinding and CIP circuits. During 2003 a contract secondary crusher was installed to optimise the capacity of the crushing plant and allow a better match between milling and oxidation capacity.

In 2009, a cyanide destruction plant was commissioned to reduce the concentration of cyanide in the tailings discharge and achieve compliance with the International Cyanide Management Code. Two years later in 2011, a paste plant was commissioned for placement of the coarse fraction of tailings in the underground mine as cemented paste backfill. The paste plant has a nominal capacity of 8% of the tailings discharged from the processing plant.

In 2016, a sulfide concentrate plant was commissioned for processing a portion of the high sulfur content flotation concentrate for export to a refinery overseas.

In April 2020, the operation was placed into care and maintenance when the PNG Government refused to renew the request by BNL for the extension of the Special Mining Lease. All production activities ceased, the majority of the workforce was made redundant, and a small team was retained to maintain the site in a safe and stable condition while negotiations for a restart were conducted.

Table 1-1 PJV Project development summary

Stage	Period	Ore processing capacity	Comments
1	Jul 1989 – Aug 1991	1,500 t/day	Construction started Jul 1989. First production Sept 1990. CIP tails stored onsite for processing at a later stage. Commenced discharge of flotation tailings to the river system.
2	Sept 1991 – Aug 1992	2,500 t/day	Increased underground mine production. Installation of pressure oxidation circuit. Installation of tailings neutralisation circuit.
3	Sept 1992 – Sept 1993	4,500 t/day	Underground ore supplemented with ore from the open pit.
4A	Oct 1993 – Mar 1996	8,500 t/day	Expansion of open pit mining. Expansion of mill facilities.
4B	Apr 1996 – Apr 2020	17,500 t/day	1996 – Addition of a second semi-autogenous grinding mill, ball mill, 350 t/day oxygen plant, 150 t/day lime kiln, increased flotation and leaching capacity, increased water storage, Hides power station capacity and other infrastructure. 1997 – Increased open pit fleet capacity from 150 to 210 kt/day. 1999 – Further expansion of flotation circuit and additional oxygen plant. 2001 – Acacia reactor. 2003 – Secondary crusher. 2009 – Cyanide destruction plant, reduces WAD-CN in discharge to <0.2mg/L 2011 – Paste plant, diverts approx 8% tailings volume to the underground mine for backfilling. 2016 – Sulfide concentrate filtration and export facility, nominal capacity 100t/day.

Stage	Period	Ore processing capacity	Comments
C&M	Apr 2020 - Present	Nil Production	Operation placed into care and maintenance while negotiations with the PNG Government and other stakeholders continued. Ceased all production related activities including drilling, blasting, mining, processing, waste rock and tailings disposal. A small team was retained to ensure the site is maintained in a safe and stable condition including minor onsite power generation, minor maintenance activities, water and waste management, safety and environmental monitoring.

2 C&M ENVIRONMENT REPORT METHODOLOGY

This C&M environment report uses a risk-based framework for assessing the environmental compliance, risk, impact and performance of the Porgera mine during C&M. The report is structured in accordance with the following framework:

1. Identify the environmental aspects of the operation (Section 3).
2. Identify appropriate physical, chemical and biological parameters to serve as indicators of natural or mine-related change within the environment (Section 3.3.1).
3. Identify locations within the environment where mine-related environmental impact may occur, these are known as test sites, and identify locations within the environment where mine-related environmental impact will not occur, these are known as reference sites (Section 3.3.2),
4. Quantify the environmental aspects of the mine operation that have the potential to interact with the environment (Section 4).
5. Describe the natural or background environmental condition and establish TVs for each indicator parameter by comparing baseline, background and guideline values (Section 4).
6. Assess compliance against legal requirements (Section 6).
7. Perform a risk assessment to determine whether potential mine-related environmental impact has occurred (Section 7).
8. Perform an impact assessment to determine whether mine-related environmental impact has occurred (Section 8).
9. Discuss findings, draw conclusions and make a determination of the operation’s overall environmental performance using multiple lines of evidence (Section 9).
10. Make recommendations for improving environmental performance and the environmental monitoring program (Section 10).

2.1 Risk Assessment Methodology

The purpose of the risk assessment stage is to determine whether potential mine-related environmental impact has occurred within the receiving environment. The risk assessment is based on a comparison of physical and chemical indicators, measured either in discharge from the site or at test sites within the receiving environment, against TVs.

If the levels of physical or chemical indicators in discharge or at test sites exceed the TV, it indicates the potential for impact to have occurred. This exceedance then triggers further and more detailed investigation to determine whether impact has actually occurred. Impact assessment requires a holistic and detailed investigation of ecosystem condition based on the relationships between chemical, physical and biological functions within the environment.

Risk assessment based on physical and chemical parameters alone is typically simpler and more efficient than an impact assessment and can therefore be conducted at a higher frequency and over a greater spatial and temporal range. An appropriately designed and executed monitoring program based on physical and chemical indicators provides a robust and economic basis for assessing risk and triggering more detailed impact assessment where required.

2.2 Establishing TVs

The Porgera risk assessment methodology for developing TVs aligns with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) approach to establishing guideline values (GVs) for physical and chemical indicators.

2.2.1 TVs derived from ecological effects data

To derive TVs from ecological effects data, measure the statistical distribution of water quality indicators either at a specific site (preferred), or an appropriate reference system(s), and also study the ecological and biological effects of physical and chemical stressors. The TV is the level of key physical or chemical stressors below which ecologically or biologically meaningful changes do not occur (ANZG 2018).

Developing valid TVs using this method requires identifying a suitable reference site and highly controlled conditions to produce well-correlated physical, chemical and biological data, consequently this method is rarely adopted. BNL has not attempted to develop TVs using this method.

2.2.2 TVs derived from baseline or regional reference site data

Where there is insufficient information on ecological effects to determine an acceptable change from the reference condition, the use of an appropriate percentile of the reference data distribution can be used to derive the trigger value (ANZG 2018). Reference data are gained either from baseline data or regional reference data.

Baseline data are gathered from the test site prior to disturbance and provide the best comparison of pre and post-disturbance conditions. Baseline data are available for Porgera Mine test sites and their use in deriving TVs is discussed further in Section 4. Note that alluvial and small-scale mining had been conducted in the Porgera Valley prior to collection of baseline data, however, the data were collected prior to beginning construction and operation of the current Porgera project and are therefore considered an appropriate baseline for the current mine.

Regional reference data are gathered from sites that are similar to and in the vicinity of the test site, but which are not directly affected by the mining operation. Reference sites should be selected from the same biogeographic and climatic region, should have similar geology, soil types and topography, and should contain a range of habitats similar to those at the test site (ANZG 2018).

The suitability of regional reference site data for establishing TVs is influenced by how well the reference sites reflect the pre-disturbance condition of the test site. If the pre-disturbance condition of the regional reference site and test site are different, then TVs based on reference data are unlikely to act as an accurate basis for assessment of mine-related change and therefore risk at the test site. Variation between regional reference site and test site conditions is usually more pronounced in regions where mining projects occur due to naturally elevated mineralisation in the test site catchment. In general, ecosystems in reference sites adjacent to mining projects have evolved with lower levels of natural mineralisation in water and stream sediment than those at the test site prior to disturbance.

BNL reference sites and an assessment of their suitability are presented in Table 3-4 and Table 3-5 respectively. A comparison of baseline and reference data is presented in Section 4. The assessment shows that the suitability of BNL reference sites as analogues for the test sites is generally fair to poor. When compared to baseline data from the test sites, reference site data exhibit lower TSS, lower pH and lower concentrations of metals in water, sediment, fish flesh and prawn flesh than baseline test site conditions.

For physicochemical stressors (e.g. TSS, pH, turbidity etc), ANZG (2018) recommends that the derivation of TVs from baseline or reference site data should be based on at least two years (24 months) of monthly monitoring data.

The TV is the percentile value (i.e. 80th%ile or 20th%ile) derived from the baseline or reference site data that represents the degree of excursion that is permitted at the test site before triggering some action

(ANZG 2018). The 80th%ile and 20th%ile are deemed to be approximately equivalent to plus or minus (±) one standard deviation around the median, and it is argued that this level of change is unlikely to result in risk of disturbance to the ecosystem (ANZG 2018). This approach has been adopted widely in Australia for monitoring wetlands and rivers and assessing ecological health (see Fukuda and Townsend 2006, Storey *et al.* 2007).

The preferred protocol is to compare the median of monthly samples from a test site over the previous 1 year (12 months), with the TV. Statistically, the median represents the most robust descriptor of the test site data. It should be noted that comparison of the test site median against the TV has previously been adopted by BNL for its Annual Environment Reports. However, due to resource constraints during the C&M period, it was not possible to conduct monthly monitoring at each site as was done under the operational environmental monitoring program. During C&M, the frequency of monitoring at most sites was reduced, resulting in a lower number of sampling events (n) than the usual n=12 that would be achieved by monthly sampling throughout a year. As a result, it became apparent during development of this C&M report, that comparing the median value from the test sites during the C&M period against the TVs using the recommended rank test (ANZG, 2018) was no longer a robust statistical approach. Instead, the C&M risk assessments for water quality, sediment quality and tissue metal are based on a comparison of the mean (average) of the data collected at the test sites during C&M against the TV, this is referred hereafter as the test site mean (TSM). The risk assessment for water-based activities and fish and prawn consumption remains consistent with previous Porgera AERs and is based on a direct comparison of the test site median against respective guideline values. The C&M environmental monitoring program is discussed further in Section 3.

Inherent in the use of 80th%ile or 20th%ile values is the fact that monitoring data should exceed the TV at least 20% of the time. Therefore, a statistical test is required to determine if the exceedance is statistically significant, rather than an artefact of variability within the dataset itself, and thus providing a greater level of confidence in the risk assessment result. As described above, BNL has applied a parametric t- test to support the comparison of the TSM against the TV and thereby statistically determine if the TSM is significantly higher, lower or not significantly different from the TV. Further description of the statistical test used in this report is provided in Section 2.7.

2.2.3 Adopting TVs provided by guidelines

For physico-chemical stressors and for toxicants, where ecological effects data, baseline data and reference site data are unavailable or unsuitable, default TVs provided by guidelines and standards can be adopted to support the risk assessment. Default guidelines and standards are typically developed by governments, industry or subject matter experts based on available evidence and a precautionary risk-based approach and are intended to be conservatively protective of the environment. The guidelines are toxicologically-based and therefore link contaminant concentrations to their effects on aquatic organisms, with the inference usually being acute toxicity. For physical and chemical indicators within the receiving environment, the default values provided by ANZG (2018) may not necessarily apply to PNG.

A summary of adopted guidelines and standards for each environmental value is presented in Table 2-1.

Table 2-1 Guidelines and Standards

Risk	Indicator	Guideline
Aquatic ecosystem health	Water quality	ANZG (2018)
	Benthic sediment quality	ANZG (2018)
	Tissue metal	USEPA (2016) – Selenium only
Drinking water	Water quality	WHO Drinking Water Guidelines *(2017)*
Water-based activities	Water quality	ANZG (2018) Guidelines for recreational water quality and aesthetics WHO Drinking Water Guidelines *(2017)*
Fish and prawn consumption	Tissue metal	As – Australia New Zealand Food Standards Code – Standard 1.4.1 – Contaminants and natural toxicants (ANZFS 2016) Cd, Hg, Pb – European Food Safety Authority (EC 2006) Cr – Hong Kong Food Adulteration (Metallic Contamination) Regulations (HK 1997) Cu, Se, Zn – Food Standards Australia New Zealand GEL for Metal Contaminants 90th%ile (ANZFA 2001)

2.2.4 Establishing locally-derived TVs

Locally-derived TVs are recommended for the situation where biological effects data are not available and where the baseline or reference data consistently exceed the default guideline TV.

The locally-derived TV is established by first comparing the TVs derived from baseline data, reference site data and the default guideline or standard TV (i.e. ANZG 2018) and then adopting whichever is highest.

Where the baseline or reference site TV is higher than the ANZG (2018) default GV, it indicates that pre-disturbance levels of those indicators are naturally higher than the dataset from which the default GVs have been derived. Adopting the higher value derived from baseline or reference data accounts for naturally elevated levels of the particular indicator, while still providing a limit to the acceptable level of change at the test site. Adopting the lower guideline value as the TV would be likely to result in frequent exceedance of the TV as a result of natural inputs and would therefore decrease its effectiveness for distinguishing between risk from mining activities and natural variability.

In cases where the default guideline value is higher than the baseline or reference TV, it indicates that pre-disturbance levels of those indicators are naturally low. Adopting the higher guideline TV provides a prudent basis upon which to allow a level of change at the test site, above that which would be provided by the baseline or reference TV, while still providing confidence that the environmental values are being protected.

The risk assessment is then performed by comparing the TSM derived from data collected at the test site during the C&M phase with the TV using a statistical test.

Based on the lack of biological effects data, elevated concentrations of some indicators in baseline data and the low suitability of the reference sites, BNL has elected to adopt this method for deriving TVs. Further details are provided in Sections 2.3 - 2.7. The comparisons between baseline, reference and guideline data for water quality, sediment quality and tissue metals are shown in Section 4.

It should be noted that C&M TVs have been derived from the most recent 24-month data for each region, however without a continuous 24 month dataset due to C&M disruptions, for this report the 24-month period is a discontinuous data set derived by joining the 7 months data between Nov 2021 and May 2022 with data collected during the last 17 months of operations prior to the site entering C&M in April 2020. The use of operation phase data for deriving TVs is considered appropriate as regional reference sites should not be influenced by mine operations, and therefore should only reflect natural change.

2.3 Water Quality TVs and Risk Assessment Matrices

2.3.1 Physical, chemical and toxicant indicators (except pH)

Water quality TVs for physical, chemical and toxicant indicators, except pH, have been established by comparing the 80th%ile value from baseline data, the 80th%ile value from the most recent 24-months regional reference site data and the respective ANZG (2018) default guideline value (GV) for 95% species protection, and then adopting the highest of the three values as the TV.

The ANZG (2018) guidelines are intended to provide government, industry, consultants and community groups with a sound set of tools that will enable the assessment and management of ambient water quality in a wide range of water resource types, and according to designated environmental values. They are the recommended limits to acceptable change in water quality that will continue to protect the associated environmental values. They are not mandatory and have no formal legal status. They also do not signify threshold levels of contamination since there is no certainty that significant impacts will occur above these recommended limits, as might be required for prosecution in a court of law. Instead, the guidelines provide certainty that there will be no significant impact on water resources values if the guidelines are not exceeded (ANZG 2018).

ANZG (2018) default GVs for physical parameters have been derived from the statistical distribution of reference data collected within five geographical regions across Australia and New Zealand (ANZG 2018).

Most of the ANZG (2018) default GVs for chemical parameters (referred to by ANZG (2018) as toxicants) have been derived from single-species toxicity tests on a range of species, because these formed the bulk of the concentration-response information. High reliability GVs were calculated from chronic 'no observable effect concentration (NOEC) tests. However, the majority of GVs are described as moderate reliability trigger values, derived from short-term acute toxicity data (from tests ≤96 h duration) by applying acute-to-chronic conversion factors (ANZG 2018).

The ANZG (2018) default GVs derived using the statistical species sensitivity distribution method were calculated at four different species protection levels, 99%, 95%, 90% and 80%. Here, protection levels signify the percentage of species expected to be protected at different concentrations of the toxicant (ANZG 2018). The 95% species protection level is most commonly used in monitoring programs.

The GVs were derived primarily according to risk assessment principles, using data from laboratory tests in control water. They represent the best current estimates of the concentrations of chemicals that should have no significant adverse effects on the aquatic ecosystem (ANZG 2018).

GVs for metals are based on dissolved metal concentrations rather than total metal concentrations as it is the dissolved fraction that is most comparable to the bioavailable fraction and therefore has the potential to cause a toxic effect. Where applicable, the ANZG (2018) default GV for 95% species protection have been hardness-modified prior to comparison with the baseline and reference site data in accordance with ANZG (2018). Hardness modification is done separately for the upper river, lower river, ORWBs and Lake Murray, and conservatively uses the 20th%ile hardness value from all test sites within each of the respective groups. Adoption of the 20th%ile value is considered a representative approach as it assumes low buffering capacity throughout the entire year, and calculating a specific hardness modified GV for each of the different regions will account for the different hardness within each region.

The comparisons between baseline data, reference site data and the ANZG (2018) default GVs for 95% species protection in the upper river, lower river, ORWBs and Lake Murray are presented in Section 4.

A summary of the TV development method is provided in Table 2-2 and the decision matrix is shown in Figure 2-1 and Table 2-3.

Table 2-2 TVs for physical, chemical and toxicant indicators in water

Indicator Parameter	Trigger Value (TV) Derivation
Water Quality: Physical, chemical and toxicant indicators (except pH)	Adopt whichever is higher: - Baseline 80th%ile (full data set) - Regional reference site 80th%ile (most recent 24-month data set), or - ANZG (2018) default guideline for 95% species protection (hardness-modified where appropriate)

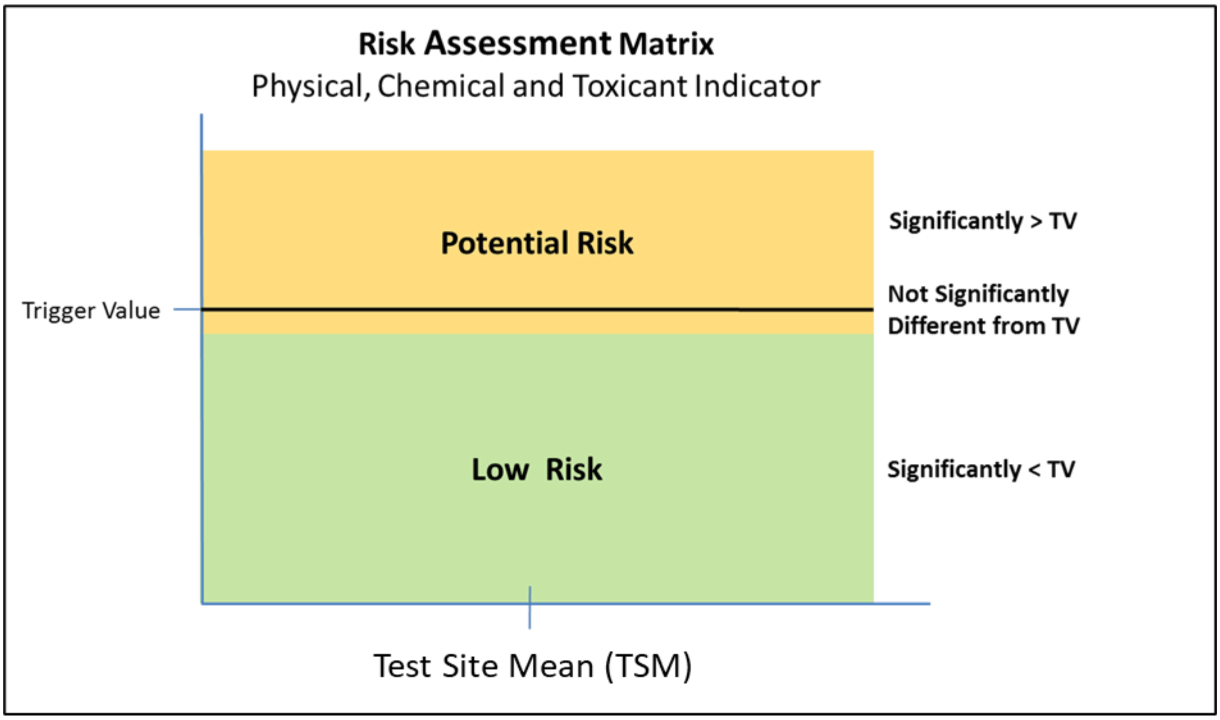


Figure 2-1 Risk assessment matrix – physical, chemical and toxicant indicators in water

Table 2-3 Risk assessment matrix – physical, chemical and toxicant indicators in water

Assessment Result	Risk Rating	Action
TSM significantly > TV	Potential Risk	Confirm whether impact has or is occurring by conducting an impact assessment based on biological indicators.
TSM not significantly different from TV And TV, TSM and TSM data set not all ≤ LOR.		
TSM not significantly different from TV And TV, TSM and TSM data set all ≤ LOR.	Low Risk	
TSM significantly < TV		

Significance = statistical significance with a probability threshold of $p = 0.05$

2.3.2 pH

Upper and lower TVs for pH in the upper river were established by comparing the 80^{th}% and 20^{th}%iles of test site baseline data, and the reference site values from the most recent 24-month data with the ANZG (2018) upper and lower limit respectively for pH for upland rivers in tropical Australia.

Upper and lower TVs for pH in the lower river and Lake Murray and ORWBs were established by comparing the 80^{th}% and 20^{th}%iles of Lake Murray baseline data and the North Lake Murray reference site values from the most recent 24-month data with the ANZG (2018) upper and lower limit respectively for pH for lowland rivers in tropical Australia.

Comparisons between upper river baseline data, reference site data and the ANZG (2018) default guidelines for upland rivers in Tropical Australia are presented in Section 4.

Comparisons between test site baseline data, lower river reference site data and the ANZG (2018) default guidelines for lowland rivers in Tropical Australia are presented in Section 4.

A summary of the TV development method is provided in Table 2-4, and the decision matrix is shown in Figure 2-2 and Table 2-5.

Table 2-4 TVs for pH in water

Indicator Parameter	Trigger Value (TV) Derivation
Water: pH – upper	Adopt whichever is higher: - Baseline 80^{th}%ile (full data set) - Regional reference 80^{th}%ile (most recent 24 month data set), or - ANZG (2018) upper limit for upland rivers in tropical Australia
Water: pH – lower	Adopt whichever is lower: - Baseline 20^{th}%ile (full data set) - Regional reference 20^{th}%ile (most recent 24 months data set), or - ANZG (2018) lower limit for upland rivers in tropical Australia

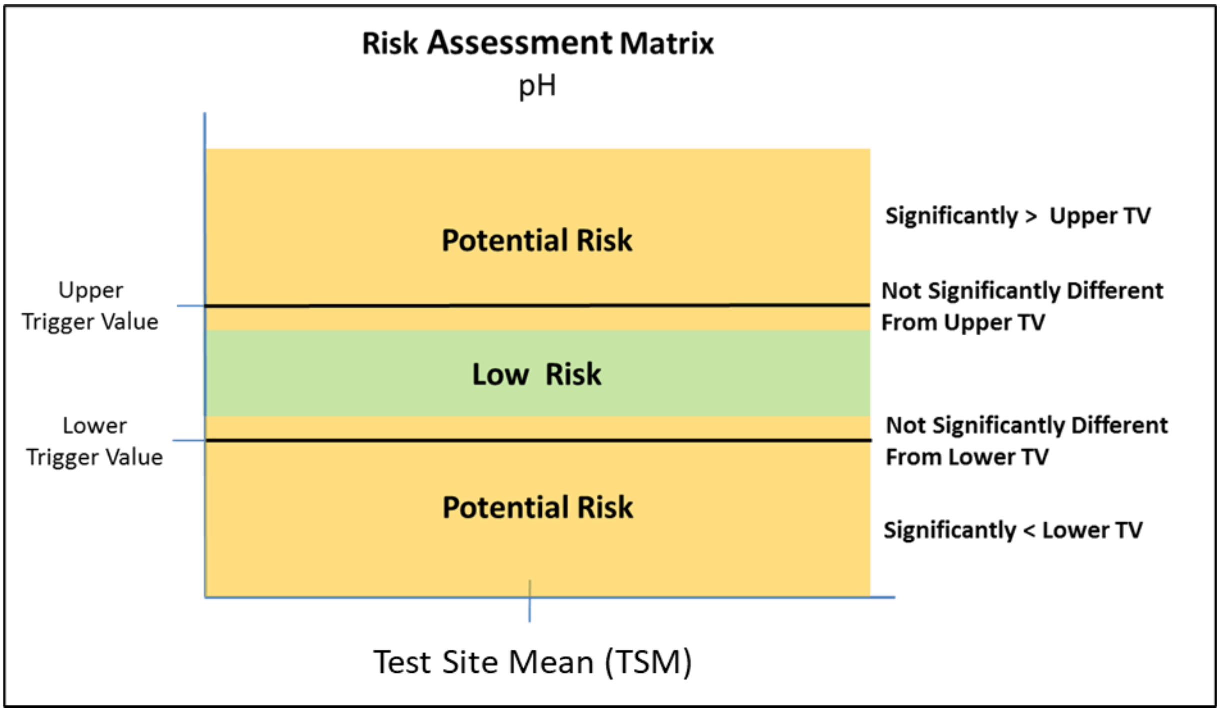


Figure 2-2 Risk assessment matrix – pH in water

Table 2-5 Risk assessment matrix – pH in water

Assessment Result	Risk Rating	Action
TSM significantly > Upper TV	Potential Risk	Confirm whether impact has or is occurring by conducting an impact assessment based on biological indicators.
TSM not significantly different from Upper TV		
Lower TSM significantly < Upper TV	Low Risk	
Upper TSM significantly > Lower TV		
TSM not significantly different from Lower TV	Potential Risk	
TSM significantly < Lower TV		

Significance = statistical significance with a probability threshold of p = 0.05

2.4 Sediment Quality TVs and Risk Assessment Matrix

Sediment quality data from the reference sites were compared against the ANZG (2018) Default Guideline Values (DGVs) (Simpson et al 2013). The guidelines include DGV and DGV-High values, which represent the 10th percentile (10th%ile) and 50th percentile (50th%ile) values for chemical concentrations associated with acute toxicity effects respectively.

The DGV is the default TV below which the frequency of adverse biological effects is expected to be very low, and if exceeded, should trigger further study. The DGV-High corresponds to the median effect concentration as detailed by Long et al. (1995) and indicates the concentration above which adverse biological effects are expected to occur (ANZG 2018).

The weak acid extractable (WAE) fraction from the whole of sediment sample is used to represent the likely maximum bioavailable fraction of metals that may cause a toxic effect, and therefore the WAE results for whole sediment are used to derive TVs and to compare against ANZG (2018) DGVs.

Baseline sediment quality conditions were not sampled at river test sites. Baseline conditions were sampled at Lake Murray, but the samples were analysed only for total extractable metals not weak acid extractable metals and are therefore not comparable with reference data or the ANZG (2018) DGV.

TVs for sediment quality for all parameters except selenium (Se) have been established by comparing the WAE whole sediment 80th%ile from the most recent 24-month reference site data against the ANZG (2018) interim sediment quality low guideline value (DGV) and adopting whichever is higher.

ANZG (2018) does not provide sediment quality TVs for selenium, therefore the TV for selenium has been established from the most recent 24-month 80th%ile from the reference data set.

Similar to water quality, the lack of suitable reference sites, particularly due to the presence of natural mineralisation in the test site catchment, means that TVs based on the reference site data alone are likely to be overly conservative. Comparisons between the upper river, the lower river and Lake Murray and ORWB reference site data and the ANZG (2018) DGVs are presented in Section 5.

Also similar to water quality, it should be noted that in cases where the TV, the TSM and the entire test site data set from which the TSM is derived are less than the analytical limit of reporting (LOR), Wilcoxon's test will find the TSM not significantly different from the TV which infers a potential risk of environmental impact. However, in these cases given that the data set from the test site indicates that the concentration of a particular parameter does not have the potential to exceed the TV, and the TV, the TSM and the TSM data set are equal to the LOR, it is considered appropriate to conclude there is low risk of potential impact rather than potential risk of environment impact. This scenario is captured in the risk assessment matrices.

A summary of the TV development method is provided in Table 2-6 and the decision matrix is shown in Figure 2-3 and Table 2-7.

Table 2-6 Sediment quality TVs

Indicator Parameter	Trigger Value (TV) Derivation
Sediment Quality	Adopt whichever is higher: - Reference site 80th%ile WAE in whole sediment (most recent 24months data set), or - ANZG (2018) revised DGV (Simpson et. al. 2013)

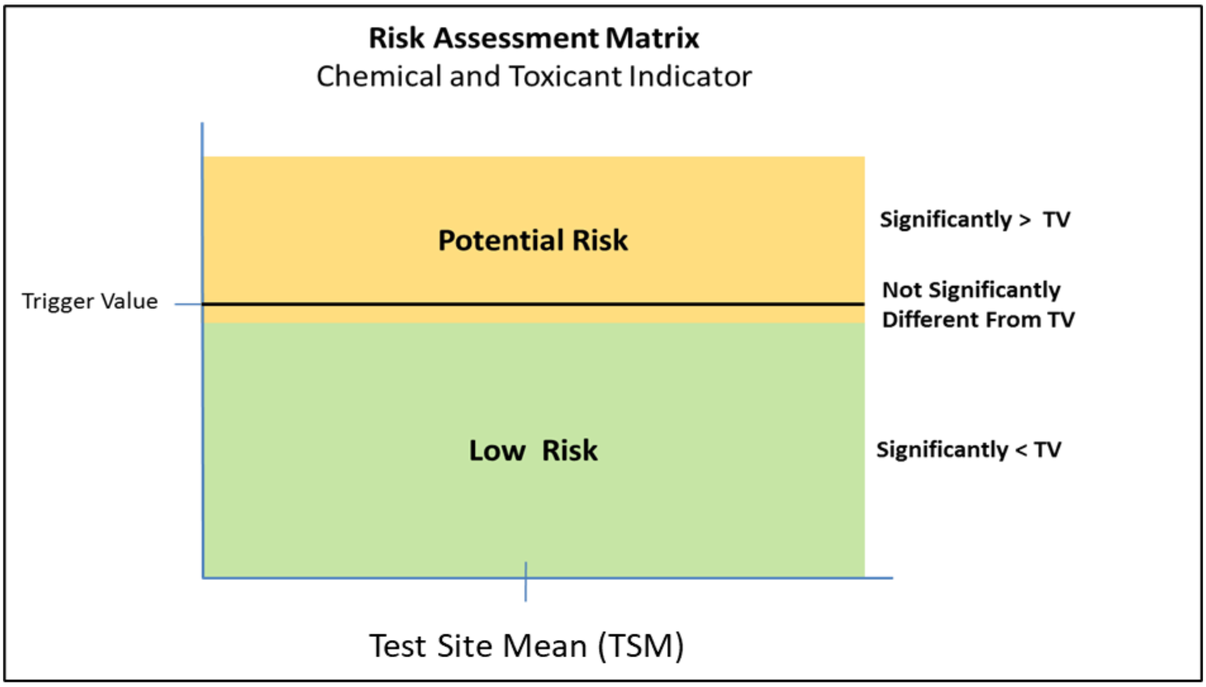


Figure 2-3 Risk assessment matrix – chemical and toxicant indicators in benthic sediment

Table 2-7 Risk assessment matrix – Chemical and toxicant indicators in benthic sediment

Assessment Result	Risk Rating	Action
TSM significantly > TV	Potential Risk	Confirm whether impact has or is occurring by conducting an impact assessment based on biological indicators.
TSM not significantly different from TV And TV, TSM and TSM data set not all ≤ LOR.		
TSM not significantly different from TV And TV, TSM and TSM data set all ≤ LOR.	Low Risk	
TSM significantly < TV		

Significance = statistical significance with a probability threshold of $p = 0.05$

2.4.1 Tissue metal TVs and risk assessment matrix

Tissue metal concentrations have been monitored in target species of fish and prawns that were selected on the basis of relative abundance and potential food sources for local villagers. The target species for the upper rivers, lowland and Lake Murray are, respectively:

- Mountain tandan, *Neosilurus equinus* and mountain prawn, *Macrobrachium handschini*;
- Sharp-snouted catfish, *Potamosilurus macrorhyncus* and giant freshwater prawn, *Macrobrachium rosenbergii; and*
- Barramundi, *Lates calcarifer*.

Pre-disturbance baseline data are available for river and Lake Murray test sites, but only for fish flesh tissue samples. TVs for tissue metal concentrations in fish and prawns for all TVs, except selenium in fish flesh, have been established by comparing the reference site 80th%ile value from the most recent

24-month data against the 80th%ile of the test site baseline data and adopting the higher value. The exception to this approach is where the baseline limit of reporting (LOR) is greater than the current limit of reporting and the baseline 80th%ile is equal to the baseline LOR. In these cases, the baseline LOR is not considered representative of actual baseline conditions, but rather represents the lowest reportable value at the time of sampling. It is considered prudent in these cases to adopt the reference 80th%ile value as the TV so as not to inadvertently overestimate the TV.

This method has been selected in the absence of any suitable effects-based guidelines for use as a comparison against reference site data and is considered representative due to the lack of natural mineralisation within the reference site catchments. However, it should be noted that reference site data could be elevated as a result of fish/prawns migrating upstream from test sites and into the reference sites, which tend to be connected tributaries.

The TV for selenium in fish flesh has been established by comparing the reference site 80th%ile value from the most recent 24-month data, the 80th%ile of the test site baseline data and the United States Environmental Protection Agency draft tissue metal criterion for protection of aquatic life (USEPA 2016). Although still in draft form, this is the best available toxic effects-based criterion for fish tissue and is therefore deemed appropriate for use.

A summary of the TV development method is provided in Table 2-8 and the decision matrix is shown in Figure 2-4 and Table 2-9.

Table 2-8 Tissue metal concentration TVs

Indicator Parameter	Trigger Value (TV) Derivation
Tissue metals – fish and prawn flesh	Adopt whichever is highest: - Baseline 80th%ile (full data set), not applicable where the baseline 80th%ile is equal to the baseline LOR. - Reference site 80th%ile (most recent 24 months), or - USEPA criterion (available for selenium (Se) only)

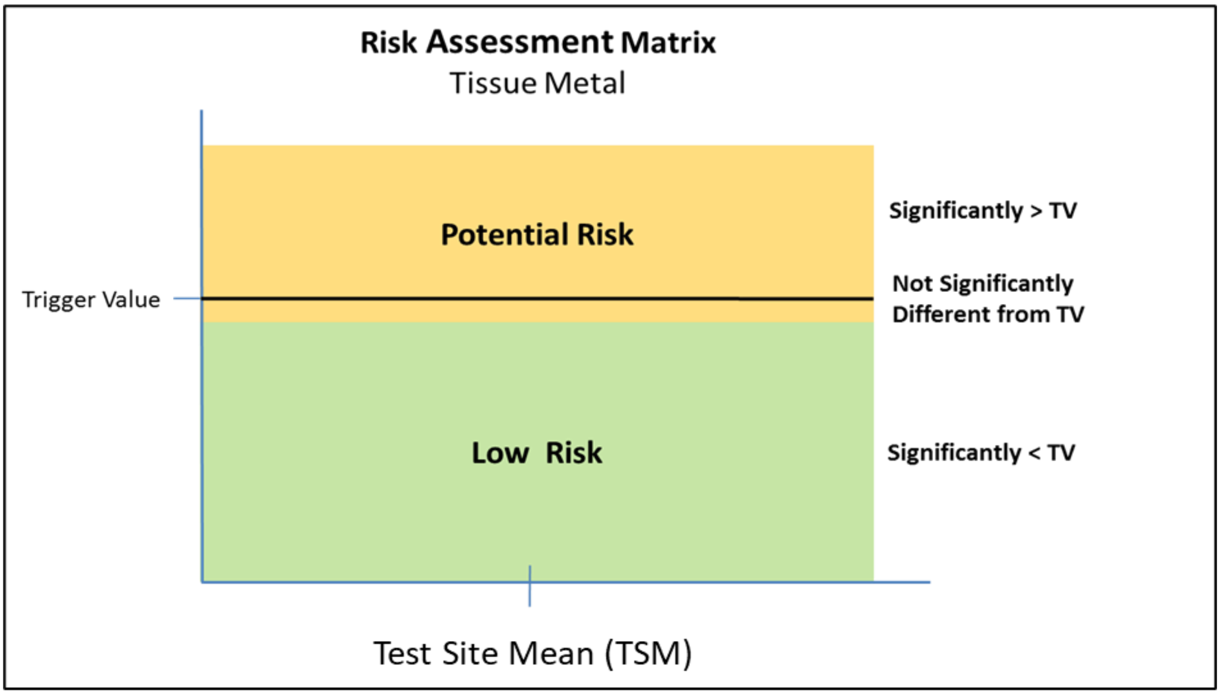


Figure 2-4 Risk assessment matrix – tissue metal concentrations

Table 2-9 Risk assessment matrix – tissue metal concentrations

Assessment Result	Risk Rating	Action
TSM significantly > TV	Potential Risk	Confirm whether impact has or is occurring by conducting an impact assessment based on biological indicators.
TSM not significantly different from TV And TV, TSM and TSM data set not all ≤ LOR.		
TSM not significantly different from TV And TV, TSM and TSM data set all ≤ LOR.	Low Risk	
TSM significantly < Trigger Value		

Significance = statistical significance with a probability threshold of p = 0.05

2.5 Water-based Activities & Fish and Prawn Consumption

Water-based activities involve contact with water, and in Porgera's context, this includes gold panning, swimming, bathing, washing clothes or fishing by communities downstream of the mine. In general, there are two kinds of exposure pathways associated with these activities: (i) dermal contact with the water body and (ii) ingestion of the water. BNL has adopted the ANZG (2018) recreational water quality guidelines as TVs to support the risk assessment. The ANZG (2018) guidelines are based on the assumption that no more than 100 mL of water is ingested during the recreational activity. An additional assessment against the WHO (2017) is also provided. The results of the risk assessment are presented in Section 7.2.

Human consumption of fish and prawns has the potential to transfer toxicants from the flesh of the animal to humans. The BNL risk assessment is based on a comparison of metal concentrations in the flesh of fish and prawns downstream of the mine against recommended levels from a range of international food standards. Where more than one recommended limit is provided by multiple documents, the lower value has been adopted. The results of the fish and prawn consumption risk assessment are presented in Section 0.

A summary of guideline trigger values adopted for water-based activities and fish and prawn consumption are shown in Table 2-10, the risk assessment decision matrix is shown in Table 2-11.

Table 2-10 Drinking water, aquatic recreation, fish and prawn consumption and air quality TVs

Indicator Parameter	Risk Assessment Trigger Value (TV) Derivation
Drinking water: Water quality – village water supplies Test Site Median (TS Median)	WHO Drinking Water Guidelines (2017)
Water-based activities: Water quality – receiving environment TS Median	ANZG (2018) Guidelines for recreational water quality and aesthetics (Chapter 5) WHO Drinking Water Guidelines (2017)

Indicator Parameter	Risk Assessment Trigger Value (TV) Derivation
Fish and prawn consumption: Tissue metals – fish and prawns TS Median	As – Australia New Zealand Food Standards Code – Standard 1.4.1 – Contaminants and natural toxicants (ANZFS 2016) Cd, Hg, Pb – European Food Safety Authority (EC 2006) Cr – Hong Kong Food Adulteration (Metallic Contamination) Regulations (HK 1997) Cu, Se, Zn – Food Standards Australia New Zealand GEL for Metal Contaminants 90th%ile (ANZFA 2001)

Table 2-11 Risk assessment matrix – drinking water, air quality and river profiles

Risk	Assessment Result	Risk Rating	Action
Drinking water	TS Median > WHO Drinking Water Guidelines	Potential risk	Conduct health risk assessment
	TS Median ≤ WHO Drinking Water Guidelines	Low	NIL
Water-based activities	TS Median > Recreation TV	Potential risk	Conduct health risk assessment
	TS Median ≤ Recreation TV	Low	NIL
Fish and prawn consumption	TS Median > Consumption TV	Potential risk	Conduct health risk assessment
	TS Median ≤ Consumption TV	Low	NIL

2.6 Impact Assessment Methodology

The purpose of the impact assessment stage is to confirm whether potential environmental risks have translated to actual environmental impact, and if so, to determine the level or significance and the likely causes of that impact.

It should be noted that although ANZG (2018) recommends further investigation of actual impact in cases where the TV is exceeded, BNL considers it prudent to conduct the impacts assessment regardless of the risk assessment result. This is done to provide confirmation of the risk assessment conclusions, to support ongoing refinement of the TVs, and to provide a direct assessment of impact for ongoing performance monitoring and full transparency of the operation’s interactions with the environment.

The aquatic ecosystem impact assessment is based on an assessment of the health of the aquatic ecosystem through the use of biological indicators such as abundance, richness and biomass of aquatic fauna.

The impact assessment is conducted by comparing biological indicators from the test sites against impact assessment trigger values or benchmarks generated from baseline and reference site data. Where the current biological condition at the test sites is found to have deteriorated compared to the TV, then impact is indicated and further investigation is required to determine the potential causes of those impacts and identify whether the causes are mine related, non-mine related or a combination of both.

Impact assessment based on population monitoring is typically performed by applying statistical analytical methods to a range of population indicators. Methods of statistical analysis range in complexity from parametric tests on univariate parameters, used to assess the difference in mean values of a single indicator between two locations, to parametric tests on multivariate parameters, used to assess the difference in means among multiple parameters and the effect of interacting parameters at multiple locations. Typical population indicators are total number of species (species richness), total number of organisms (abundance), biomass, presence of disease and species assemblage (species presence and absence, and composition).

The most appropriate impact assessment method for any given data set consists of the combination of statistical analysis and indicator type(s), which provide the greatest level of confidence in the assessment results. The ability of different assessment methods to deliver confidence is driven by the available data set, which is ultimately dictated by; the actual condition of the environment being monitored; the sampling method(s) being applied; the duration of the program; and the frequency of sampling.

In its previous annual environment reports (AERs), BNL applied an alternative method for impact assessment which was based on the comparison of the trend of ecosystem indicators between test and reference sites. This approach was necessary as the application of non-standard sampling methods across different monitoring sites meant that the data being captured were not suitable for direct comparison between reference and test sites.

In 2016, PJV began application of new, improved, standardised methods for monitoring fish and prawn populations in the upper and lower sections of the Lagaip/Strickland system, in an attempt to gain more robust and less variable data. Replicated sampling was performed on a quarterly basis at selected upper and lower river reference and test sites for a range of indicator parameters.

In parallel with implementing improved monitoring methods with the aim of reducing data variance, PJV commissioned Wetland Research & Management (WRM) in 2017 to conduct a review of the biological monitoring data, make recommendations on the most appropriate indicators, TVs and statistical analyses for conducting impact assessment for the AER, and explain how to interpret the statistics correctly. This proposed approach for impact assessment should be as consistent, where possible, with the risk-based approach currently used for water and sediment quality as per ANZG (2018). Where this was not possible, then the most appropriate alternative approach should be developed. The aim of the review was to enable BNL to reach accurate conclusions on ecological impacts, and thereby provide more confidence in the biology impact assessment. This new method of impact assessment, reported in WRM (2017), has been used in all subsequent AERs and in this C&M monitoring report.

PJV's environmental monitoring program currently uses TVs for assessing risk from modified water and sediment quality, and tissue metal concentrations (fish & prawns). These TVs are calculated from the most recent 24 months of observations at the relevant regional reference site. This approach aligns with ANZG (2018) recommendations for environmental monitoring, whereby TVs are set at the 80th percentile (80%ile) for upper TVs (or 20th percentile (20%ile) for lower TVs such as pH and DO), of the reference condition. For a robust and accurate impact assessment on fish and prawn catch data, basing TVs on the most recent 24 months reference site data was not considered suitable because of i) the combination of sampling methods used, ii) high variability inherent in the catch and often low catch rates, iii) naturally smaller populations and differing species assemblages at some reference sites compared to test sites, and iv) the non-independence of catch at reference and test sites (WRM, 2019).

WRM (2017) undertook a comprehensive review of the biological monitoring data to developed trigger values (TVs) for impact assessment for the most appropriate indicators, maintaining the risk-based approach as used for water and sediment quality and as per ANZG (2018). Therefore, 80th and 20th percentiles and medians of reference and baseline data were used to select the most appropriate TVs. Value judgement was used to select whether the 80th percentile, 20th percentile or median/mean was most appropriate for each specific TV depending on the test site being selected. Generally, the 20th percentile of reference or baseline data would be selected, with the test site data having to decline below the 20th percentile before an impact was concluded. However, if the available reference site had naturally lower diversity or abundance of the attribute being assessed at the test site, and it was considered that a decline at the test site to below the 20th percentile would reflect an extreme impact, then the median or 80th percentile was selected, depending on the relative difference between the test and reference/baseline data. This approach was applied on a case by case basis across all indices and test sites, and as a result the selected TVs for impact assessment vary between 20th percentile, 80th percentile or mean/median, but retain the underpinning precept of ANZG (2018).

2.6.1 Fish and prawn TVs and impact assessment matrix

Biological indicators such as richness, abundance and biomass can vary between reference and test sites and within reference and test sites over time. Therefore, the impact assessment trigger values and assessment methodology must provide an assessment of both changes between reference and test sites and also within test sites over time.

Ideally this is performed by comparing current biological conditions at the test sites against current biological condition at the reference sites and also comparing current biological conditions at the test sites against historical, pre-disturbance or baseline biological conditions at the test site. In reality there are many challenges associated with achieving this including: how well the environmental conditions at the reference site match that of the test site; different hydrological, chemical, physical, habitat and anthropogenic factors will influence similarity of the biological conditions at each area; and therefore how appropriate the reference site is as a benchmark for the test site; and additionally, the quality of historical data that have been collected from the test and reference sites. The predominant factor in data quality and comparability is whether the same standardised sampling methods have been applied over time because data from different methods cannot be reliably compared.

In 2017, BNL engaged Wetland Research Management (WRM 2018) to conduct a review of the biological monitoring data, make recommendations on the most appropriate indicators, trigger values (TVs) and statistical analyses for conducting impact assessment for the AER, and explain how to interpret the statistics correctly. This proposed approach for impact assessment was to be as consistent, where possible, with the risk-based approach currently used for water and sediment quality as per ANZECC/ARMCANZ (2000). But where this was not possible, then the most appropriate alternative approach was to be developed. The aim of the review was to enable BNL to reach accurate conclusions on ecological impacts.

WRM (2018) found that the reference sites and test sites used in the BNL monitoring program are not directly comparable due to the inherent difference in channel size, habitat conditions, water quality (*i.e.* TSS) *etc.* between the main channel test sites and reference sites on smaller tributaries. This inherent difference limits direct comparison between test and reference sites. Also, because the test and reference sites are not independent, it is highly likely that an impact at a test site will also affect fish populations at the reference site due to migration, *etc*. Therefore, it is not strictly valid to conduct impact assessment by comparing current communities at test sites to current communities at reference sites. Additionally, there are no suitable pre-mine data or, for some methods, data from early years post-commencement of mining, from which to develop TVs, due to a change to sampling methodology over time.

To overcome these challenges, the TVs recommended by WRM (2018) are based on the best use of available data from reference and test sites to derive a range of impact assessment TVs which together provide a basis for assessing the current biological conditions at the test sites against both the current biological conditions at the reference sites and the historical biological conditions at both the test and reference sites.

The impact assessment TVs recommended by WRM (2018) are presented in Table 2-12. The adopted TVs were determined to provide the most reliable and appropriate benchmark against which the current biological condition at the test sites could be compared to support a determination of whether impact had occurred. The current biological condition at each test site is represented by the mean of each indicator derived from the C&M monitoring program between November 2021 and May 2022.

Note that prawns are not used as indicator species within Lake Murray; this is due to prawn sampling not being done there.

The impact assessment decision matrix is presented in Table 2-13. It should be noted that where multiple TVs are applied to each indicator, an assessment of performance against all TVs using a weight of evidence approach is undertaken to reach a final assessment of whether or not impact is occurring.

2.6.1.1 Deriving impact assessment TVs for the upper river

In the upper river, impact assessment was conducted by testing differences in total abundance and biomass of prawn species *M handschini* and *M. lorentzi* and overall prawn abundance and biomass using replicated electroseining, and abundance and biomass of *N equinus* and overall fish abundance and biomass using replicated hook and line fishing. WRM (2018) determine that in the upper river, Ok Om was determined to be the most appropriate reference site for test sites Wasiba and Wankipe. Values for reference Ok Om were lower than those for the test sites. The 80th%ile values for Ok Om were therefore considered more appropriate for use as TVs for total species abundance and total biomass, as using 20th%ile or even average values would mean the TV would be too low to be protective of existing fish communities at Wasiba and Wankipe. This is in acknowledgment that a TV derived from the 80th%ile of Ok Om data is likely to be overly-conservative in some years.

For TVs specific to *N. equinus*, the average values for Ok Om were considered more appropriate than the 80th%ile values, as the latter would have produced an overly conservative TV that would over-estimate the risk of impact at the test sites, while TVs based on the 20th%ile would not be sufficiently protective.

Values for prawn abundance and biomass at reference Ok Om were lower than those for Wasiba, but slightly higher than those for Wankipe. The average values for Ok Om were therefore considered more appropriate for use as TVs for all parameters, as the numerous low values in the data meant using 20%ile values as TVs would be too low to be protective of existing populations at Wasiba, in particular. This is in acknowledgment that a TV derived from the average of baseline data is likely to be overly-conservative in some years. (WRM 2018)

2.6.1.2 Deriving impact assessment TVs for the lower river

In the lower river, impact assessment was conducted by testing changes in fish species richness, abundance and biomass derived from quarterly gill netting. In the lower river it was determined that Tomu was the more appropriate reference site for SG4, and Baia the more appropriate reference site for Bebelubi. Therefore, TVs for SG4 and Bebelubi were calculated from data for Tomu and Baia, respectively. To avoid potential confounding effects of ‘fishing down’ over consecutive sampling days, only data from the first day’s catch on each occasion was used.

There also appeared to be a ‘fishing-down’ effect at SG4 and Tomu due to the combination of higher frequency sampling and increased number of replicates since 2002, and population growth in nearby villages (WRM 2017). Available data suggest that since at least 2007, there have been downward trends in species abundance and biomass at both Tomu and SG4. Because of these trends and the inter-dependence of reference and test site, it was not considered valid to derive TVs for SG4 using recent data from reference Tomu. Nor are there pre-mine data for either site to use as baseline for derivation of TVs. Therefore, the earliest periods post-commencement of mining shown to have a high and stable species composition at both Tomu and SG4 were taken to be ‘baseline’ for derivation of TVs for univariate parameters. The idea being that although this period may not necessarily represent pre-mine baseline, it provides a benchmark against which future change may be assessed and is sufficiently early in mine life to likely not reflect mine impacts. This stable ‘baseline’ period was 1999 – 2004. There are few data prior to this period for Tomu, though there are 11 records for SG4 for the period 1989 - 1999.

These early records possibly better represent pre-mine conditions at SG4, than do later records for reference Tomu. As such, they were used to develop an alternate set of TVs for SG4.

The same approach used for developing TVs using reference data from Tomu, was used to develop TVs for Bebelubi using reference data from Baia. The period of record is relatively short for both Baia and Bebelubi, though there were no statistically significant trends with time at either site. Data for the earliest years 2006 - 2008, were therefore used as benchmark or ‘baseline’ to develop TVs from reference Baia, again acknowledging current condition may not reflect pre-mine condition at either site. In order that TVs allow for a degree of variability, they were developed from three years of ‘baseline’ data (*i.e*. 2006 to 2008), rather than one or two years.

Values for species richness and abundance at reference Tomu were lower than those for test site SG4, while values for biomass were higher. The average values for baseline (1999 - 2004) data for species richness and abundance at Tomu were therefore considered more appropriate for use as TVs, as the 20th%ile values would be too low to be protective of existing populations at SG4. For biomass however, the 20th%ile value for Tomu was considered more appropriate as the TV, as the average value would have produced an overly conservative TV and therefore an over-estimation of impact at test site SG4.

For alternative TVs for SG4, derived from baseline data for that site (1989 - 1998), the average values for species richness, abundance and biomass were considered more appropriate, as the numerous low values in the baseline data meant using 20th%ile values as TVs would be too low to be protective of existing populations at SG4. This is in acknowledgment that a TV derived from the average of baseline data is likely to be overly-conservative in some years. TV derived from the average of the most recent 24 months / 8 sampling events data from Tomu was also used.

For reference Baia, values for all parameters were lower than for test Bebelubi. The 80th%ile values for baseline (2006 - 2008) data for species richness, abundance and biomass at Baia were therefore considered more appropriate for use as TVs than the 20th%ile or even the average values, as the numerous low values in the Baia reference data meant using 20th%ile or average values as TVs would be too low to be protective of existing populations at Bebelubi. The 80th%ile was also less conservative than 90th%ile or 95th%ile values which would have produced overly conservative TVs and therefore an over-estimation of impact at Bebelubi. TV derived from the average of the most recent 24 months / 8 sampling events data from Baia was also used. (WRM 2018)

It should be noted that C&M TVs have been derived from most recent 24-month data for each region, however without a continuous 24 month dataset due C&M disruptions, for this report the 24-month period is a discontinuous data set derived by joining the 7 months data between Nov 2021 and May 2022 with data collected during the last 17 months of operations prior to the site entering C&M in April 2020. The use of operation phase data for deriving TVs is considered appropriate as regional reference sites should not be influenced by mine operations, and therefore should only reflect natural change.

2.6.1.3 Deriving impact assessment TVs for Lake Murray

In Lake Murray, impact assessment was conducted by testing changes in fish species richness, abundance and biomass derived from replicated gill netting on a biannual sampling campaign. In Lake Murray, it is also not possible to validly conduct impact assessment by comparing current communities at test sites to current communities at the reference site. This is because the reference and test sites are not independent, being one waterbody, and it is highly likely that an impact at a test site will also affect fish populations at the reference site. To avoid potential confounding effects of ‘fishing down’ over consecutive sampling days, only data from the first day’s catch on each occasion were used.

Data prior to 2001 (*i.e*. 1989 - 2000) are available for test site Miwa, but there are few data for this period for test site Pangoa or reference Maka. These earlier data show relatively high inter-annual variability but are more likely to represent pre-mine communities at Miwa. Therefore, additional TVs were also calculated for species richness, abundance and biomass at Miwa, based on 1989 - 2000 data.

Values for species richness and abundance at reference Maka were higher than those for test Miwa and Pangoa, while values for species richness were similar. The 20th%ile values for the baseline (2001 - 2006) data for Maka were therefore considered more appropriate for use as TVs for all parameters, as the average values would have produced an overly conservative TV and therefore an over-estimation of impact at test sites.

For alternative TVs for Miwa, derived from baseline data for that site (1989 - 2000), the average values for species richness, abundance and biomass were considered more appropriate, as the numerous low values in this baseline data set meant using 20th%ile values as TVs would be too low to be protective of existing populations at Miwa. This is in acknowledgment that a TV derived from the average of baseline data is likely to be overly-conservative in some years. (WRM 2017)

Table 2-12 Impact assessment trigger values

Region	Test Site	Species	Indicator	Trigger Value Source
Upper River	Wasiba & Wankipe	Fish	Total fish abundance Total fish biomass	**Ok Om Reference** - 80th%ile of the most recent 24-months / 8 sampling events from upper river reference site Ok Om.
			N.equinus abundance *N.equinus* biomass	**Ok Om Reference** - Average of the most recent 24-months / 8 sampling events from upper river reference site Ok Om.
		Prawns	Total prawn abundance Total prawn biomass *M. handschini* abundance *M. handschini* biomass *M. lorentzi* abundance *M. lorentzi* biomass	**Ok Om Reference** - Average of the most recent 24-months / 8 sampling events from upper river reference site Ok Om.
Lower River	Bebelubi	Fish	Total fish richness Total fish abundance Total fish biomass	**Option A1 Baia ‘ Baseline’** - 80th%ile 2006-2008 **Option A2 Baia Reference** - Average previous 24 months / 8 sampling events
	SG4	Fish	Total fish biomass	**Option B1 Tomu ‘Baseline’** - 20th%ile 1999-2004 **Option B2 SG4 Baseline** - 20th%ile 1989-1998 **Option B3 Tomu Reference** **-** Average previous 24 months / 8 sampling events
			Total fish richness Total fish abundance	**Option B1 Tomu ‘Baseline’** - Average 1999-2004 **Option B2 SG4 Baseline** - Average 1989-1998 **Option B3 Tomu Reference** **-** Average previous 24 months / 8 sampling events

Region	Test Site	Species	Indicator	Trigger Value Source
Lake Murray	Miwa	Fish	Total fish richness Total fish abundance Total fish biomass	**Option C1 Maka 'Baseline'** - 20th%ile 2001-2006 **Option C2 Miwa 'Baseline'** - Mean 1989-2000 **Maka Reference** - Average previous 24 months / 8 sampling events
	Pangoa	Fish	Total fish richness Total fish abundance Total fish biomass	**Option C1 Maka 'Baseline'** - 20th%ile 2001-2006 **Maka Reference** Average previous 24 months / 8 sampling events

Table 2-13 Impact assessment matrix – Biological indicators for fish and prawn

Assessment Result	Impact Assessment	Action
Test site mean significantly > TV	No Impact	Investigate cause of impact to determine if the impact is caused by mine related or non-mine related factors.
Test site mean not significantly different from TV.		
Test site mean significantly < TV	Impact	

2.7 Testing for Statistical Significance

Tests of statistical significance are performed as part of the risk and impact assessments to provide a statistical basis for drawing conclusions. Using the statistical tests allows the assessment result to be described as 'significantly greater than', 'significantly less than' or 'not significantly different from' the relevant trigger value, and ultimately to provide confidence that the result is valid and not being influenced by the inherent characteristics of the dataset under consideration.

The test used for determining significance at the risk assessment stage for data collected in the care and maintenance period is a parametric t-test with a probability threshold of $p = 0.05$. A parametric test, such as the t-test was considered a more robust statistical approach than non-parametric 1-Sample Wilcoxon rank testing, given the lower number (< 24) of data points for test sites in the care and maintenance period, and rank tests do not perform well on small data sets. Therefore, due to the smaller number of sampling events conducted during the care and maintenance period compared to the routine AER period, the parametric t-test was used in risk and impact assessment.

The Spearman Rank Test is used to assess trends over time, with a probability threshold of $p = 0.05$. This test uses ranked data, and so is independent of the absolute values, but is ideal for use on data monotonically related, as it is not dependant on data having a linear relationship (as are linear regression or Pearson Product Moment Correlation).

Two statistical tests were performed for impact assessment: Spearman rank correlation (rho) and parametric t-test. Spearman rank correlation (rho) was used to statistically test for significant long-term trends across sampling dates. Where Spearman correlation showed a significant long-term trend, Regression Analysis was used to test if this trend was linear. One sample t-test was performed to determine if there was a statistically significant difference between the test site average and relevant trigger value. Significance level for both tests is $p = 0.05$.

A parametric test, such as the t-test was considered a more robust statistical approach than non-parametric rank testing, given quarterly sampling will only produce a low number (< 4) of data points for test sites in any given year, and rank tests do not perform well on small data sets. A parametric test is also more justified for classical "impact assessment" as it is testing actual data means and variance against a threshold value, rather than using ranked data.

All tests are performed with the Minitab software package. The procedure for determining significance involves integrating the significance test into the risk and impact assessment matrices. The procedures for testing significance in the risk and impact assessments for water quality, sediment quality, tissue metals and fish and prawn populations are shown as expanded assessment matrices in Appendices.

3 C&M ENVIRONMENTAL MONITORING PROGRAM

BNL undertake the operational environmental monitoring, auditing and reporting program, which is outline in the BNL Environmental Monitoring, Auditing and Reporting (MARP) Plan. The program culminated each year in the production of the Porgera Annual Environment Report (AER), which provided a thorough assessment of the site's environmental performance, compliance and an environmental risk and impact assessment of the receiving environment.

On the 24th April 2020, the mine was placed into care and maintenance following the Government of Papua New Guinea's decision not to grant an extension of the Porgera Special Mining Lease.

Prior to being placed in care and maintenance, BNL undertook an extensive environmental monitoring program focussed on the operational activities of the mine and also on the condition of the receiving environment, spanning from the mine site to approximately 600 km downstream. The last operation AER prior to C&M was reported to the State as the 2019 AER (BNL 2019).

Since being placed into care and maintenance, the scale of the environmental monitoring program has been significantly reduced due to a reduction in workforce numbers and site capacity to support field work in remote areas.

Environmental monitoring during care and maintenance has been conducted in accordance with the Porgera Environmental Security Health Safety Plan - Care and Maintenance, which was reviewed and approved by the PNG Government.

As the site shifted its focus back towards re-starting normal operations, the scope of the monitoring program was increased voluntarily by BNL to begin to align with operational phase monitoring program. Specifically, the full suite of environmental indicator monitoring was re-started in May 2020 at all test and reference sites within upper river, lower river and Lake Murray to support risk and impact assessment, beyond that require by the Porgera Environmental Security Health Safety Plan - Care and Maintenance.

Monitoring at all operational phase reference and test sites was not conducted throughout the entire C&M period due to logistical and safety challenges. As a result, data are not available for all reference and test sites for the 18-month period from May 2020 to November 2021, and therefore the assessment approaches have been modified, as required under the restricted sampling program.

Historically, the Porgera AER risk and impact assessments have used data from the previous 12-months to represent environmental conditions at the test sites, and data from the previous 24-months to represent environmental conditions at the reference sites. The break in monitoring at most test and reference sites during the C&M phase means that only 6-months data are available for the test and reference sites during the C&M period, from November 2021 to May 2022. The risk and impact assessment methodologies have been modified to account for this change by; using 6-months data from November 2021 to May 2022, to represent environmental conditions at the test sites, and using the most recent 24-months data to represent environmental conditions at the reference sites. The 24-month data set for the reference sites is a discontinuous set from October 2018 to March 2020 (18-months) and then from November 2021 to May 2022 (6-months).

To achieve the required number of samples to support derivation of the TVs, it has therefore been necessary to use data collected from reference sites prior to the C&M period, while the mine was still in operation. The nature of the reference sites, being free of mine-related inputs, means that it is considered appropriate to use pre-C&M data from the reference sites to support TV derivation. A summary of all monitoring conducted at each site since to commencement of operations and throughout care and maintenance is shown in Table 3-6.

3.1 Environmental Aspects

The operation has a range of associated environmental aspects, which are defined by ISO 14001 (2015) as activities which have the ability to interact with the environment. Significant environmental aspects of the operation are riverine tailings disposal, waste rock disposal, water extraction and discharge, hazardous substances transport, storage and use, and waste management.

Each aspect is monitored and quantified to determine the risk it poses to the environmental values of the receiving environment, to determine whether the management techniques applied are achieving the desired level of control and to determine whether actions taken to improve performance are effective. Table 3-1 provides an outline of the operation’s environmental aspects and the associated physical and chemical parameters that are monitored to quantify each aspect.

Table 3-1 C&M Phase Environmental aspects and monitoring parameters

Environmental Aspect	Physical Parameters	Chemical & Toxicant Parameters	Biological Parameters
Waste rock disposal to water via the erodible waste rock dumps	Volume discharged	Metal concentrations	NA – applied only in receiving environment
Other discharges to water: - Mine contact runoff - Treated sewage effluent	Volume discharged, TSS concentration	pH, conductivity, metal concentrations Total hydrocarbons Free chlorine BOD_5 Total N and P	Faecal coliforms
Waste generation	Volume generated % to landfill %incinerated % recycled	Waste type	NA

Table 3-2 Operational Phase Environmental aspects and monitoring parameters

Environmental Aspect	Physical Parameters	Chemical & Toxicant Parameters	Biological Parameters
Riverine tailings disposal	Volume discharged, TSS concentration	pH, conductivity, metal concentrations, WAD CN	NA – applied only in receiving environment
Waste rock disposal to water	Volume discharged	Metal concentrations	NA – applied only in receiving environment

Environmental Aspect	Physical Parameters	Chemical & Toxicant Parameters	Biological Parameters
Other discharges to water: - Mine contact runoff - Treated sewage effluent	Volume discharged, TSS concentration	pH, conductivity, metal concentrations Total hydrocarbons Free chlorine BOD_5 Total N and P	Faecal coliforms
Waste rock disposal to land	Area disturbed Volume of waste rock disposed	Metal concentrations	NA – applied only in receiving environment
Water extraction	Volume extracted	NA	NA – applied only in receiving environment
Discharge to air	Emission rate, particulate concentration	Metal concentrations Greenhouse gas volume	NA – applied only in receiving environment
Land disturbance	Area disturbed % rehabilitated	NA	NA
Resource consumption	Volume consumed Consumption efficiency	NA	NA
Waste generation	Volume generated % to landfill %incinerated % recycled	Waste type	NA

3.2 Baseline Environmental Monitoring

Baseline data referenced in this report have been sourced from NSR (1990), NSR Environmental Consultants PTY LTD, *Environmental Baseline Porgera Gold Mine Volume 1 and Volume 2*, April 1990.

3.3 Environmental Conditions

To determine the scope and magnitude of the interactions between the mine operation’s environmental aspects and the receiving environment, it is necessary to identify suitable parameters to act as indicators of the interaction, to identify locations within the receiving environment at which the interaction is likely to take place (test sites) and to identify locations within the environment where no interaction will take place (reference sites). This will ultimately allow a comparison of the same indicators between the test site and reference site and determination of the spatial extent and magnitude of mine-related changes within the receiving environment.

3.3.1 Indicator parameters

The parameters monitored within the receiving environment have been selected based on their suitability for:

- Supporting assessment of compliance against legal and other requirements.
- Assessing the potential impact within the receiving environment as a result of the operation's environmental aspects.
- Assessing the environmental performance of the operation, linked to environmental Key Performance Indicators (KPIs).

Table 3-3 outlines the physical, chemical and biological parameters that are monitored at both the test sites and reference sites to support compliance, impact and performance assessments.

Table 3-3 Receiving environment monitoring indicator parameters

Environmental Aspect	Physical	Chemical & Toxicant	Biological
Riverine tailings disposal (Operational phase only)	River profiling: cross-sections. Water quality: TSS concentration	Water quality: pH, conductivity, metal concentration, WAD-CN. Benthic sediment quality: Metal concentration. Fish and prawn tissue: Metal concentration.	Species richness, abundance and biomass of fish and prawns. Macroinvertebrate assemblages.
Waste rock disposal to water	River profiling: cross-sections. Water quality: TSS concentration, Sediment grain size	Water quality: pH, conductivity, metal concentration. Benthic sediment quality: Metal concentration. Fish and prawn tissue: Metal concentration.	Species richness, abundance and biomass of fish and prawns. Macroinvertebrate assemblages.
Waste rock disposal to land	Area of disturbance. Volume of waste rock disposed to land. Volume solid waste disposed to land.	Geotechnical characteristics: Competency. Geochemical characteristics: Metal concentrations, acid producing potential.	Terrestrial flora and fauna communities.
Water extraction	Flow downstream of water extraction points.	NA	Macroinvertebrate assemblages.
Discharge to air	Air Quality: particulate concentration.	Air Quality: Metal concentration	NA
Land disturbance	Area of disturbance	NA	Terrestrial flora and fauna communities.
Resource consumption	Consumption volume Consumption efficiency	NA	NA

Environmental Aspect	Physical	Chemical & Toxicant	Biological
Waste generation	Area of disturbance.	NA	Terrestrial flora and fauna communities.

NA - Not Applicable

3.3.2 Monitoring locations

Environment monitoring locations are categorised as test sites and reference sites. Test sites are those sites downstream of the mine, receiving discharge from the mine, whereas reference sites are in a similar geographical setting, generally adjacent to the test sites, but not receiving discharge from the mine. The test and reference sites at which receiving environment monitoring is conducted are listed in Table 3-4. The table also lists which reference sites are used as analogues for each test site. The locations of the monitoring sites are shown in Figure 3-1 and Figure 3-2 shows monitoring locations within Lake Murray. Table 3-5 gives an assessment of reference site suitability.

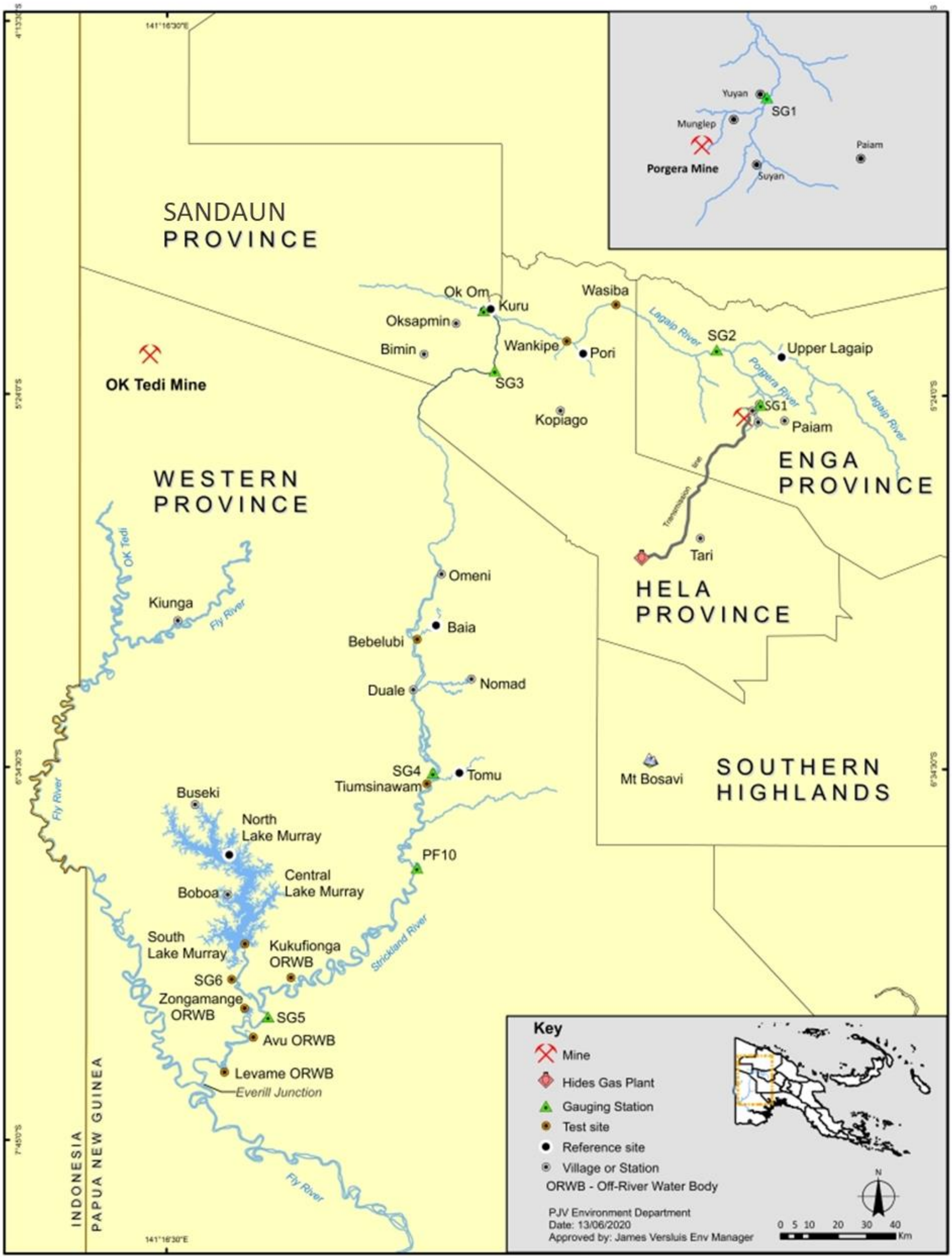


Figure 3-1 Receiving environment monitoring sites

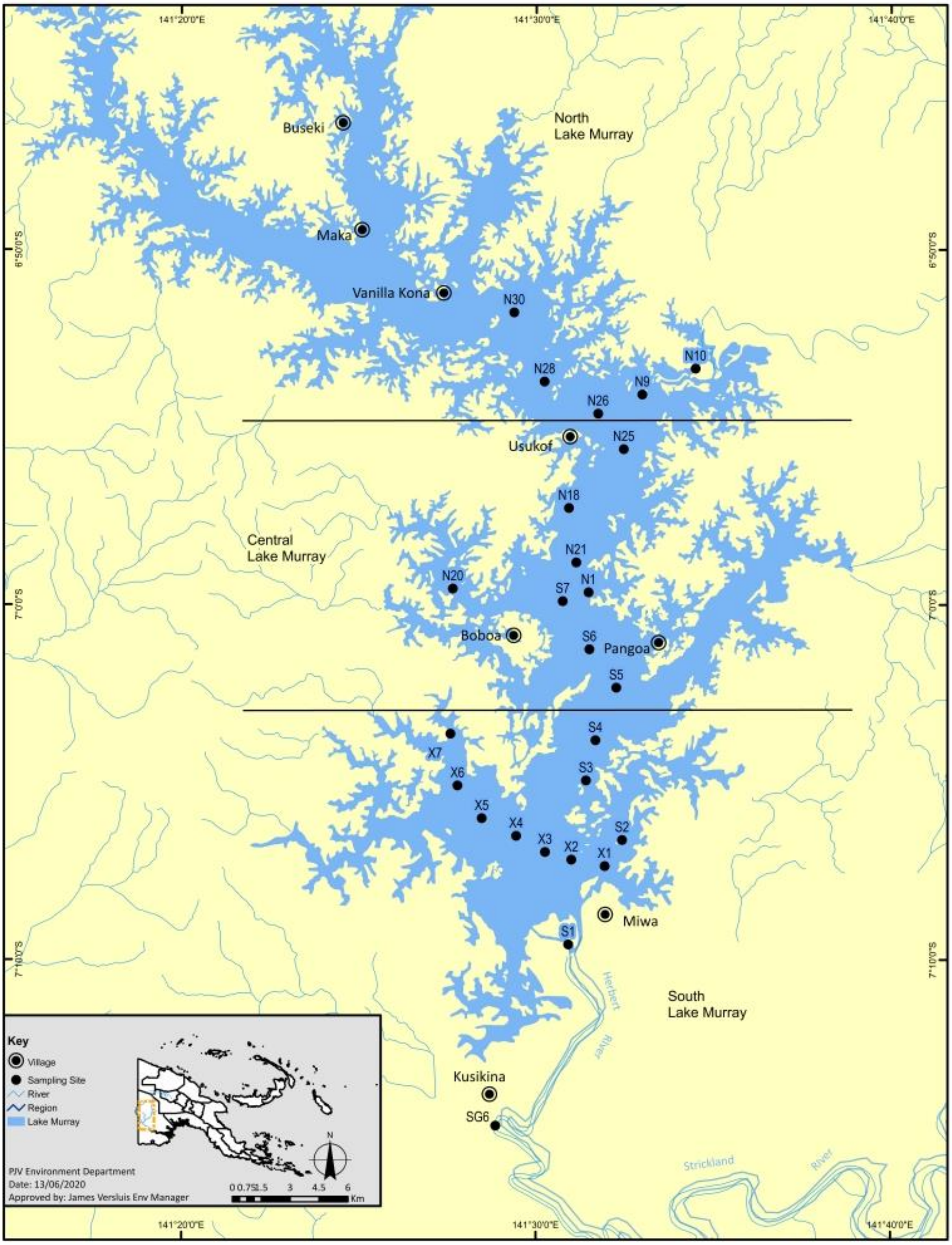


Figure 3-2 Lake Murray monitoring locations

Table 3-4 Test sites, related reference sites and indicator parameters

Receiving Environment Test Site		Reference Sites and Parameters				
		Profile	Water and/or Sediment	Tissue Metal	Fish & Prawn Biology	Macro-invertebrate Biology
Upper River	SG1	NAR	Upper Lagaip Pori Kuru Ok Om	NA[1]	NA[1]	NA[1]
	SG2	NAR	Upper Lagaip Pori Kuru Ok Om	NA[1]	NA[1]	Upper Lagaip Ok Om
	Wasiba	NA[1]	Upper Lagaip Pori Kuru Ok Om	Ok Om	Ok Om	Upper Lagaip Ok Om
	Wankipe	NA[1]	Upper Lagaip Pori Kuru Ok Om	Ok Om	Ok Om	Upper Lagaip Ok Om
	SG3	NA[1]	Upper Lagaip Pori Kuru Ok Om	NA[1]	NA[1]	Upper Lagaip Ok Om
Lower Strickland River	Bebelubi	NA[1]	Baia	Baia	Baia	NA[1]
	SG4	NA[1]	Tomu	Tomu	Tomu	NA[1]
	PF10	NAR	NA[1]	NA[1]	NA[1]	NA[1]
	SG5 Upstream of Everill Junction	NA[1]	Baia Tomu	Baia Tomu	NA[1]	NA[1]
Lake Murray	South Lake Murray Central Lake Murray SG6	NA[1]	North Lake Murray	North Lake Murray	North Lake Murray	NA[1]
Off-River Water Bodies	Kukufionga Zongamange Avu Levame	NA[1]	Baia Tomu	NA[1]	NA[1]	NA[1]

NAR – No appropriate reference site

NA[1] – Indicator not applied at monitoring site

Table 3-5 Assessment of reference site suitability

Reference Site	Suitability Assessment for Indicator Parameters				Reference site characteristics affecting suitability
	Physical[1]	Chemicals and Toxicants[2]	Fish & Prawn Biology	Macro-invertebrate Biology	
Upper Lagaip	Good	Poor	Poor	Good	Lower natural mineralisation than test site baseline. Naturally depauperate fish and prawn populations. Fish and prawns potentially exposed to test site conditions if migrating between test and reference sites.
Pori	Poor	Poor	Poor	NA	Small tributary compared to main river reference sites. Lower natural mineralisation than test site baseline. Lower flows. Lower suspended sediment. Different habitat types. Reference site biology potentially indirectly impacted (i.e. fish and prawn migration). Fish and prawns potentially exposed to test site conditions if migrating between test and reference sites.
Kuru	Fair	Poor	Poor	NA	Small tributary compared to main river reference sites. Lower natural mineralisation than test site baseline. Lower flows. Lower suspended sediment. Different habitat types. Reference site biology potentially indirectly impacted (i.e. fish and prawn migration). Fish and prawns potentially exposed to test site conditions if migrating between test and reference sites.
Ok Om	Good	Poor	Fair	Fair	Lower natural mineralisation than test site baseline. Fish and prawns potentially exposed to elevated test site conditions if migrating between test and ref sites.

Reference Site	**Suitability Assessment for Indicator Parameters**				**Reference site characteristics affecting suitability**
	Physical[1]	**Chemicals and Toxicants**[2]	**Fish & Prawn Biology**	**Macro-invertebrate Biology**	
Baia	Fair	Fair	Poor	NA	Medium size tributary compared to main river reference sites. Lower natural mineralisation than test site baseline. Different habitat types. Reference site biology potentially indirectly impacted (i.e. fish and prawn migration). Fish and prawns potentially exposed to test site conditions if migrating between test and ref sites. Ref sites will naturally support lower fish species richness and standing stock biomass than the main river.
Tomu	Fair	Fair	Poor	NA	Medium size tributary compared to main river reference sites. Lower natural mineralisation than test site baseline. Different habitat types. Reference site biology potentially indirectly impacted (i.e. fish and prawn migration). Fish and prawns potentially exposed to test site conditions if migrating between test and ref sites. Ref sites will naturally support lower fish species richness and standing stock biomass than the main river.
North Lake Murray	Good	Fair	Fair	NA	North Lake Murray is physically connected to the central and southern lake and can be theoretically potentially influenced by mine aspects.

1 – For water

2 – For water, benthic sediment and tissue metals

3.3.3 Schedule and execution

A summary of compliance with the environmental monitoring requirements of the Porgera Environmental Security Health Safety Plan - Care and Maintenance Table 3-7. The operation achieved 99% compliance with the environmental monitoring requirements of the Porgera Environmental Security Health Safety Plan - Care and Maintenance, some monitoring was not completed to plan due to security concerns.

Table 3-6 Summary of Monitoring at each test and reference sites conducted during operational and care and maintenance phases

Region	Type	Name	Phase	Parameters & Monitoring Periods				
				Water & Sediment	Tissue Metal	Fish & Prawn Biology	Macro-invertebrate Biology	Profile
Upper River	Test	SG1	Operations	May 1998 – June 2015	Not monitored	Not monitored	Not monitored	June 1983 – June 2015
			Care & Maintenance	Not monitored	Not monitored	Not monitored	Not monitored	Not monitored
		SG2	Operations	February 1998 – February 2020	July 2014 – September 2014	July 2014 – September 2014	2014-2016 & 2019	July 1990 – June 2017
			Care & Maintenance	November 2021	Not monitored	Not monitored	Not monitored	Not monitored
		Wasiba	Operations	January 2014 – March 2020	January 1998 – January 2020	January 1998 – January 2020	2014-2016 & 2019	Not monitored
			Care & Maintenance	November 2021 – May 2022	November 2021 & May 2022	November 2021 & May 2022	February 2022	Not monitored
		Wankipe	Operations	November 1993 – February 2020	October 1991 – January 2020	October 1991 – January 2020	2014-2016 & 2019	Not monitored
			Care & Maintenance	November 2021 – May 2022	November 2021 & May 2022	November 2021 & May 2022	February 2022	Not monitored
		SG3	Operations	January 1990 – April 2020	Not monitored	Not monitored	2014-2016 & 2019	Not monitored
			Care & Maintenance	May 2020 – April 2022	Not monitored	Not monitored	February 2022	Not monitored
	Ref	Upper Lagaip	Operations	May 1998 – February 2020	June 1998 – October 2014	June 1998 – October 2014	2014 – 2016 and 2019	Not monitored
			Care & Maintenance	January – February 2022	Not monitored	Not monitored	February 2022	Not monitored

Region	Type	Name	Phase	Parameters & Monitoring Periods				
				Water & Sediment	Tissue Metal	Fish & Prawn Biology	Macro-invertebrate Biology	Profile
		Pori	Operations	July 1994 – March 2020	1988: November 2003 – September 2018	1988: November 2003 – September 2018	2014 – 2016	Not monitored
			Care & Maintenance	December 2021 – May 2022	Not monitored	Not monitored	Not monitored	Not monitored
		Kuru	Operations	May 2005 – March 2020	March 2000 – September 2018	March 2000 – September 2018	2014 - 2016	Not monitored
			Care & Maintenance	December 2021 – May 2022	Not monitored	Not monitored	Not monitored	Not monitored
		Ok Om	Operations	October 1993 – March 2020	November 1988 – January 2020	November 1988 – January 2020	2014 – 2016 and 2019	Not monitored
			Care & Maintenance	August 2020 – May 2022	November 2021 & March 2022	November 2021 & March 2022	February 2022	Not monitored
Lower Strickland River	Test	Bebelubi	Operations	October 2006 – February 2020	April 2006 – December 2019	April 2006 – December 2019	Not monitored	Not monitored
			Care & Maintenance	November 2021 – March 2022	December 2021 & March 2022	December 2021 & March 2022	Not monitored	Not monitored
		SG4/Tiumsinawam	Operations	June 1994 – February 2020	June 1989 – February 2020	June 1989 – February 2020	Not monitored	January 2000 – May 2019
			Care & Maintenance	November 2021 – March 2022	December 2021 & March 2022	December 2021 & March 2022	Not monitored	Not monitored
		PF10	Operations	Not monitored	Not monitored	Not monitored	Not monitored	August 2000 – May 2019
			Care & Maintenance	Not monitored	Not monitored	Not monitored	Not monitored	Not monitored

Region	Type	Name	Phase	Parameters & Monitoring Periods				
				Water & Sediment	Tissue Metal	Fish & Prawn Biology	Macro-invertebrate Biology	Profile
		SG5	Operations	August 1997 – December 2019	June 2006 – November 2014	June 2006 – November 2014	Not monitored	May 2011 – May 2019
			Care & Maintenance	January 2022	Not monitored	Not monitored	Not monitored	Not monitored
		Upstream of Everill Junction	Operations	October 2017 – November 2019	May 2010 – November 2012	May 2010 – November 2012	Not monitored	Not monitored
			Care & Maintenance	January 2022	Not monitored	Not monitored	Not monitored	Not monitored
	Ref	Baia	Operations	October 2006 – February 2020	April 2006 – December 2019	April 2006 – December 2019	Not monitored	Not monitored
			Care & Maintenance	November 2021 – March 2022	December 2021 & March 2022	December 2021 & March 2022	Not monitored	Not monitored
		Tomu	Operations	May 2005 – February 2020	June 1989 – February 2020	June 1989 – February 2020	Not monitored	Not monitored
			Care & Maintenance	November 2021 – March 2022	December 2021 & March 2022	December 2021 & March 2022	Not monitored	Not monitored
Lake Murray	Test	South Lake Murray	Operations	November 1996 – November 2019	June 1989 – November 2019	June 1989 – November 2019	Not monitored	Not monitored
			Care & Maintenance	January 2022	January 2022	January 2022	Not monitored	Not monitored
		Central Lake Murray	Operations	December 1995 – November 2019	November 1988 – November 2019	November 1988 – November 2019	Not monitored	Not monitored
			Care & Maintenance	January 2022	January 2022	January 2022	Not monitored	Not monitored
		SG6	Operations	May 1997 – November 2019	Not monitored	Not monitored	Not monitored	Not monitored

Region	Type	Name	Phase	Parameters & Monitoring Periods				
				Water & Sediment	Tissue Metal	Fish & Prawn Biology	Macro-invertebrate Biology	Profile
			Care & Maintenance	January 2022	Not monitored	Not monitored	Not monitored	Not monitored
	Ref	North Lake Murray	Operations	December 1995 – November 2019	August 1993 – November 2019	August 1993 – November 2019	Not monitored	Not monitored
			Care & Maintenance	January 2022	January 2022	January 2022	Not monitored	Not monitored
Off-River Water Bodies	Test	Kukufionga	Operations	May 2001 – November 2019	July 2005 – November 2014	July 2005 – November 2014	Not monitored	Not monitored
			Care & Maintenance	January 2022	Not monitored	Not monitored	Not monitored	Not monitored
		Zongamange	Operations	May 2009 – November 2019	November 1990 – July 2013	November 1990 – July 2013	Not monitored	Not monitored
			Care & Maintenance	January 2022	Not monitored	Not monitored	Not monitored	Not monitored
		Avu	Operations	May 2009 – November 2019	November 2012	November 2012	Not monitored	Not monitored
			Care & Maintenance	January 2022	Not monitored	Not monitored	Not monitored	Not monitored
		Levame	Operations	August 2015 – November 2019	December 2007 – November 2012	December 2007 – November 2012	Not monitored	Not monitored
			Care & Maintenance	January 2022	Not monitored	Not monitored	Not monitored	Not monitored

Table 3-7 Compliance to the Care and Maintenance monitoring plan in 2022

Discipline	Compliance to Plan (%)
Biology	99
Hydrology	99
Chemistry	99

3.3.4 QA & QC

BNL incorporates thorough quality assurance and quality control (QA & QC) into the monitoring and reporting program to ensure the data being reported are accurate and representative.

The QA & QC program consists of operator training and competency assessment, equipment calibration, method validation, field blanks (for airborne contamination of water samples), field duplicates, certified reference material, proficiency testing and inter-laboratory analysis. Analysis of metals in water, benthic sediment, and prawn and fish tissue were performed by National Association of Testing Authorities (NATA)-certified National Measurement Institute (NMI) laboratory in Sydney, Australia.

The results of the QA & QC program show that sampling and analytical techniques are providing representative and valid results for all water, sediment, tissue metal and biological monitoring results. The performance of QA & QC samples have improved over recent years due to a number of continual improvement initiatives that have been applied to the monitoring program including:

- Updating standard operating procedures and application of staff training and competency assessment;
- Change from latex to nitrile gloves;
- Change from picric acid to cyanoprobe method for WAD CN analysis;
- Consistent sample tracking and timely data review processes; and

Some of the results from proficiency testing (PTA) samples fell outside the acceptable range, BNL will continue to investigate these deviations and apply corrective action, including the development of a SOP for performing PTA analysis and ensuring the results are double-checked prior to submission.

Overall, the data provided by the monitoring and reporting program, and subsequently presented in this report, are deemed representative and valid.

Opportunities to improve the QA & QC program are:

- Continue training and competency system development and implementation.
- Repeat the two-yearly CSIRO monitoring program and laboratory audit in 2023.

A full review of QA & QC performance is provided in Appendix A.

4 C&M ENVIRONMENTAL ASPECTS

This section provides a summary of key operational parameters and environmental aspects during the care and maintenance phase and throughout the history of the operation. A summary of results is presented in Table 4-1.

Table 4-1 Mine production and environmental aspects summary up until May 2022 and LOM totals

Operational and Environmental Aspects	May 2020 – May 2022	Life of Mine Total	Comments
Ore processed (Mt)	0	143.0	No production during C&M
Gold production (oz)	0	21,404,134	No production during C&M
Competent waste rock produced (Mt)	0	442.6	No production during C&M
Incompetent waste rock produced – Anawe (Mt)	1.09	243.0	By-product of open pit drainage management.
Incompetent waste rock produced – Anjolek (Mt)	0	255.0	By-product of open pit drainage management.
Tailings discharged (Mt)	0	138.1	No production during C&M
Sewage discharge (m^3)	82,835	NA	Significantly reduced during C&M
Mine contact rainfall runoff (Mm^3)	34.93	NA	Consistent with previous years.
Area land disturbed (ha)	0	2,393	61% of total leased area is disturbed. No change during C&M
Area of disturbed land under rehab (ha)	0	240	10% of total disturbed land. No change during C&M

NA – Not Applicable

4.1 Water Use

Figure 4-1 shows water consumption intensity between 2009 and 2022. There was no ore processing or gold production during C&M, and therefore no water use efficiency statistics.

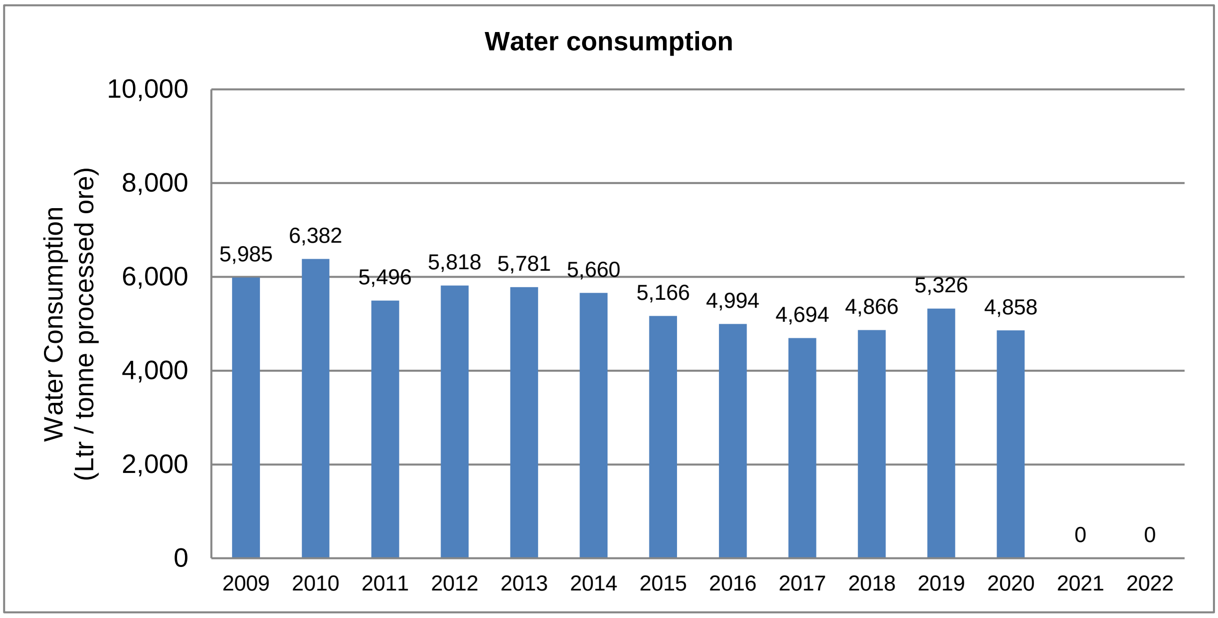


Figure 4-1 Water use efficiency 2009 - 2022

4.2 Land Disturbance

Porgera mine holds ten leases with a total area of 3,933 ha as shown in Table 4-2. The Special Mining Lease (SML) includes the mines, process plant and majority of project infrastructure. The other Leases for Mining Purposes (LMP) are areas associated with the mining operation such as waste rock dumps, Suyan accommodation camp, limestone quarry and water supply. The company also maintains Exploration Leases (EL), which surround the SML and some key LMPs, for on-going exploration. Mining Easements (ME) are held for utilities such as power transmission lines and water supply pipelines. The EL and ME land areas are not included in this report.

The annual disturbance survey was not conducted in 2022, Table 4-2 presents data for the disturbed areas and leases in 2019, however since there were no mining or rehabilitation activities, the 2019 figures remain current.

Table 4-2 Areas of cumulative land disturbance and reclamation to May 2022

Lease	Total Lease Area (ha)	Total Disturbed Area (ha)	Undisturbed (ha)	Under Progressive Reclamation (ha)
SML	2107	1382	725.2	240
Kogai LMP	424	197	227.3	0
Kaiya LMP	602	345	256.8	0
Anawe North LMP 72	219	122	98.1	0
Anawe South LMP 77	204	133	71.6	0
Anawe LMP3	81	81	0.0	0
Suyan LMP	69	45	24.8	0

Lease	**Total Lease Area (ha)**	**Total Disturbed Area (ha)**	**Undisturbed (ha)**	**Under Progressive Reclamation (ha)**
Pangalita LMP	135	67	67.7	0
Waile LMP	85	16	69.3	0
Aipulungu Weir LMP	5.8	5.8	0.0	0
TOTAL	**3,933**	**2,393**	**1,541**	**240** **(10.0% of disturbed)**

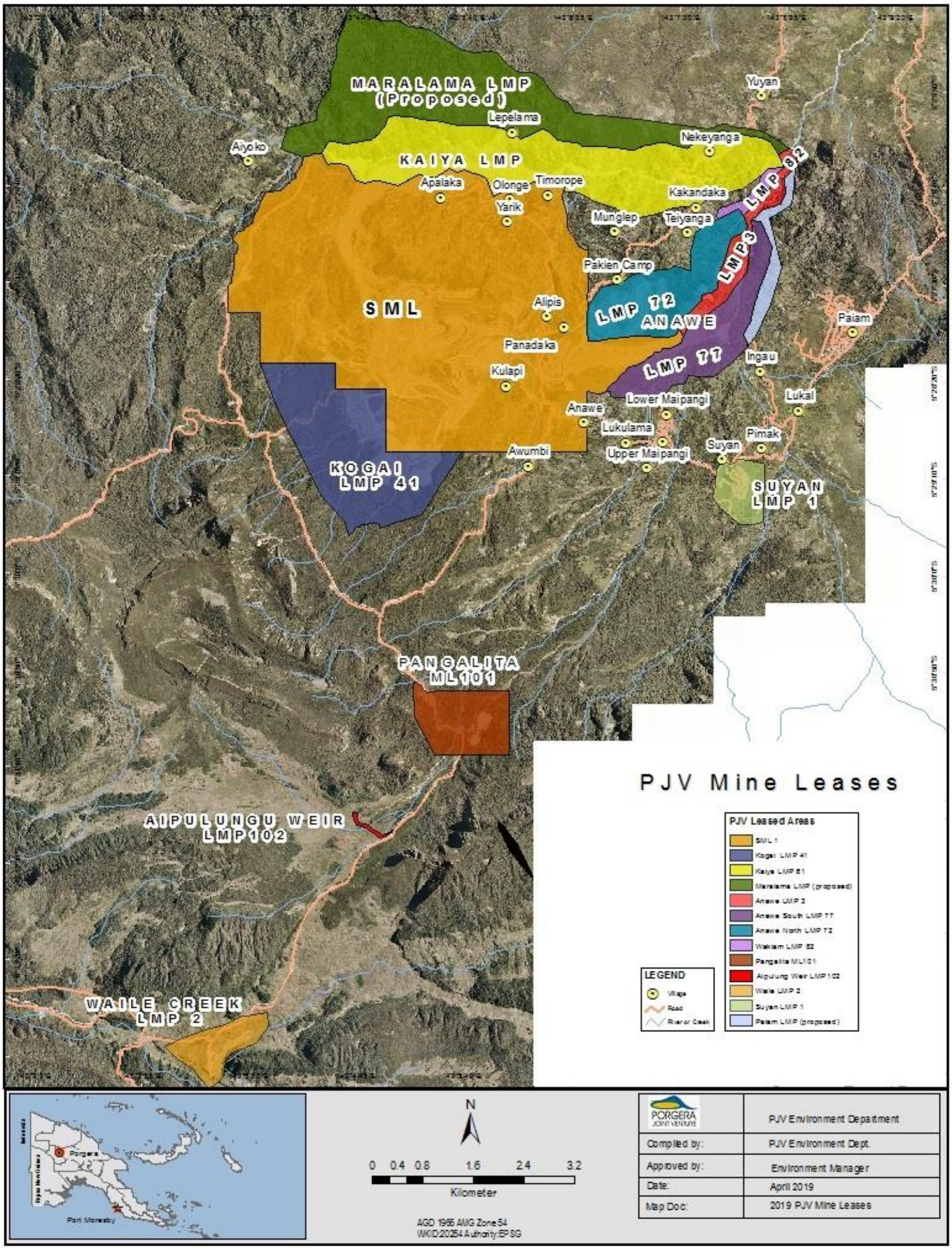


Figure 4-2 Boundaries of special mining lease and other leases for mining purposes

4.3 Waste Rock Production

During the operational phase, the mine generated two types of waste rock which are differentiated by their physical characteristics. Competent or hard rock has high shear strength and is not prone to weathering, and therefore maintains its structural integrity after it has been mined. Incompetent waste rock, comprising colluvium and mudstones has low shear strength and is prone to weathering, breaking down rapidly into sand and silt-sized particles on exposure to air and water after mining. Competent rock is selectively mined and stored in engineered waste rock dumps, which are constructed as a series of terraces into the hillside. Incompetent waste rock is placed in erodible dumps that behave similar to and resemble natural landslides in the area.

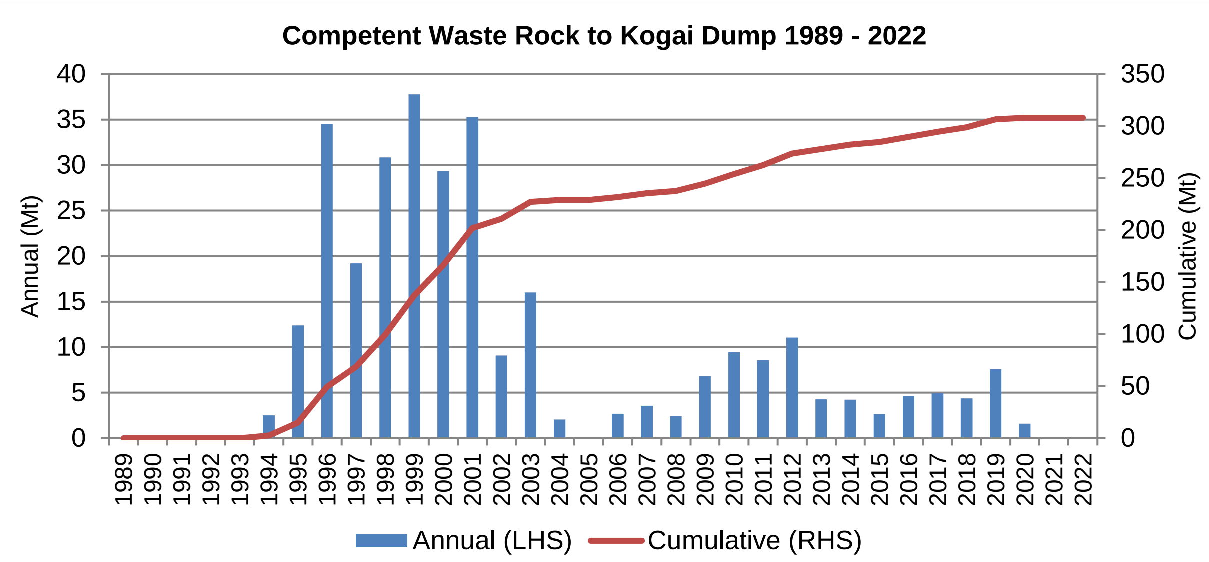
The mass of competent and incompetent waste rock mined between 1989 and May 2022 and the corresponding disposal locations are presented in Table 4-3. The data show that to date, the quantity of competent waste rock placed at Kogai dump is approximately twice the total amount placed at Anawe North competent dump since dumping commenced at Anawe in 2001, while similar quantities of incompetent waste rock have been placed in the Anjolek and Anawe erodible dumps.

Table 4-3 Total quantities of waste rock placed in each dump 1989 – 2022

Waste Dump	Total Quantity (Mt)
Anawe North Competent	134.5
Kogai Competent	308.1
Competent Sub-Total	**442.6**
Anawe Erodible	243.0
Anjolek Erodible	255.0
Erodible Sub-Total	**498.0**
TOTAL	**940.6**

4.3.1 Kogai competent dump

The total quantity of waste rock placed at Kogai competent dump since 1992 was 308.1 Mt. Figure 4-3 shows the annual and cumulative quantities placed at Kogai since construction of the dump began in 1992. As can be seen from the graph, most of the waste was placed between 1995 and 2001 when mining was being carried out at the upper stages of the open pit. There was no waste rock production and placement since April 2020 when the mine was put under care and maintenance.

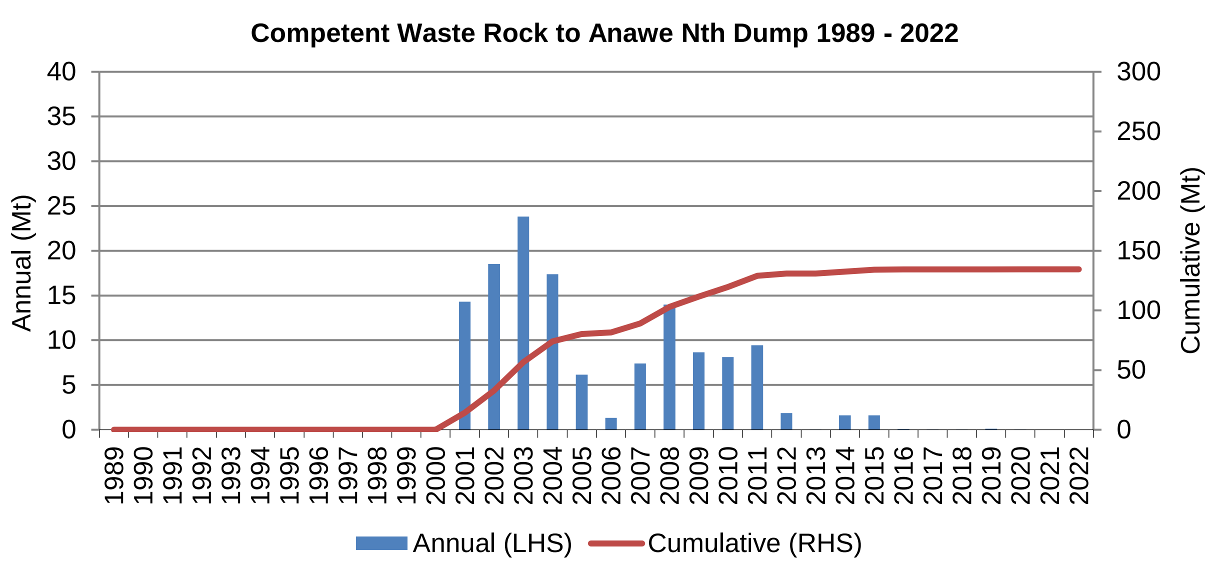


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-3 Yearly tonnages of competent waste rock placed at Kogai Dump 1989 – 2022

4.3.2 Anawe North competent dump

The total quantity of competent waste rock placed at Anawe North dump since construction began in 2001 was 134.5Mt. Figure 4-4 shows annual and cumulative quantities of competent waste rock placed at Anawe North. There has been no waste rock placed at Anawe North competent dump since 2015.



LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

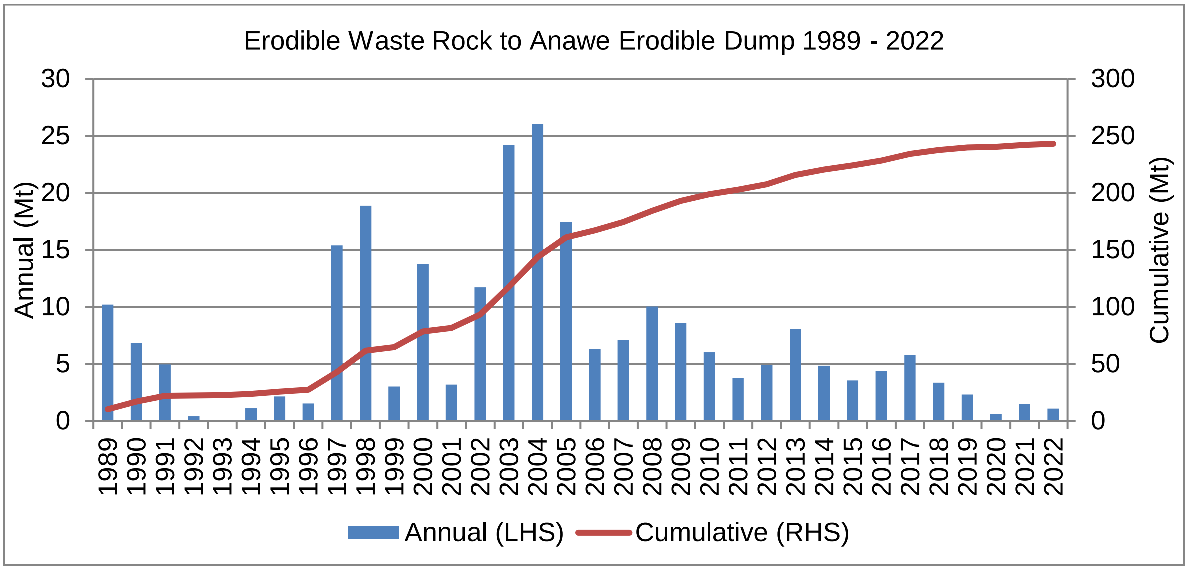
Figure 4-4 Yearly tonnages of competent waste rock placed at Anawe North Dump 1989 – 2022

4.4 Incompetent Waste Rock Disposal

Incompetent waste rock is disposed in either the Anawe or Anjolek erodible dumps. Fluvial processes from rainfall runoff gradually erode the unconsolidated waste from within the dumps into the river system. Most of the materials placed at both dumps are either from the open pit mining operations or mud accumulated in the bottom of the open pit and from certain failed areas.

4.4.1 Anawe erodible dump

A total of 1.46 Mt in 2021 and 1.09 Mt in 2022 was placed in the Anawe erodible dump, the majority of which was mudstone material excavated from the bottom of the open pit. Figure 4-5 shows the annual tonnages of incompetent waste rock placed in the Anawe dump since dumping began there in 1989.

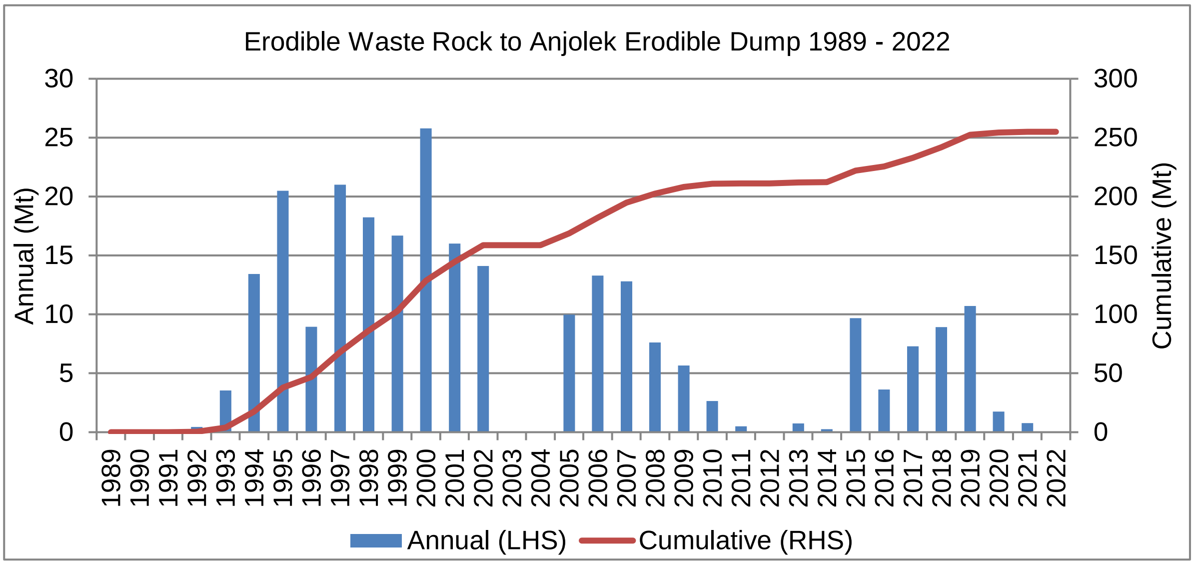


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-5 Yearly tonnages of incompetent waste rock placed at Anawe Erodible Dump 1989-2022

4.1.1 Anjolek erodible dump

There was 0.77 Mt of waste rock discharged to the toe of the Anjolek erodible dump in 2021. The material was generated through dewatering of the open pit mine, and discharged in slurry form via the Yarik Portal. This activity ceased in 2022 due to improved water and mud management within the open pit mine, as a result there was no slurry discharge from the pit bottom into the Anjolek Dump via Yarik Portal in 2022. The pit continued to free drain through the Yarik Portal and erodible waste was mined using excavators and trucks and disposed to the Anawe erodible dump. Figure 4-6 shows the tonnage of incompetent waste rock placed in the Anjolek erodible dump since dumping began in 1992.



LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-6 Yearly tonnages of incompetent waste rock placed at Anjolek Erodible Dump 1989-2022

4.5 Status of the Erodible Dumps in 2022

During the operational phase of the mine, the Anawe and Anjolek erodible waste rock dumps received low strength waste rock and mudstone from the open pit and underground mines. The material was deposited by dump truck at a tip-head located at the head of the Porgera River (Anawe) and head of Anjolek Creek (Anjolek), which flows into the Kaiya River. The location of the Anawe and Anjolek erodible dumps is shown in Figure 4-7.

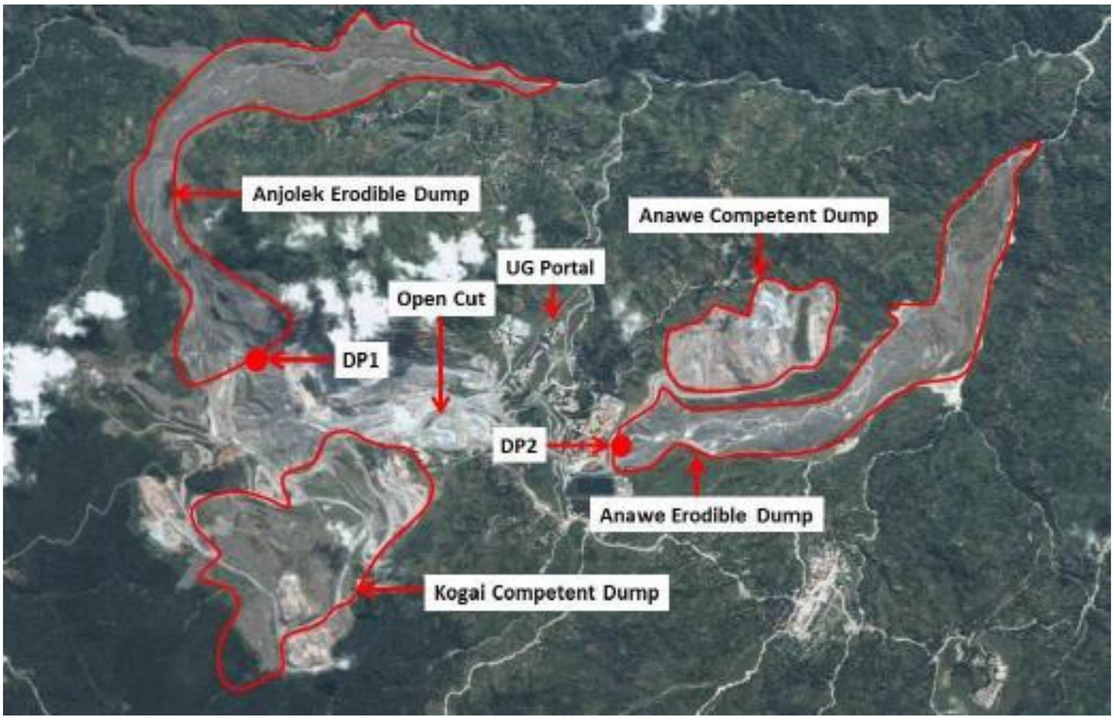


Figure 4-7 Location of Anawe and Anjolek Erodible Waste Rock Dumps

In the years leading up to April 2020, when the site was placed into C&M, rates of waste dumping continued to be relatively low in a historical context. The total amount dumped to Anawe in 2019 was 2.3 Mt and Anjolek received 10.7 Mt which was the highest annual total since 2007, but is still substantially less that the dumping rates reported between 1994 and 2002, where the annual rate peaked at almost 26 Mt.

During care and maintenance, disposal of waste rock by dump truck to the tip head of the Anjolek dump ceased, in 2021 discharge of sediment in slurry form to the toe of the dump via the Yarik Portal continued as a result of dewatering the open pit. This activity was required to help maintain the site in a safe and stable condition and formed part of BNL's obligations under the C&M Safety, Health, Environment and Security Management Plan. A total of 0.77 Mt of sediment was discharged in 2021. Slurry discharge ceased in 2022, with waste material being mined from the bottom of the pit and discharged to the Anawe erodible dump.

The Anawe dump, received 1.46 Mt in 2021 and 1.09 Mt in 2022 as a result of mud mining in the bottom of the pit to maintain drainage.

Overall, the volume of erodible waste rock discharged from the site during C&M was significantly less than during the operation phase.

This section presents an overview of the condition of the Anjolek and Anawe erodible dumps during the care and maintenance phase as of September 2022. The information presented here has been provided through routine visual (ground based and aerial) and satellite inspections conducted by the BNL geotechnical and environment teams throughout the C&M phase.

4.5.1 Anawe erodible dump

Aerial inspections undertaken throughout the C&M phase and satellite InSAR analysis of ground displacement conducted in April 2022, showed that there had been relatively little change to the overall condition of the Anawe dump during C&M.

The Anawe erodible dump is located between the Apalaka ridge and toe of Porgera Station slope. The dump runs in a relatively gentle slope (14%). Anawe creek flows adjacent to the southern flank of the dump and meets Pongema River at the southeast toe of the dump. The Pongema River flows between the toes of the dump and toe of Paiam slope and continues down the Pongema gorge. The Anawe erodible dump is designed to cater for mud/slurry mainly from stage 5A bottom pit and 30% of incompetent rock (black sediments & brown mudstone). The upper and middle segments are filled with erodible dump material (mostly mud/slurry), the lower segment is vegetated grassland steppe.

Figure 4-8 shows the head of the Anawe erodible dump and Figure 4-9 shows the middle section of the dump looking upstream and Figure 4-10 shows the toe of the Anawe dump being gradually eroded by the Porgera River, with established vegetation on the surface of the dump on the lower section and toe.

As per the InSAR satellite monitoring, the line of sight (LOS) results from the descending orbit indicated a slower movement along the periphery of the dump. The average annual LOS displacement rates (ATS1-ATS4) range from +14mm/yr to -18mm/yr. The acceding orbit of rapid motion tracking (RMT) data indicated the highest LOS annual displacement rates reaches -1.3m/yr with an acceleration during the last 6 months period, while stable at the northern end of the dump. See Figure 4-11 and Figure 4-12.

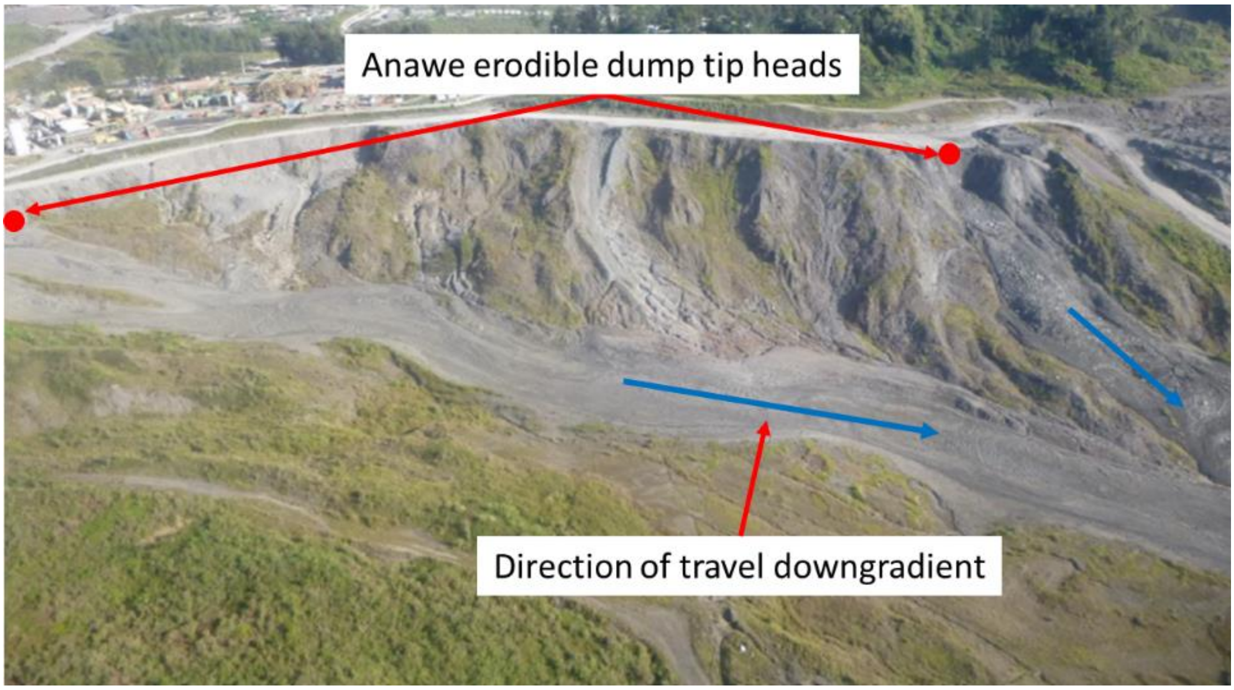


Figure 4-8 Anawe erodible dump tip heads September 2022

Figure 4-9 Anawe erodible dump – looking upstream towards the tip head August 2022

Figure 4-10 Anawe erodible dump toe intersecting the Porgera river – looking upstream towards the tip head August 2022

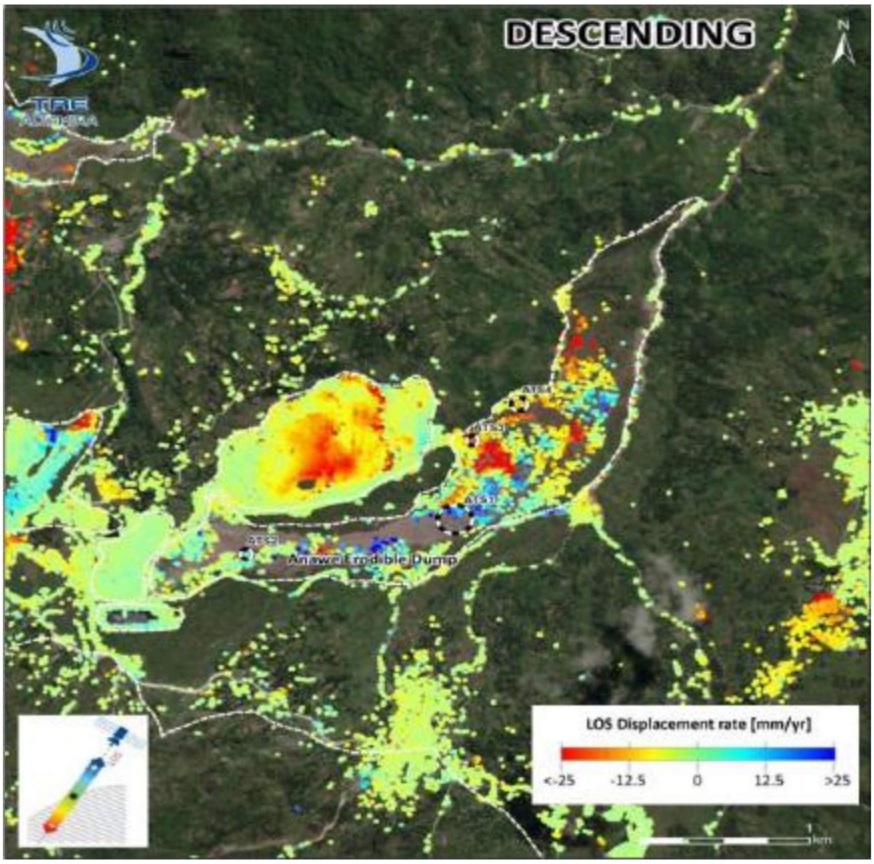


Figure 4-11 Descending SqueeSAR displacement rate in the Anawe Erodible Dump

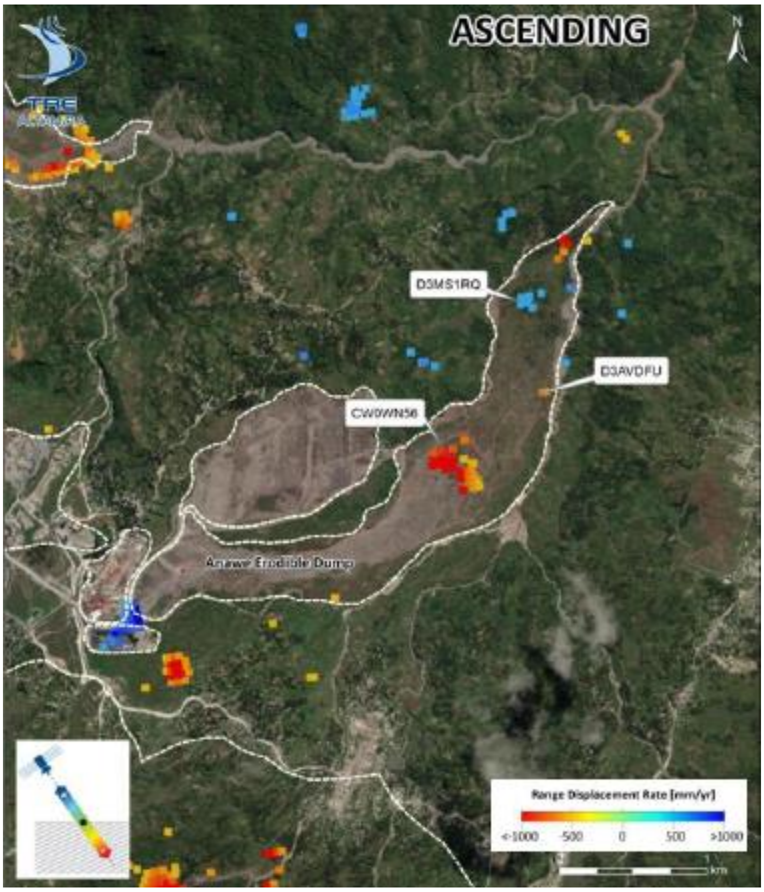


Figure 4-12 Ascending RMT (range) results within the Anawe Erodible Dump

4.5.2 Anjolek erodible dump

Monitoring during the C&M period showed that the Anjolek dump has remained inactive since 24th April 2020 when the mine Care and Maintenance period commenced.

The Anjolek erodible dump is located in a gully between two (2) ridges (Peruk & Kaiya). The slope of the dump is relatively gentle (14%). Kaiya Creek runs along the northern flank of the dump. Another creek flowing from the east crosses the upper middle segment of the dump and runs along the southern flank of the dump. The erodible dump is designed to cater for incompetent waste rock mainly black sediments and brown mudstone and rocks of low strength that gradually disintegrate into silt. The dump is profiled as such; the tip head and upper segment is of fragmented rocks, the middle and lower segments are of disintegrated materials (debris/silt). Since entering C&M the middle and lower segments have become sparsely vegetated while other areas exposed the *in situ* brown mudstone. The two (2) creeks intersecting the dump along the northern and southern flanks are scouring the *in situ* brown mudstone and gradually widening the channels.

Figure 4-13 shows the Anjolek erodible dump tip head, Figure 4-14 shows the middle section of the dump, where a lobe of previously dumped material, which was observed in 2019 moving downgradient over the body of the dump ('rafting'), appears to have now slowed and is gradually eroding. Figure 4-15 shows the toe of the Anjolek erodible dump being gradually eroded by the Kaiya River.

InSAR satellite monitoring showed acceleration in the northwest sector (-23mm/yr vertical) while the east_west motion is limited to 9mm/yr towards west was being observed in the south sector. Displacement rates for the last 6months are consistent with those observed during the previous monitoring except for ATS3 which shows an acceleration. The descending orbit RMT results show 1.3m/yr movement towards the satellite in the northern sector and 1.0m/yr of movement away from the satellite in the southern sector. See Figure 4-16 and Figure 4-17.

Figure 4-13 Anjolek erodible dump tip head September 2022

Figure 4-14 Anjolek erodible dump – lobe of previously dumped material stabilising and eroding – looking upstream August 2022

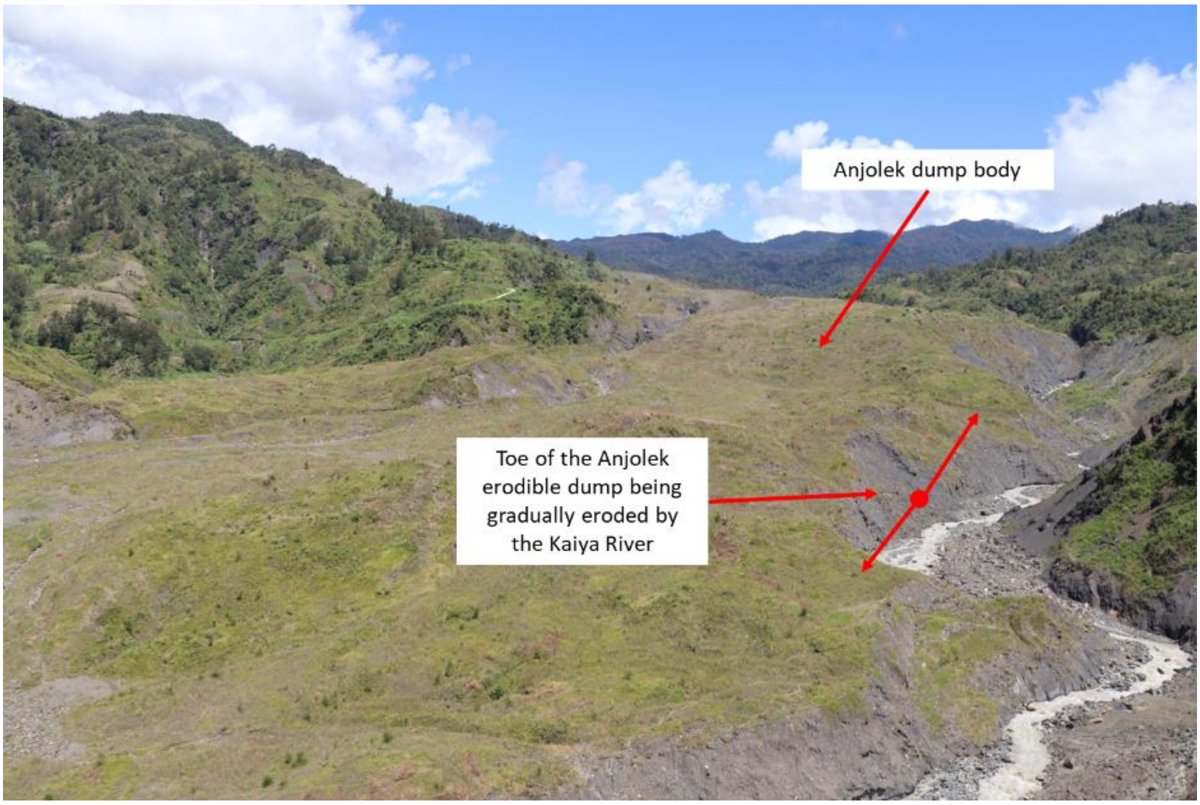


Figure 4-15 Anjolek erodible dump toe intersecting the Kaiya River – looking upstream towards the tip head August 2022

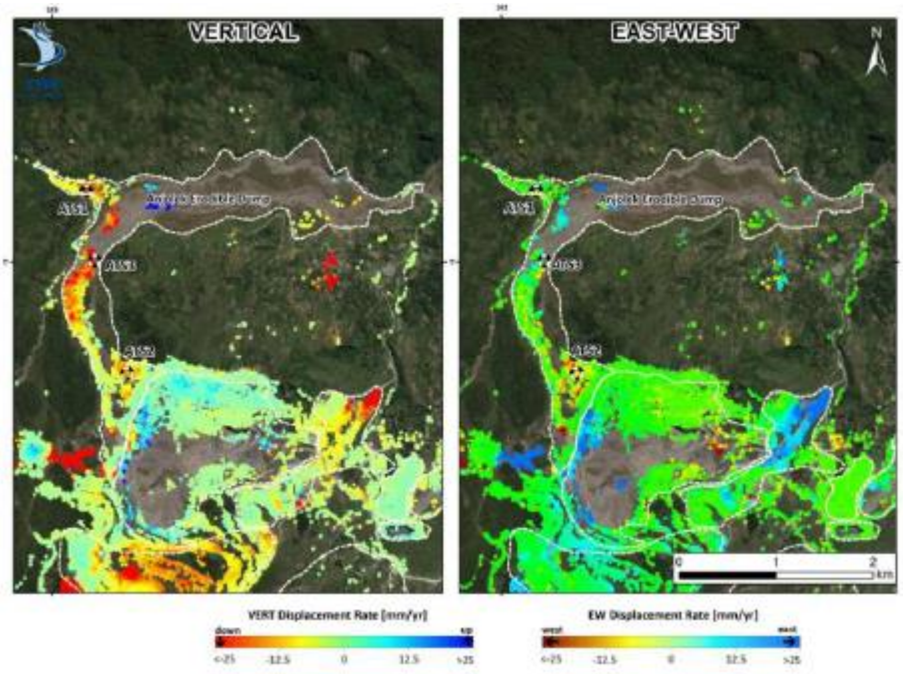


Figure 4-16 2D SqueeSAR displacement rates in the Anjolek erodible dump

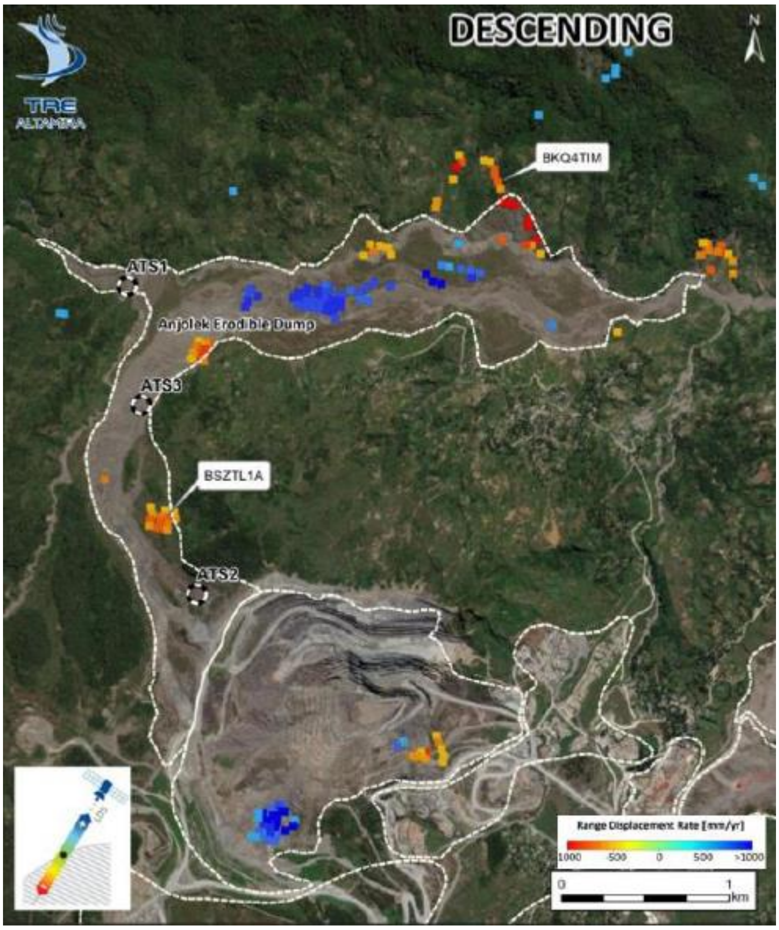
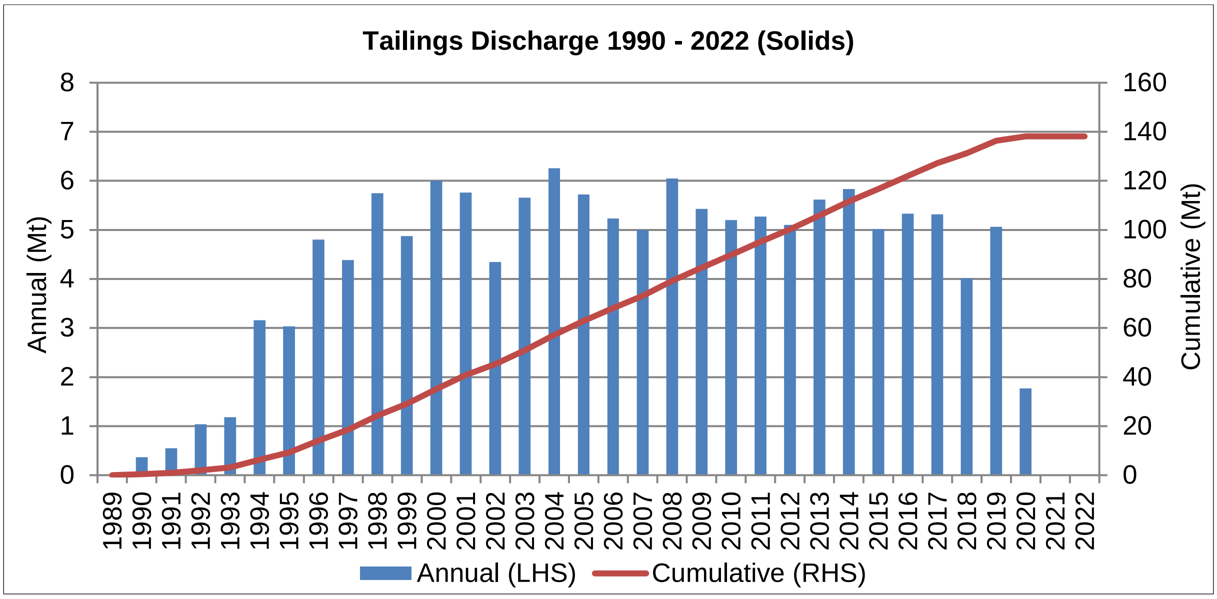


Figure 4-17 Descending RMT (range) results within the Anjolek erodible dump

4.6 Tailings Disposal

4.6.1 Riverine tailings disposal

There has been no tailings discharge to the river system since the site entered care and maintenance. During the operational phase, between 1996 and 2019 the site discharged an average of 5.29 Mt of tailings solids contained in slurry to the head of the Porgera River via the Anawe erodible dump, with a peak of 6.25 Mt in 2004. Between the commencement of operations in 1990 and entering C&M in April 2020, a total of 138.13 Mt of tailings solids has been discharged. Figure 4-18 shows the total mass discharged since operations commenced in 1990.



LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-18 Annual and cumulative tailings discharge mass (Mt) (dry solids) (1989-2022)

Table 4-4 shows the 20th%ile, median and 80th%ile values for water quality in the tailings slurry between January 2015 and April 2020. The data shows that historically, water contained in the tailings slurry exhibited elevated EC and elevated concentrations of TSS, dissolved cadmium, dissolved copper, dissolved iron, dissolved nickel and dissolved zinc when compared to the upper river TV, indicating a risk to aquatic organisms from these elements.

Table 4-5 shows the 20th%ile, median and 80th%ile values for sediment quality in the tailings slurry between January 2015 and April 2020. The data shows that historically, the solids contained in the tailings slurry exhibited elevated EC and elevated concentrations of WAE silver, arsenic, cadmium, copper, mercury, nickel, lead and zinc when compared to the upper river TV, indicating a risk to aquatic organisms from these elements.

Table 4-4 Tailings slurry discharge quality from May 2015 – April 2020 (µg/L except where shown), (Sample Count n = 242)

Parameter	UpRiv TV	20%ile	Median	80%ile
pH	6.0-8.2	6.4	6.6	7.1
EC	228	3,164	4,090	4,680
WAD-CN*	NA	0.20	0.20	0.20
Sulfate*	NA	1,750	2,750	3,700
ALK-T*	NA	180	236	284

Parameter	UpRiv TV	20%ile	Median	80%ile
TSS*	2837	82,000	120,000	179,320
Hardness*	NA	2,937	3,450	3,893
Ag-D	0.05	0.01	0.02	0.05
Ag-T	NA	500	1,400	2,400
As-D	24	0.30	0.86	2.5
As-T	NA	11,000	22,000	35,000
Cd-D	0.36	23	54	109
Cd-T	NA	552	1,000	1,808
Cr-D	1.0	0.10	0.18	0.57
Cr-T	NA	4,416	8,300	13,000
Cu-D	1.4	9.7	29	70
Cu-T	NA	7,740	12,000	18,000
Fe-D	75	8	29	460
Fe-T	NA	2,240,000	4,380,000	6,340,000
Hg-D	0.60	0.07	0.14	0.40
Hg-T	NA	45	90	150
Ni-D	21	599	1,040	1,600
Ni-T	NA	3,200	4,900	7,180
Pb-D	7.9	0.10	0.10	0.51
Pb-T	NA	26,400	61,400	98,000
Se-D	11	1.2	1.7	2.7
Se-T	NA	91	100	130
Zn-D	20	5,062	14,800	32,460
Zn-T	NA	110,000	189,000	310,000
🟧	> UpRiv TV = Potential Risk			

^ std units, # µS/cm, * mg/L, **mg $CaCO_3$/L, D - Dissolved fraction, T – Total, NA – Not Applicable

Table 4-5 Tailings slurry discharge sediment quality from May 2015 – April 2020 (mg/kg dry, whole fraction), (Sample Count n = 213)

Parameter	UpRiv TV	20%ile	Median	80%ile
Ag-TD	NA	12	17	25
Ag-WAE	1.0	0.37	0.58	1.3
As-TD	NA	200	250	330
As-WAE	20	36	52	100
Cd-TD	NA	7.3	12.0	16
Cd-WAE	1.5	4.5	7.5	10
Cr-TD	NA	77	92	110
Cr-WAE	80	19	24	30
Cu-TD	NA	100	130	160
Cu-WAE	65	76	93	115
Fe-TD	NA	42640	50600	56860

Parameter	UpRiv TV	20%ile	Median	80%ile
Fe-WAE	NA	11,400	14100	18720
Hg-TD	NA	0.80	1.10	1.6
Hg-WAE	0.15	0.11	0.22	0.40
Ni-TD	NA	40	49	58
Ni-WAE	21	21	28	36
Pb-TD	NA	544	870	1,180
Pb-WAE	50	91	131	210
Se-TD	NA	0.66	0.83	1.1
Se-WAE	0.25	0.14	0.22	0.41
Zn-TD	NA	1,220	2,090	2,776
Zn-WAE	200	732	1220	1730
🟧	> UpRiv TV = Potential Risk			

WAE – Weak-acid extractable, TD - Total digest, NA – Not Applicable

4.7 Other Discharges to Water

4.7.1 Treated sewage effluent

The total volume of treated sewage effluent discharged from the five Sewage Treatment Plants (STP) that service the mine site and accommodation camps in 2021 are shown in Figure 4-19 and confirms that discharge volumes from all STPs were within the respective environment permit limits.

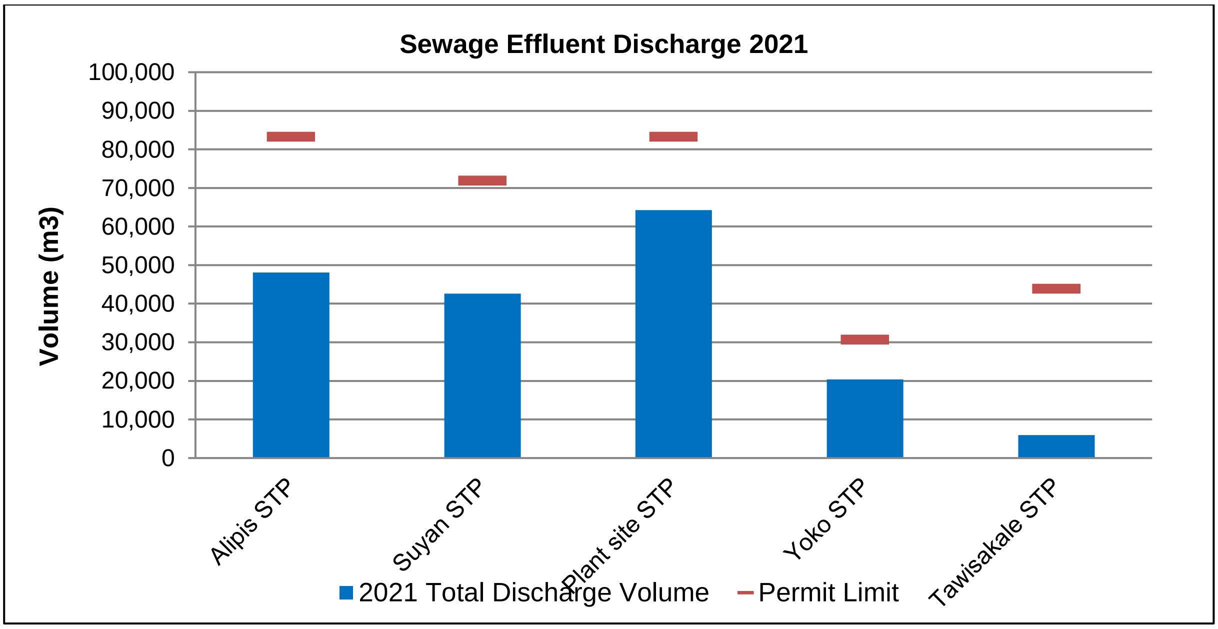


Figure 4-19 Total annual discharge volumes of treated sewage for 2021

The total volume of treated sewage effluent discharged from the five treatment plants that service the mine site and accommodation camps in 2022 are shown in Figure 4-20 confirms that discharge volumes from all STPs were within the respective environment permit limits. The results presented below are from January to May 2022.

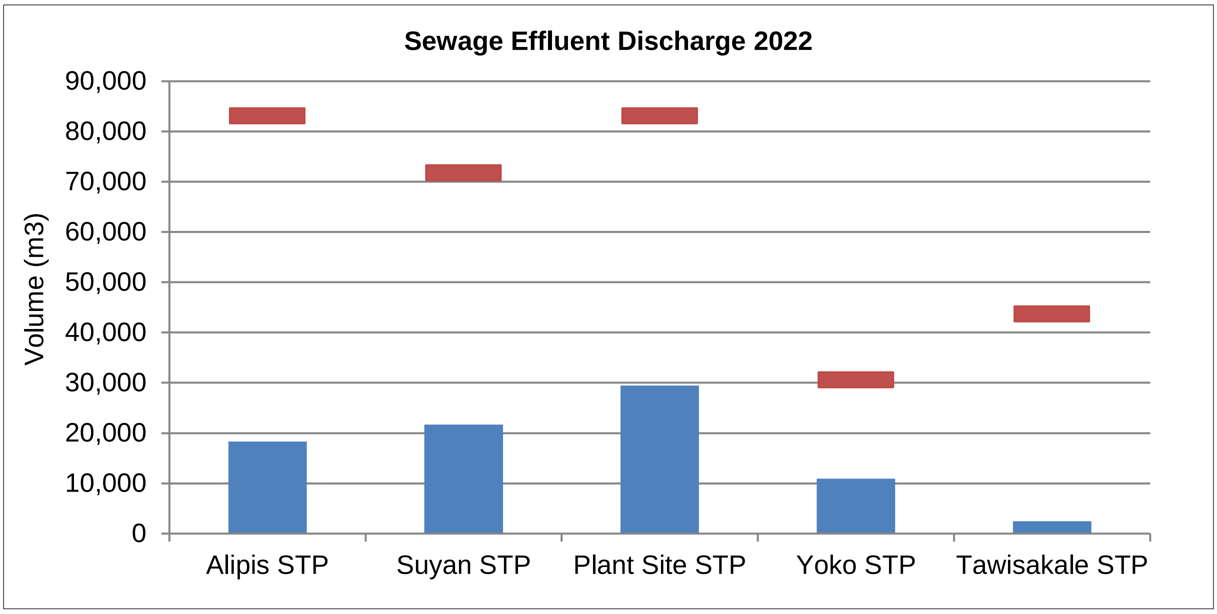


Figure 4-20 Total annual discharge volumes of treated sewage up to May 2022

The quality of the discharge from each STP is monitored for Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD_5) and Faecal Coliforms. Monitoring results are shown in Figure 4-21 to Figure 4-23 respectively for 2021 and Figures 4-24 to Figure 4-26 for 2022. Operation of the sewage treatment plants achieved compliance with the environmental permit criteria for TSS, BOD_5 and faecal coliform criteria throughout 2021 and from January to May 2022.

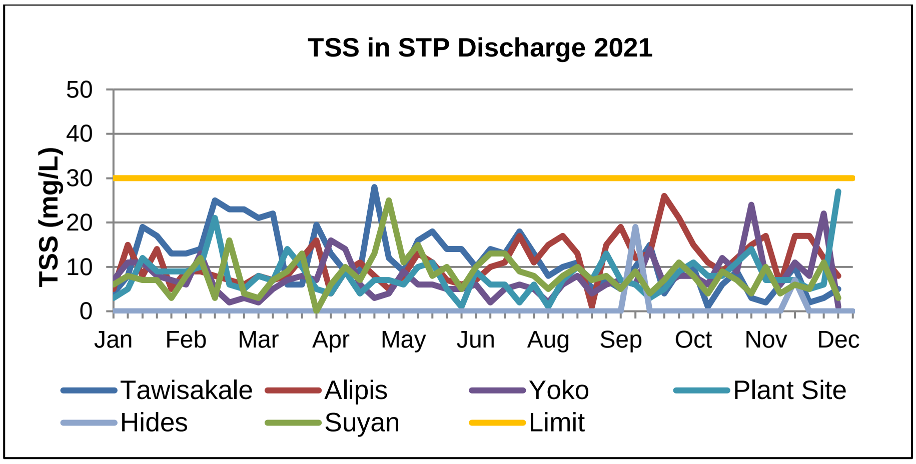


Figure 4-21 Average monthly TSS concentration in treated sewage discharges in 2021

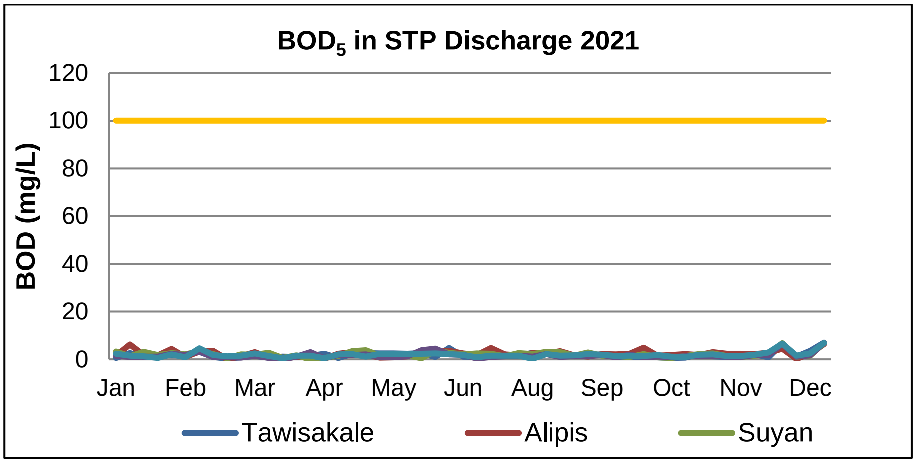


Figure 4-22 Average monthly BOD₅ concentration in treated sewage discharges in 2021

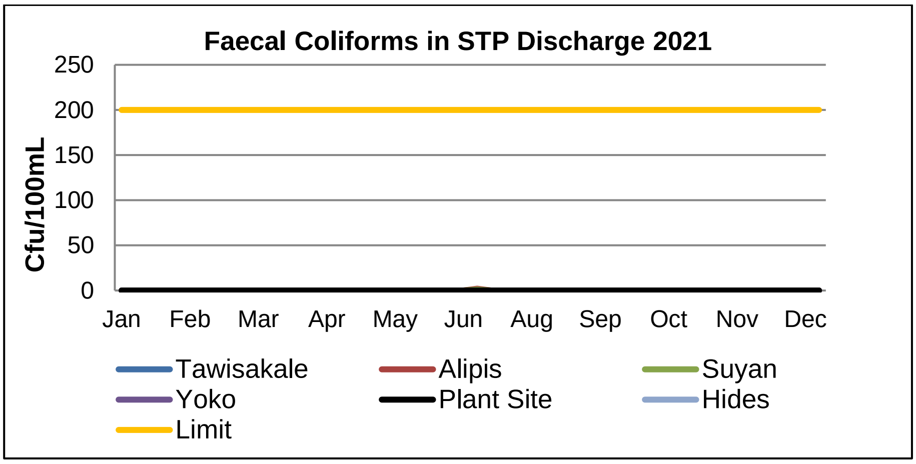


Figure 4-23 Average monthly faecal coliform count in treated sewage discharges in 2021

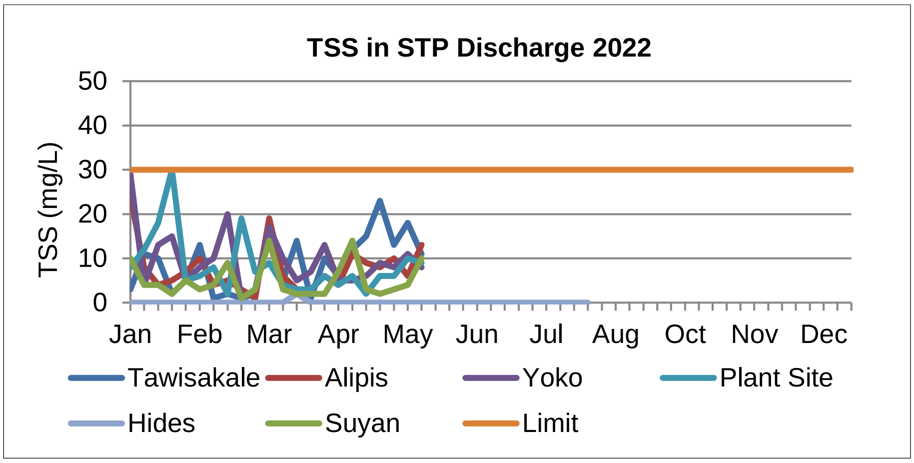


Figure 4-24 Average monthly TSS concentration in treated sewage discharge up to May 2022

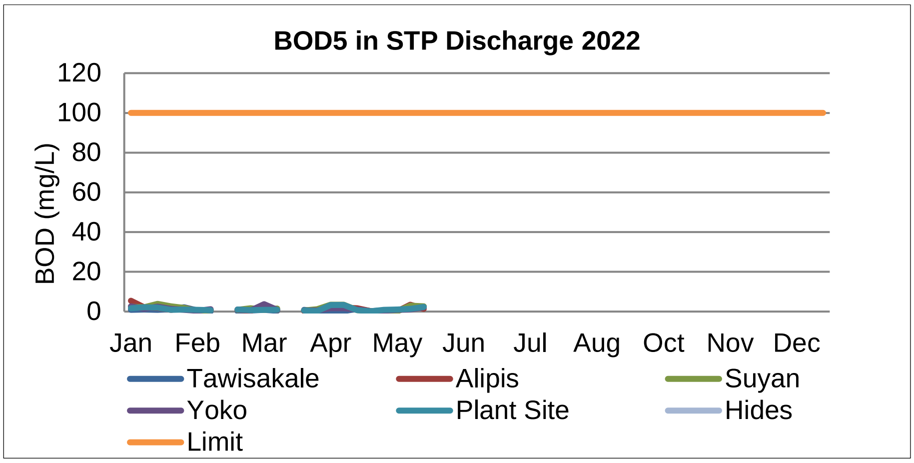


Figure 4-25 Average monthly BOD$_5$ concentration in treated sewage discharge up to May 2022

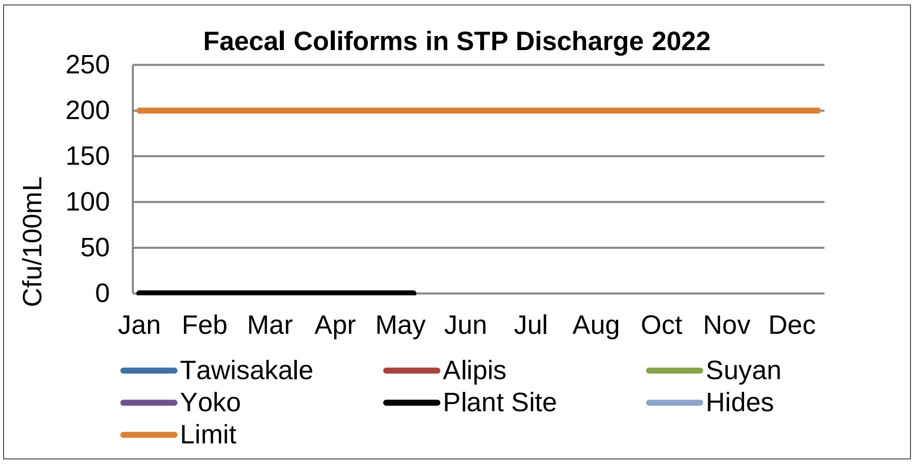


Figure 4-26 Average monthly faecal coliform count in treated sewage discharge up to May 2022

4.7.2 Oil/water separator effluent

The mine operates 21 oil-water separators at maintenance workshops and fuel storage and refuelling installations.

Figure 4-27 shows monthly average hydrocarbon concentrations from oil-water separators and the receiving creeks, compared against the internal site-developed target of 30 mg/L.

Figure 4-28 shows monthly average hydrocarbon concentrations from oil-water separators and a local creek, compared against the internal site-developed target of 30 mg/L from January to May 2022.

Hydrocarbons were detected in low concentrations at oil water separator discharge points and at the receiving creek, however the concentrations were well below the site target and are not considered to pose a risk to the environment or human health.

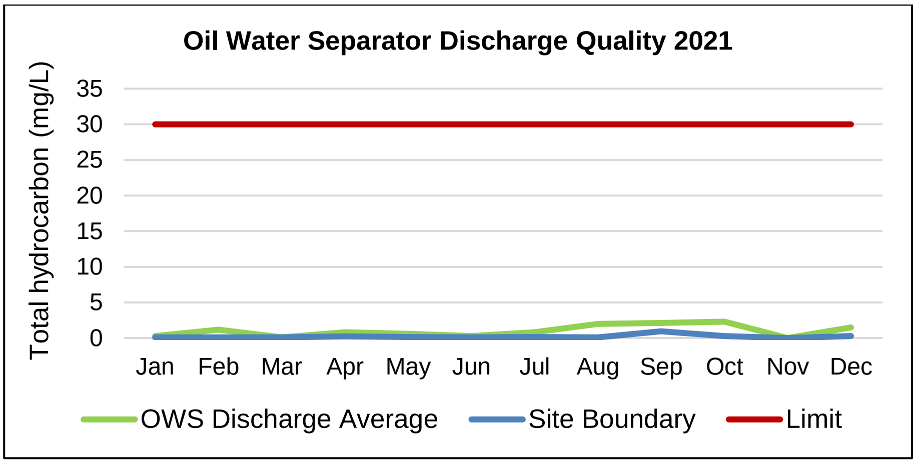


Figure 4-27 Average monthly total hydrocarbon concentrations in oil-water separator discharges in 2021

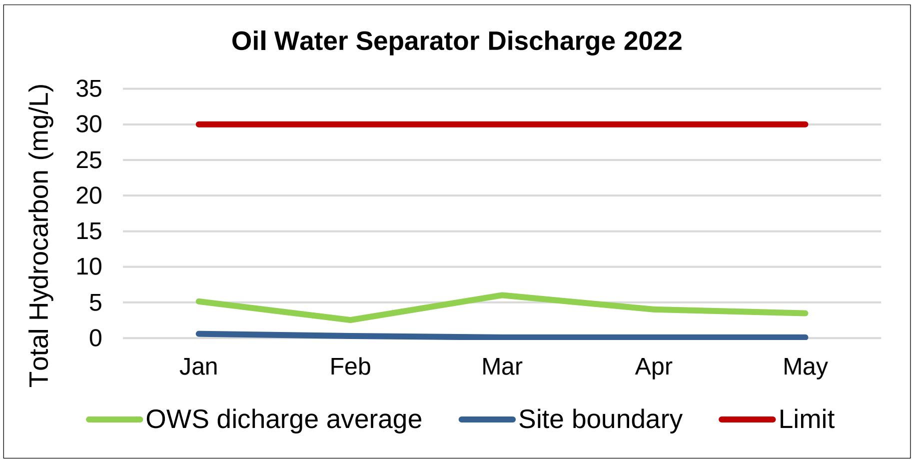


Figure 4-28 Average monthly total hydrocarbon concentrations in oil-water separator discharges up to May 2022.

4.1.2 Mine contact runoff

Mine contact runoff is rainfall runoff from land disturbed by the mining operation and therefore has the potential to contribute contaminants, particularly metals, to the receiving environment. The volume and quality of mine contact runoff are described in the following sections.

4.7.2.1 Contact runoff volumes

Table 4-6 shows the estimated volume of contact runoff from land disturbed by mining operations in 2021 and Table 4-7 shows the estimated volume of contact runoff from land disturbed by mining operations during January to May 2022. It is impractical to measure runoff volumes and these have been estimated from rainfall and catchment areas.

Table 4-6 Estimated volumes of contact runoff from mine lease areas 2021

Location	**Total Rainfall run off 2021(Mm^3)**	**Permit Limit (Mm^3/y)**
Starter Dump A (DP3)	0.7	1.8
Civil crusher to Kogai Creek (DP4)	0.04	0.1
Kogai waste dump to Kogai Creek (DP5)	18	1,680

Location	Total Rainfall run off 2021(Mm^3)	Permit Limit (Mm^3/y)
Open Pit and UG Mine drainage tunnel to Kogai Creek (DP6)	0.72	12
Anawe stable dump to Wendoko Creek (DP7)	3.7	4.5
Runoff from Hides to a tributary of the Tagari River (DP16)	0.03	0.1
TOTAL	**23.5**	**1,700**

Table 4-7 Estimated volumes of contact runoff from mine lease areas up to May 2022

Location	Total Rainfall run (Mm^3)	Permit Limit (Mm^3/y)
Starter Dump A (SDA) (DP3)	0.3	1.8
Civil crusher to Kogai Creek (DP4)	0.02	0.1
Kogai waste dump to Kogai Creek (DP5)	7.2	1,680
Open Pit and UG Mine drainage tunnel to Kogai Creek (DP6)	2.8	12.1
Anawe stable dump to Wendoko Creek (DP7)	1.5	4.5
Runoff from Hides to a tributary of the Tagari River (DP16)	0.02	0.1
TOTAL	**11.8**	**1,700**

4.7.2.2 Contact runoff water and sediment quality

The quality of water and sediment contained in runoff from within the mining lease is dictated by the land use within the contributing catchment. Table 4-8 identifies the land uses within the contributing catchment for each monitoring site and the locations of the sites are shown in Figure 4-29.

Table 4-8 Mine contact runoff monitoring sites

Monitoring site name	Land Uses
28 Level (underground water discharged at adit)	Underground mine
SDA Toe	Competent waste rock dump
Kogai Culvert	Competent waste rock dump Crushing and grinding Workshops Sewage treatment plant Hazardous substance storage
Kogai stable dump toe area	Competent waste rock dump
Lime Plant discharge	Limestone processing
Yakatabari Creek downstream of 28 Level discharge	Underground mine Workshops Sewage treatment plant Hydrocarbons substance storage

Monitoring site name	**Land Uses**
The following sites were monitored during the operational phase of the mine, but not monitored during C&M due to security concerns.	
Kaiya River at Yuyan Bridge	Open cut mine Underground mine Erodible waste rock dump
Kaiya River downstream of Anjolek erodible dump	Erodible waste rock dump
Wendoko Creek downstream of Anawe Nth stable dump	Competent waste rock dump
Yunarilama/Yarik portal	Open cut mine Underground mine

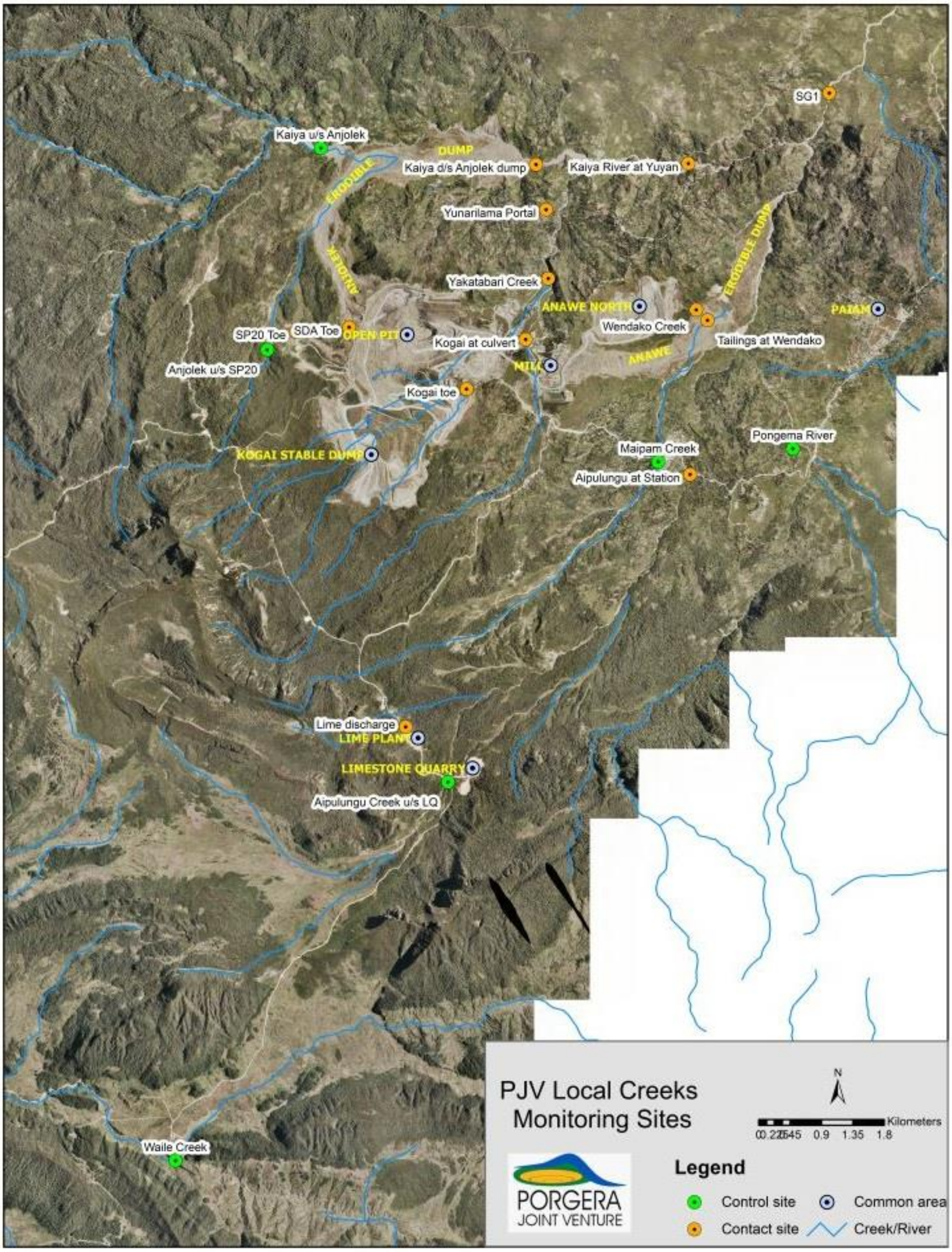


Figure 4-29 Mine contact runoff sampling location

Median values from monthly monitoring conducted between November 2021 and May 2022 at mine contact runoff sites are shown in Table 4-9, amber indicates values that exceeded or were not significantly different from the upper river TV. Samples were not collected from SDA Toe, Kaiya River downstream Anjolek Dump, Wendoko Creek downstream of Anawe North Dump or Yunarilama Portal during the C&M period due to ongoing community and security issues.

Compared to the upper river TVs, water discharged from 28 level exhibited elevated electrical conductivity (EC), most likely due to the presence of sulfide mineralogy within the underground mine, and elevated dissolved chromium and dissolved zinc, also generated from the mineralogy of the underground mine.

Runoff from Kogai Culvert exhibited elevated EC, dissolved cadmium, dissolved copper and dissolved zinc. Runoff from Kogai Dump Toe exhibited elevated EC, dissolved cadmium, dissolved chromium and dissolved zinc. Runoff quality at both sites is influenced by the Kogai stable waste rock dump and drainage from the stockpile and crushing circuit. The water quality at this site is typical of neutral mine drainage and indicates that oxidation/reduction and neutralisation are occurring within the waste rock dump due to the presence of sulfides and carbonates. Alkaline pH indicates a net neutralising capacity within the waste rock, which is beneficial for preventing low pH runoff and reducing the concentration of dissolved/bioavailable metals.

Discharge from the lime plant exhibited elevated pH, owing to the presence of limestone minerals in the plant area, and dissolved chromium and copper.

In Yakatabari Creek downstream of 28 level, water quality showed elevated EC, TSS and dissolved chromium.

A summary of trends of water quality parameters between 2013 and 2022 in contact runoff is presented in Table 4-10. Details of the statistical analysis are shown in Volume 2. The analysis shows that concentrations of a number of analytes have increased at a number of sites during the period. Of note are trends of increasing concentrations of TSS, dissolved chromium and mercury at Yunarilama Portal. At 28 level there was an increasing trend of dissolved nickel concentration.

The median concentrations of WAE metals and total metals in sediment in runoff from the mine areas are shown in Table 4-9. Of note are elevated WAE silver, arsenic, cadmium, nickel, lead and zinc in sediment discharged from 28 level, Kogai Culvert, Kogai Stable Dump Toe and Yakatabari Creek DS 28 Level. Elevated lead and zinc in sediment is a reflection of the geology of the Porgera ore body which contains sphalerite, which is a zinc mineral, and galena which is a lead mineral.

Table 4-9 Contact water quality November 2021 to May 2022 median concentrations (µg/L except where shown) (n=7)

Parameter	UpRivs TV	28 Level	SDA Toe	Kaiya Riv D/S Anj dump	Kogai Culvert	Kogai Dump Toe	Lime Plant	Wendoko Crk D/S Anawe Nth	Yakatabari Crk D/S 28 Level	Yunarilama @ Portal
pH^	6.0-8.2	8.0	NS	NS	8.3	8.1	9.8	NS	8.5	NS
EC$^{\#}$	219	897	NS	NS	892	1,644	99	NS	869	NS
WAD-CN*	NA	0.2	NS	NS	0.2	0.2	0.2	NS	0.2	NS
Sulfate*	NA	308	NS	NS	385	680	2.0	NS	200	NS
ALK-T**	NA	152	NS	NS	158	231	42	NS	113	NS
TSS*	2,837	7.0	NS	NS	260	30	36	NS	4,100	NS
Hardness**	NA	407	NS	NS	461	869	41	NS	120	NS
Ag-D	0.05	0.01	NS	NS	0.013	0.01	0.01	NS	0.02	NS
Ag-T	NA	0.055	NS	NS	1.6	0.12	0.03	NS	61	NS
As-D	24	0.76	NS	NS	1.4	0.56	0.32	NS	7.3	NS
As-T	NA	1.7	NS	NS	23	4	0.91	NS	540	NS
Cd-D	0.35	0.05	NS	NS	0.089	0.97	0.05	NS	0.05	NS
Cd-T	NA	0.05	NS	NS	1.8	1.5	0.05	NS	39	NS
Cr-D	1.0	0.10	NS	NS	0.14	0.12	1.2	NS	0.29	NS
Cr-T	NA	0.14	NS	NS	11	1.4	3.3	NS	340	NS
Cu-D	1.4	0.20	NS	NS	0.79	0.44	1.2	NS	0.81	NS
Cu-T	NA	0.38	NS	NS	14	4.2	2.0	NS	600	NS
Fe-D	75	1.70	NS	NS	5.8	2.9	5.6	NS	3.2	NS
Fe-T	NA	1,070	NS	NS	17,400	2,040	350	NS	238,300	NS
Hg-D	0.60	0.05	NS	NS	0.05	0.05	0.05	NS	0.05	NS
Hg-T	NA	0.05	NS	NS	0.17	0.05	0.05	NS	10	NS
Ni-D	21	2.2	NS	NS	0.82	1.4	0.50	NS	1.8	NS
Ni-T	NA	2.8	NS	NS	11	3.6	0.93	NS	310	NS
Pb-D	7.5	0.1	NS	NS	0.15	0.47	0.1	NS	0.31	NS
Pb-T	NA	2.0	NS	NS	140	36	1.5	NS	4,000	NS
Se-D	11	0.2	NS	NS	0.2	0.2	0.2	NS	0.25	NS
Se-T	NA	0.2	NS	NS	0.51	0.2	0.2	NS	6.2	NS
Zn-D	20	13[1]	NS	NS	21	160	2.1	NS	15	NS
Zn-T	NA	47	NS	NS	310	260	6.5	NS	7,180	NS

🟧	> UpRiv TV = Potential Risk

^std units, #µS/cm, * mg/L, **mg $CaCO_3$/L, D = Dissolved fraction, T = Total, NA – Not applicable, NS - Not sampled in 2021 and 2022, [1] Although TSM falls below the TV, the 2021 – 2022 dataset contains some values that do exceed the TV, this increases the standard deviation of the dataset and as a result, the TSM is found to be not statistically significantly different from the TV

Table 4-10 Trends of water quality contact runoff 2013 - 2022 (as tested using Spearman Rank Correlation)

Parameter	28 Level	SDA Toe*	Kaiya Riv D/S Anj Dump	Kogai at Culvert	Kogai Dump Toe	Lime Plant	Wendoko Creek D/S Anawe Nth	Yakatabari Creek D/S 28 Level	Yunarilama / Yarik @ Portal
pH	🟧	🟩	🟩	🟧	🟧	🟩	🟩	🟧	🟧
EC	🟧	🟧	🟩	🟩	🟧	🟩	🟩	🟩	🟩
WAD-CN	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Sulfate	🟧	🟧	🟩	🟧	🟧	🟩	🟩	🟩	🟧
ALK-T	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
TSS	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
Hardness	🟧	🟧	🟩	🟧	🟧	🟩	🟩	🟩	🟩
Ag-D	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Ag-T	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩
As-D	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
As-T	🟩	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Cd-D	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Cd-T	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Cr-D	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
Cr-T	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Cu-D	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Cu-T	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Fe-D	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Fe-T	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Hg-D	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
Hg-T	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Ni-D	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Ni-T	🟩	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Pb-D	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Pb-T	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Se-D	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Se-T	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Zn-D	🟩	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Zn-T	🟩	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩

🟩	Decreased or no change over time
🟧	Increased over time

D - Dissolved fraction, T - Total

Table 4-11 Contact Sediment Quality November 2021 to May 2022 median values (mg/kg dry, whole fraction) (n=3)

Parameter	UpRiv TV	28 Level	SDA Toe	Kaiya Riv D/S Anj dump	Kogai Culvert	Kogai Dump Toe	Lime Plant	Wendoko Crk D/S Anawe Nth	Yakatabari Crk D/S 28 Level	Yunarilama @ Portal
Ag-WAE	1.0	2.8	NS	NS	1.3	2.0	0.09	NS	5.1	NS
Ag-TD	NA	8.7	NS	NS	6.3	11	0.24	NS	12	NS
As-WAE	20	69	NS	NS	8.9	40	2.0	NS	28	NS
As-TD	NA	140	NS	NS	47	180	7.9	NS	94	NS
Cd-WAE	1.5	1.9	NS	NS	0.35	5.1	0.35	NS	2.1	NS
Cd-TD	NA	3.8	NS	NS	1.0	9.5	0.55	NS	2.7	NS
Cr-WAE	80	8.1	NS	NS	2.5	4.2	7.3	NS	8.4	NS
Cr-TD	NA	38	NS	NS	22	45	18	NS	79	NS
Cu-WAE	65	29	NS	NS	9.3	29	7	NS	47	NS
Cu-TD	NA	75	NS	NS	38	80	12	NS	73	NS
Hg-WAE	0.15	0.02	NS	NS	0.07	0.06	0.01	NS	0.04	NS
Hg-TD	NA	0.94	NS	NS	0.67	1.2	0.05	NS	1.4	NS
Ni-WAE	24	31	NS	NS	4.5	8.8	2.0	NS	13	NS
Ni-TD	NA	54	NS	NS	22	33	6.3	NS	51	NS
Pb-WAE	50	220	NS	NS	88	460	1.8	NS	230	NS
Pb-TD	NA	260	NS	NS	130	550	2.0	NS	290	NS
Se-WAE	0.29	0.19	NS	NS	0.22	0.23	0.11	NS	0.23	NS
Se-TD	NA	0.73	NS	NS	0.76	0.69	0.17	NS	0.78	NS
Zn-WAE	200	690	NS	NS	66	660	41	NS	330	NS
Zn-TD	NA	960	NS	NS	310	1,680	65	NS	800	NS

🟧 > UpRiv TV = Potential Risk

WAE – Weak Acid Extractable, TD – Total Digest NA – TV Not applicable NS – Not sampled

5 BACKGROUND ENVIRONMENTAL CONDITIONS AND TRIGGER VALUES

The environmental conditions of all natural systems will change throughout time due to natural variations in climate, geography and biology. An objective of the care and maintenance environment report is to determine how much change has occurred within the environment at reference sites downstream of the Porgera Mine not affected by mine inputs.

Operational activities that have the potential to interact with the environment (the environmental aspects) have been discussed and quantified in Section 4.

The purpose of this section is to quantify the natural, non-mine related changes within the environment adjacent to and downstream of the Porgera mine during C&M. This information is then used to determine what degree of change observed at the test sites is attributable to natural change and what degree is attributable to the mine environmental aspects. The objectives of this section are to:

1. Quantify the climatic condition, meteorological and hydrological conditions at the mine site and within the receiving environment between January 2021 and May 2022;
2. Describe the background environmental physical, chemical and biological conditions of aquatic ecosystems not influenced by the operation (i.e. reference site condition) and identify and quantify the natural changes at those sites during the period and the past 10 years of operation; and
3. Establish risk assessment and impact assessment TVs and performance criteria for physical, chemical and biological conditions at Upper River, Lower River, ORWBs and Lake Murray to support the compliance, risk and impact assessments in Sections 6, 7 and 8 respectively.

5.1 Climate

Monitoring of rainfall around the mine site and along the river system continued during the care and maintenance period. The sites monitored include Anawe, Open Pit, and at SG3 compliance monitoring point on the Strickland River.

5.1.1 Rainfall Summary

5.1.1.1 Anawe plant site

Figure 5-1 and Figure 5-2 show monthly total rainfall at Anawe plant site between January 2021 and May 2022 against long-term monthly means. Below average monthly rainfall was experienced in February, March and April of 2022, otherwise, monthly rainfall during this period was consistent with historical records.

Annual rainfall in 2021 was 3,744 mm against a long-term mean of 3,766 mm, total rainfall from January to May 2022 is below the monthly averages. The historical rainfall at Anawe is shown in Figure 5-3.

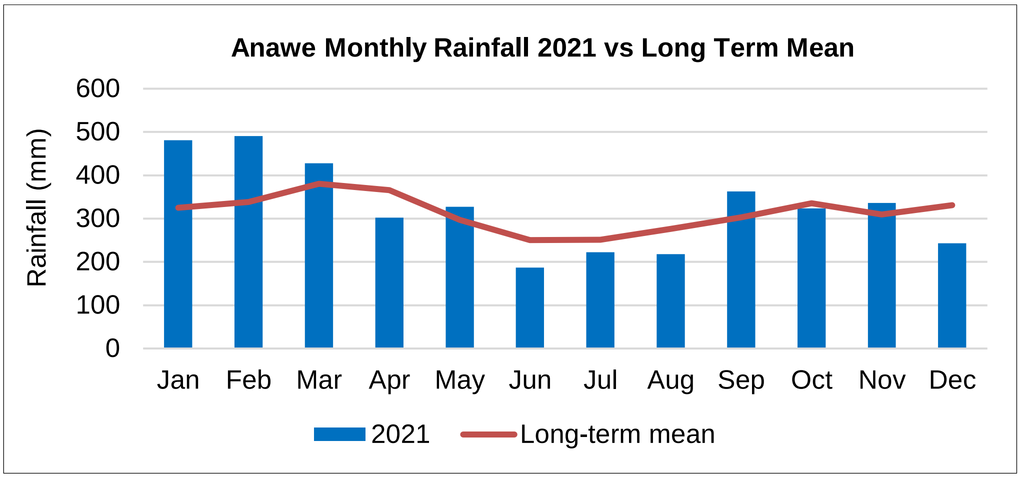


Figure 5-1 Monthly rainfall at Anawe Plant site during 2021 compared to long-term monthly means

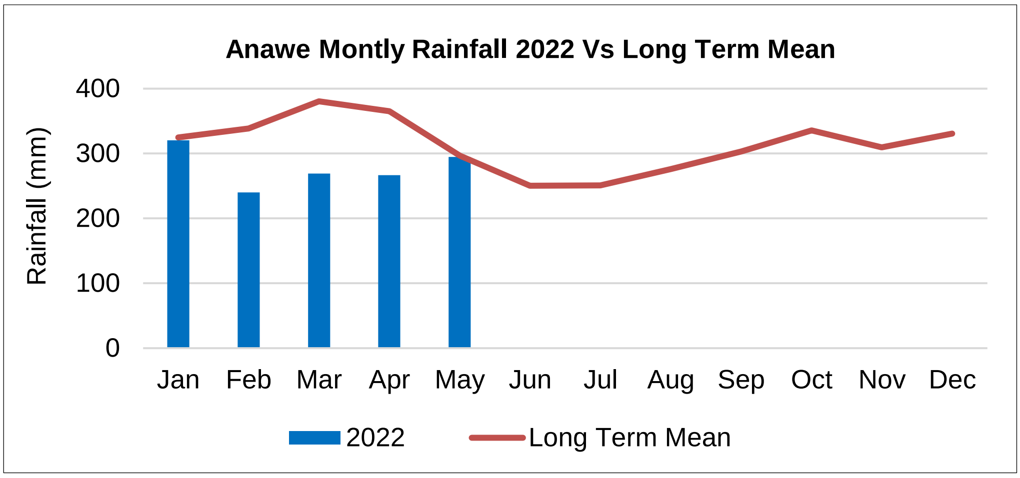


Figure 5-2 Monthly rainfall at Anawe Plant site during 2022 compared to long-term monthly means

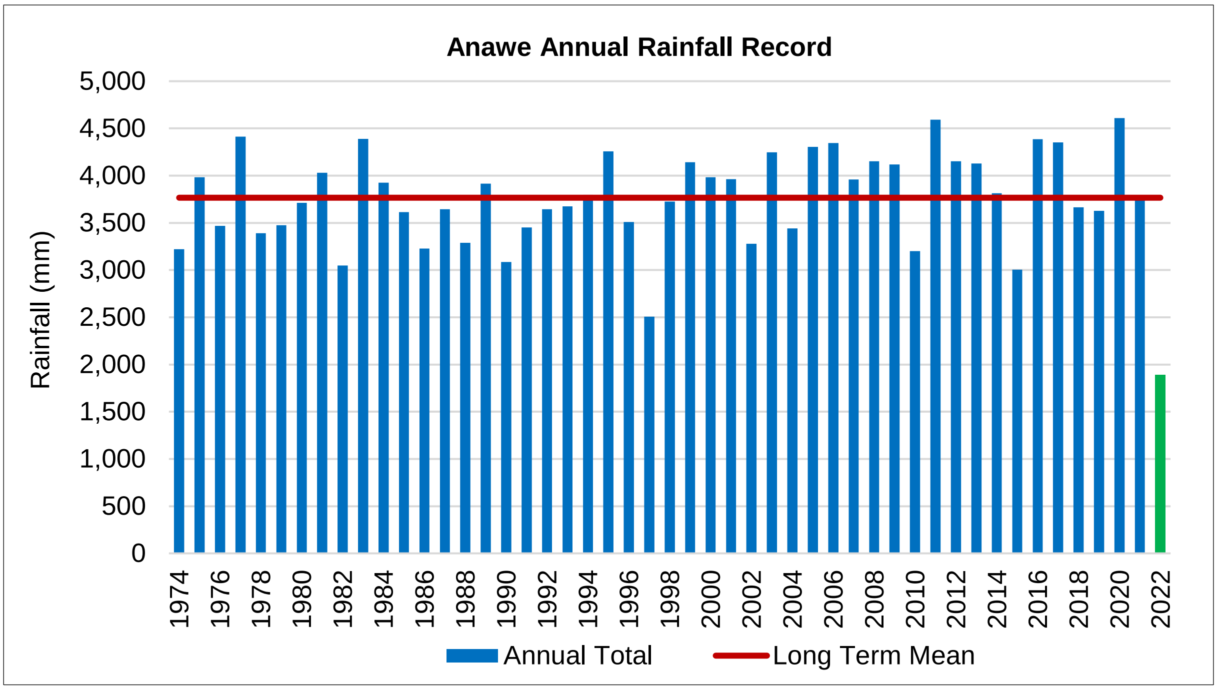


Figure 5-3 Comparison of annual total rainfall at Anawe Plant site with long-term annual means (LTM) 1974 – 2022. NB Data for 2022 is January to May (inclusive) only

5.1.1.2 Open pit

Figure 5-4 and Figure 5-5 shows total monthly rainfall at the Open pit between January 2021 and May 2022 against long-term monthly means. Below average monthly rainfall was experienced in April, May, June, August and December of 2021 otherwise, monthly rainfall during this period was consistent with historical records.

Annual rainfall in 2021 was 4,085 mm against a long-term mean of 3,766 mm, total rainfall from January to May 2022 is below the monthly averages. Figure 5-6 shows the historical annual totals.

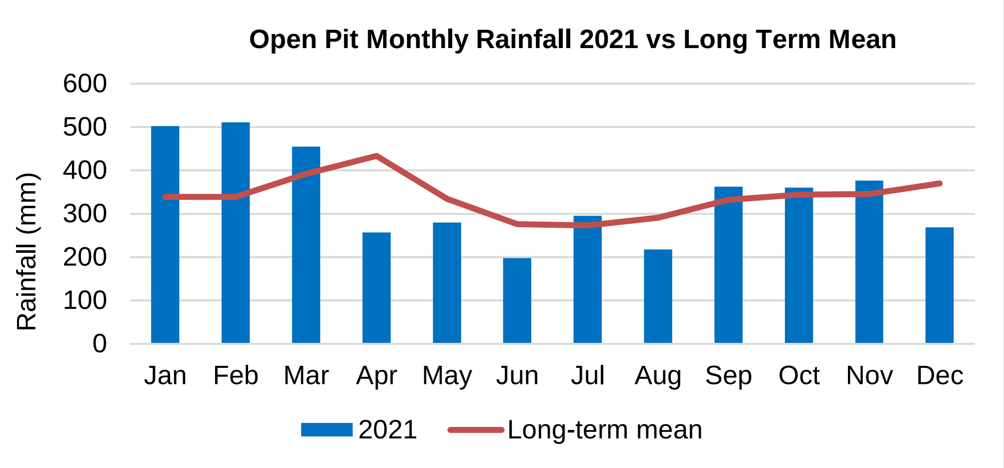


Figure 5-4 Rainfall at the Open Pit during 2021 compared to long-term monthly means

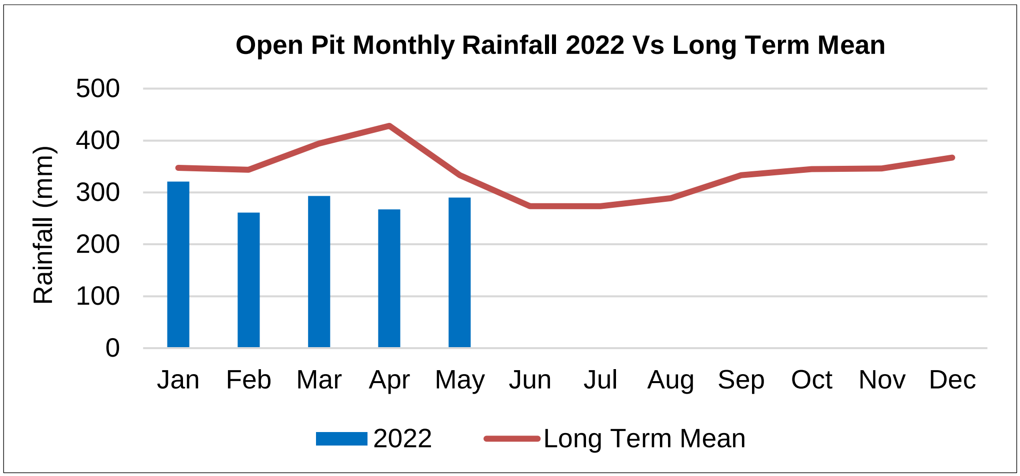


Figure 5-5 Rainfall at the Open Pit during 2022 compared to long-term monthly means

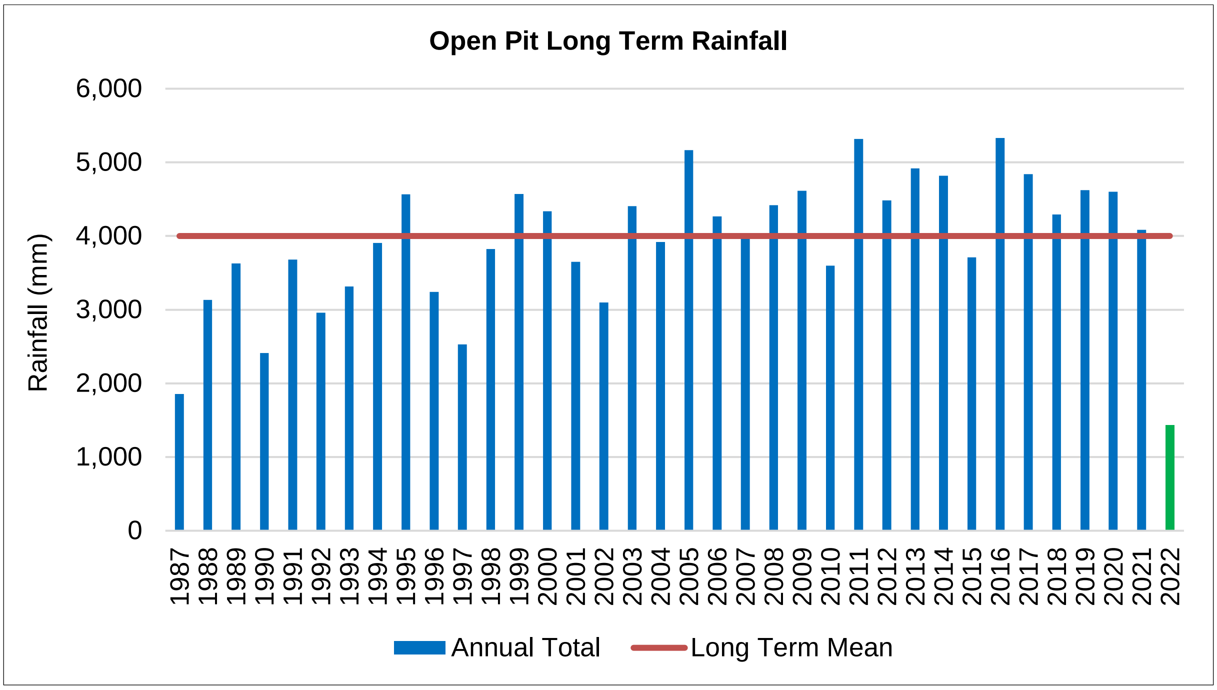


Figure 5-6 Comparison of annual total rainfall at Open Pit site with long-term annual means (LTM) 1987–2022. NB Data for 2022 is January to May (inclusive) only

5.1.1.3 SG3

Figure 5-7 and Figure 5-8 shows total monthly rainfall at SG3 between January 2021 and May 2022 against long-term monthly means. Above average monthly rainfall was experienced throughout 2021 and below average monthly rainfall was experienced in February, March, April and May of 2022.

Annual rainfall in 2021 was 2,664 mm against long-term mean of 1,774 mm, total rainfall in 2022 is below the year to date average, Figure 5-9 shows the historical annual totals.

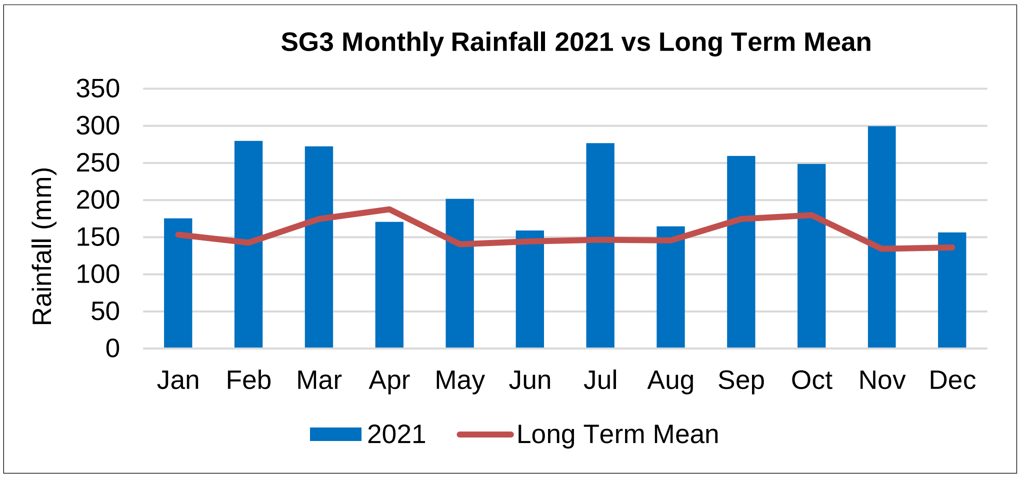


Figure 5-7 Rainfall at SG3 during 2021 compared to long-term monthly means

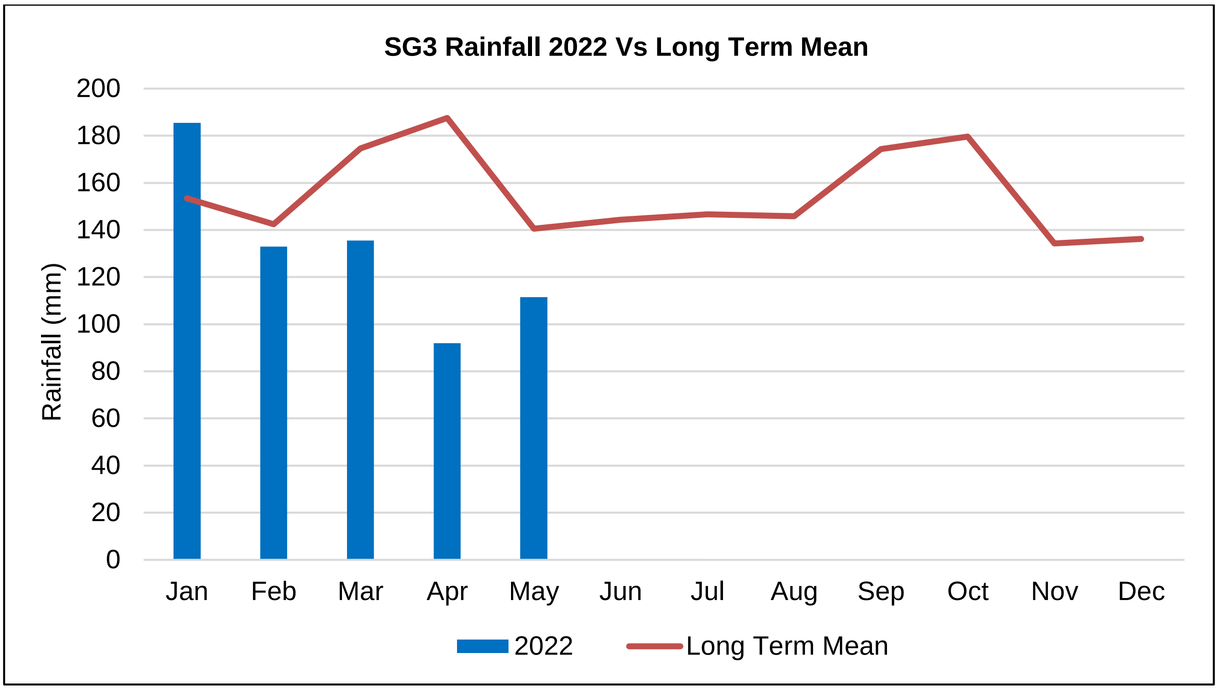


Figure 5-8 Rainfall at SG3 during 2022 compared to long-term monthly means

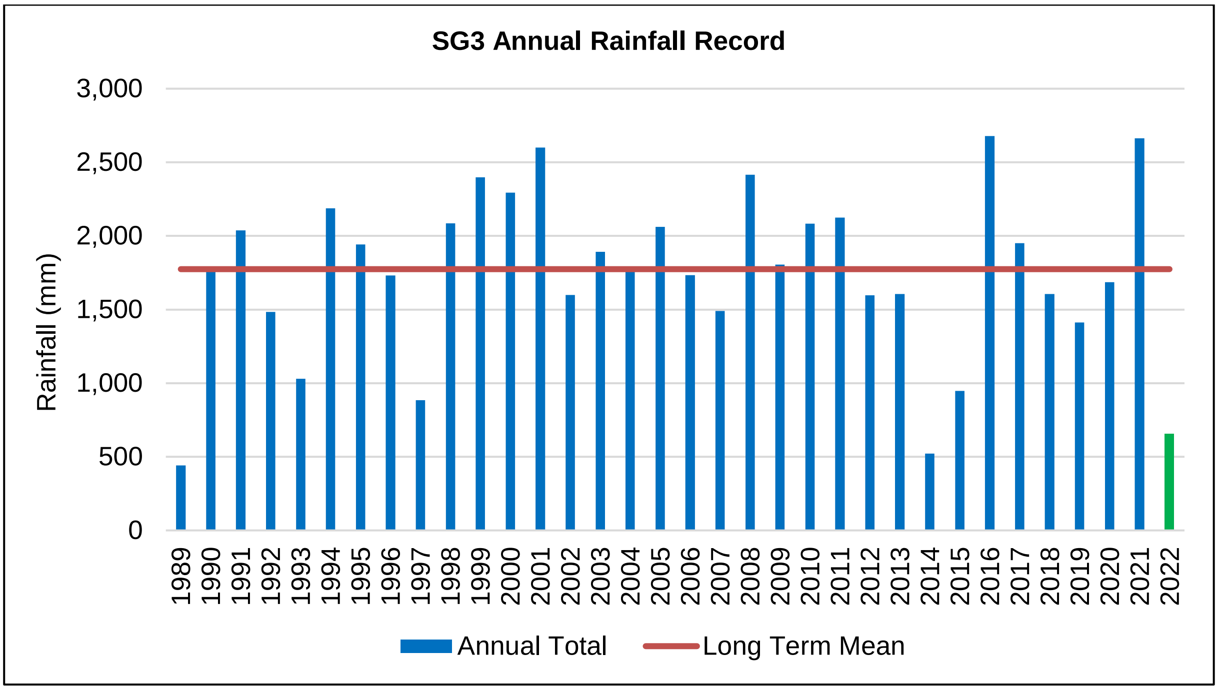


Figure 5-9 Comparison of annual total rainfall at SG3 with long-term annual means (LTM) 1989–2022. NB Data for 2022 is January to May (inclusive) only

5.2 Background Water Quality and Trigger Values

This section presents a comparison of water quality data collected at test sites prior to mining operations commencing (baseline data), with data collected from reference sites during the previous 24-months and the guideline values for 95% species protection from ANZG (2018).

In accordance with the methodology outlined in Section 2.3 of this report, the data are compared and the highest value for each parameter is then adopted as the 2022 TV for use in the water quality risk assessment presented in Section 7. The sites are grouped into regions; Upper River, Lower River, ORWBs and Lake Murray, to support development of specific TVs for each region.

Data from local reference sites are presented to describe the quality of non-mine-related contributions to the receiving environment and are not used to derive receiving environment TVs.

Note that monitoring at all reference sites was not conducted throughout the entire C&M period due to logistical and safety challenges. Monitoring at reference sites was conducted monthly up until April 2020 when the site was placed into care and maintenance. Monitoring at reference sites re-commenced in December 2021 and continues on a monthly basis. Therefore, reference site data are not available for the 18 month from May 2020 to November 2021. To achieve the required number of samples to support derivation of the TVs, it has therefore been necessary to use data collected from reference sites prior to the C&M period, while the site was still in operation. The nature of the reference sites, being free of mine-related inputs, means that it is considered appropriate to use pre-C&M data from the reference sites to support TV derivation.

Water quality TVs for metals were established based on the dissolved concentrations. Dissolved concentrations are a better measure of the concentration of metal that is bioavailable and therefore have the potential to cause toxicity. Total metals concentrations include bioavailable, non-bioavailable and particle-bound metals, the use of total metals concentrations will overestimate the fraction that is bioavailable and therefore overestimate potential toxicity.

5.2.1 Upper River

This section presents the water quality data for the upper river region collected from test sites prior to mining operations commencing (baseline data), the most recent 24 months data from the reference sites and default guideline values from ANZG (2018).

In accordance with Section 2.3 of this report, the data are compared and the highest is then adopted as the 2022 TV for use in the water quality risk assessment presented in Section 7. Data summaries and presentation of water quality TVs for the upper river reference sites are presented in Table 5-1.

Reference site data used for comparison are generated by combining the data from each of the upper river reference sites; Upper Lagaip, Pori, Kuru and Ok Om. Reference sites within the upper river region exhibited slightly alkaline pH, occasionally elevated TSS and the presence of arsenic, chromium, copper, iron, nickel, lead and zinc.

Analysis of trends between 2013 and 2022 indicate that most parameters reduced at the reference sites, the exception being pH and dissolved zinc which showed an increasing trend. Trend analysis results are shown in Table 5-2 and graphical representation of dissolved and total zinc and pH data from each site showing increasing and decreasing trends respectively are presented in Figure 5-10.

Baseline data in the upper river region exhibited alkaline pH and elevated concentrations of TSS, dissolved arsenic, copper, iron, mercury, lead and zinc compared to the upper river reference sites. This indicates that baseline water quality within the Porgera-Lagaip-Strickland catchment, which hosts the Porgera deposit at its headwaters, was characterised by naturally elevated concentrations of dissolved and total metals prior to mining commencing compared to the regional reference sites.

Upon comparison of reference and baseline data with the ANZG (2018) GVs for 95% species protection, the highest values for each indicator and therefore the value adopted as the 2022 TV were from the following sources:

- Reference site data: pH, EC
- Baseline data: TSS, dissolved iron, nickel and zinc
- ANZG (2018) GVs: Dissolved silver, arsenic, cadmium, chromium, copper, mercury, lead and selenium.

Table 5-1 Summarised water quality for upper river test sites for baseline, and reference sites for the C&M period presenting 20th%ile, median and 80th%ile of data for each site. ANZG (2018) default GV for 95% species protection provided for comparison (µg/L except where indicated)

Parameter	UpRiv Ref 24 month (n=148)			SG1 Baseline (n=15)			SG2 Baseline (n=24)			SG3 Baseline (n=25)			Baseline SG1, SG2 & SG3 (n=64)			ANZG (2018) 95%	UpRiv TV
	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80%ile		
pH^	7.5	7.8	8.2	7.8	8.0	8.1	7.7	7.9	8.2	7.8	7.9	8.1	7.8	7.9	8.1	6.0-8.0	6.0-8.2
EC$^{\#}$	136	190	219	168	180	190	178	185	226	176	188	204	170	185	202	NA	219
Sulfate*	6.0	13	29	10	12	16	18	21	31	28	30	34	15	22	32		
Alk-T**	49	70	103	110	117	122	110	150	263	96	106	124	106	117	169		
TSS*	63	265	1100	222	401	2496	258	1462	4874	743	1428	2663	258	1188	2837	NA	2837
Hardness**	56	73	108	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
Ag-D	0.01	0.01	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05	0.05
Ag-T	0.01	0.037	0.08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
As-D	0.39	0.50	0.67	ND	ND	ND	1.7	1.7	1.7	0.5	0.5	1.2	0.5	0.5	1.7	24	24
As-T	0.80	2.5	11.0	1.8	3.5	11	2.0	3.7	10	4.2	9	15	2	5.5	13		
Cd-D	0.05	0.05	0.05	ND	ND	ND	0.05	0.05	0.05	ND	ND	ND	0.05	0.05	0.05	0.35***	0.35
Cd-T	0.05	0.05	0.090	0.2	0.2	0.4	0.2	0.2	0.4	0.2	0.6	1	0.2	0.2	0.8		
Cr-D	0.17	0.33	0.7	ND	ND	ND	133	133	133	ND	ND	ND	0.5	0.5	0.5	1.0	1.0
Cr-T	2.0	10	40	ND	ND	ND	0.5	0.5	0.5	ND	ND	ND	133	133	133		
Cu-D	0.32	0.57	1	1.1	1.2	1.4	0.56	0.9	7.2	1	1.7	4.3	0.98	1.4	4.1	1.4	1.4
Cu-T	1.4	7.5	28	5.2	15	66	8.8	41	146	7.4	36	68	7	29	82		
Fe-D	6.7	13	28	75	75	75	57	75	75	75	75	75	75	75	75	NA	75
Fe-T*	1.8	10	39	14	17	104	13	40	203	23	64	118	13	44	148		
Hg-D	0.05	0.05	0.06	ND	ND	ND	0.2	0.2	0.2	0.05	0.05	0.05	0.08	0.13	0.17	0.60	0.60
Hg-T	0.05	0.05	0.094	0.10	0.10	0.16	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1		
Ni-D	0.5	0.6	0.8	13	15	15	5.7	9.1	15	11	15.7	23	10	15	21	19***	21
Ni-T	1.8	13	50	16	16	16	20	20	179	10	12	94	12	20	90		
Pb-D	0.1	0.1	0.26	0.30	0.30	0.64	0.26	0.30	0.38	0.3	0.3	1.3	0.3	0.3	1.0	7.5***	7.5
Pb-T	0.83	4	20	4.36	12	160	6.1	18	139	3.6	23	59	4.4	19	82		
Se-D	0.2	0.2	0.2	ND	ND	ND	0.07	0.07	0.07	ND	ND	ND	0.07	0.07	0.07	11	11
Se-T	0.2	0.20	0.73	ND	ND	ND	0.25	0.25	0.25	ND	ND	ND	0.25	0.25	0.25		
Zn-D	1.0	2.4	6.7	0.18	0.2	0.42	0.28	0.40	0.64	0.8	4.3	25	0.48	1.4	20	14***	20
Zn-T	4.4	23	100	25	77	374	30	79	623	45	131	249	26	103	376		

^ std units, $^{\#}$µS/cm, *mg/L, **mg CaCO3/L, ***Hardness modified, D – Dissolved fraction, T – Total fraction, NA – Not applicable, ND – Not determined

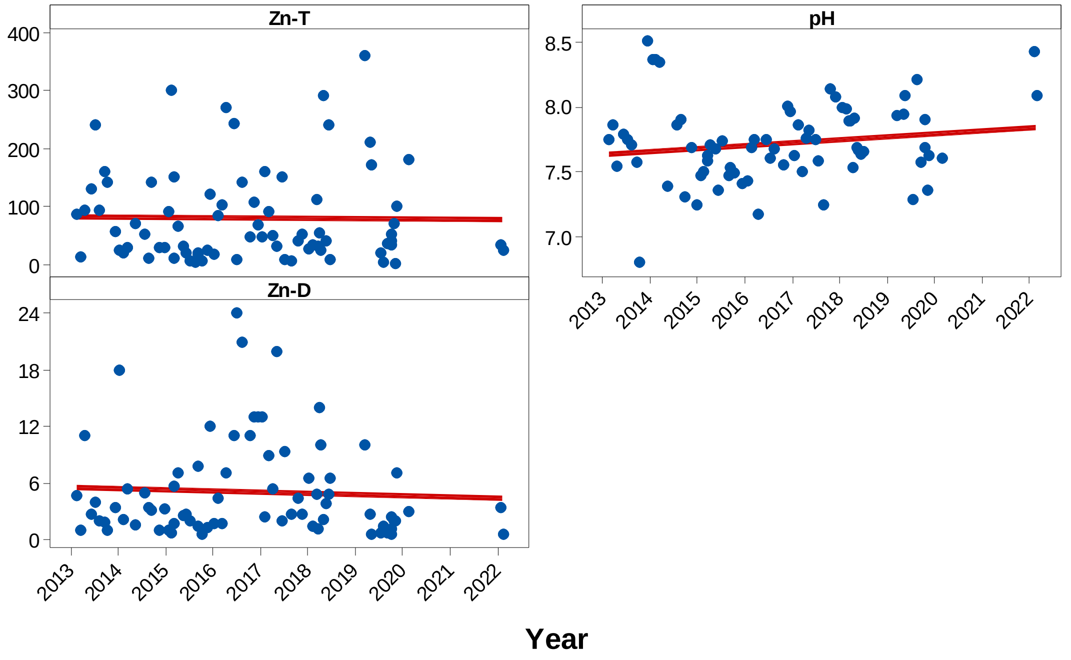
Baseline data were collected from the test sites prior to mine operations commencing

Table 5-2 Trends for water quality at upper river reference sites 2013-2022 as determined by Spearman Rank correlation against time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2022)
Upper River Ref (Trend of all data from 2013 - 2022)	pH	0.394	<0.001	Increased over time
	EC	-0.141	0.002	Reduced over time
	TSS	0.070	0.131	No change over time
	Ag-D*	-0.720	<0.001	Reduced over time
	Ag-T	-0.505	<0.001	Reduced over time
	As-D*	-0.396	<0.001	Reduced over time
	As-T	-0.023	0.611	No change over time
	Cd-D*	-0.627	<0.001	Reduced over time
	Cd-T	-0.426	<0.001	Reduced over time
	Cr-D*	-0.211	<0.001	Reduced over time
	Cr-T	-0.047	0.314	No change over time
	Cu-D*	-0.377	<0.001	Reduced over time
	Cu-T	-0.047	0.308	No change over time
	Fe-D	-0.027	0.566	No change over time
	Fe-T	-0.029	0.536	No change over time
	Hg-D*	-0.121	0.009	Reduced over time
	Hg-T	-0.104	0.024	Reduced over time
	Ni-D*	-0.197	<0.001	Reduced over time
	Ni-T	-0.037	0.417	No change over time
	Pb-D*	-0.360	<0.001	Reduced over time
	Pb-T	-0.021	0.655	No change over time
	Se-D*	-0.570	<0.001	Reduced over time
	Se-T*	-0.306	<0.001	Reduced over time
	Zn-D	0.102	0.027	Increased over time
	Zn-T	-0.028	0.548	No change over time

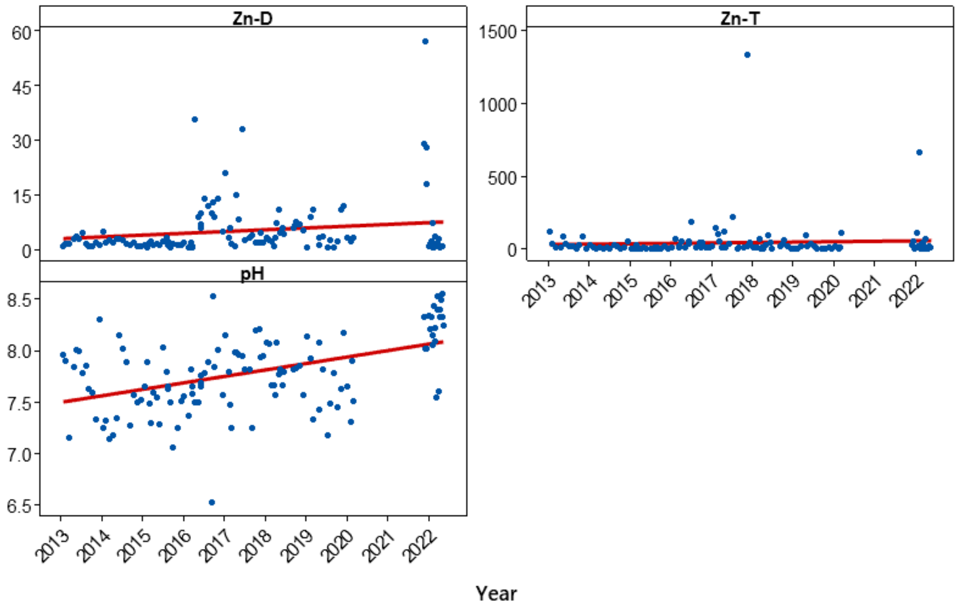
D - Dissolved fraction, T - Total fraction

* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate no change over time, which is representative of actual conditions.



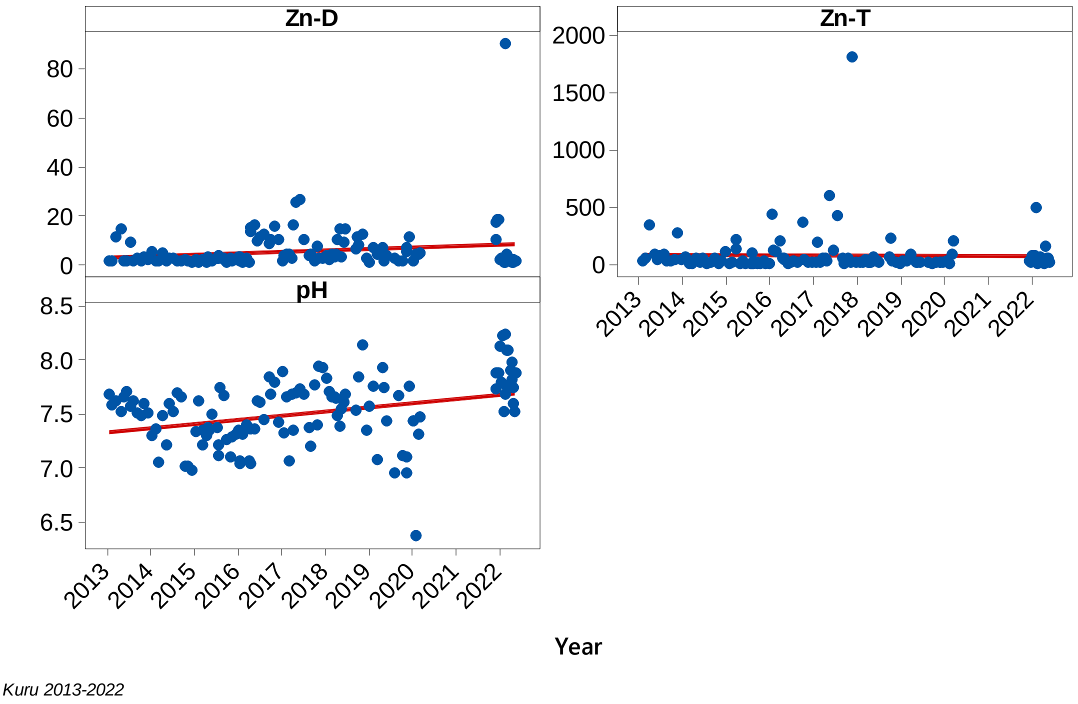
Upper Lagaip 2013-2022

Upper Lagaip dissolved and total zinc concentrations (µg/L) and pH 2013 - 2022 (Ref site)

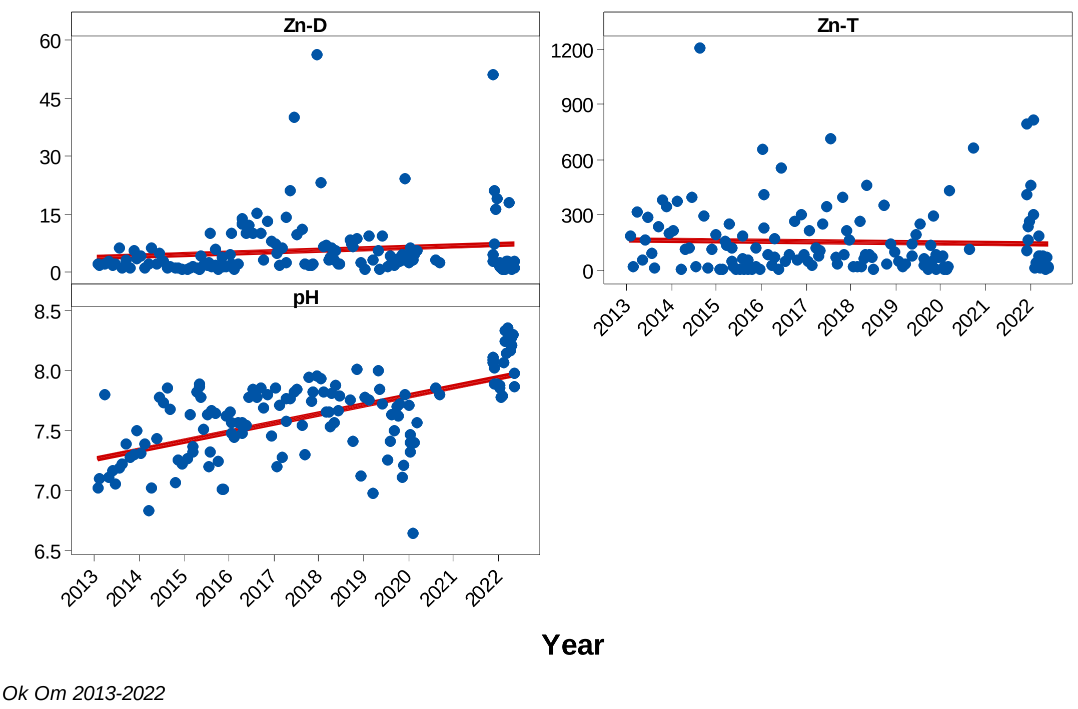


Pori 2013-2022

Pori dissolved and total zinc concentrations (µg/L) and pH 2013 - 2022 (Ref site)



Kuru dissolved and total zinc concentrations (µg/L) and pH 2013 - 2022 (Ref site)



Ok Om dissolved and total zinc concentrations (µg/L) and pH 2013 - 2022 (Ref site)

Figure 5-10 Trend analysis Upper River reference sites water quality (scatter plot of all data from 2013 – 2022 with linear trend line)

5.1.1 Lower River & Off-River Water Bodies

This section presents the water quality data for the lower river region collected from test sites prior to mining operations commencing (baseline data), from the most recent 24-months data from the reference sites and default guideline values from ANZG (2018).

In accordance with Section 2.3 of this report, the data are compared and the highest is then adopted as the 2022 TV for use in the water quality risk assessment for test sites in the lower river region and ORWBs, which is presented in Section 7. Data summaries and presentation of water quality TVs for the lower river and ORWBs are presented Table 5-3.

Reference data were generated by combining the data from each of the lower river reference sites; Baia and Tomu. Reference sites within the lower river region exhibited occasionally elevated TSS and the presence of arsenic, chromium, copper, iron, nickel, lead and zinc.

Analysis of trends between 2013 and 2022 indicated that most parameters either reduced or stayed constant at the reference sites, with the exception of TSS and total chromium, copper, iron and zinc, which showed an increasing trend at both sites. Trend analysis results are shown in Table 5-4 and graphical representation of TSS and total chromium, copper, iron and zinc data from each site showing trends is presented in Figure 5-11.

Baseline data in the lower river region exhibited similar conditions to the reference sites in the most recent 24 months with alkaline pH, elevated concentrations of TSS and the presence of arsenic, chromium, copper, iron, nickel, lead and zinc. These results indicate some natural mineralisation in the lower river region although at lower concentrations than the upper river region.

Upon comparison of reference and baseline data with the ANZG (2018) GVs for 95% species protection, the highest values for each indicator and therefore the value adopted as the 2022 TV were from the following sources:

- Reference site data: EC.
- Baseline data: TSS, dissolved iron and nickel.
- ANZG (2018) GVs: Dissolved silver, arsenic, cadmium, chromium, copper, mercury, lead, selenium and zinc.

Table 5-3 Summarised water quality for lower river test sites for baseline and reference sites for previous 24 months, presenting 20th%ile, median and 80th%ile of data for each site. ANZG (2018) default GV for 95% species protection provided for comparison (µg/L except where indicated)

Parameter	**LwRiv Ref 24 Month (n=33)**			**Baseline LwRiv (n=36)**			**ANZG (2018) 95%**	**LwRiv & ORWB TV**
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
pH^	7.0	7.4	7.7	7.8	8.0	8.1	6.0-8.0	6.0-8.1
EC$^{\#}$	50	110	175	140	150	170	250	175
Sulfate*	2.0	4.0	6.6	10	15	18		
ALK-T**	26	62	74	83	93	101		
TSS*	40	98	822	326	638	983	NA	983
Hardness**	18	45	81	ND	ND	ND		
Ag-D	0.01	0.01	0.02	ND	ND	ND	0.05	0.05
Ag-T	0.01	0.01	0.06	ND	ND	ND		
As-D	0.11	0.43	0.92	0.60	0.70	0.80	24	24
As-T	0.26	1.1	9.0	3.5	5.5	8.0		
Cd-D	0.05	0.05	0.05	0.07	0.08	0.09	0.20	0.20
Cd-T	0.05	0.05	0.21	0.60	0.90	1.0		
Cr-D	0.19	0.38	0.61	0.50	0.50	0.50	1.0	1.0
Cr-T	1.64	5.7	32	18	34	46		
Cu-D	0.45	0.65	0.93	0.50	0.85	1.4	1.4	1.4
Cu-T	1.8	5.3	23	8.0	18	26		

Parameter	LwRiv Ref 24 Month (n=33)			Baseline LwRiv (n=36)			ANZG (2018) 95%	LwRiv & ORWB TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
Fe-D	6.9	17	25	0.64	75	75	NA	75
Fe-T*	2.02	5.7	31	17	37	49		
Hg-D	0.05	0.05	0.06	ND	ND	ND	0.60	0.60
Hg-T	0.05	0.05	0.09	0.10	0.10	0.10		
Ni-D	0.50	0.50	0.65	3.6	10	15	11	15
Ni-T	1.92	6.0	38	10	23	24		
Pb-D	0.10	0.10	0.16	0.30	0.50	0.70	3.4	3.4
Pb-T	0.62	2.00	11	5.6	10	19		
Se-D	0.20	0.20	0.20	0.20	0.25	0.30	11	11
Se-T	0.20	0.20	0.38	0.20	0.20	0.50		
Zn-D	1.2	1.9	7	0.50	1.0	2.9	8.0	8.0
Zn-T	8.1	17	74	28	68	94		

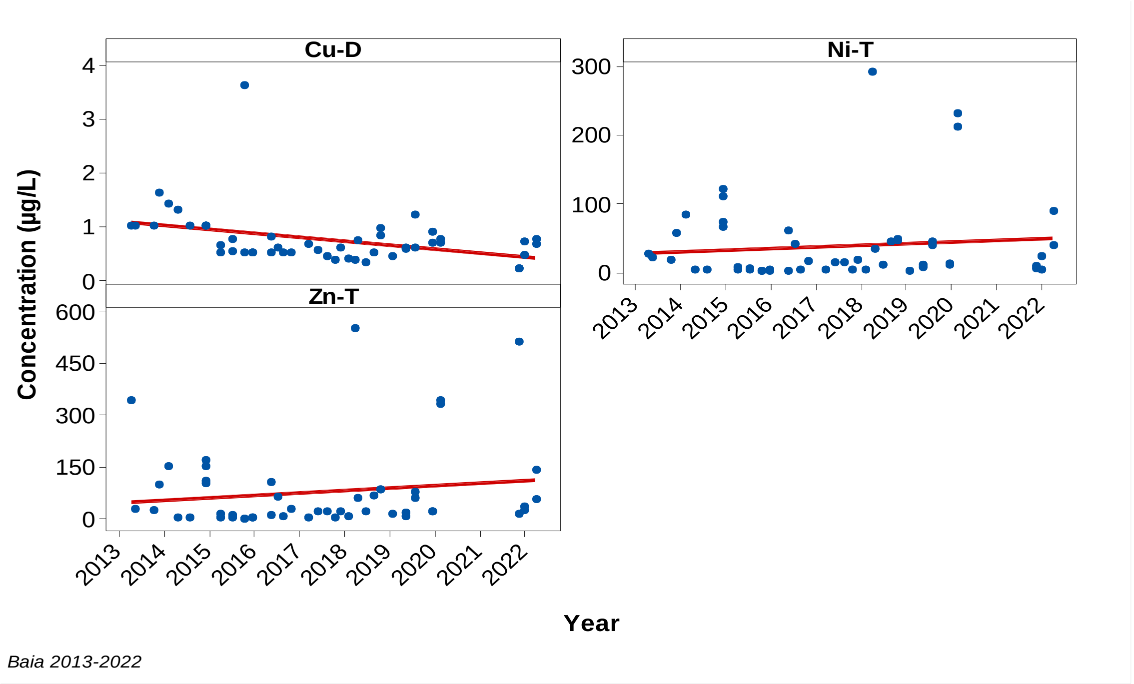
^ std units, $^{\#}$µS/cm, *mg/L, **mg CaCO3/L, D – Dissolved fraction, T – Total fraction, NA – Not applicable, ND – Not determined

Table 5-4 Trends for water quality at lower river reference sites 2013-2022 as determined by Spearman Rank correlation against time

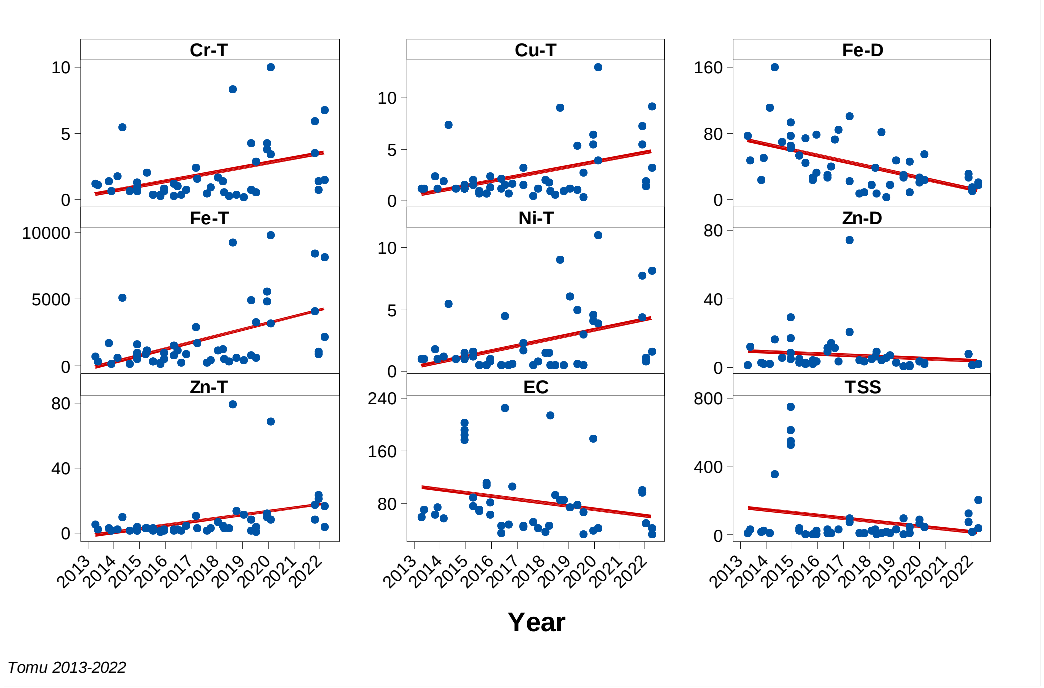
Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2022)
Lower River Ref (Trend of all data from 2013 - 2022)	pH	-0.061	0.552	No change over time
	EC	-0.094	0.362	No change over time
	TSS	0.245	0.016	Increased over time
	Ag-D*	-0.785	<0.001	Reduced over time
	Ag-T*	-0.580	<0.001	Reduced over time
	As-D*	-0.391	<0.001	Reduced over time
	As-T*	-0.047	0.644	No change over time
	Cd-D*	-0.700	<0.001	Reduced over time
	Cd-T*	-0.250	0.012	Reduced over time
	Cr-D*	-0.112	0.269	No change over time
	Cr-T	0.203	0.044	Increased over time
	Cu-D*	-0.410	<0.001	Reduced over time
	Cu-T	0.236	0.018	Increased over time
	Fe-D	-0.362	<0.001	Reduced over time
	Fe-T	0.257	0.01	Increased over time
	Hg-D*	-0.127	0.207	No change over time
	Hg-T*	-0.167	0.098	No change over time
	Ni-D*	-0.376	<0.001	Reduced over time
	Ni-T	0.187	0.063	No change over time
	Pb-D*	-0.501	<0.001	Reduced over time
	Pb-T	0.172	0.088	No change over time
	Se-D*	-0.718	<0.001	Reduced over time
	Se-T*	-0.414	<0.001	Reduced over time
	Zn-D	-0.182	0.070	No change over time
	Zn-T	0.313	0.001	Increased over time

D - Dissolved fraction, T - Total fraction

* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate no change over time, which is representative of actual conditions.



Baia dissolved copper, total nickel and zinc concentrations (µg/L) 2013 - 2022 (Ref site)



Tomu dissolved iron and zinc (µg/L), conductivity (µS/cm), TSS (mg/L), and total chromium, copper, iron, nickel and zinc concentrations (µg/L) 2013 - 2022 (Ref site)

Figure 5-11 Trend analysis Lower River reference sites water quality (scatter plot of all data from 2013 – 2022 with linear trend line)

5.2.2 Lake Murray

This section presents the water quality data for Lake Murray collected from test sites prior to mining operations commencing (baseline data), the most recent 24-months data from the reference sites and default guideline values from ANZG (2018).

In accordance with Section 2.3 of this report, the data are compared and the highest is then adopted as the 2022 TV for use in the water quality risk assessment presented in Section 7. Data summaries and presentation of water quality TVs for Lake Murray are presented Table 5-5.

Reference data were generated from the North Lake Murray region. Reference sites exhibited neutral pH, low TSS and low concentrations of most metals with the notable presence of detectable concentrations copper, mercury and zinc.

Analysis of trends between 2013 and 2022 indicate that most parameters remained constant at the reference sites, with the exception of pH and dissolved zinc which showed an increasing trend. Trend analysis results are shown in Table 5-6.

Baseline data in the Lake Murray regions exhibited similar conditions to the reference sites in the most recent 24 months. These results indicate some natural mineralisation in Lake Murray although at lower concentrations than the upper river region.

Upon comparison of reference and baseline data with the ANZG (2018) GVs for 95% species protection, the highest values for each indicator and therefore the value adopted as the 2022 TV were from the following sources.

- Reference site data: EC.
- Baseline data: TSS, dissolved cadmium, iron and zinc
- ANZG (2018) GVs: Dissolved silver, arsenic, chromium, copper, mercury, nickel, lead and selenium.

Table 5-5 Summarised water quality data for Lake Murray test sites for baseline and reference sites for previous 24 months, presenting 20th%ile , median and 80th%ile of data for each site. ANZG (2018) default GV for 95% species protection provided for comparison (µg/L except where indicated)

Parameter	NORTHERN LAKE MURRAY (n=40)			Lake Murray (LM1) Baseline (n=10)			Lake Murray (LM2) Baseline (n=10)			Lake Murray LM1 and LM2 Baseline (n=20)			LMY ORWBs REF	LMY ORWBs Baseline	ANZG (2018) 95%	LMY TV
	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80%ile	20%ile	Median	80%ile				
pH	5.1	6.6	7.2	6.3	6.4	6.4	6.3	6.4	6.6	6.3	6.4	6.6	5.1-7.2	6.3-6.6	6.0-8.0	5.1-8.0
EC#	14	17	21	15	15	15.5	15	15	15.5	15	15	15.5	21	16	250	21
Sulfate	1.0	2.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0				
ALK-T*	7.0	10	13	7.7	8.1	8.8	7.9	8.1	8.5	7.8	8.1	8.7				
TSS*	2.0	3.0	7.0	6.0	7.0	9.0	4.6	6.0	8.2	5.4	6.5	9.0	7	9.0	NA	9
Hardness*	5.0	5.0	7.0	ND	ND	ND	ND	ND	ND	ND	ND	ND				
Ag-D	0.01	0.01	0.02	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.02	ND	0.05	0.05
Ag-T	0.01	0.01	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND				
As-D	0.12	0.13	0.14	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.14	0.50	24	24
As-T	0.17	0.21	0.23	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50				
Cd-D	0.05	0.05	0.05	0.10	0.20	0.80	0.10	0.10	0.64	0.10	0.10	0.72	0.05	0.72	0.20	0.72
Cd-T	0.05	0.05	0.05	2.0	4.1	5.1	0.4	1.1	1.3	0.70	1.4	4.8				
Cr-D	0.11	0.18	0.33	0.10	0.10	0.44	0.10	0.10	0.20	0.10	0.10	0.40	0.33	0.40	1.0	1.0
Cr-T	0.26	0.34	0.47	0.10	0.10	0.4	0.10	0.25	1.3	0.10	0.15	0.60				
Cu-D	0.28	0.33	0.53	0.10	0.10	0.10	0.10	0.10	0.20	0.10	0.10	0.10	0.53	0.10	1.4	1.4
Cu-T	0.31	0.45	0.63	0.26	0.40	0.80	0.10	0.30	0.52	0.10	0.30	0.70				
Fe-D	58	110	172	138	255	342	166	230	324	148	250	340	172	340	NA	340
Fe-T	606	990	1416	762	1005	1072	898	945	1024	898	980	1072				
Hg-D	0.05	0.05	0.08	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.08	ND	0.60	0.60
Hg-T	0.05	0.05	0.06	0.30	0.30	0.3	0.30	0.30	0.30	0.30	0.30	0.30				
Ni-D	0.50	0.50	0.50	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.50	1.0	11	11
Ni-T	0.50	0.50	0.58	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0				
Pb-D	0.10	0.10	0.18	0.20	0.20	0.7	0.20	0.20	0.62	0.20	0.20	0.70	0.18	0.70	3.4	3.4
Pb-T	0.10	0.12	0.19	0.50	1.0	1.9	0.40	0.80	1.4	0.38	0.90	1.7				
Se-D	0.20	0.20	0.20	0.70	0.80	0.9	0.70	0.70	0.80	0.70	0.70	0.90	0.20	0.90	11	11
Se-T	0.20	0.20	0.20	0.90	0.90	0.9	0.70	0.80	1.0	0.70	0.90	1.0				
Zn-D	1.7	4.7	7.5	0.05	0.05	0.14	0.05	0.50	1.0	0.05	0.08	0.80	7.5	0.80	8.0	8.0
Zn-T	0.9	1.8	6.0	1.2	2.0	2.7	1.3	2.0	2.88	1.3	2	2.8				

^ std units, #µS/cm, *mg/L, **mg CaCO3/L, D – Dissolved fraction, T – Total fraction, NA – Not applicable, ND – Not determined

Baseline data were collected from the test sites prior to mine operations commencing.

Table 5-6 Trends for water quality in Lake Murray 2013 - 2022 as determined using Spearman Rank Correlation against time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2022)
Lake Murray Ref (Trend of all data from 2013 - 2022)	pH	0.215	0.053	No change over time
	EC	-0.363	0.001	Reduced over time
	TSS	-0.499	<0.001	Reduced over time
	Ag-D*	-0.488	<0.001	Reduced over time
	Ag-T*	-0.624	<0.001	Reduced over time
	As-D*	-0.588	<0.001	Reduced over time
	As-T*	-0.435	<0.001	Reduced over time
	Cd-D*	-0.271	0.014	Reduced over time
	Cd-T*	-0.615	<0.001	Reduced over time
	Cr-D*	-0.203	0.067	No change over time
	Cr-T*	-0.526	<0.001	Reduced over time
	Cu-D*	-0.603	<0.001	Reduced over time
	Cu-T*	-0.645	<0.001	Reduced over time
	Fe-D*	0.055	0.621	No change over time
	Fe-T*	0.158	0.155	No change over time
	Hg-D*	-0.135	0.226	No change over time
	Hg-T*	-0.010	0.930	No change over time
	Ni-D*	-0.443	<0.001	Reduced over time
	Ni-T*	-0.553	<0.001	Reduced over time
	Pb-D*	0.146	0.190	No change over time
	Pb-T*	-0.596	<0.001	Reduced over time
	Se-D*	-0.271	0.014	Reduced over time
	Se-T*	-0.620	<0.001	Reduced over time
	Zn-D	0.198	0.074	No change over time
	Zn-T	-0.179	0.108	No change over time

D - Dissolved fraction, T - Total fraction

* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate no change over time, which is representative of actual conditions.

5.3 Background Benthic Sediment Quality and Trigger Values

This section presents the sediment quality data collected from test sites prior to mining operations commencing (baseline data), the most recent 24 months data from the reference sites and revised ANZG (2018) sediment default guideline values (SDGVs) from Simpson et al (2013). In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2022 TV for use in the sediment quality risk assessment presented in Section 7. The sites are grouped into regions; Local Sites, Upper River, Lower River, ORWBs and Lake Murray.

Data from local reference sites are presented to describe the quality of non-mine-related contributions to the receiving environment and are not used to derive receiving environment TVs.

The weak-acid-extractable (WAE) metal concentrations from the whole sediment fraction have been used to develop the TVs as opposed to the total digest (TD). The WAE concentrations best represent the concentration of metals that are weakly bound and so likely to become bioavailable and therefore have potential to cause toxicity. Concentrations of total digestible metals include weakly and strongly bound sediment metals, and therefore the use of total digestible metals concentrations will overestimate the fraction likely to become readily bioavailable and therefore overestimate potential toxicity.

5.3.1 Upper River

This section presents sediment quality data collected from test sites prior to mining operations commencing (baseline data), the most recent 24 months data from the reference sites and revised SDGVs ANZG (2018) for the upper river region.

In accordance with Section 2.3 of this report, the data are compared and the highest is then adopted as the 2022 TV for use in the sediment quality risk assessment presented in Section 7. Note that baseline WAE metal concentrations are not available, therefore TD metals on the <63µm fraction are provided for comparison purposes only.

Reference data were generated by combining the data from each of the upper river reference sites; Upper Lagaip, Pori, Kuru and Ok Om. Reference sites within the upper river region exhibited detectable concentrations of arsenic, chromium, copper, nickel, lead and zinc.

Analysis of trends between 2013 and 2022 for TD and WAE metals shows increasing concentrations of WAE arsenic, WAE chromium, WAE copper, WAE lead, WAE nickel and WAE zinc. Concentrations of all other metals either reduced or did not change over the time period. Trend analysis results are shown in Table 5-8 and graphical representation of WAE arsenic, WAE chromium, WAE copper, WAE lead, WAE nickel and WAE zinc showing increasing trends is presented in Figure 5-12.

Baseline data in the upper river region exhibited detectable concentrations of chromium, copper, nickel, lead and zinc. This indicates that baseline sediment quality within the Porgera-Lagaip-Strickland catchment, which hosts the Porgera deposit at its headwaters, was characterised by naturally elevated concentrations of metals prior to mining commencing.

Upon comparison of reference and baseline data with the ANZG (2018) SDGVs, the highest values for each indicator and therefore the value adopted as the 2022 TV were from the following sources:

- Reference site data: WAE selenium and nickel
- SDGVs: WAE silver, arsenic, cadmium, chromium, copper, mercury, lead, zinc.

Table 5-7 Summarised sediment quality data for upper river reference sites for previous 24 months. SDGVs are provided for comparison (mg/kg dry, whole fraction)

Parameter	UpRivs Ref 24 month (n = 145)			UpRivs Baseline (<63µm) (n = 2)			ANZG (2018) SDGV	UpRiv TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
Ag-WAE	0.05	0.05	0.05	ND	ND	ND	1.0	1.0
Ag-TD	0.05	0.06	0.10	ND	ND	ND		
As-WAE	1.4	1.8	2.4	ND	ND	ND	20	20
As-TD	8.6	11	14	6.5	10	14		
Cd-WAE	0.05	0.05	0.062	ND	ND	ND	1.5	1.5
Cd-TD	0.05	0.05	0.080	0.06	0.08	0.098		
Cr-WAE	1.4	3.9	8.5	ND	ND	ND	80	80
Cr-TD	18	24	93	28	31	33		
Cu-WAE	4.0	6.3	14	ND	ND	ND	65	65
Cu-TD	14	24	44	133	175	217		
Hg-WAE	0.01	0.01	0.01	ND	ND	ND	0.15	0.15
Hg-TD	0.04	0.060	0.080	ND	ND	ND		

Parameter	UpRivs Ref 24 month (n = 145)			UpRivs Baseline (<63µm) (n = 2)			ANZG (2018) SDGV	UpRiv TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
Ni-WAE	4.3	10	24	ND	ND	ND	21	24
Ni-TD	25	34	110	23	29	34		
Pb-WAE	5.9	7.7	9.5	ND	ND	ND	50	50
Pb-TD	10	15	17	13	17	20		
Se-WAE	0.1	0.16	0.29	ND	ND	ND	NA	0.29
Se-TD	0.3	0.51	0.72	0.46	0.50	0.54		
Zn-WAE	12	20	35	ND	ND	ND	200	200
Zn-TD	65	87	98	92	113	133		

WAE = Weak-Acid-Extractable on whole sediment (i.e. the bioavailable fraction); TD = Total Digest on whole sediment; NA = Not applicable; ND = Not determined

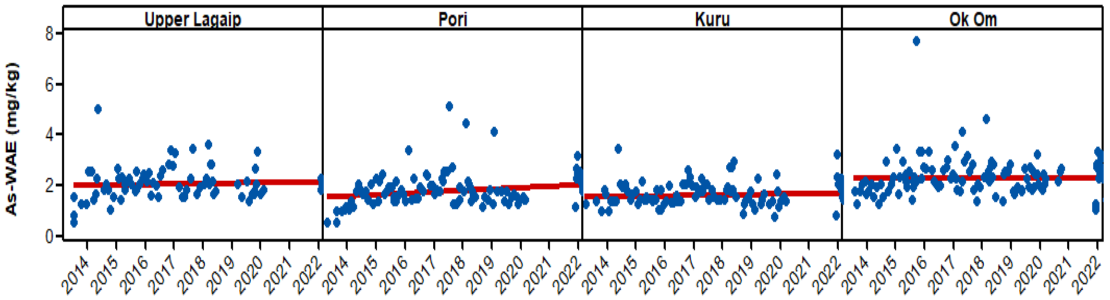
Baseline data were data collected from the test sites prior to mine operations commencing

Table 5-8 Trends for sediment quality for upper river reference sites determined by Spearman Rank correlation against time (2013 – 2022)

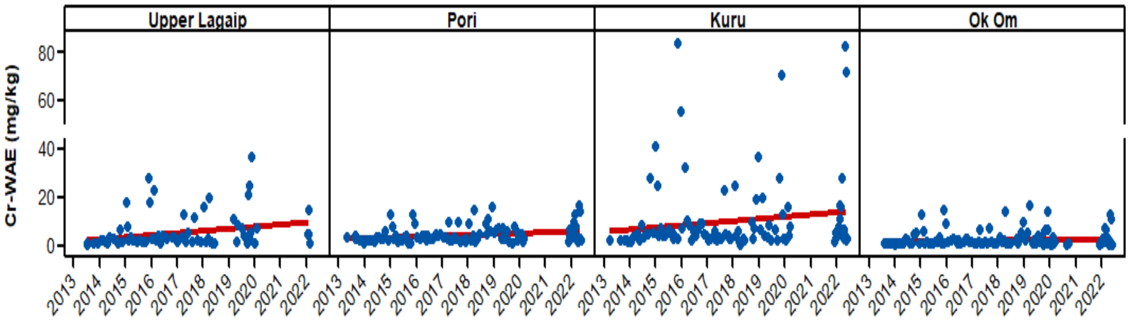
Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2022)
UpRivs Ref (Trend of all data WAE and TD from 2013-2022)	Ag-WAE*	-0.806	<0.001	Reduced over time
	Ag-TD*	-0.758	<0.001	Reduced over time
	As-WAE	0.131	0.007	Increased over time
	As-TD	0.093	0.056	No change over time
	Cd-WAE*	-0.703	<0.001	Reduced over time
	Cd-TD*	-0.797	<0.001	Reduced over time
	Cr-WAE	0.152	0.002	Increased over time
	Cr-TD	-0.1	0.039	Reduced over time
	Cu-WAE	0.127	0.009	Increased over time
	Cu-TD	-0.040	0.409	No change over time
	Pb-WAE	0.225	<0.001	Increased over time
	Pb-TD	-0.065	0.178	No change over time
	Hg-WAE*	-0.185	<0.001	Reduced over time
	Hg-TD*	0.075	0.121	No change over time
	Ni-WAE	0.192	<0.001	Increased over time
	Ni-TD	0.029	0.556	No change over time
	Se-WAE*	-0.488	<0.001	Reduced over time
	Se-TD*	-0.02	0.68	No change over time
	Zn-WAE	0.264	<0.001	Increased over time
	Zn-TD	-0.03	0.533	No change over time

WAE = Weak-Acid-Extractable, TD - Total digest, LOR - Limit of Reporting

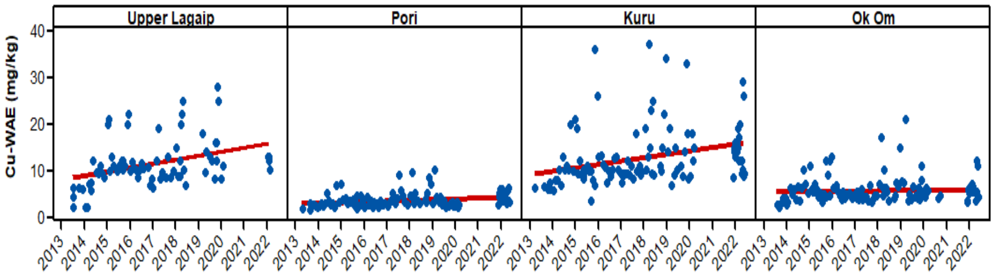
* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate no change over time, which is representative of actual conditions.



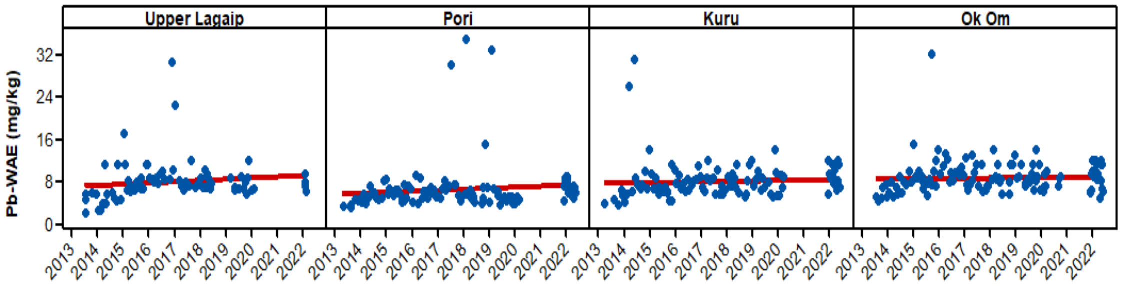
WAE Arsenic concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2022



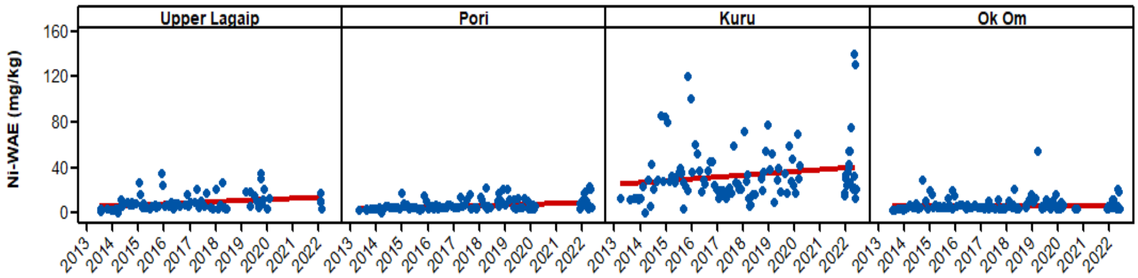
WAE Chromium concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2022



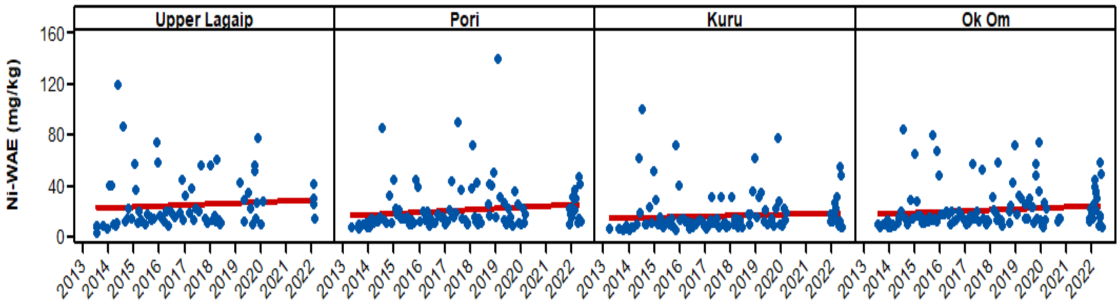
WAE Copper concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2022



WAE Lead concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2022



WAE Nickel concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2022



WAE Zinc concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2022

Figure 5-12 Trend analysis upper rivers sediment quality showing elements with statistically significant increasing trends (scatter plot of all data from 2013 – 2022 with linear trend line)

5.3.2 Lower River and Off-River Water Bodies

This section presents sediment quality data collected from test sites prior to mining operations commencing (baseline data), the most recent 24 months data from the reference sites and revised ANZG (2018) sediment default guideline values (SDGVs) from Simpson et al (2013) for the lower river region.

In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2022 TV for use in the sediment quality risk assessment presented in Section 7. Note that baseline WAE metal concentrations were not available, therefore TD metals on the <63µm fraction are provided for comparison purposes only. A summary of the analysis and lower river and ORWB sediment TVs are presented in Table 5-9.

Reference data were generated by combining the data from each of the lower river reference sites; Baia and Tomu. Reference sites within the lower river region exhibited detectable concentrations of arsenic, chromium, copper, nickel, lead and zinc. Analysis of trends between 2013 and 2022 show all metals either reduced or did not change over the time period. Trend analysis results are shown in Table 5-10. Baseline data in the lower river region exhibited detectable concentrations of arsenic, cadmium, chromium, copper, nickel, lead and zinc. These results indicate the presence of metals likely reflecting local geological differences between the lower and upper river regions.

Upon comparison of reference and baseline data with the SDGVs, the highest values for each indicator and therefore the value adopted as the 2022 TV were from the following sources:

- Reference site data: WAE selenium
- SDGVs: WAE silver, arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc.

Table 5-9 Summarised sediment quality data for lower river reference sites for previous 24 months. DGVs are provided for comparison (mg/kg dry whole fraction)

Parameter	LwRiv REF (n=32)			LwRiv Baseline (<63µm)			ANZG (2018) SDGV	LwRiv & ORWBs TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
Ag-WAE	0.05	0.05	0.05	ND	ND	ND	1.0	1.0
Ag-TD	0.05	0.05	0.05	ND	ND	ND		
As-WAE	0.33	0.61	0.9	ND	ND	ND	20	20
As-TD	1.6	2.3	4.0	2.8	10	14		
Cd-WAE	0.05	0.054	0.09	ND	ND	ND	1.5	1.5
Cd-TD	0.05	0.07	0.11	2.4	2.4	2.4		
Cr-WAE	1.7	4.2	6.2	ND	ND	ND	80	80
Cr-TD	32	48	55	12	12	12		
Cu-WAE	2.8	3.7	5.0	ND	ND	ND	65	65
Cu-TD	11	14	18	24	24	24		
Hg-WAE	0.01	0.01	0.01	ND	ND	ND	0.15	0.15
Hg-TD	0.01	0.017	0.02	0.34	0.57	0.94		
Ni-WAE	3.2	6.7	10	ND	ND	ND	21	21
Ni-TD	39	55	66	38	38	38		
Pb-WAE	2.2	2.6	3.5	ND	ND	ND	50	50
Pb-TD	3.7	5.5	6.2	22	22	22		
Se-WAE	0.10	0.10	0.23	ND	ND	ND	NA	0.23
Se-TD	0.12	0.19	0.40	0.2	0.2	0.2		
Zn-WAE	10	17	20	ND	ND	ND	200	200
Zn-TD	56	90	120	105	138	190		

- WAE - Weak acid extractable, TD - Total digest
- Baseline data were data collected from the test sites prior to mine operations commencing.

Table 5-10 Trends for sediment quality for lower river reference sites determined by Spearman Rank correlation against time (2013 – 2022)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2022)
LwRivs Ref (Trend of all data WAE and TD from 2013-2022)	Ag-WAE*	-0.780	<0.001	Reduced over time
	Ag-TD*	-0.865	<0.001	Reduced over time
	As-WAE	-0.185	0.094	No change over time
	As-TD	-0.134	0.222	No change over time
	Cd-WAE*	-0.678	<0.001	Reduced over time

Sediment Quality	**Parameter**	**Spearman's rho**	**p-Value (p=0.05)**	**Trend (2013 – 2022)**
Site				
	Cd-TD*	-0.694	<0.001	Reduced over time
	Cr-WAE	-0.272	0.013	Reduced over time
	Cr-TD	-0.116	0.289	No change over time
	Cu-WAE	-0.051	0.647	No change over time
	Cu-TD	0.070	0.524	No change over time
	Hg-WAE*	-0.285	0.009	Reduced over time
	Hg-TD*	-0.156	0.155	No change over time
	Ni-WAE	-0.215	0.051	No change over time
	Ni-TD	-0.260	0.016	Reduced over time
	Pb-WAE	-0.368	0.001	Reduced over time
	Pb-TD	-0.273	0.012	Reduced over time
	Se-WAE	-0.577	<0.001	Reduced over time
	Se-TD	-0.456	<0.001	Reduced over time
	Zn-WAE	-0.199	0.072	No change over time
	Zn-TD	-0.059	0.593	No change over time

WAE - Weak acid extractable, TD - Total digest, LOR - Limit of Reporting

* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate no change over time, which is representative of actual conditions.

5.3.3 Lake Murray

This section presents sediment quality data collected from test sites prior to mining operations commencing (baseline data), the most recent 24 months data from the reference sites and revised ANZG (2018) sediment default guideline values (SDGVs) from Simpson et al (2013) for the Lake Murray region. In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2022 TV for use in the sediment quality risk assessment presented in Section 7. Note that baseline WAE metal concentrations are not available, therefore TD metals on the <63µm fraction are provided for comparison purposes only. A summary of the analysis and TVs are shown in Table 5-11.

Reference data were generated by combining the data from each of the Lake Murray reference sites at North Lake Murray. Reference sites within the Lake Murray region exhibited detectable concentrations of arsenic, chromium, copper, nickel, lead and zinc. Analysis of trends between 2013 and 2022 shows the increasing concentrations of WAE arsenic, TD arsenic, TD copper, WAE mercury, TD mercury, WAE nickel, and WAE zinc. Concentrations of all other metals either reduced or did not change over the time period. Trend analysis results are shown in Table 5-12 and Figure 5-13 shows scatter plots for all metals with increasing trends.

Baseline data in the lower river region exhibited detectable concentrations of arsenic, chromium, copper, nickel, lead and zinc. These results indicate some natural mineralisation in the Lake Murray region although at lower concentrations than the upper river region.

Upon comparison of reference and baseline data with the SDGVs, the highest values for each indicator and therefore the value adopted as the 2022 TV were from the following sources:

- Reference site data from Nth Lake Murray: WAE selenium
- SDGVs: WAE silver, arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc.

Table 5-11 Summarised sediment quality data for Lake Murray reference sites for previous 24 months, presenting 20th%ile, median and 80th%ile of data for each site. DGVs are provided for comparison (mg/kg dry whole fraction)

Parameter	**Northern Lake Murray (n = 30)**			**LMY Baseline (<63µm)**			**ANZG (2018) SDGV**	**LMY TV**
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
Ag-WAE	0.05	0.05	0.05	ND	ND	ND	1.0	1.0
Ag-TD	0.05	0.05	0.06	ND	ND	ND		
As-WAE	0.79	1.1	2.0	ND	ND	ND	20	20
As-TD	4.5	5.1	5.8	2.8	10	14		
Cd-WAE	0.06	0.09	0.11	ND	ND	ND	1.5	1.5
Cd-TD	0.09	0.10	0.12	2.4	2.4	2.4		
Cr-WAE	4.2	4.9	5.7	ND	ND	ND	80	80
Cr-TD	36	40	46	12	12	12		
Cu-WAE	8.4	11	13	ND	ND	ND	65	65
Cu-TD	19	22	26	24	24	24		
Hg-WAE	0.03	0.04	0.04	ND	ND	ND	0.15	0.15
Hg-TD	0.15	0.16	0.17	0.34	0.57	0.94		
Ni-WAE	7.9	9.7	11	ND	ND	ND	21	21
Ni-TD	29	33	38	38	38	38		
Pb-WAE	5.2	7.0	8.9	ND	ND	ND	50	50
Pb-TD	12	13	15	22	22	22		
Se-WAE	0.11	0.20	0.85	ND	ND	ND	NA	0.85
Se-TD	0.63	0.80	1.42	0.2	0.2	0.2		
Zn-WAE	32	43	48	ND	ND	ND	200	200
Zn-TD	93	105	120	105	138	190		

WAE – Weak-Acid-Extractable, TD - Total digest, NA - Not applicable; ND - Not determined.

Baseline data were data collected from the test sites prior to mine operations commencing.

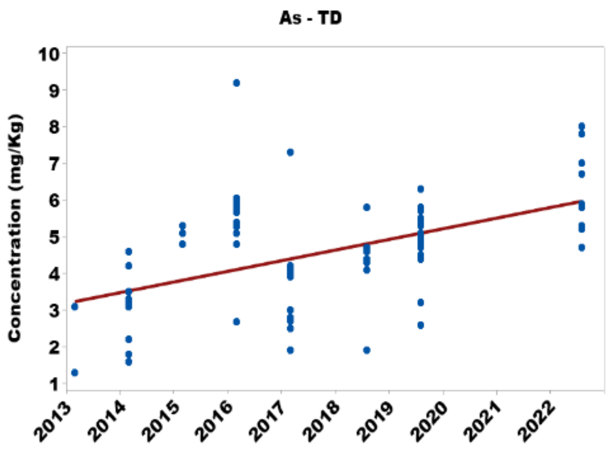
Table 5-12 Trends for sediment quality Lake Murray reference sites determined by Spearman Rank correlation against time (2013 - 2022)

Sediment Quality Site	**Parameter**	**Spearman's rho**	**p-Value (p=0.05)**	**Trend (2013 – 2022)**
Lake Murray Ref (Trend of all data WAE from 2013 – 2022 TD from 2013 - 2022)	Ag-WAE*	-0.705	<0.001	Reduced over time
	Ag-TD*	-0.742	<0.001	Reduced over time
	As-WAE	0.604	<0.001	Increased over time
	As-TD	0.470	<0.001	Increased over time
	Cd-WAE*	-0.436	<0.001	Reduced over time
	Cd-TD*	-0.584	<0.001	Reduced over time
	Cr-WAE	-0.346	0.002	Reduced over time
	Cr-TD	-0.118	0.309	No change over time
	Cu-WAE	-0.020	0.863	No change over time
	Cu-TD	0.233	0.043	Increased over time

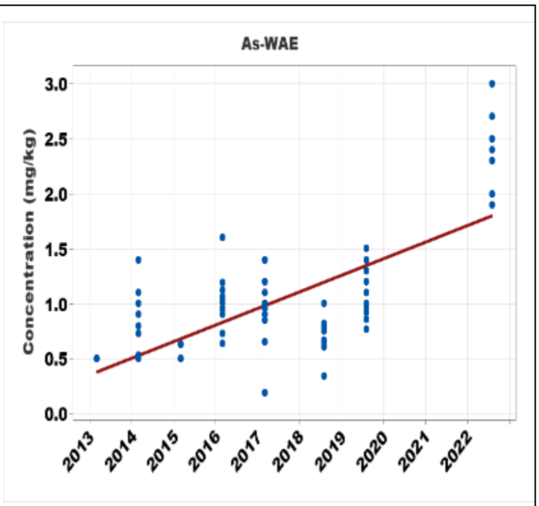
Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2022)
	Hg-WAE	0.297	0.009	Increased over time
	Hg-TD*	0.420	<0.001	Increased over time
	Ni-WAE	0.334	0.003	Increased over time
	Ni-TD	0.167	0.15	No change over time
	Pb-WAE	0.097	0.404	No change over time
	Pb-TD	0.072	0.535	No change over time
	Se-WAE*	0.138	0.236	No change over time
	Se-TD	0.501	<0.001	Increased over time
	Zn-WAE	0.275	0.016	Increased over time
	Zn-TD	0.330	0.004	Increased over time

WAE – Weak-Acid-Extractable, TD - Total digest, LOR - Limit of Reporting

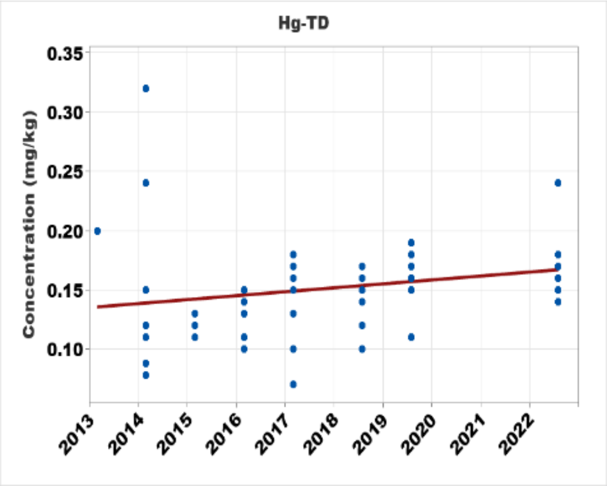
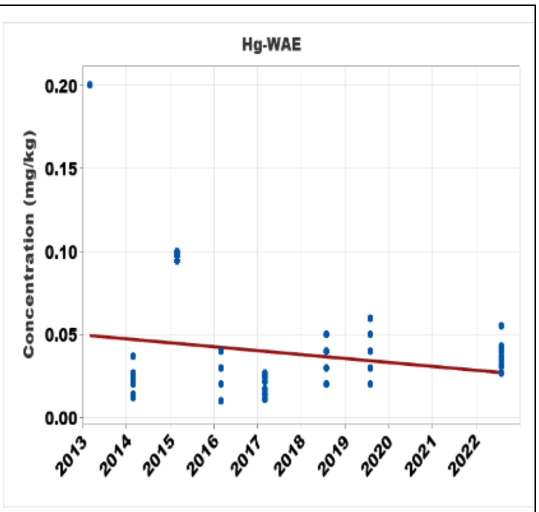
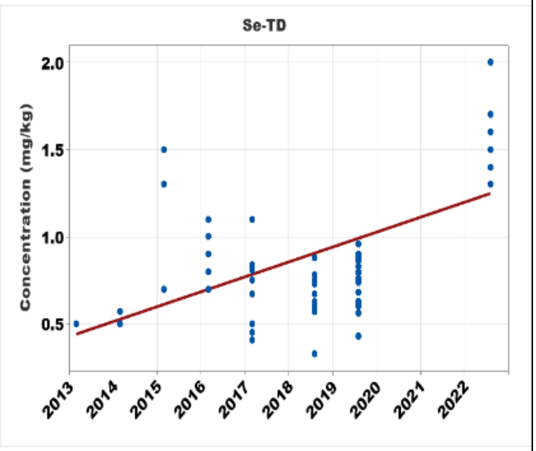
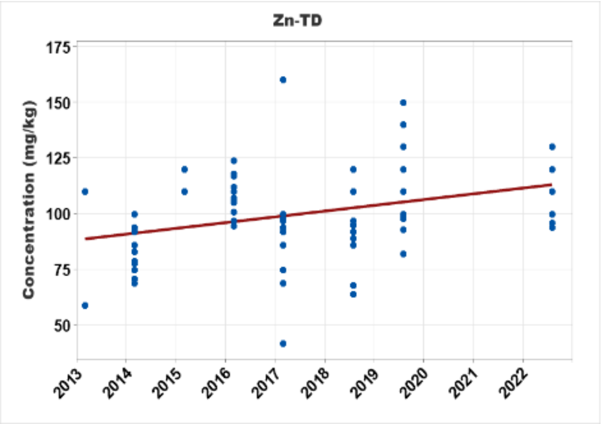
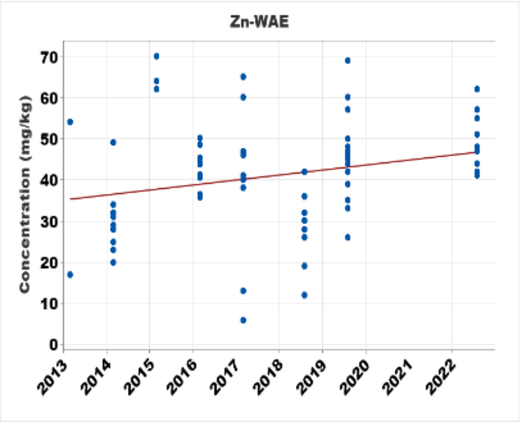
* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate no change over time, which is representative of actual conditions.

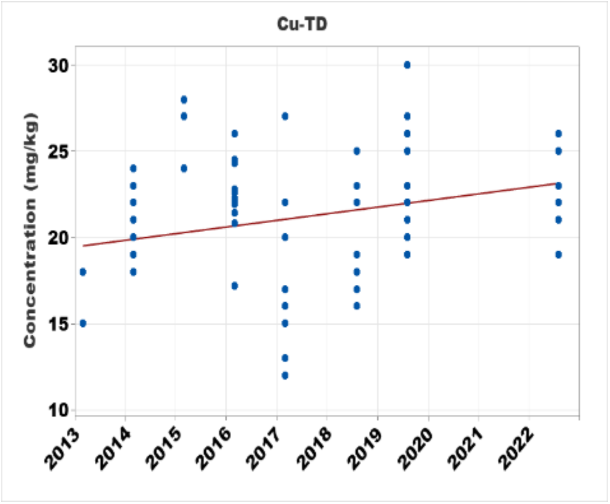


LMY As-TD concentrations (mg/kg dry whole fraction) (Ref site)



LMY As-WAE concentrations (mg/kg dry whole fraction) (Ref site)

 **LMY Hg-TD concentrations (mg/kg dry whole fraction) (Ref site)**	 **LMY Hg-WAE concentrations (mg/kg dry whole fraction) (Ref site)**
 **LMY Ni-TD concentrations (mg/kg dry whole fraction) (Ref site)**	 **LMY Se-TD concentrations (mg/kg dry whole fraction) (Ref site)**
 **LMY Zn-TD concentrations (mg/kg dry whole fraction) (Ref site)**	 **LMY Zn-WAE concentrations (mg/kg dry whole fraction) (Ref site)**



LMY Cu-TD concentrations (mg/kg dry whole fraction) (Ref site)

Figure 5-13 Trend analysis LMY reference sites sediment quality (scatter plot for all data from 2013 – 2022 with linear trend line)

5.4 Background Tissue Metal Concentrations and Trigger Values

This section presents tissue metal data for biota samples collected from test sites prior to mining operations commencing (baseline data), from reference sites during the previous 24 months and comparison of selenium with the applicable US EPA guideline value.

In accordance with Section 2.3 of this report, the data are compared and the highest is then adopted as the 2022 TV for use in the tissue metal risk assessment presented in Section 7. The sites are grouped into regions; Upper River, Lower River and Lake Murray. Tissue metal sampling is not performed in the ORWBs.

5.4.1 Upper River

A summary of tissue metal TVs for the upper river reference sites are presented in Table 5-13 and Table 5-14.

Reference data were generated from the upper river reference site Ok Om, as this is the only upper river reference site where monitoring of fish and prawns is conducted. Fish flesh at the reference site within the upper river region exhibited detectable concentrations of arsenic, cadmium, chromium, copper, mercury, selenium and zinc. Prawn abdomen at the upper river reference site exhibited detectable concentrations of all nine metals analysed. The results indicate a degree of natural mineralisation and bioaccumulations at the upper river reference site. It should be noted that movement of fish and prawns between test sites and reference sites is also possible, but it is very difficult to determine the origin and migration of each individual fish or prawn.

Analysis of trends between 2013 and 2022 indicates that concentrations for arsenic in fish flesh and lead in prawn abdomen have increased overtime. All other metals at the reference site remained either constant or decreased. Trend analysis results are shown in Table 5-15 and Table 5-16, while graphs showing increasing arsenic and lead concentrations in fish and prawns respectively is shown in Figure 5-14.

Baseline data for fish flesh tissue metals in the upper river region exhibited detectable concentrations of arsenic, cadmium, copper, mercury, nickel, lead, selenium and zinc. This indicates that baseline tissue metals in fish within the Porgera-Lagaip-Strickland River catchment, which hosts the Porgera deposit at its headwaters, was characterised by elevated concentrations of tissue metals prior to mining commencing, compared to the regional reference sites.

Upon comparison of reference and baseline data with the US EPA guidelines value, the highest values for each indicator and therefore the value adopted as the 2022 TV were from the following sources. It should be noted that where the baseline 80th%ile is equal to the baseline LOR and the baseline LOR is greater than the 2022 reference site 80%ile, the 2022 reference 80th%ile value is adopted as the TV, this is considered a conservative approach so the TV is not unintentionally inflated due to historical LORs.

- Reference site data:
  - Fish flesh: chromium
  - Prawn abdomen: arsenic, cadmium, chromium, copper, mercury, nickel, lead, selenium and zinc.
- Baseline data:
  - Fish flesh: arsenic, cadmium, copper, mercury, lead, nickel, zinc.
  - Prawn abdomen: NA
- US EPA Guidelines:
  - Fish flesh: selenium
  - Prawn abdomen: NA

Table 5-13 Tissue metal data for upper river reference site Ok Om for previous 24 months, and baseline data from Wankipe (As, Cd, Cr, Cu) (µg/g wet wt.)

Site	Sample	n	As		Cd		Cr		Cu	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
UR Ref (Ok Om)	Fish Flesh	24	0.014	0.050	0.004	0.010	0.010	0.050	0.160	0.204
	Prawn Ab	24	0.033	0.040	0.003	0.003	0.020	0.037	4.350	6.940
Wankipe baseline	Fish Flesh	28	0.20	0.20	0.01	0.02	ND	ND	0.21	0.48
Trigger Value	Fish Flesh	-	-	0.200		0.02		0.05		0.48
	Prawn Ab	-	-	0.040		0.003		0.037		6.9

n – number of samples, ND - Not Determined, Ab – Abdomen, * Baseline 80th%ile falls below the 2019 LOR, so reference 80th%ile is used as the TV

Table 5-14 Tissue metal data for upper river reference site Ok Om for previous 24 months, Wankipe baseline, and applicable US EPA guideline value (Hg, Ni, Pb, Se, Zn) (µg/g wet wt.)

Site	Sample	n	Hg		Ni		Pb		Se		Zn	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
UR Ref (Ok Om)	Fish Flesh	24	0.038	0.044	0.01	0.01	0.01	0.01	0.23	0.29	4.6	5.4
	Prawn Ab	24	0.01	0.01	0.01	0.013	0.01	0.01	0.475	0.57	13	14
Wankipe baseline	Fish Flesh	28	0.07	0.08	0.1	0.10	0.07	0.17	0.2	0.2	8.9	10
USEPA (2014)	Fish Flesh		NA	NA	NA	NA	NA	NA	2.26 (11.3 dry wt.)		NA	NA
Trigger Value	Fish Flesh	-		0.08		0.10		0.17		2.26		10
	Prawn Ab	-		0.01		0.013		0.01		0.57		14

n – number of samples, NA - Not Applicable, dry wt. - dry weight, Ab - Abdomen

Table 5-15 Trends of metals in fish flesh for upper river reference sites 2013 - 2022 determined by Spearman Rank correlation against time

Fish Flesh Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013–2022)
UpRivs Ref (Trend of Ok Om data 2013-2022)	As	0.167	0.036	Increased over time
	Cd	-0.728	<0.001	Reduced over time
	Cr	0.056	0.488	No change over time
	Cu	-0.272	0.001	Reduced over time
	Hg	-0.186	0.019	Reduced over time
	Ni	#	0.999	No change over time
	Pb	-0.14	0.08	No change over time
	Se	-0.108	0.178	No change over time
	Zn	-0.158	0.047	Reduced over time

All results within this data set are equal to the LOR. The Spearman rank test cannot determine a rho or p-value in these cases, however the result is no change over time for these cases.

Table 5-16 Trends of metals in prawn abdomen for upper river reference sites 2013 - 2022 determined by Spearman Rank correlation against time

Prawn Abdomen Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013–2022)
UpRivs Ref (Trend of Ok Om data 2013-2022)	As	0.002	0.976	No change over time
	Cd	-0.828	<0.001	Reduced over time
	Cr	-0.018	0.82	No change over time
	Cu	-0.495	<0.001	Reduced over time
	Hg	#	#	No change over time
	Ni	-0.313	<0.001	Reduced over time
	Pb	0.198	0.013	Increased over time
	Se	0.024	0.763	No change over time
	Zn	-0.131	0.102	No change over time

* The trend indicated by Spearman's rho and P of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate no change over time, which is representative of actual conditions.

All results within this data set are equal to the LOR. The Spearman rank test cannot determine a rho or p-value in these cases, however the result is no change over time for these cases.

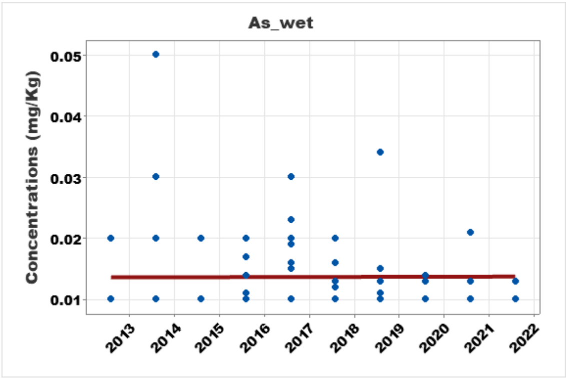
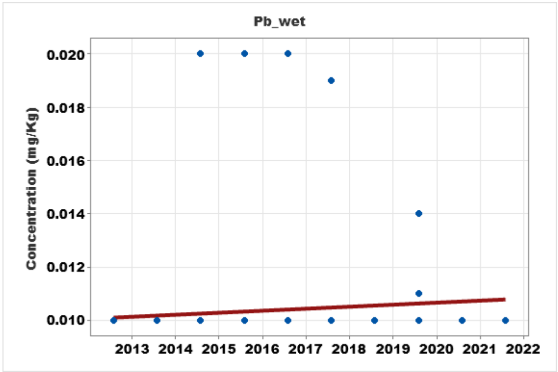
	
Arsenic concentration (µg/g wet wt.) in fish – Upper River reference (Ok Om 2013 – 2022)	**Lead concentration (µg/g wet wt.) in prawn – Upper River reference (Ok Om 2013 – 2022)**

Figure 5-14 Trend analysis of arsenic and nickel concentration in fish (µg/g wet wt) and lead and mercury concentration in prawn abdomen (µg/g wet wt) – Upper River reference sites Ok Om 2013 – 2022. Graph shows weak increasing linear trend.

5.4.2 Lower River

A summary of tissue metal TVs for the lower river reference sites are presented in Table 5-17 and Table 5-18.

Reference site data were generated by combining the most recent 24 months data from each of the lower river reference sites; Baia and Tomu. Fish flesh at the lower river reference sites exhibited detectable concentrations of chromium, copper, mercury, selenium and zinc. Prawn abdomen at the lower river reference site exhibited detectable concentrations of arsenic, chromium, copper, selenium and zinc. The results indicate a degree of natural mineralisation at the lower river reference sites.

Analysis of trends between 2013 and 2022 indicated increasing trends of arsenic and chromium in fish flesh. All other metals either reduced or did not change over the same period for both fish flesh and prawn abdomen. Trend analysis results are shown in Table 5-19 and Table 5-20, graphical representation of arsenic and chromium in fish flesh data showing increasing trends is presented in Figure 5-15.

Baseline data for fish flesh tissue metal in the lower river region exhibited detectable concentrations of arsenic, chromium, copper, mercury, nickel, selenium and zinc, which indicates a degree of natural mineralisation at the lower river test sites prior to the commencement of mining.

Upon comparison of reference and baseline data with the US EPA guideline value, the highest values for each indicator and therefore the value adopted as the 2022 TV were from the following sources:

- Reference data:
  - Fish flesh: cadmium and chromium
  - Prawn abdomen: arsenic, cadmium, chromium, copper, mercury, nickel, lead, selenium and zinc.
- Baseline data:
  - Fish flesh: arsenic, copper, mercury, nickel, lead and zinc.
  - Prawn abdomen: NA
- US EPA Guidelines:
  - Fish flesh: selenium
  - Prawn abdomen: NA

Table 5-17 Tissue metal data for lower river reference sites for previous 24 months and baseline for SG4 (As, Cd, Cr, Cu) (µg/g wet wt.)

Site	Sample	n	As		Cd		Cr		Cu	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
LR Ref (Baia & Tomu)	Fish Flesh	48	0.01	0.01	0.003	0.003	0.01	0.017	0.076	0.093
	Prawn Ab	42	0.071	0.099	0.003	0.003	0.032	0.047	6.85	9.34
SG4 baseline	Fish Flesh	19	0.036	0.071	0.003	0.003	0.024	0.026	0.13	0.17
Trigger Value	Fish Flesh	-	-	0.071		0.003		0.017		0.17
	Prawn Ab	-	-	0.099		0.003		0.047		9

n – Number of samples, Ab – Abdomen

Table 5-18 Tissue metal data for lower river reference sites for previous 24 months, baseline for SG4, and applicable US EPA guideline value (Hg, Ni, Pb, Se, Zn) (µg/g wet wt.)

Site	Sample	n	Hg		Ni		Pb		Se		Zn	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
LR Ref (Baia & Tomu)	Fish Flesh	48	0.036	0.049	0.01	0.01	0.01	0.01	0.086	0.136	2.6	3.2
	Prawn Ab	42	0.01	0.01	0.01	0.01	0.01	0.01	0.26	0.32	11	13
SG4 baseline	Fish Flesh	19	0.06	0.12	0.076	0.17	0.026	0.03	0.13	0.2	3.3	7.5
USEPA (2014)	Fish Flesh		NA	NA	NA	NA	NA	NA	2.26 (11.3 dry wt.)		NA	NA
Trigger Value	Fish Flesh	-		0.12		0.17		0.03		2.3		7.5
	Prawn Ab	-		0.01		0.01		0.01		0.32		13

n – Number of samples, NA - Not Applicable, Ab – Abdomen

Table 5-19 Trends of metals in fish flesh at lower river reference site 2013 - 2022 determined by Spearman Rank correlation against time

Fish flesh Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (2013–2022)
LwRivs Ref (Trend of all data 2013-2022)	As	0.175	0.025	Increased over time
	Cd	-0.682	<0.001	Reduced over time
	Cr	0.239	0.002	Increased over time
	Cu	-0.308	<0.001	Reduced over time
	Hg	-0.507	<0.001	Reduced over time
	Ni	0.131	0.097	No change over time
	Pb	0.121	0.123	No change over time
	Se	-0.449	<0.001	Reduced over time
	Zn	-0.096	0.223	No change over time

Table 5-20 Trends of metals in prawn abdomen at lower river reference sites 2013 - 2022 determined by Spearman Rank correlation against time

Prawn Abdomen Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (2013–2022)
LwRivs Ref (Trend of all data 2013-2022)	As	0.08	0.162	No change over time
	Cd	-0.744	<0.001	Reduced over time
	Cr	-0.185	0.001	Reduced over time
	Cu	0.037	0.521	No change over time
	Hg	#	#	No change over time
	Ni	-0.174	0.002	Reduced over time
	Pb	0.001	0.988	No change over time
	Se	-0.032	0.579	No change over time
	Zn	-0.101	0.078	No change over time

* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate no change over time, which is representative of actual conditions.

All results within this data set are equal to the LOR. The Spearman rank test cannot determine a rho or p-value in these cases, however the result is no change over time for these cases.

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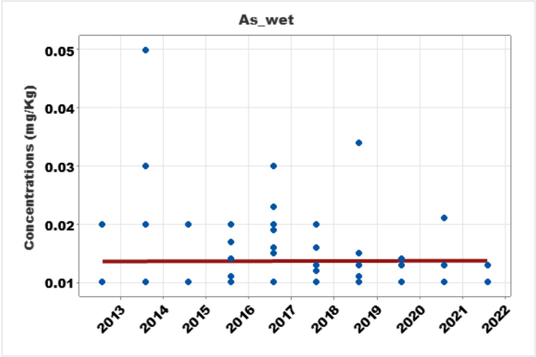

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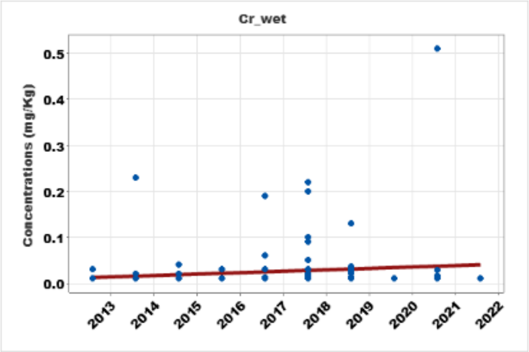

Fish
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<td>Arsenic concentrations (µg/g wet wt.) – Lower River reference sites combined 2013 - 2022</td>
<td>Chromium concentrations (µg/g wet wt.) – Lower River reference sites combined 2013 - 2022</td>
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Figure 5-15 Trend analysis of arsenic and chromium concentration (µg/g wet wt.) in fish – Lower River reference sites combined 2013 – 2022. Graphs show weak increasing linear trend.

5.4.3 Lake Murray

Data summaries and presentation of tissue metal TVs for the Lake Murray reference sites are presented in Table 5-21 and Table 5-22.

Reference data were generated from the Lake Murray reference site Maka. Fish flesh at the Lake Murray region reference sites exhibited detectable concentrations of arsenic, copper, mercury, selenium and zinc. Prawns were not sampled in Lake Murray.

Analysis of trends between 2013 and 2022 indicated that the concentration of chromium in fish flesh increased while concentrations of all other metals had either reduced or did not change over the time period. Trend analysis results are shown in Table 5-23, graphical representation of chromium in fish flesh data showing increasing trends is presented in Figure 5-15.

Baseline data for fish flesh tissue metal in the Lake Murray region exhibited detectable concentrations of arsenic, chromium, copper, mercury, nickel, selenium and zinc, indicating a degree of natural mineralisation at the Lake Murray test sites prior to the commencement of mining.

Upon comparison of reference and baseline data with the US EPA guideline value, the highest values for each indicator and therefore the value adopted as the 2022 TV were from the following sources:

- Reference site data:
  - Fish flesh: cadmium and mercury.
- Baseline data:
  - Fish flesh: arsenic, chromium, copper, lead, Nickel and zinc.
- US EPA Guidelines:
  - Fish flesh: selenium

Table 5-21 Summarised tissue metal data for Lake Murray reference sites for previous 24 months and Miwa baseline (As, Cd, Cr, Cu), presenting median and 80th%ile of data for each site (µg/g wet wt.)

Site	Sample	n	As		Cd		Cr		Cu	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
Maka	Fish Flesh	12	0.011	0.016	0.003	0.003	0.010	0.014	0.086	0.089
Miwa baseline	Fish Flesh	7	0.039	0.053	0.002	0.002	0.022	0.028	0.16	0.203
Trigger Value	Fish Flesh	-	-	0.05		0.003		0.028		0.203

n – Number of samples

Table 5-22 Summarised tissue metal data for Lake Murray reference sites for previous 24 months, Miwa baseline and applicable US EPA guideline value (Hg, Ni, Pb, Se, Zn), presenting median and 80th%ile of data for each site (µg/g wet wt.)

Site	Sample	n	Hg		Ni		Pb		Se		Zn	
			Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile	Median	80%ile
Maka	Fish Flesh	12	0.235	0.34	0.010	0.01	0.01	0.01	0.285	0.330	2.5	2.7
Miwa baseline	Fish Flesh	7	0.110	0.17	0.100	0.19	0.053	0.071	0.13	0.17	2.9	3.1
USEPA (2014)	Fish Flesh		NA	NA	NA	NA	NA	NA	2.26 (11.3 dry wt.)		NA	NA
Trigger Value	Fish Flesh	-		0.34		0.19		0.071		2.3		3.1

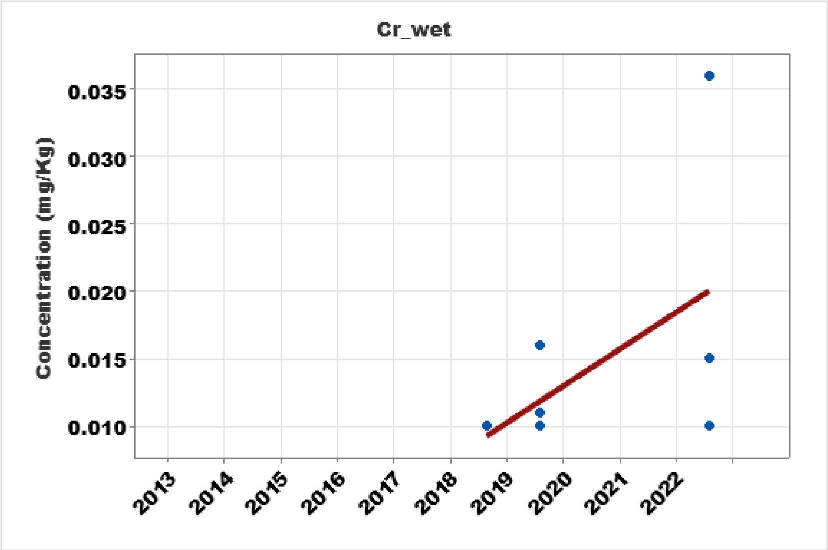
n – Number of samples, NA – not applicable

Table 5-23 Trends of metals in fish flesh at Lake Murray and ORWB reference sites 2013-2022 determined by Spearman Rank correlation against time

Fish Flesh	Element	Spearman's rho	p-Value (p=0.05)	Trend (2013-2022)
Site				
LMY Ref Site (Maka) (Trend of all data 2013-2022)	As	0.23	0.409	No change over time
	Cd	-0.618	0.014	Reduced over time
	Cr	0.562	0.029	Increased over time
	Cu	-0.206	0.462	No change over time
	Hg	-0.555	0.032	Reduced over time
	Ni	0.37	0.175	No change over time
	Pb	#	#	No change over time
	Se	0.333	0.225	No change over time
	Zn	-0.129	0.646	No change over time

* The trend indicated by Spearman's rho and P of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate no change over time, which is representative of actual conditions.

All results within this data set are equal to the LOR. The Spearman rank test cannot determine a rho or p-value in these cases, however the result is no change over time for these cases.



Chromium concentrations (µg/g wet wt.) in Fish – Lake Murray reference site 2013 – 2022

Figure 5-16 Trend analysis of chromium concentration (µg/g wet wt.) in fish – Lake Murray reference site (Maka) 2013 – 2022. Graphs show weak increasing linear trend.

5.5 Background Aquatic Biology and Impact Assessment Criteria

Impact assessment trigger values for biological indicators in the upper river, lower river and Lake Murray have been developed in accordance with the methodology outlined in Section 2 of this report.

A summary of biological indicator parameters and TVs for the upper river, lower river and Lake Murray are presented in Table 5-24, Table 5-25 and Table 5-26 respectively.

Table 5-24 Trigger Values for Upper River Impact Assessment

Test Site	Indicator Parameter		TV Source	TV
Wasiba & Wankipe	Fish	Total Fish Abundance	Ok Om Reference - 2021	3.6
		Total Fish Biomass (g)		176.0
		N. equinus Abundance		2.4
		N. equinus Biomass (g)		136.4
		Total Fish Abundance	Ok Om Reference - 2022	4.2
		Total Fish Biomass (g)		223.3
		N. equinus Abundance		3.2
		N. equinus Biomass (g)		197.8
	Prawn	Total Prawn Abundance	Ok Om Reference - 2022	7.2
		Total Prawn Biomass		30.6
		M. handschini Abundance		3.5
		M. handschini Biomass		16.3
		M. lorentzi Abundance		3.7
		M. lorentzi Biomass		14.2

Table 5-25 Trigger Values for Lower River Impact Assessment

Test Site	Indicator Parameter		TV Source	TV
Bebelubi	Fish	Total Fish Richness	Option A1 Baia ‘Baseline’	3.0
		Total Fish Abundance		15.0
		Total Fish Biomass		8.4
		Total Fish Richness	Option A2 Baia ‘Reference’	3.2
		Total Fish Abundance		9.9
		Total Fish Biomass		6.1
SG4	Fish	Total Fish Richness	Option B1 Tomu ‘Baseline’	5.2
		Total Fish Abundance		24.8
		Total Fish Biomass		13.5
		Total Fish Richness	Option B2 SG4 Baseline	5.0
		Total Fish Abundance		21.8
		Total Fish Biomass		15.4

Test Site	Indicator Parameter		TV Source	TV
		Total Fish Richness	Option B3 Mean of Tomu Reference	4.5
		Total Fish Abundance		13.5
		Total Fish Biomass		7.6

Table 5-26 Trigger Values for Lake Murray Impact Assessment

Test Site	Indicator Parameter		TV Source	TV
Miwa	Fish	Total Fish Richness	20th percentile of Maka baseline (2001 - 2006)	1.9
		Total Fish Abundance		4.8
		Total Fish Biomass		19.7
		Total Fish Richness	Mean of Miwa baseline (1989 - 2000)	3.8
		Total Fish Abundance		19.4
		Total Fish Biomass		66.7
		Total Fish Richness	Maka Reference	5.0
		Total Fish Abundance		10.9
		Total Fish Biomass		20.9
Pangoa	Fish	Total Fish Richness	20th percentile of Maka baseline (2001 - 2006)	1.9
		Total Fish Abundance		4.8
		Total Fish Biomass		19.7
		Total Fish Richness	Maka Reference	5.0
		Total Fish Abundance		10.9
		Total Fish Biomass		20.9

6 COMPLIANCE

This Section provides a summary of the operation's compliance with the conditions of its two environmental permits issued by the PNG Government, and the PJV Environmental, Security, Health and Safety Plan for Care and Maintenance (PJV 2020), also reviewed and approved by the PNG Government.

A summary of compliance against the conditions of each permit and plan is shown in Table 6-1. Overall, the site achieved compliance with 100% of the permit and plan conditions during care and maintenance.

All Sewage Treatment Plant (STPs) discharges complied with individual permit criteria for Total Suspended Solids (TSS), Biological Oxygen Demand (BOD5) and Fecal Coliform counts during the entire care and maintenance period.

River monitoring site SG3 is located at the end of the permitted mixing zone and is the location at which permit water quality criteria apply. During the operation phase of the mine, and in accordance with the requirements of the Porgera environment permit and EMMP, sampling at SG3 was conducted for a period of five (5) consecutive days per month, at 6-hourly intervals during daylight hours. This approach provides 16 individual samples per month and 196 per sampled per annum. SG3 is a very remote site and is only accessible by helicopter. Monthly sampling at SG3 required BNL staff to camp at SG3 for the 5-day period.

During C&M, due to resource constraints on helicopters, environment staff and emergency response capabilities, sampling at SG3 was scaled back due to a single weekly sample. This approach maintained frequent sampling at SG3, with the objective of providing data representative of actual variations in water and sediment quality but could be performed with a return helicopter trip on each day and so did not require BNL staff to camp at the site. SG3 sampling during the C&M phase commenced in April 2020 and continues on weekly basis. The compliance assessment presented in this section compares the median value of data collected between January 2021 to April 2022.

Sampling at SG1 was not conducted due to safety issues and only a single sample was collected at SG2 due to safety issues.

Table 6-2 is a summary of water quality results measured at SG3 during 2022 and shows that water quality at SG3 complied with the permit criteria during 2022. Water quality data for river monitoring sites upstream of SG3 are also presented and show that water quality at these sites also complied with the SG3 criteria during 2022.

Table 6-1 Compliance summary 2022

Permit	% Compliance	Comments
Waste Discharge Permit WD – L3 (121)	100%	Compliant with all forty-one (41) conditions.
Water Extraction Permit WE – L3 (91)	100%	Compliant with all eight (8) conditions.
Care and Maintenance Plan	100%	Compliance to C&M Plan.
TOTAL	**100%**	Target is 100% compliance.

Table 6-2 Median water quality at Upper River Test Sites against SG3 permit criteria November 2021 - May 2022 (µg/L except where shown)

Site	n	pH	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Ni-D	Pb-D	Zn-D
SG1	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
SG2	1	7.7	0.04	0.83	0.05	0.27	0.2	1.3	0.1	2.7
Wasiba	24	8.2	0.01	0.78	0.05	0.25	0.61	0.69	0.10	2.2
Wankipe	24	8.2	0.01	0.76	0.05	0.19	0.58	0.65	0.10	1.6
SG3	35	8.1	0.01	0.68	0.05	0.24	0.61	0.67	0.10	1.7
SG3 Permit Criteria		**6.5 – 9.0**	**4.0**	**50**	**1.0**	**10**	**10**	**50**	**3.0**	**50**

🟩	Compliant
🟧	Non-Compliant

D – Dissolved fraction, ^ standard pH units

Note: There is no permit criterion for mercury (Hg)

NS – Not sampled due to community unrest, which restricted safe access.

7 RISK ASSESSMENT

7.1 Water Quality, Sediment Quality and Tissue Metals Risk Assessment

7.1.1 Water quality

7.1.1.1 Upper River, Lower River and ORWBs

The risk assessment for water quality at the upper river, lower river and ORWBs involved comparing the 2021-2022 mean value at each test site against the relevant TV in accordance with the risk assessment procedure described in Section 2. The test site mean is derived from the 2021 and 2022 data set.

The comparison of the mean against the TV is supported by a statistical analysis using t-tests to ensure any conclusions are based on sound statistics and are not an artefact of the data set. The results of the risk assessment for the upper river, lower river and ORWBs are summarised in Table 7-1, Table 7-2 and Table 7-3 respectively. Detailed results of the statistical analysis are shown in Volume 2.

Highland and lowland river systems within PNG typically exhibit a naturally high sediment load and are exposed to episodic variations in TSS concentrations. Periods of high TSS result from periods of high rainfall with a prevalence of large-scale erosion and landslides, whereas periods of low TSS reflect periods of low rainfall with reduced erosion and sediment transport. Periods of elevated TSS concentration shown in baseline and reference data reflect these processes.

The risk assessment showed that the 2021-2022 mean pH at all upper river, lower river and ORWB test sites were within the upper and lower pH TVs, with the exception of Wasiba in the upper river, which was not significantly different from the upper TV.

The 2021-2022 mean EC at Bebelubi was not significantly different from the TV, at Kukufionga mean EC was higher than the TV and at Levame mean EC was not significantly different from the TV. At all other test sites within the upper river, lower river and ORWBs, the 2021-2022 mean EC was less than the TV, indicating low risk.

The 2021-2022 mean TSS concentration at all upper river, lower river and ORWB test sites were significantly less than the respective TVs, with the exception of SG4, where the 2021-2022 mean for TSS was not significantly different from the TV.

The risk assessment results for water indicated that the 2021-2022 mean concentration of dissolved zinc at Bebelubi and SG4 were significantly greater than the TV, indicating potential risk. Concentrations of all other metals at all other locations in the upper river, lower river and ORWBs were below their respective TVs, indicating low risk.

It should be noted that the approach to risk assessment differs from the approach to compliance assessment presented in Section 6 in that **the risk assessment compares the mean** value derived from C&M monitoring data against TVs, and **the compliance assessment compares the median** value from C&M monitoring against the permit water quality criteria. As discussed in Section 2.2.2, the risk assessment methodology for this C&M report has been modified from the methodology previously employed by BNL in its AERs. The AERs have used the preferred approach to risk assess of comparing the test site median against the TVs, however the reduced frequency of monitoring during C&M meant that the most appropriate statistical test for the smaller C&M data set was to use compare the mean against the TV. It is for this reason that the data presented in Table 7-1 (mean values) does not match the data presented Table 6-2 (median values).

Table 7-1 Risk assessment – mean water quality at upper river test sites in 2021-2022 compared against UpRivs TVs showing which indicators pose low and potential risk (µg/L except where shown)

Site	n	pH^	TSS*	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
SG2	1	7.7	950	221	0.04	0.83	0.05	0.27	0.20	8.6	0.05	1.3	0.10	0.20	2.70
Wasiba	26	8.2[1]	1,557	208	0.01	0.79	0.05	0.32	0.62	4.9	0.05	0.70	0.10	0.21	3.84
Wankipe	24	8.2	1,774	210	0.01	0.76	0.05	0.28	0.66	5.3	0.06	0.66	0.10	0.22	7.1
SG3	103	8.1	1,706	200	0.04	0.69	0.05	0.28	0.78	17	0.06	0.71	0.13	0.21	8.8
UpRivs WQ TV		**6.0-8.2**	**2,837**	**219**	**0.05**	**24****	**0.35**	**1**	**1.4**	**75**	**0.6**	**21**	**7.5**	**11**	**20**
🟩	Low risk = significantly < TV														
🟨	Potential risk = not significantly different from TV OR significantly > TV														

^ std units, D - Dissolved fraction, * mg/L, **Arsenic (III)

[1] Not statistically significantly different from the TV

Table 7-2 Risk assessment – Mean water quality results at lower river test sites in 2021-2022 compared against LwRiv TVs showing which indicators pose low and potential risk (µg/L except where shown)

Site	n	pH^	TSS*	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Bebelubi	6	7.6	487	171[1]	0.01	0.60	0.05	0.48	0.46	6.3	0.08	0.53	0.10	0.20	38
SG4	6	7.6	662[1]	142	0.01	0.59	0.05	0.44	0.72	9.9	0.07	0.60	0.10	0.20	11
SG5	6	8.2	747	171	0.01	0.86	0.05	0.16	1.1	14.3	0.05	0.71	0.13	0.20	2.8
LwRivs WQ TV		**6.0-8.1**	**983**	**175**	**0.05**	**24****	**0.09**	**1**	**1.4**	**75**	**0.6**	**15**	**3.4**	**11**	**8**
🟩	Low risk = significantly < TV														
🟨	Potential risk = significantly > TV OR not significantly different from TV														

^ std units, * mg/L, D - Dissolved fraction, Arsenic (III)

[1] Not statistically significantly different from the TV

Table 7-3 Risk Assessment – Mean water quality results at ORWB test sites in 2021-2022 compared against ORWB TVs showing which indicators pose low and potential risk (µg/L except where shown)

Site	n	pH^	TSS*	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Kukufionga	6	7.7	75	204	0.01	2.3	0.05	0.10	0.64	1.8	0.05	0.5	0.10	0.20	2.1
Zongamange	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Avu	6	7.3	21	49	0.01	0.6	0.05	0.26	0.50	487	0.05	0.8	0.12	0.20	3.7
Levame	6	7.9	7.0	173[1]	0.01	0.9	0.05	0.10	1.8	5.0	0.05	0.5	0.10	0.20	1.6
ORWB WQ TV		**6.0-8.0**	**983**	**175**	**0.05**	**24****	**0.2**	**1**	**1.4**	**75**	**0.6**	**15**	**3.4**	**11**	**8**
🟩	Low risk = significantly < TV														
🟨	Potential risk = not significantly different from TV OR significantly > TV														

^ std units, D - Dissolved fraction, * mg/L, **Arsenic (III)

< = Below the level of detection

Trends of water quality in the upper river, lower river and ORWB test sites over the period 2013-2022 are summarised in Table 7-4 to Table 7-6. Detailed results are shown in Volume 2.

The results showed that in the upper river pH at Wasiba, Wankipe and SG3, and dissolved iron at SG3 exhibited a statistically significant increasing trend over the period. In the lower river pH, TSS and dissolved zinc at SG5 exhibited a statistically significant increasing trend over the period. In the ORWBs, TSS and dissolved copper at Kukufionga, dissolved lead a Zongamange and dissolved chromium, iron and nickel at Avu exhibited statistically significant increasing trends over the period. Monitoring has not been conducted at Zongamange since 2019. Graphical representation of trends at these sites are shown in Figure 7-1.

Table 7-4 Water quality trends at the upper river test sites 2013-2022

Site	pH	TSS	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
SG2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Wasiba	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Wankipe	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG3	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩
🟩	Reduced over time, no change over time or system wide increasing trend													
🟨	Increased over time													

D - Dissolved fraction

Table 7-5 Water quality trends at the lower river test sites 2013- 2022.

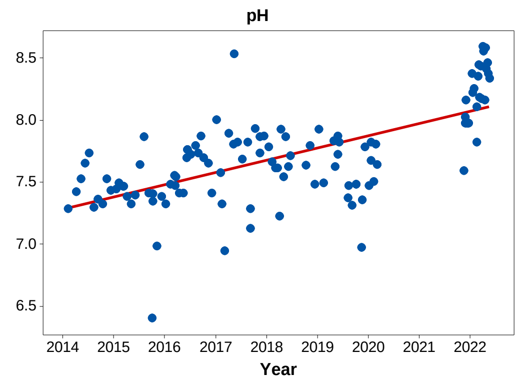
Site	pH	TSS	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Bebelubi	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG4	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG5	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨
🟩	Reduced or no change over time													
🟨	Increased over time													

D - Dissolved fraction

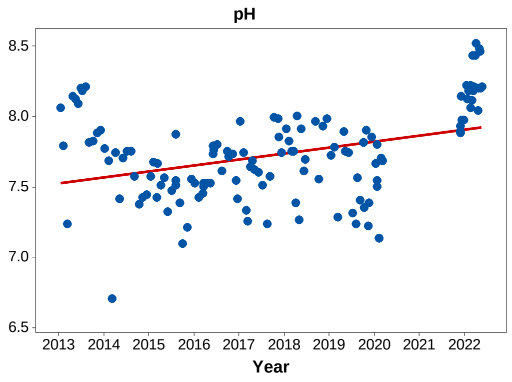
Table 7-6 Water quality trends at ORWB test sites 2013-2022 (Zongamange 2013 – 2019)

Site	pH	TSS	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Kukufionga	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩
Zongamange	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩
Avu	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟩	🟩
Levame	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
🟩	Reduced or no change over time													
🟨	Increased over time													

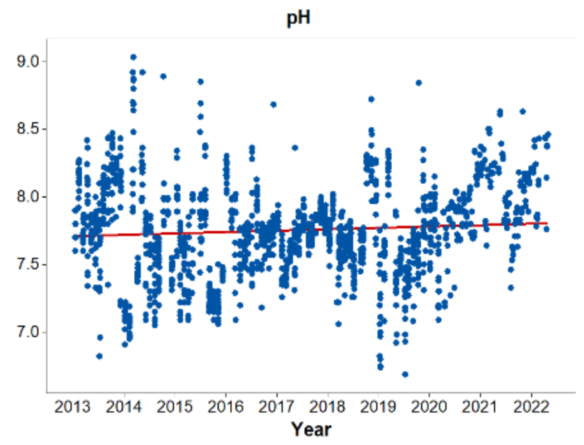
D - Dissolved fraction



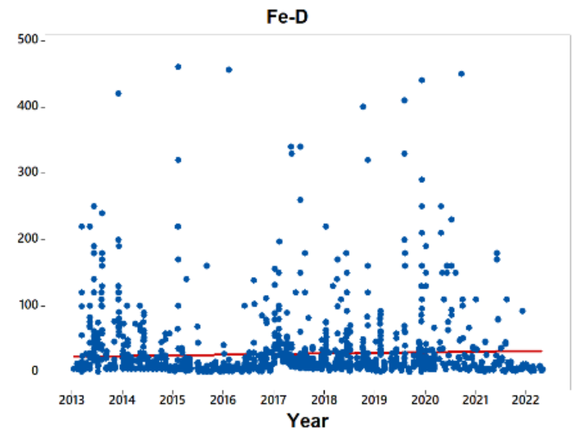
Wasiba pH (Test Site) 2013 – 2022



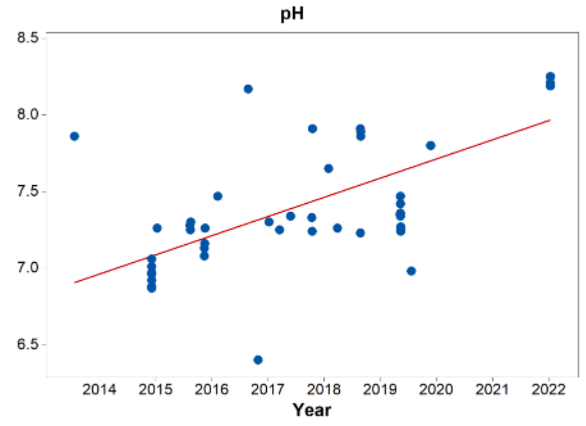
Wankipe pH (Test Site) 2013 – 2022



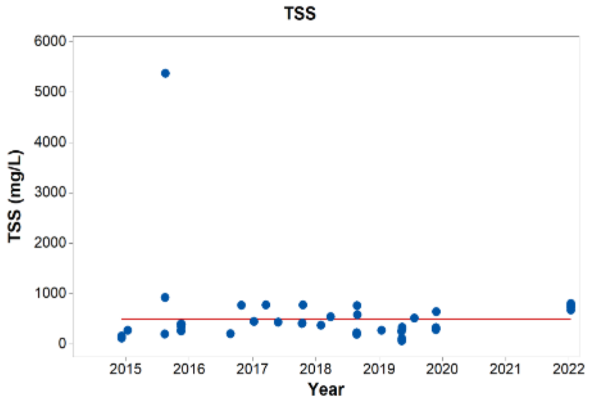
SG3 pH (Test Site) 2013 – 2022



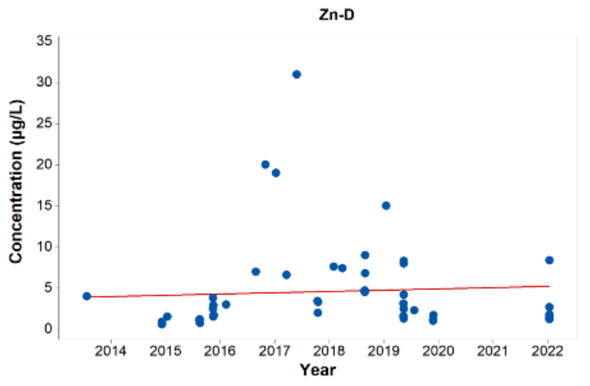
SG3 dissolved iron concentrations (µg/L) (Test Site 2013 – 2022



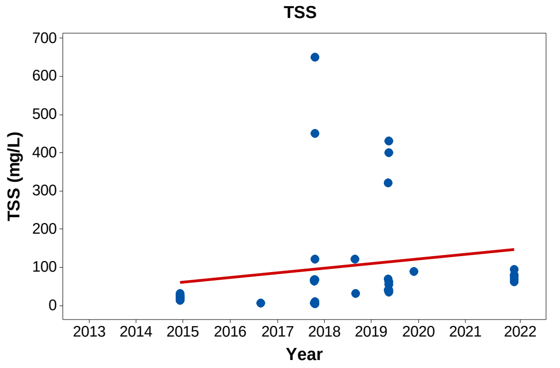
SG5 pH (Test Site) 2013 – 2022



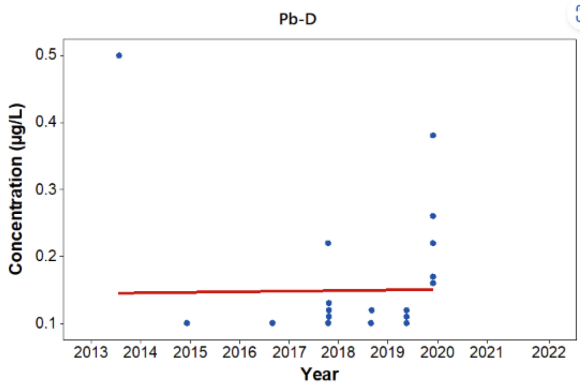
SG5 TSS concentrations (mg/L) (Test Site 2013 – 2022



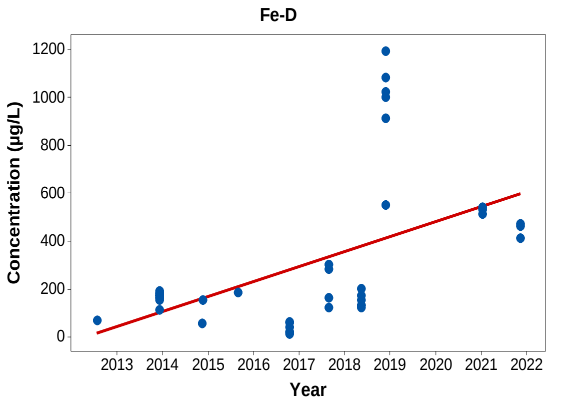
SG5 dissolved zinc concentrations (µg/L) (Test Site) 2013 – 2022



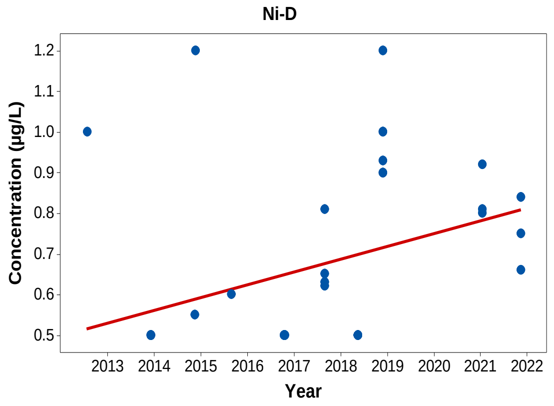
Kukufionga TSS concentrations (µg/L) (Test Site) 2013 – 2022



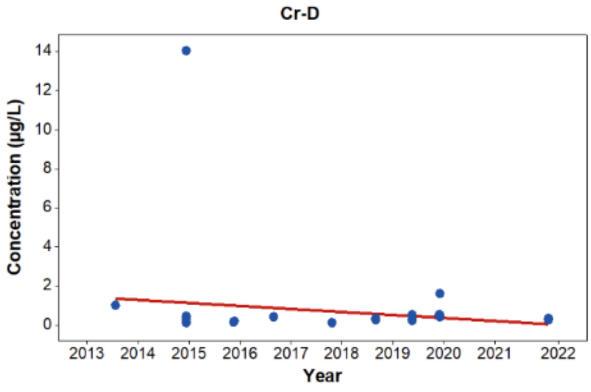
Zongamange dissolved lead concentrations (µg/L) (Test Site) 2013 – 2022



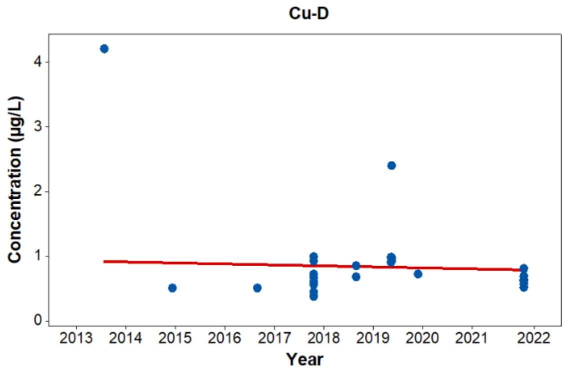
Avu dissolved iron concentrations (µg/L) (Test Site) 2013 – 2022



Avu dissolved nickel concentrations (µg/L) (Test Site) 2013 – 2022



Avu dissolved chromium concentrations (µg/L) (Test Site) 2013 – 2022



Kukufionga dissolved copper concentrations (µg/L) (Test Site) 2013 – 2022

Figure 7-1 Trend analysis upper rivers, lower rivers and ORWB water quality showing elements with statistically significant increasing trends (scatter plot of all data from 2013 – 2022 with linear trend line)

7.1.1.2 Lake Murray

A summary of the water quality risk assessment results for Lake Murray is shown in Table 7-7 and shows that the 2021-2022 mean for dissolved copper at Central Lake was not significantly different from the TV, and EC at SG6 was significantly higher than the TV, both indicating potential risk. All other parameters at all other sites were less than the respective TVs.

Trend analysis results are presented in Table 7-8 and show a statistically significant increasing trend in pH, dissolved nickel and dissolved zinc in the Central Lake, pH in the Southern Lake, and pH, dissolved nickel and dissolved lead at SG6. Graphical representation of these trends is shown in Figure 7-2. Details of the statistical analysis are shown in Volume 2.

Table 7-7 Risk Assessment – Mean water quality results at Lake Murray test sites in 2021-2022 compared against LMY TVs showing which indicators pose low and potential risk (µg/L except where shown)

Site	**n**	**pH^**	**TSS***	**EC**	**Ag-D**	**As-D**	**Cd-D**	**Cr-D**	**Cu-D**	**Fe-D**	**Hg-D**	**Ni-D**	**Pb-D**	**Se-D**	**Zn-D**
Central Lake - Pangoa	10	6.7	6.9	16.6	0.02	0.14	0.14	0.12	1.2[1]	202	0.05	0.6	0.10	0.20	2.7
Southern Lake - Miwa	19	6.9	4.8	14.3	0.01	0.20	0.05	0.13	0.3	199	0.07	0.6	0.12	0.20	1.4
SG6	6	7.3	6.8	38	0.01	0.49	0.05	0.12	0.3	217	0.05	0.6	0.11	0.20	1.2
Lake Murray WQ TV		**5.1-8.0**	**9**	**21**	**0.05**	**24****	**0.72**	**1**	**1.4**	**340**	**0.6**	**11**	**3.4**	**11**	**8**
🟩	Low risk = significantly < TV														
🟧	Potential risk = not significantly different from TV OR significantly > TV														

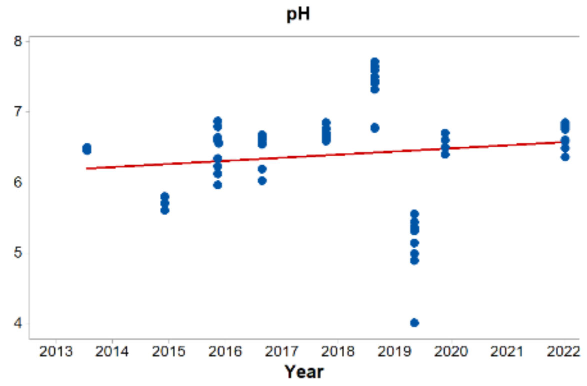
^ std units, D - Dissolved fraction, * mg/L, **Arsenic (III)

[1] Not statistically significantly different from the TV

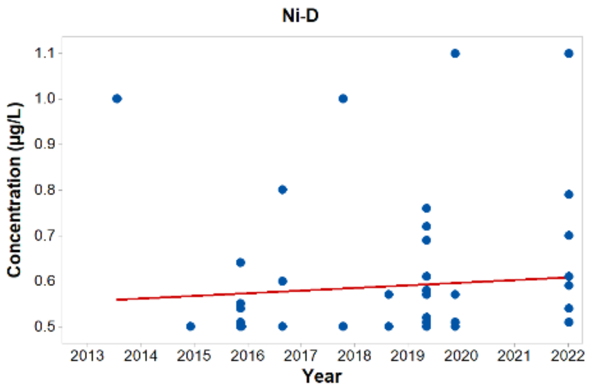
Table 7-8 Water quality trends at Lake Murray test sites 2013-2022

Site	**pH**	**TSS**	**EC**	**Ag-D**	**As-D**	**Cd-D**	**Cr-D**	**Cu-D**	**Fe-D**	**Hg-D**	**Ni-D**	**Pb-D**	**Se-D**	**Zn-D**
Central Lake - Pangoa	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟧
Southern Lake - Miwa	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG6	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟩	🟩
🟩	Reduced or no change over time													
🟧	Increased over time													

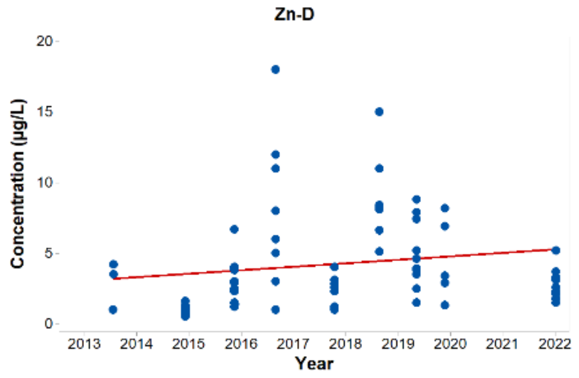
D - Dissolved fraction



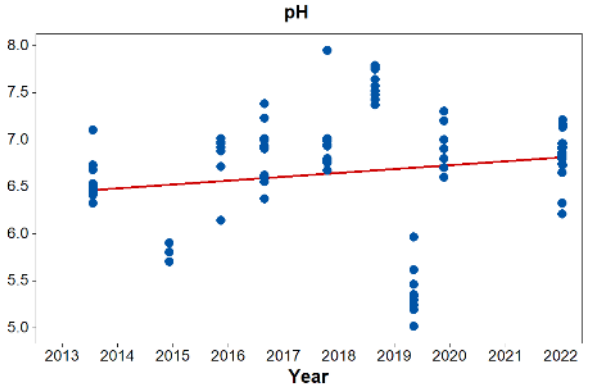
Central Lake pH (Test site) 2013 – 2022



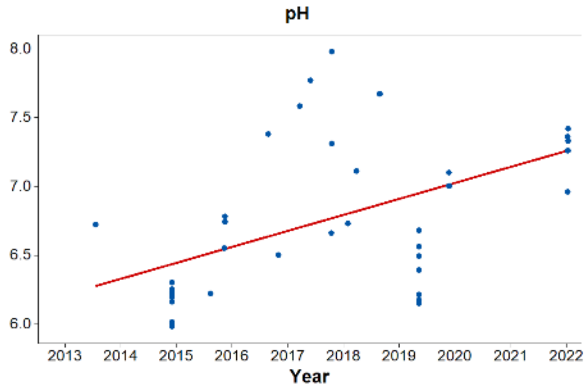
Central Lake dissolved nickel concentrations (µg/L) (Test Site) 2013 – 2022



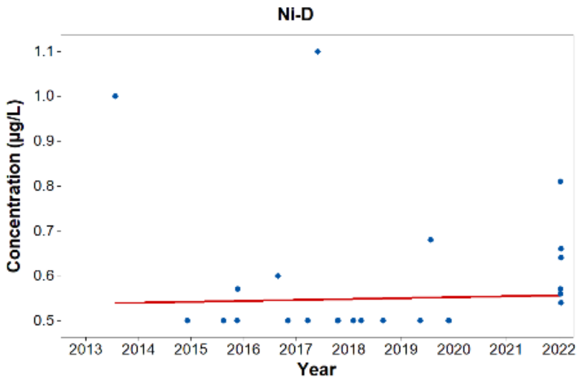
Central Lake dissolved zinc concentrations (µg/L) (Test Site) 2013 – 2022



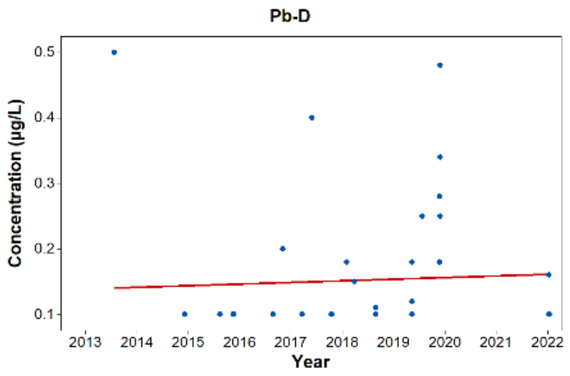
South Lake pH (Test Site) 2013 – 2022



SG6 pH (Test Site) 2013 – 2022



SG6 dissolved nickel concentrations (µg/L) (Test Site) 2013 – 2022



SG6- dissolved lead concentrations (µg/L) (Test Site) 2013 – 2022

Figure 7-2 Trend analysis Lake Murray water quality showing elements with statistically significant increasing trends (scatter plot of all data from 2013 – 2022 with linear trend line)

7.1.2 Sediment quality

7.1.2.1 Upper River, Lower River and ORWBs

Similar to water quality, elevated concentrations of WAE metals in sediment have the potential to cause chronic and/or acute toxic effects to organisms within the receiving environment, including humans, and as a result can potentially affect aquatic ecosystem health and ecosystem biodiversity.

The results of the risk assessment for sediment quality in the upper river are presented in Table 7-9 and show that the result from a single sampling event at SG2 recorded higher WAE lead and WAE selenium in comparison to the respective TVs. The 2021-2022 TSM for WAE nickel at Wankipe and SG3 were not significantly different from the TV and the 2021-2022 TSM for WAE selenium at all upper river sites were significantly higher than the TV.

Results for the lower river are presented in Table 7-10 and show that the 2021-2022 mean for WAE selenium at Bebelubi and SG4 were not significantly different from the TV while the 2021-2022 mean for WAE selenium at SG5 was higher than the TV.

Results for the ORWBs are presented in Table 7-11 and show that the 2021-2022 mean for WAE lead at Avu and WAE nickel at Levame were not significantly different from the respective TVs.

The results of trend analysis of sediment quality in the upper river are shown in Table 7-12 and showed a statistically significant increasing trend for WAE chromium and WAE nickel at SG2, WAE nickel at Wankipe and WAE copper and WAE nickel at SG3 between 2013 and 2022. Trends for all other metals showed no statistically significant change between 2013 and 2022.

The results of trend analysis of sediment quality in the lower river are shown in Table 7-13 and show no statistically significant increasing trends for any indicators, meaning no statistically significant change has occurred between 2013 and 2022.

Results for trend analysis of sediment in the ORWBs are shown in Table 7-14 and show a statistically significant increasing trend for WAE arsenic at Zongamange between 2013 and 2019. Trends for all other metals showed no statistically significant change between 2013 and 2022.

Graphical representation of the statistically significant increasing trends is shown in Figure 7-3. Detailed results of the statistical analysis are shown in Volume 2.

Table 7-9 Risk Assessment – Mean sediment quality results at upper river test sites in 2021-2022 compared against UpRivs TVs showing which indicators pose low and potential risk (mg/kg dry, whole sediment)

Site	n	Ag-WAE	As-WAE	Cd-WAE	Cr-WAE	Cu-WAE	Hg-WAE	Ni-WAE	Pb-WAE	Se-WAE	Zn-WAE
SG2	1	0.05	2.2	0.22	0.92	6.2	0.01	3.4	84	0.21	35
Wasiba	29	0.06	3.4	0.24	4.3	8.5	0.01	16.5	26.5	0.30	52
Wankipe	27	0.06	3.7	0.21	5.1	8.4	0.01	20[1]	28.2	0.31	49
SG3	28	0.12	3.3	0.18	3.3	6.8	0.02	17[1]	19.2	0.23	26
UpRivs Sed TV		**1**	**20**	**1.5**	**80**	**65**	**0.15**	**21.8**	**50**	**0.15**	**200**

🟩	Low risk = significantly < TV
🟨	Potential risk = not significantly different from TV OR significantly > TV

WAE – Weak-Acid-Extractable [1] Not statistically significantly different from the TV

Table 7-10 Risk Assessment – Mean sediment quality results at lower river test sites in 2021-2022 compared against LwRivs TVs showing which indicators pose low and potential risk (mg/kg dry, whole sediment)

Site	n	Ag-WAE	As-WAE	Cd-WAE	Cr-WAE	Cu-WAE	Hg-WAE	Ni-WAE	Pb-WAE	Se-WAE	Zn-WAE
Bebelubi	6	0.05	2.1	0.08	3.4	5.3	0.01	8.8	8.3	0.26[1]	17
SG4	6	0.05	2.2	0.08	2.3	6.7	0.01	7.3	9.4	0.28[1]	19
SG5	6	0.05	3.2	0.17	2.6	10	0.01	8.2	10.7	0.33	30
LowRivs Sed TV		**1**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.226**	**200**

🟩	Low risk = significantly < TV
🟨	Potential risk = not significantly different from TV OR significantly > TV

WAE – Weak-Acid-Extractable [1] Not statistically significantly different from the TV

Table 7-11 Risk assessment – Mean sediment quality results at ORWB test sites in 2021-2022 compared against ORWB TVs showing which indicators pose low and potential risk (mg/kg dry, whole sediment)

Site	n	Ag-WAE	As-WAE	Cd-WAE	Cr-WAE	Cu-WAE	Hg-WAE	Ni-WAE	Pb-WAE	Se-WAE	Zn-WAE
Kukufionga	6	0.05	5.9	0.20	3.2	16	0.01	10.0	17.7	0.58	33
Zongamange	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Avu	6	0.20	9.6	0.41	4.6	26	0.01	12.0	47.3[1]	0.70	82
Levame	6	0.05	4.5	0.14	14.8	16	0.01	13.4[1]	15.0	0.40	31
ORWB Sed TV		**1**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.852**	**200**

🟩	Low risk = significantly < TV
🟨	Potential risk = not significantly different from TV OR significantly > TV

WAE – Weak-Acid-Extractable [1] Not statistically significantly different from the TV

Table 7-12 Sediment quality trends at upper river test sites 2013-2022 (mg/kg dry, whole sediment)

Site	**Ag - WAE**	**As - WAE**	**Cd - WAE**	**Cr - WAE**	**Cu - WAE**	**Hg - WAE**	**Ni - WAE**	**Pb - WAE**	**Se - WAE**	**Zn - WAE**
SG2	🟩	🟩	🟩	🟧	🟩	🟩	🟧	🟩	🟩	🟩
Wasiba	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Wankipe	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟩
SG3	🟩	🟩	🟩	🟩	🟧	🟩	🟧	🟩	🟩	🟩
🟩	No change or reduced over time									
🟧	Increased over time									

WAE – Weak-Acid-Extractable

Table 7-13 Sediment quality trends of sediment quality at lower river test sites 2013-2022 (mg/kg dry, whole sediment)

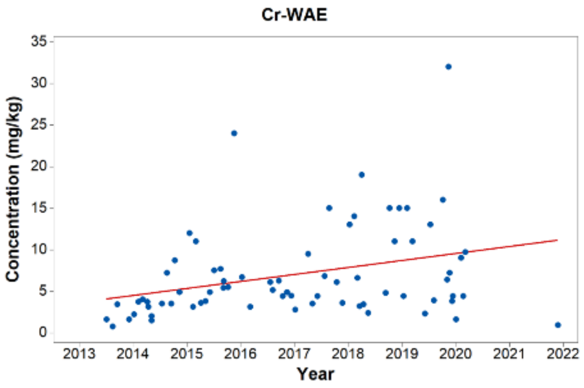
Site	**Ag - WAE**	**As - WAE**	**Cd - WAE**	**Cr - WAE**	**Cu - WAE**	**Hg - WAE**	**Ni - WAE**	**Pb - WAE**	**Se - WAE**	**Zn - WAE**
Bebelubi	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG4	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG5	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
🟩	No change or reduced over time									
🟧	Increased over time									

WAE – Weak-Acid-Extractable

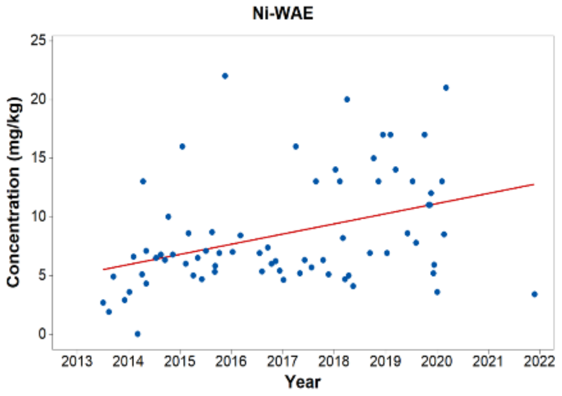
Table 7-14 Sediment quality trends at Lake Murray and ORWB test sites 2013-2022 (mg/kg dry, whole sediment)

Site	**Ag - WAE**	**As - WAE**	**Cd - WAE**	**Cr - WAE**	**Cu - WAE**	**Hg - WAE**	**Ni - WAE**	**Pb - WAE**	**Se - WAE**	**Zn - WAE**
Kukufionga	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Zongamange (to 2019)	🟩	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Avu	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟩
Levame	🟩	🟧	🟩	🟩	🟧	🟩	🟩	🟩	🟧	🟩
🟩	No change or reduced over time									
🟧	Increased over time									

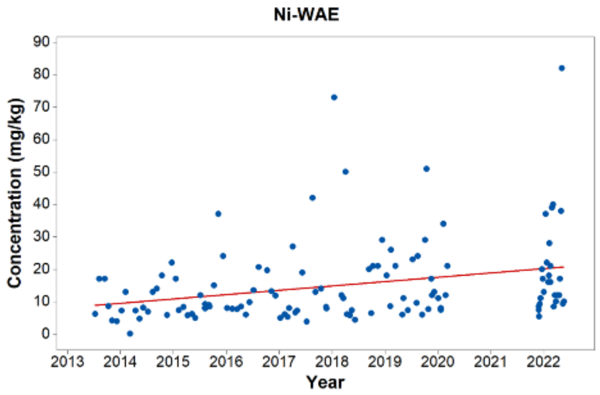
WAE - Weak-Acid-Extractable



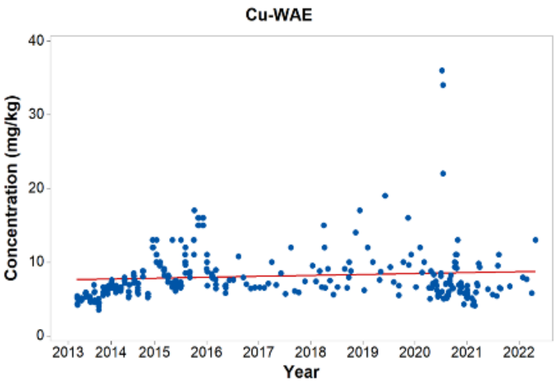
SG2 – WAE chromium concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022



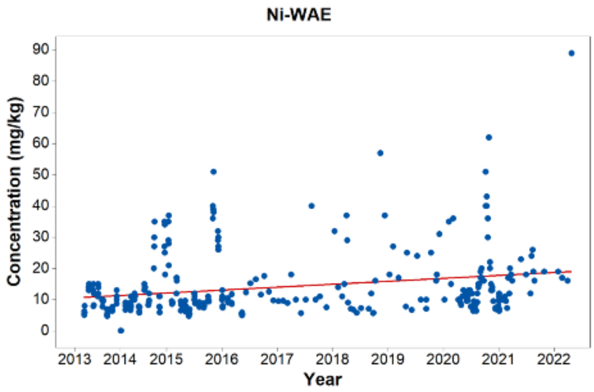
SG2 – WAE nickel concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022



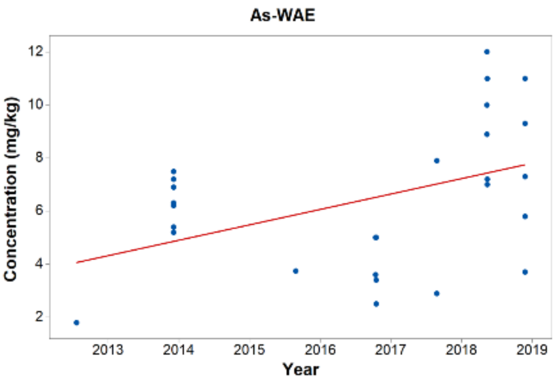
Wankipe – WAE nickel concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022



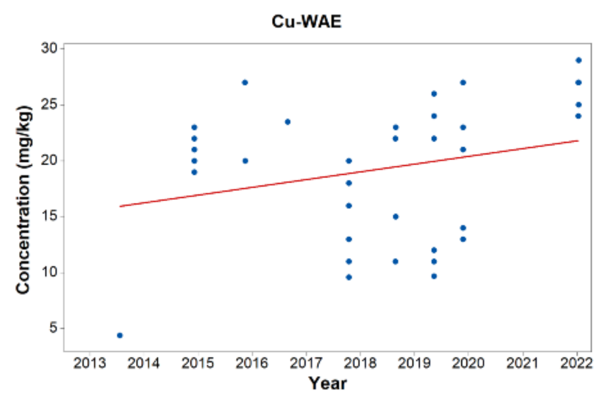
SG3 – WAE copper concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022



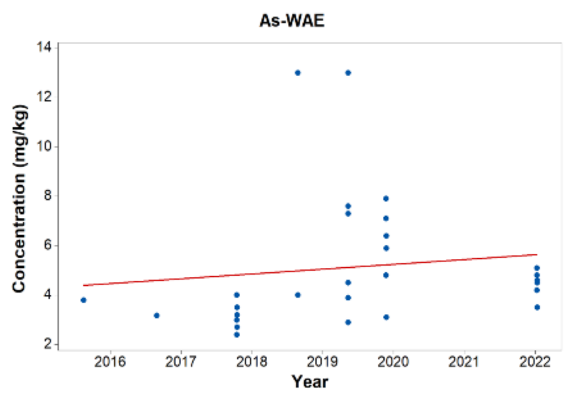
SG3 – WAE nickel concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022



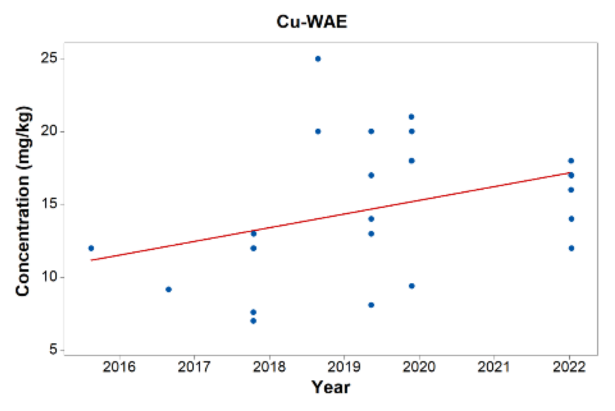
Zongamange – WAE arsenic concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022



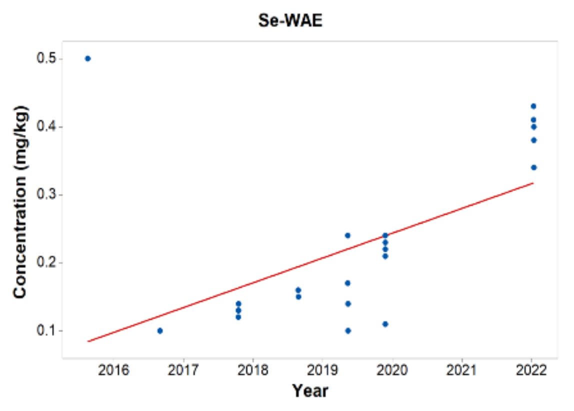
Avu – WAE copper concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022



Levame – WAE arsenic concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022



Levame – WAE copper concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022



Levame – WAE selenium concentrations (mg/kg dry, whole sediment) (Test site) 2013 – 2022

Figure 7-3 Trend analysis upper river, lower river and ORWB test site sediment quality showing statistically significant increasing trends in (mg/kg dry, whole sediment) (scatter plot of all data from 2013 – 2022 with linear trend line)

7.1.2.2 Lake Murray

The results of the risk assessment for WAE metals concentrations in sediment at Lake Murray test sites are presented in Table 7-15. The risk assessment shows that the 2021-2022 mean for most metals at most sites were below their respective TVs, with the exception of WAE selenium at Central Lake, which was not significantly different to the TV.

Analysis of trends of benthic sediment quality at Lake Murray test sites is presented in Table 7-16 and Figure 7-4 show a statistically significant increasing trend for WAE arsenic at Central Lake and SG6 between 2013 and 2022. Trends for all other metals showed no statistically significant change between 2013 and 2022. Detailed results of the statistical analysis are shown in Volume 2.

Table 7-15 Risk assessment – Mean sediment quality results at Lake Murray test sites in 2021-2022 compared against LMY TVs showing which indicators pose low and potential risk (mg/kg dry, whole sediment)

Site	n	Ag-WAE	As-WAE	Cd-WAE	Cr-WAE	Cu-WAE	Hg-WAE	Ni-WAE	Pb-WAE	Se-WAE	Zn-WAE
LMY Central	10	🟩 0.09	🟩 2.9	🟩 0.14	🟩 5.2	🟩 11	🟩 0.03	🟩 13	🟩 15	🟨 0.89[1]	🟩 53
LMY Southern	11	🟩 0.25	🟩 3.8	🟩 0.20	🟩 4.4	🟩 15	🟩 0.05	🟩 9	🟩 32	🟩 0.46	🟩 59
LMY SG6	6	🟩 0.28	🟩 6.3	🟩 0.27	🟩 4.3	🟩 20	🟩 0.02	🟩 11	🟩 25	🟩 0.46	🟩 53
Lake Murray Sed TV		**1**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.852**	**200**
🟩	Low risk = significantly < TV										
🟨	Potential risk = not significantly different from TV OR significantly > TV										

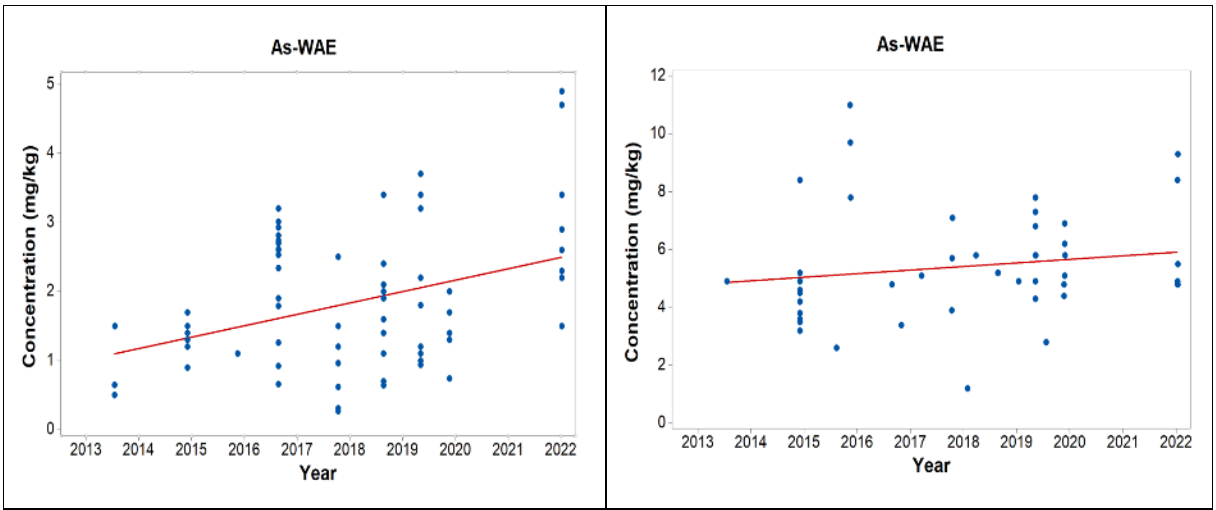
WAE – Weak-Acid-Extractable

[1] Not statistically significantly different from the TV

Table 7-16 Sediment quality trends at Lake Murray and ORWB test sites 2013-2022 (mg/kg dry, whole sediment)

Site	Ag - WAE	As - WAE	Cd - WAE	Cr - WAE	Cu - WAE	Hg - WAE	Ni - WAE	Pb - WAE	Se - WAE	Zn - WAE
Central Lake	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Southern Lake	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG6	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
🟩	No change or reduced over time									
🟨	Increased over time									

WAE - Weak-Acid-Extractable



Central Lake – WAE arsenic concentrations (mg/kg dry, whole sediment) (Test site) 2013 - 2022

SG6 – WAE arsenic concentrations (mg/kg dry, whole sediment) (Test site) 2013 - 2022

Figure 7-4 Trend analysis Lake Murray site sediment quality showing statistically significant increasing trends in (mg/kg dry, whole sediment) (scatter plot of all data from 2013 – 2022 with linear trend line)

7.1.3 Tissue metals

7.1.3.1 Upper and Lower Rivers

The results of the tissue metal risk assessment for the upper and lower rivers are shown in Table 7-17 and Table 7-18 respectively.

The assessment showed that at Wasiba in the upper river the 2021-2022 mean for nickel in fish flesh and chromium, lead, selenium and zinc in prawn abdomen were not significantly different from the TVs.

At Wankipe, the 2021-2022 mean for chromium, copper and nickel in fish flesh and cadmium, chromium, copper, nickel, lead and zinc in prawn abdomen were not significantly different to the respective TVs.

In the lower river, the risk assessment showed that at Bebelubi, the 2021-2022 mean for chromium in fish flesh and arsenic, lead, selenium and zinc in prawn abdomen were not significantly different from the TVs. At SG4, chromium in fish flesh and arsenic, cadmium, chromium, copper, nickel, selenium and zinc in prawn abdomen were not significantly different from the TV.

A summary of results from trend analysis performed for the upper and lower rivers is presented in Table 7-19 and Table 7-20. The results showed that in the upper river, concentrations of chromium in prawn abdomen at Wasiba showed a statistically significant increasing trend between 2013 and 2022. In the lower river, no indicator concentrations showed a statistically significant increasing trend between 2013 and 2022. Scatter plots with linear trend lines for metals with statistically significant increasing trends are shown in Figure 7-5. Detailed results of the statistical analysis are shown in Volume 2.

Table 7-17 Risk assessment – Mean tissue metal results at upper river test sites in 2021-2022 compared against UpRivs TVs showing which indicators pose low and potential risk (µg/g wet wt.)

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Wasiba	Fish Flesh	6	0.02	0.004	0.02	0.33	0.05	0.01[1]	0.01	0.37	5.7
	Prawn Ab	6	0.02	0.003	0.07[1]	4.10	0.01	0.01	0.01[1]	0.60[1]	13.3[1]
Wankipe	Fish Flesh	6	0.01	0.004	0.18[1]	0.37[1]	0.05	0.04[1]	0.02	0.29	4.8
	Prawn Ab	6	0.03	0.003[1]	0.05[1]	9.28[1]	0.01	0.02[1]	0.01[1]	0.42	14.0[1]
UpRivs TV	Fish Flesh		0.20	0.020	0.05	0.48	0.08	0.01	0.17	2.26	10.4
	Prawn Ab		0.04	0.003	0.04	6.94	0.01	0.01	0.01	0.57	14.0
🟩	Low risk = significantly < TV										
🟧	Potential risk = significantly > TV OR not significantly different from TV										

Ab – Abdomen

[1] Not statistically significantly different from the TV

Table 7-18 Risk assessment – Mean tissue metal results at lower river test sites in 2021-2022 compared against LwRivs TVs showing which indicators pose low and potential risk (µg/g wet wt.)

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Bebelubi	Fish Flesh	6	0.01	0.003	0.02[1]	0.08	0.04	0.03	0.01	0.12	2.4
	Prawn Ab	6	0.08[1]	0.003	0.03	5.58	0.01	0.01	0.01[1]	0.36[1]	12[1]
SG4	Fish Flesh	6	0.01	0.003	0.02[1]	0.08	0.06	0.03	0.01	0.15	4.1
	Prawn Ab	6	0.07[1]	0.01[1]	0.04[1]	7.22[1]	0.01	0.01[1]	0.01	0.33[1]	11.3[1]
LwRivs TV	Fish Flesh		0.07	0.003	0.02	0.17	0.12	0.17	0.03	2.26	7.5
	Prawn Abdo		0.10	0.003	0.05	9.34	0.01	0.01	0.01	0.32	13.0
🟩	Low risk = significantly < TV										
🟧	Potential risk = significantly > TV OR not significantly different from TV										

Ab – Abdomen

[1] Not statistically significantly different from the TV

Table 7-19 Tissue metal trends at upper river test sites 2013 - 2022

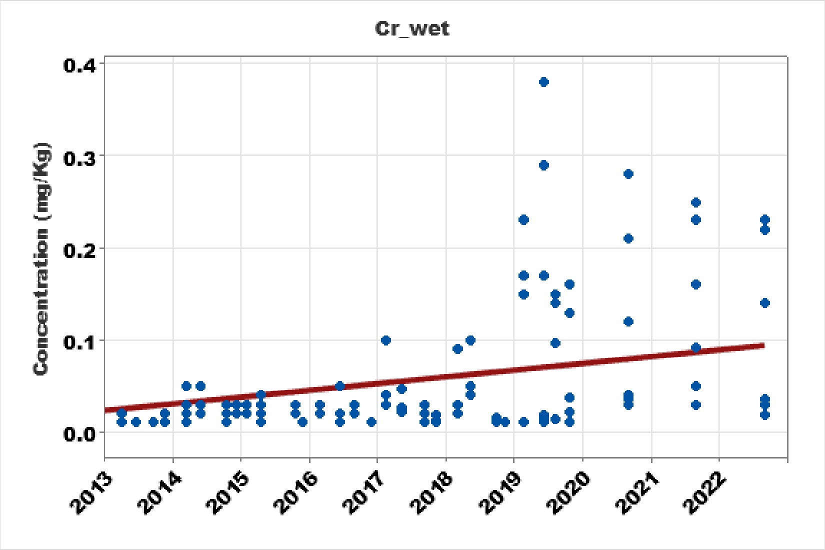
Site	Sample	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Wasiba	Fish Flesh	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Prawn Ab	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟩	🟩
Wankipe	Fish Flesh	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Prawn Ab	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
🟩	No change or reduced over time									
🟧	Increased over time									

Ab – Abdomen

Table 7-20 Tissue metal trends at lower river test sites 2013–2022

Site	Sample	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Bebelubi	Fish Flesh	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Prawn Ab	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG4	Fish Flesh	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Prawn Ab	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
🟩	No change or reduced over time									
🟧	Increased over time									

Ab – Abdomen



Wasiba – Chromium concentration (µg/g wet wt.) in prawn abdomen (2013 – 2022)

Figure 7-5 Trend analysis of statistically significant increasing trends in tissue metal at upper river test sites 2013 - 2022.

7.1.3.2 Lake Murray

The results of the tissue metal risk assessment for Lake Murray are shown in Table 7-21. The assessment showed that the 2021-2022 mean for arsenic, chromium, mercury and zinc in fish flesh at Pangoa was not significantly different from the TV and the 2021-2022 mean for chromium, nickel and zinc in fish flesh at Miwa was not significantly different from the TV. The 2022 TSM for all other metals in fish flesh were less than the TVs. It should be noted that the very low sample count (n) at these sites during C&M reduces the power of the statistical test.

A summary of results from trend analysis performed for Lake Murray sites is presented in Table 7-22 and showed that all parameters at Pangoa either reduced or did not change between 2010 and 2022, and at Miwa between 2010 and 2022. Detailed results of the direct comparison are shown in Volume 2.

Table 7-21 Risk assessment – Mean tissue metal results at Lake Murray test site in 2021-2022 compared against Lake Murray TVs showing which indicators pose low and potential risk (µg/g wet wt.)

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Centra Lake - Pangoa	Fish Flesh	2	0.03[1]	0.003	0.01[1]	0.10	0.28[1]	0.01	0.01	0.34	2.9[1]
Southern Lake - Miwa	Fish Flesh	3	0.02	0.003	0.03[1]	0.13	0.01	0.17[1]	0.01	0.25	3.9[1]
Lake Murray TV	Fish Flesh		0.05	0.003	0.03	0.20	0.34	0.19	0.07	2.26	3.12
🟩	Low risk = significantly < TV										
🟧	Potential risk = significantly > TV OR not significantly different from TV										

Ab – Abdomen [1] Not statistically significantly different from the TV

Table 7-22 Tissue metal trends at Lake Murray test sites (Miwa 2010–2022) (Pangoa 2002 – 2022)

Site	Sample	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Pangoa	Fish Flesh	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Miwa	Fish Flesh	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
🟩	No change or reduced over time									
🟧	Increased over time									

7.1.4 Discussion and Overall Risk Assessment

This section presents a discussion of the individual risk assessments carried out based on water quality, sediment quality and tissue metal concentrations in fish and prawns at test sites downstream of the mine. The discussion is based on a weight of evidence approach which considers the concentration of contaminants of concern in the discharge from the mine, the level of risk posed by each individual element in water, sediment and tissue at each site and concludes with an overall assessment of risk. This process is intended to identify those contaminants of concern which are deemed to pose a material potential risk to the receiving environment.

Where further assessment supports the result of the initial risk assessment, that result is maintained, however, in some cases, this process has resulted in a change of the initial risk assessment result from potential risk to low risk. The final risk assessment results have been categorised in accordance with the criteria outlined in Table 7-23.

Table 7-24, Table 7-25 and Table 7-26 provide a compilation of final risk assessment results for each physical and chemical toxicant in water, sediment, fish tissue and prawn abdomen, for the purposes of comparison throughout the receiving environment and between matrices.

Table 7-23 Initial and final risk assessment criteria

Key	Initial Risk Assessment Result	Final Risk Assessment Result
🟩	Low risk	Low risk
■	Potential risk	Low risk
🟧	Potential risk	Potential risk

As a general finding, it should be noted that the concentrations of all metals and metalloids within prawn and fish tissues at all sites within the upper and lower rivers were below applicable food standards and therefore do not pose a risk to human health from these contaminants if consumed. A comparison against food standards is provided in Section 0.

Table 7-24 Summary of mine discharge water quality compared against respective TVs and receiving environment water quality risk assessment results, showing indicators in discharge (median) and test sites (mean) that pose potential risk to the receiving environment in November 2021 – May 2022 (µg/L except where indicated)

Region	Site	WATER												
		pH^	TSS*	EC#	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Discharge	Tailngs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	28 Level	8.0	7	897	0.01	0.76	0.05	0.1	0.2	0.05	2.2	0.1	0.20	13[1]
	SDA Toe	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kaiya Riv D/S Anj dump	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kogai Culvert	8.3	260	892	0.013	1.4	0.089	0.14	0.79	0.05	0.82	0.15	0.20	21
	Kogai Dump Toe	8.1	30	1,644	0.01	0.56	0.97	0.12	0.44	0.05	1.4	0.47	0.20	160
	Lime Plant	9.8	36	99	0.01	0.32	0.05	1.2	1.2	0.05	0.5	0.1	0.20	2.1
	Wendoko Crk D/S Anawe Nth	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Yakatabari Crk D/S 28 Level	8.5	4,100	869	0.02	7.3	0.05	0.29	0.81	0.05	1.8	0.31	0.25	15
	Yunarilama @ Portal	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Upper River	SG1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SG2	7.7	950	221	0.04	0.83	0.05	0.27	0.20	0.05	1.3	0.10	0.20	2.7
	Wasiba	8.2[1]	1,557	208	0.01	0.79	0.05	0.32	0.62	0.05	0.70	0.10	0.21	3.8
	Wankipe	8.2	1,774	210	0.01	0.76	0.05	0.28	0.66	0.06	0.66	0.10	0.22	7.1
	SG3	8.1	1,706	200	0.04	0.69	0.05	0.28	0.78	0.06	0.71	0.13	0.21	8.8
Lower River	Bebelubi	7.6	487	171[1]	0.01	0.60	0.05	0.48	0.46	0.08	0.53	0.10	0.20	38
	SG4	7.6	662[1]	142	0.01	0.59	0.05	0.44	0.72	0.07	0.60	0.10	0.20	11
	SG5	8.2	747	171	0.01	0.86	0.05	0.16	1.1	0.05	0.71	0.13	0.20	2.8
ORWBs	Kukufionga	7.7	75	204	0.01	2.3	0.05	0.10	0.64	0.05	0.5	0.10	0.20	2.1
	Zongamange	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Avu	7.3	21	49	0.01	0.6	0.05	0.26	0.50	0.05	0.8	0.12	0.20	3.7
	Levame	7.9	7.0	173[1]	0.01	0.9	0.05	0.10	1.8	0.05	0.5	0.10	0.20	1.6
Lake Murray	Pangoa, Central Lake Murray	6.7	6.9	16.6	0.02	0.14	0.14	0.12	1.2[1]	0.05	0.6	0.10	0.20	2.7
	Miwa, Southern Lake Murray	6.9	4.8	14.3	0.01	0.20	0.05	0.13	0.31	0.07	0.6	0.12	0.20	1.4
	SG6	7.3	6.8	38.2	0.01	0.49	0.05	0.12	0.27	0.05	0.6	0.11	0.20	1.2

🟩	Low Risk	🟩	Low Risk - Initial assessment showed potential risk – downgraded to low risk after further investigation	🟨	Potential Risk

^ std units, * mg/L, # µS/cm, D = Dissolved fraction, [1] Although TSM falls below the TV, the 2019 dataset contains some values that do exceed the TV, this increases the standard deviation of the dataset and as a result, the TSM was not statistically significantly different from the TV. NS = Not sampled during 2021-2022. NS – Not sampled. ND – No Discharge

Table 7-25 Summary of mine discharge sediment quality compared against respective TVs and receiving environment sediment quality risk assessment results, showing indicators in discharge (median) and test sites (mean) that pose low and potential risk to the receiving environment from November 2021 – May 2022 (mg/kg dry, whole fraction)

Region	Site	SEDIMENT									
		Ag - WAE	As - WAE	Cd - WAE	Cr- WAE	Cu - WAE	Hg - WAE	Ni - WAE	Pb - WAE	Se - WAE	Zn - WAE
Discharge	Tailings	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	28 Level	2.8	69	1.9	8.1	29	0.02	31	220	0.19	690
	SDA Toe	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kaiya Riv D/S Anj dump	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kogai Culvert	1.3	8.9	0.35	2.5	9.3	0.07	4.5	88	0.22	660
	Kogai Dump Toe	2	40	5.1	4.2	29	0.06	8.8	460	0.23	660
	Lime Plant	0.09	2	0.35	7.3	7	0.01	2	1.8	0.11	41
	Wendoko Crk D/S Anawe Nth	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Yakatabari Crk D/S 28 Level	5.1	28	2.1	8.4	47	0.04	13	230	0.23	330
	Yunarilama @ Portal	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Upper River	SG1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SG2	0.05	2.2	0.22	0.92	6.2	0.01	3.4	84	0.21	35
	Wasiba	0.06	3.4	0.24	4.3	8.5	0.01	16.5	26.5	0.30	52
	Wankipe	0.06	3.7	0.21	5.1	8.4	0.01	20[1]	28.2	0.31	49
	SG3	0.12	3.3	0.18	3.3	6.8	0.02	17[1]	19.2	0.23	26
Lower River	Bebelubi	0.05	2.1	0.08	3.4	5.3	0.01	8.8	8.3	0.26[1]	17
	SG4	0.05	2.2	0.08	2.3	6.7	0.01	7.3	9.4	0.28[1]	19
	SG5	0.05	3.2	0.17	2.6	10	0.01	8.2	10.7	0.33[1]	30
ORWBs	Kukufionga	0.05	5.9	0.20	3.2	16	0.01	10.0	17.7	0.58	33
	Zongamange	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Avu	0.20	9.6	0.41	4.6	26	0.01	12.0	47.3[1]	0.70	82
	Levame	0.05	4.5	0.14	14.8	16	0.01	13.4[1]	15.0	0.40	31
Lake Murray	Pangoa, Central Lake Murray	0.09	2.9	0.14	5.2	11	0.03	13	15	0.89[1]	53
	Miwa, Southern Lake Murray	0.25	3.8	0.20	4.4	15	0.05	9	32	0.46	59
	SG6	0.28	6.3	0.27	4.3	20	0.02	11	25	0.46	53

🟩	Low Risk	🟩	Low Risk - Initial assessment showed potential risk – downgraded to low risk after further investigation	🟧	Potential Risk

WAE – Weak acid extraction, [1] Although TSM falls below the TV, the 2019 dataset contains some values that do exceed the TV, this increases the standard deviation of the dataset and as a result, the TSM was not statistically significantly different from the TV.

Table 7-26 Summary of receiving environment water quality, sediment quality and tissue metals risk assessment results, showing indicators at test sites that pose low and potential risk to the receiving environment in 2019

Region	Site	Indicator	Unit	WATER, SEDIMENT, TISSUE METAL COMBINED												
				pH^	TSS*	EC	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Upper River	Wasiba	Water-D	µg/L	8.2[1]	1,557	208	0.01	0.79	0.05	0.32	0.62	0.05	0.70	0.10	0.21	3.8
		Sed-WAE	mg/kg	-	-	-	0.06	3.4	0.24	4.3	8.5	0.01	16.5	26.5	0.30	52
		Fish Flesh	µg/g	-	-	-	-	0.02	0.004	0.02	0.33	0.05	0.01[1]	0.01	0.37	5.7
		Prawn Abdo	µg/g	-	-	-	-	0.02	0.003	0.07[1]	4.10	0.01	0.01	0.01[1]	0.60[1]	13.3[1]
	Wankipe	Water-D	µg/L	8.2	1,774	210	0.01	0.76	0.05	0.28	0.66	0.06	0.66	0.10	0.22	7.08
		Sed-WAE	mg/kg	-	-	-	0.06	3.7	0.21	5.1	8.4	0.01	20[1]	28.2	0.31	49
		Fish Flesh	µg/g	-	-	-	-	0.01	0.004	0.18[1]	0.37[1]	0.05	0.04[1]	0.02	0.29	4.8
		Prawn Abdo	µg/g	-	-	-	-	0.03	0.003[1]	0.05[1]	9.28[1]	0.01	0.02[1]	0.01[1]	0.42	14.0[1]
Lower River	Bebelubi	Water-D	µg/L	7.6	487	171[1]	0.01	0.60	0.05	0.48	0.46	0.08	0.53	0.10	0.20	38
		Sed-WAE	mg/kg	-	-	-	0.05	2.07	0.08	3.42	5.27	0.01	8.75	8.28	0.26[1]	16.5
		Fish Flesh	µg/g	-	-	-	-	0.01	0.003	0.02[1]	0.08	0.04	0.03	0.01	0.12	2.4
		Prawn Abdo	µg/g	-	-	-	-	0.08[1]	0.003	0.03	5.58	0.01	0.01	0.01[1]	0.36[1]	12[1]
	SG4	Water-D	µg/L	7.6	662[1]	142	0.01	0.59	0.05	0.44	0.72	0.07	0.60	0.10	0.20	11
		Sed-WAE	mg/kg	-	-	-	0.05	2.21	0.08	2.27	6.67	0.01	7.25	9.37	0.28[1]	18.8
		Fish Flesh	µg/g	-	-	-	-	0.01	0.003	0.02[1]	0.08	0.06	0.03	0.01	0.15	4.1
		Prawn Abdo	µg/g	-	-	-	-	0.07[1]	0.01[1]	0.04[1]	7.22[1]	0.01	0.01[1]	0.01	0.33[1]	11.3[1]
Lake Murray	C. Lake - Pangoa	Water-D	µg/L	6.7	6.9	16.6	0.02	0.14	0.14	0.12	1.2[1]	0.05	0.6	0.10	0.2	2.7
		Sed-WAE	mg/kg	-	-	-	0.09	2.9	0.14	5.2	11	0.03	13	15	0.89[1]	53
		Fish Flesh	µg/g	-	-	-	-	0.03[1]	0.003	0.01[1]	0.10	0.28[1]	0.01	0.01	0.34	2.9[1]
	S. Lake - Miwa	Water-D	µg/L	6.9	4.8	14.3	0.01	0.20	0.05	0.13	0.31	0.07	0.6	0.12	0.2	1.4
		Sed-WAE	mg/kg	-	-	-	0.25	3.8	0.20	4.4	15	0.05	9	32	0.46	59
		Fish Flesh	µg/g	-	-	-	-	0.02	0.003	0.03[1]	0.13	0.01	0.17	0.01	0.25	3.9[1]

🟩	Low Risk	🟩	Low Risk - Initial assessment showed potential risk – downgraded to low risk after further investigation	🟧	Potential Risk

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[1] Although TSM falls below the TV, the 2019 dataset contains some values that do exceed the TV, this increases the standard deviation of the dataset and as a result, the TSM was not statistically significantly different from the TV.

7.1.4.1 pH

Rainfall runoff discharged from the lime plant exhibited elevated pH as a result of contact with limestone and hydrated lime within the lime plant area (Table 7-24). The discharge flow rate is relatively low compared to flows within the receiving environment, which also exhibit alkaline conditions due to the naturally occurring limestone geology in the contributing catchment. The risk posed by elevated pH in discharge from the lime plant is low and localised, being restricted to the area immediately downstream of the discharge point. The pH of all other discharges from the mine was within the upper and lower bounds of the TV for the upper rivers and posed low risk of impact to the receiving environment (Table 7-24).

Within the receiving environment downstream of the Porgera River, at all sites with the exception of Wasiba in the upper river, the pH was within upper and lower bounds of the respective TVs, indicating low risk to the condition of the receiving environment (Table 7-24).

At Wasiba, the mean pH in 2021-2022 was not significantly different from the upper river TV (Table 7-24) for pH and the trend for pH between 2013 and 2022 shows pH increasing (Table 7-4).

As a result of discharges from the mine site posing low risk to pH in the receiving environment, the 2021-2022 TSM for pH at Wasiba being not significantly different from the TV and the increasing trend in pH at Wasiba, the result of the initial risk assessment for pH at Wasiba is considered to be driven by natural, localised conditions and is not related to the operation of the Porgera Mine. As a result, the initial risk assessment for pH at Avu has been adjusted from potential risk to low risk. The change is reflected in Table 7-24.

7.1.4.2 Total Suspended Solids

TSS in water discharged from the site during 2021-2022 typically did not exceed the upper river TV for TSS, indicating low risk (Table 7-24). However, TSS in water discharged from Yakatabari Crk D/S 28 Level did exceed the upper river TV, indicating risk (Table 7-24), and although not sampled during 2021-2022 due to security reasons, the TSS of water discharged from Yunarilama @ Portal (Yarik Portal) is also expected to have exceeded the TV.

The cessation of tailings discharge and the significant reduction in the volume of erodible waste rock discharged from the site has reduced mine-related TSS contributions to the receiving environment during C&M.

Within the receiving environment in 2021-2022, the mean concentration of TSS at all sites within the upper river, lower river, ORWBs and Lake Murray was below the respective TVs with the exception of SG4 in the lower river, where the mean TSS concentration in 2021-2022 was not significantly different from the TV, therefore indicating potential risk (Table 7-24).

However, in the context of reduced TSS discharge from the mine during C&M and given that large river systems within PNG are prone to periods of elevated TSS, the initial result of the risk assessment for TSS at SG4 is considered to be within the natural range of TSS and is therefore not considered to be related to the operation of the Porgera Mine. As a result, the initial risk assessment result for TSS at SG4 has been adjusted from potential risk to low risk. The change is reflected in Table 7-24.

7.1.4.3 Electrical Conductivity (EC)

Electrical conductivity (EC) is a measure of waters capability to pass electrical current, which in turn is directly related to the concentration of ions in the water. Conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and carbonate compounds.

EC is elevated in all discharge points from the operation and is driven by elevated concentrations of total dissolved salts primarily; sulfates, calcium, magnesium, sodium and potassium. These ions are present in the natural geology of the Porgera deposit, but are concentrated in certain streams due to the mining and processing activities.

Elevated EC in discharge from the competent waste rock dumps (Wendoko Creek downstream of Anawe Nth and Yakatabari Creek D/S 28 level) is driven by high concentrations of sulfate, generated from the redox reaction occurring within the competent waste rock dumps (Table 7-24).

At all other sites, elevated EC is driven by a range of ions (calcium, magnesium, sodium and potassium) present in the discharge generated from the host geology.

At all test sites within the upper river (SG2, Wasiba, Wankipe and SG3), the 2021-2022 mean EC was less than the TV, indicating low risk (Table 7-24).

In the lower river and ORWBs, the 2021-2022 mean EC was greater than the TV at ORWB Kukufionga and not significantly different from the TV at Bebelubi and ORWB Levame, indicating potential risk. At SG4, SG5 and ORWB Avu, the 2021-2022 mean EC was less than the TV, indicating low risk (Table 7-24).

In Lake Murray, the 2021-2022 mean EC was greater than the TV at SG6, indicating potential risk and less than the TV at Pangoa, Central Lake Murray and Miwa, Southern Lake Murray, indicating low risk (Table 7-24).

It should be noted that during the operational phase of the mine, the tailings discharge exhibited high EC due to high concentrations of calcium sulfate which is formed when sulfate in the tailings steam is combined with calcium hydroxide (slaked lime), which is added to the tailings stream to raise the pH prior to discharge. The results of the 2019 risk assessment (BNL, 2019) showed potential risk posed by EC at all upper river sites (SG2, Wasiba, Wankipe, SG3) and lower river sites Bebelubi, SG4 and Miwa, Southern Lake Murray. EC showed a reducing trend with increasing distance from the mine, and discharge from the mine was deemed to be the likely driver of elevated EC in the river system.

The results of the risk assessment show the reduction in EC observed during C&M at the upper river test sites has brought EC in water at the upper river test sites below the upper river TV for EC. Figure 7-6 shows EC at Wasiba between 20.06.2018 and 18.05.2022, before and after the site entered C&M in April 2020.

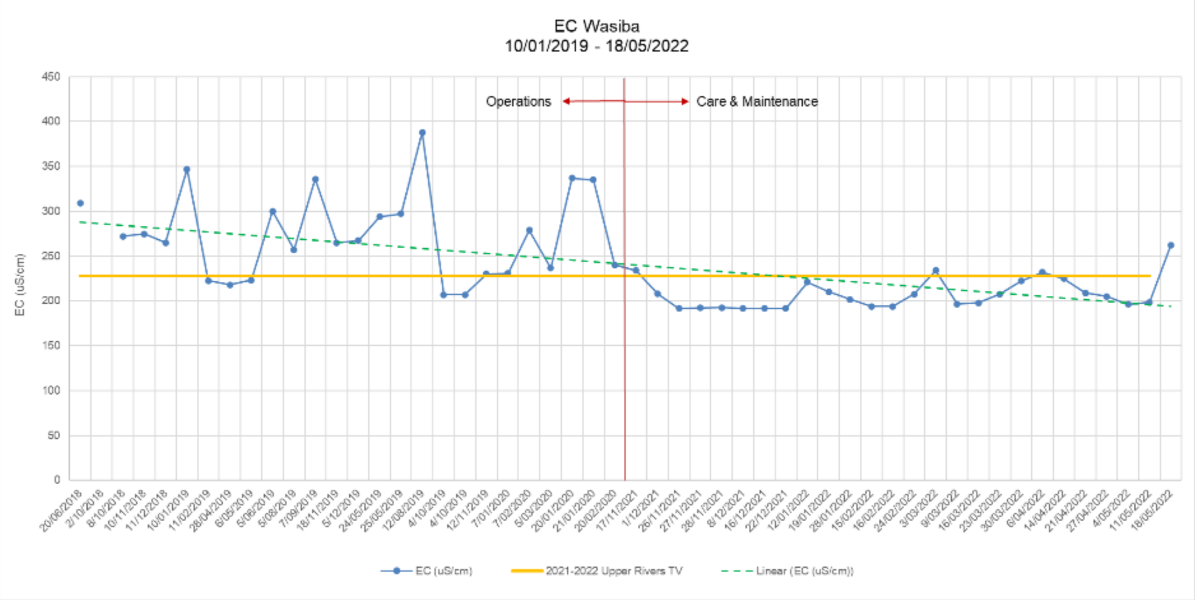


Figure 7-6 EC at Wasiba between 25th January 2018 and 27th March 2022

Given that the results of the risk assessment for the upper river test sites in 2021-2022 show the mean EC is less than the upper river TV, it can be concluded that EC at these sites in 2021-2022 is reflective of reference conditions and that the cessation of tailings discharge has resulted in the change observed at the upper river test sites driven by a decline in sulfate, sodium and potassium.

In the lower river, the 2021-2022 TV for EC is 186 µS/cm and for Lake Murray is 21 µS/cm, both below the upper river TV of 228 µS/cm. The higher TV in the upper river indicates higher natural EC in the upper river sites compared to the Lower River and Lake Murray reference sites. Naturally elevated EC in the upper river test and reference sites is a possible source of elevated EC being observed at the lower river, ORWB and Lake Murray test sites in 2021-2022. The lower river test sites are located on the main channel of the Strickland River, which naturally receives flow from the upper river. The Lower River and Lake Murray reference sites, upon which the lower river, ORWB and Lake Murray TVs are derived, do not receive flows from the upper Strickland River.

Additionally, there is declining trend shown for EC at all upper river, lower river, ORWB and Lake Murray test sites between 2013 and 2022.

Therefore, the overall risk posed by EC at Bebelubi, Kukufionga, Levame and SG6 in 2021-2022 is considered low, and the results of the initial risk assessment for EC at these sites have been modified from potential risk to low risk. The change is reflected in Table 7-24 and Table 7-27.

Table 7-27 Comparison of 2019 and 2021-2022 risk assessment results for EC in water

Region	Site	WATER EC	
		2019	2021 - 2022
Discharge	Tailings	3,900	No Discharge
	28 Level	717	897
	SDA Toe	NS	NS
	Kaiya Riv D/S Anj Dump	274	NS
	Kogai Culvert	815	892
	Kogai Stable Dump Toe	1,747	1,644
	Lime Plant	1,157	99
	Wendoko Creek D/S Anawe Nth	2,127	NS
	Yakatabari Creek D/S 28 Level	635	869
	Yunarilama/Yarik @ Portal	1,904	NS
Upper River	SG1	NS	NS
	SG2	286	221
	Wasiba	265	208
	Wankipe	239	210
	SG3	233	200
Lower River	Bebelubi	217	171[1]
	SG4	182[1]	142
	SG5	159	171
ORWBs	Kukufionga	157	204
	Zongamange	110	NS
	Avu	55	49
	Levame	165[1]	173[1]
Lake Murray	Central Lake - Pangoa	16	16.6
	Southern Lake - Miwa	23	14.3
	SG6	84	38.2

7.1.4.4 Silver (Ag)

The 2021-2022 the median concentration of dissolved silver in water discharged from the mine was below the upper river TV at all monitored discharge points (Table 7-24), which is consistent with discharge water quality during the operational phase (BNL, 2019).

WAE silver in sediment discharged from 28 Level, Kogai Culvert, Kogai Dump Toe and Yakatabari Crk D/S 28 Level were greater than the upper river TV (Table 7-25), which is also consistent with discharge sediment quality during the operational phase (BNL, 2019).

Within the receiving environment, the mean concentration of dissolved silver in water (Table 7-24), WAE silver in sediment (Table 7-25) and silver in the tissue of prawns and fish (Table 7-26), was below their respective TVs, indicating low risk.

Therefore, the risk posed by silver to the condition of the receiving environment downstream of the Porgera River in 2021-2022 was low.

7.1.4.5 Arsenic (As)

The 2021-2022 mean concentrations of dissolved arsenic in all contact waters discharged from the mine were below the upper river TV and therefore posed a low risk to the receiving environment (Table 7-24).

In sediment discharged from the operation in 2021-2022, the mean concentration of WAE arsenic in sediment discharged from 28 level exceeded the upper river TV, indicating potential risk (Table 7-25). Historically, the concentration of WAE arsenic in tailings sediment has exceeded the upper river TV (BNL, 2019).

The 2021-2022 mean concentrations of arsenic in prawn abdomen and fish tissue in the upper river was less than the upper river TV, indicating low risk (Table 7-26). At Bebelubi and SG4 in the lower river, the 2021-2022 mean concentration of arsenic in prawn abdomen was not significantly different from the TV, indicating potential risk and the mean concentration of arsenic in fish flesh was below the TV, indicating low risk (Table 7-26).

At Pangoa, Central Lake Murray the 2021-2022 mean concentration of arsenic in fish flesh was less than the TV, indicating low risk, and at Miwa, Southern Lake Murray, the 2021-2022 mean concentration of arsenic in fish flesh was not significantly different from the TV, indicating potential risk (Table 7-26).

The trend analysis showed the concentrations of arsenic in water reduced or did not change at all test sites between 2002 and 2022 (Table 7-4, Table 7-5, Table 7-6, Table 7-8). The concentration of WAE arsenic in sediment at all upper and lower river test sites either reduced or did not change between 2013 and 2022 (Table 7-12 and Table 7-13). In the ORWBs, the concentration of WAE in sediment at Zongamange and Levame showed an increasing trend between 2013 and 2022 and at Kukufionga and Avu, the concentration of WAE in sediment either reduced or did not change between 2013 and 2022 (Table 7-14). The analysis showed that the concentrations of arsenic in prawn abdomen and fish tissue at all test sites in the upper and lower river between 2013 and 2022 (Table 7-19 and Table 7-20), and for fish tissue in Lake Murray between 2002 and 2022 reduced or did not change (Table 7-22).

Overall, because of low concentrations of arsenic in discharge from the mine site and low concentrations in water, sediment and prawn and fish tissue throughout the upper river, lower river, ORWBs and Lake Murray, the risk posed by arsenic to the receiving environment is considered low. Pangoa, Central Lake Murray where the mean concentration of arsenic in fish flesh exceeded the TV also showed an increasing trend in WAE arsenic in sediment. However, given the result for fish tissue is not significantly different from the TV, and that the trend for arsenic in fish tissue is not increasing, the risk posed by arsenic in fish tissue is considered low. Arsenic at Central Lake Pangoa will continue to be monitored.

Therefore, the results of the initial risk assessment for arsenic in prawn abdomen at Bebelubi and SG4, and for fish flesh in Central Lake Murray at Pangoa have been adjusted from potential risk to low risk, the change is reflected in Table 7-26.

7.1.4.6 Cadmium (Cd)

The 2021-2022 mean concentration of dissolved cadmium in water discharged from Kogai Culvert and Kogai Dump Toe and the 2021-2022 mean concentration of WAE cadmium in sediment discharged from 28 Level, Kogai Dump Toe and Yakatabari Crk D/S 28 Level were greater than the upper river TV, indicating potential risk (Table 7-24 and Table 7-25). Historically, tailings discharge has exhibited elevated dissolved cadmium in water and WAE cadmium in sediment (BNL, 2019).

Within the receiving environment, dissolved cadmium in water at all sites was less than the respective TVs, indicating low risk. It should be noted that at all test sites except Pangoa, Central Lake Murray, the 2021-2022 mean concentration of dissolved cadmium in water was less than the limit of reporting at 0.05 µg/L (Table 7-24).

The 2021-2022 mean WAE cadmium concentration in sediment at all test sites was below the respective TVs indicating low risk (Table 7-25).

At Wankipe in the upper river and at SG4 in the lower river, the 2021-2022 mean concentration of cadmium in prawn abdomen was not significantly different from the TV, indicating potential risk (Table 7-26). The 2021-2022 mean concentration of cadmium in prawn abdomen and fish flesh at all other upper river, lower river and Lake Murray sites was below the respective TVs, indicating low risk (Table 7-26).

Trends for dissolved cadmium in water, WAE cadmium in sediment and cadmium in prawn abdomen and fish tissue at all test sites either decreased or did not change between 2013 and 2022 (Table 7-12, Table 7-13 and Table 7-14).

As a result of reduced cadmium discharge from the mine, low concentrations of cadmium in water and sediment and in prawn abdomen and fish tissue at all other sites throughout the receiving environment, the overall risk posed by cadmium throughout the receiving environment is considered low. Therefore, the results of the initial risk for prawn abdomen at Wankipe and SG4 have been adjusted from potential risk to low risk. This change is reflected in Table 7-27.

7.1.4.7 Chromium (Cr)

The 2021-2022 mean concentration of dissolved chromium in water discharged from the Lime Plant exceeded the upper river TV, and at Kogai Culvert, Kogai Dump Toe, indicating potential risk. The 2021-2022 mean concentration of dissolved chromium in water from all other discharge points were below the upper river TV, indicating low risk (Table 7-24). Historically, the concentrations of dissolved and WAE chromium in tailings discharge has been low and posed a low risk (BNL, 2019).

The 2021-2022 mean concentrations of WAE chromium in sediment discharged from the site were below the upper river TV, indicating low risk (Table 7-25).

In the receiving environment, the 2021-2022 mean concentrations of dissolved chromium in water at all test sites were below the respective TVs, indicating low risk (Table 7-24).

In the receiving environment, the 2021-2022 mean concentrations of WAE chromium in sediment at all test sites were below the respective TVs, indicating low risk (Table 7-25).

The risk assessment for tissue metals showed that the 2021-2022 mean concentration of chromium in prawn abdomen at Wasiba, prawn abdomen and fish tissue at Wankipe, fish flesh at Bebelubi, fish flesh and prawn abdomen at SG4 and fish flesh at Miwa, Southern Lake Murray were all not significantly different from their respective TVs, indicating potential risk (Table 7-26). The 2021-2022 mean concentration of chromium in fish flesh at Wasiba and in prawn abdomen at Bebelubi was less than the TV, indicating low risk (Table 7-26).

Trend analysis showed dissolved chromium in water at all test sites either reduced or didn't change between 2013 and 2022 (Table 7-4, Table 7-5, Table 7-6). The concentrations of WAE chromium in sediment at all test sites, except SG2, either reduced or did not change over time (Table 7-12, Table

7-13, Table 7-14). The concentrations of chromium in prawn abdomen and fish tissue, except prawn abdomen at Wasiba, either reduced or did not change over time (Table 7-19, Table 7-20 and Table 7-22).

Overall, the risk of chromium to the condition of the receiving environment downstream of the Porgera River in 2021-2022 was low. This is due to the combination of lower concentrations of chromium in discharge from the site during C&M and previously during the operational phase, low risk indicated by concentrations of dissolved chromium in water and WAE chromium in sediment throughout the receiving environment and that the concentrations of chromium in prawn abdomen at Wasiba, prawn abdomen and fish tissue at Wankipe, fish flesh at Bebelubi, fish flesh and prawn abdomen at SG4 and fish flesh at Miwa, Southern Lake Murray were less than, but not significantly different from their respective TVs.

As a result, the initial risk assessments for chromium in prawn abdomen at Bebelubi and SG4 and in fish flesh at Miwa have been adjusted from potential risk to low risk, the change is reflected in Table 7-26.

7.1.4.8 Copper (Cu)

The 2021-2022 mean concentration of dissolved copper in water discharged from Kogai Culvert and the Lime Plant exceeded the upper river TV indicating potential risk (Table 7-24). The 2021-2022 mean concentration of dissolved copper in water discharged from all other sites was below the TV (Table 7-24). Historically, the concentration of dissolved copper in tailings has been elevated and found to pose a potential risk to the receiving environment (BNL, 2019).

The mean concentration of WAE copper in sediment discharged from the mine site in 2021-2022 was below the upper river TV, indicating low risk (Table 7-25). Historically, the concentration of WAE copper in tailings sediment has been elevated and found to pose a potential risk to the receiving environment (BNL, 2019).

Within the receiving environment, the 2021-2022 mean concentration of dissolved copper in water at all upper river and lower river test sites was below their respective TVs, indicating low risk (Table 7-24). In the ORWBs, the 2021-2022 mean concentration of dissolved copper in water was below the TV at all test sites, except for Levame, where the 2021-2022 mean was greater than the TV, indicating potential risk at Levame (Table 7-24). The 2021-2022 mean concentration of dissolved copper in water at Pangoa, Central Lake Murray was not significantly different from the TV and less than the TV at Miwa, Southern Lake Murray and SG6 (Table 7-24).

The mean concentration of copper in prawn abdomen and fish tissue in the upper river at Wasiba in 2021-2022 were below the TV, and the mean concentration of copper in prawn abdomen and fish tissue in the upper river at Wankipe were not significantly different from the TV in 2021-2022 (Table 7-26).

In the lower river, the 2021-2022 mean concentration of copper in fish flesh and prawn abdomen at Bebelubi and in fish flesh at SG4 was less than the TV. The 2021-2022 mean concentration of copper in prawn abdomen at SG4 was not significantly different from the TV (Table 7-26). At Pangoa, Central Lake Murray and Miwa, Southern Lake Murray, the 2021-2022 mean concentration of copper in fish flesh was less than the TV, indicating low risk (Table 7-26).

Trend analysis showed concentrations of dissolved copper in water either reduced or did not change between 2013 and 2022 at all test sites within the upper river, lower river, ORWBs and Lake Murray except at SG3 in the upper river and ORWBs Avu and Levame where the concentration of dissolved copper in water increased between 2013 and 2022 (Table 7-4, Table 7-5, Table 7-6 and Table 7-8). The concentration of copper in prawn abdomen and fish tissue at all upper river, lower river and Lake Murray test sites either reduced or did not change between 2013 and 2022 (Table 7-19, Table 7-20 and Table 7-22).

Overall, the risk to the receiving environment posed by copper in 2021-2022 is considered low due to the combination of low concentrations of dissolved copper in water and WAE copper in sediment discharged from the mine during C&M, low concentrations of dissolved copper in water and WAE copper in sediment at all test sites throughout the receiving environment. Where the initial risk assessment result showed potential risk for copper in prawn abdomen and fish tissue at Wankipe and prawn abdomen at SG4 and dissolved copper in water at Pangoa, Central Lake Murray, the 2021-2022 mean was not significantly different from the TV, and trends for dissolved copper in water, WAE copper in sediment and copper in prawn abdomen and fish tissue at all three sites either reduced or did not change over time. Therefore, the results of the initial risk assessment are considered to reflect the natural concentrations of copper in prawn abdomen and fish tissue and are not considered to be related to activities at the Porgera Mine.

As a result, the initial risk assessment results for copper in prawn abdomen and fish tissue at Wankipe and prawn abdomen at SG4 and dissolved copper in water at Pangoa, Central Lake Murray have been revised from potential risk to low risk, the change is reflected in Table 7-26.

7.1.4.9 Mercury (Hg)

The 2021-2022 mean concentrations of mercury in water discharged from all sites were below the upper river TV, indicating low risk (Table 7-24). Historically, the concentration of dissolved mercury in tailings has been low and indicated low risk (BNL, 2019).

The mean concentration of WAE mercury in sediment discharged from the mine in 2021-2022 was below the upper river TV, indicating low risk (Table 7-25). Historically, WAE mercury concentrations in tailings have been elevated, indicating a potential risk (BNL, 2019).

In prawn abdomen and fish tissue at all test sites throughout the upper river and lower river, the mean concentration of mercury was below the respective TVs, indicating low risk (Table 7-26). In Lake Murray, the 2021-2022 mean concentration of mercury in fish tissue at Pangoa, Central Lake Murray was not significantly different from the TV, indicating potential risk, and lower than the TV at Miwa, Southern Lake Murray, indicating low risk (Table 7-26).

The trend analysis showed concentrations of dissolved mercury in water, WAE mercury in sediment and mercury in prawn abdomen and fish tissue at all test sites either reduced or did not change between 2013 and 2022 (Table 7-4, Table 7-5, Table 7-6, Table 7-8, Table 7-12, Table 7-13, Table 7-14, Table 7-16, Table 7-19, Table 7-20 and Table 7-22).

Overall, given that the only indicator showing potential risk for mercury is fish flesh at Pangoa, Central Lake Murray, where the 2021-2022 mean was not significantly different from the TV, that all other indicators at all other sites indicate low risk posed by mercury in water, sediment, fish flesh and prawn abdomen and that the trend for mercury in all indicators at all sites is either reducing or not changing over time, the risk posed by mercury is considered to be low.

As a result, the initial risk assessment result for mercury in fish tissue at Pangoa, Central Lake Murray has been revised from potential risk to low risk, the change is reflected in Table 7-26.

It should also be noted that historically Lake Murray is known to contain fish with elevated mercury concentrations and this pre-dates the Porgera mine (Bowles et al, 2002).

7.1.4.10 Nickel (Ni)

The 2021-2022 mean concentration of dissolved nickel in water discharged from the site was below the upper river TV, indicating low risk (Table 7-24). Historically, the concentration of dissolved nickel in tailings was elevated, indicating potential risk (BNL, 2019).

The mean concentration of WAE nickel in sediment discharged from 28 level during 2021-2022 was above the upper rivers TV, indicating potential risk (Table 7-25). The mean WAE nickel in sediment discharged from all other sampled discharge points in 2021-2022 was below the upper river TV, indicating low risk (Table 7-25). Historically, the concentration of WAE nickel in tailings sediment has been elevated and indicated potential risk (BNL, 2019).

In the receiving environment, the mean 2021-2022 concentration of dissolved nickel in water at all test sites was below the respective TVs (Table 7-24).

The 2021-2022 mean concentration of WAE nickel in sediment was not significantly different from the upper river TV at Wankipe and SG3 and not significantly different from the lower river TV at ORWB Levame (Table 7-25). At all other test sites, the mean 2021-2022 concentration of WAE nickel in sediment was below the respective TVs (Table 7-25).

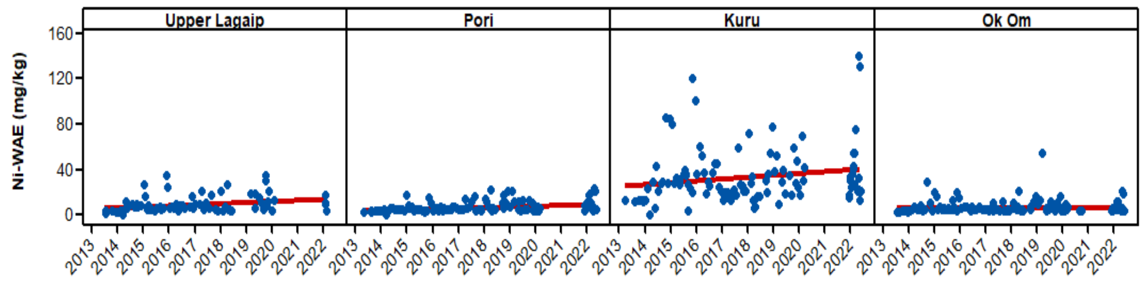
The tissue metal risk assessment showed that the 2021-2022 mean concentration of nickel in fish flesh at Miwa, Southern Lake Murray was greater than the TV, indicating potential risk (Table 7-26). At Wasiba, the 2021-2022 mean concentration of nickel in fish flesh and prawn abdomen at Wankipe and prawn abdomen at SG4 was not significantly different from the respective TVs, indicating potential risk (Table 7-26). The 2021-2022 mean concentration of nickel in prawn abdomen at Wasiba, prawn abdomen and fish tissue at Bebelubi, fish flesh at SG4 and fish flesh at Pangoa, Central Lake Murray were below the respective TVs, indicating low risk (Table 7-26).

The trend analysis showed an increasing trend for dissolved nickel in water at ORWB Avu, Pangoa (Table 7-6) and at Central Lake Murray and SG6 (Table 7-8) and an increasing trend for WAE nickel in sediment at SG2, Wankipe and SG3 in the upper river between 2013 and 2022 (Table 7-12). Trends for dissolved nickel in water, WAE nickel in sediment and nickel in prawn abdomen and fish tissue at all other sites either reduced or did not change between 2013 and 2022 (Table 7-4, Table 7-5, Table 7-6, Table 7-8, Table 7-12, Table 7-13, Table 7-14, Table 7-16, Table 7-19, Table 7-20 and Table 7-22).

Upon further analysis it is noted that the concentrations of WAE nickel in sediment at the upper river reference sites, Upper Lagaip, Pori, Kuru and Ok Om, also exhibited increasing trends between 2013 and 2022, with Kuru especially exhibiting elevated natural WAE nickel in sediment, shown in Figure 7-7. Additionally, WAE nickel and total nickel concentrations at Wasiba and SG3 were observed to increase during the care and maintenance phase, shown in Figure 7-8 through Table 7-11. These results suggest that nickel concentrations in sediment within the upper river are driven by natural, non-mine related, sources of nickel.

Overall, given the reduction of nickel inputs from the mine during C&M, elevated nickel and increasing trends for nickel in WAE sediment at the upper river reference sites, and an increase in WAE nickel in sediment at upper river test sites Wankipe and SG3 during C&M, nickel is considered to pose a low risk to the condition of the receiving environment.

Therefore, the results of the initial risk assessment for nickel in prawn abdomen at Bebelubi and SG4 have been revised from potential risk to low risk, the change is reflected in Table 7-26.



WAE Nickel concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2022

Figure 7-7 Trends for WAE nickel in sediment at upper river reference sites between 2013 and 2022.

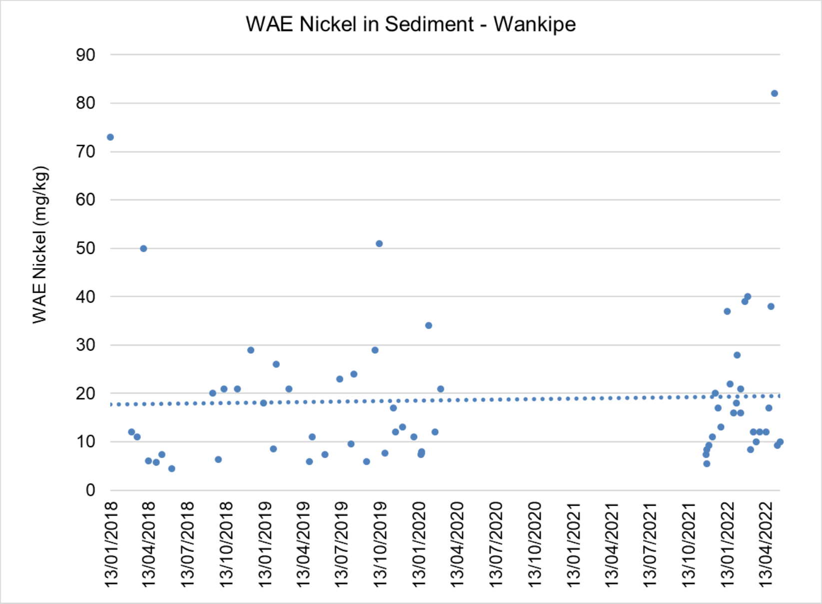


Figure 7-8 WAE nickel in sediment at Wankipe between January 2018 and May 2022

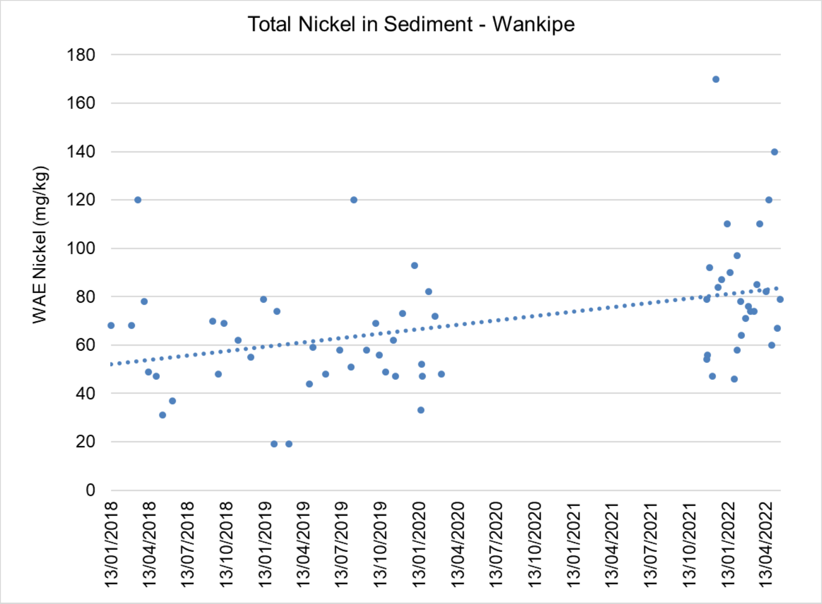


Figure 7-9 Total nickel in sediment at Wankipe between January 2018 and May 2022

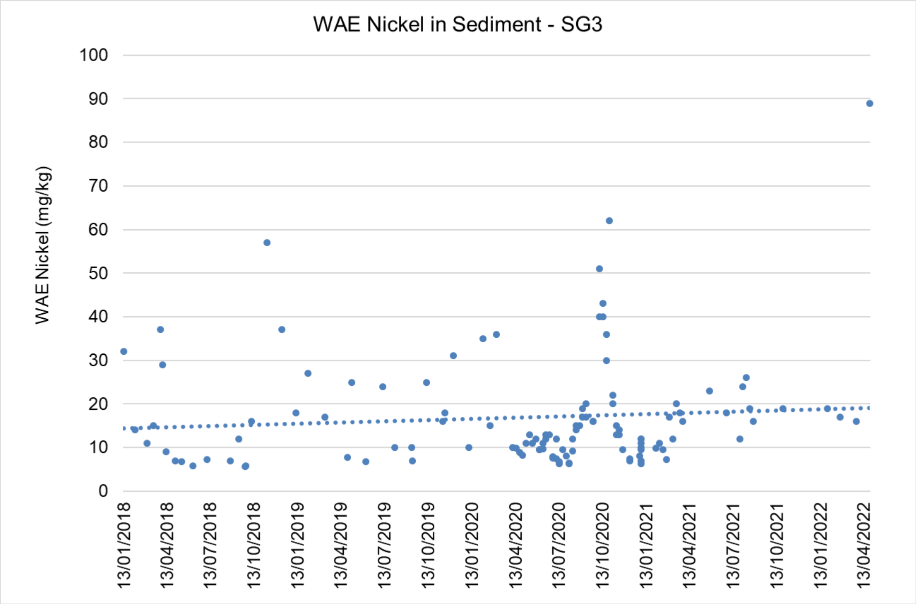


Figure 7-10 WAE nickel in sediment at SG3 between January 2018 and May 2022

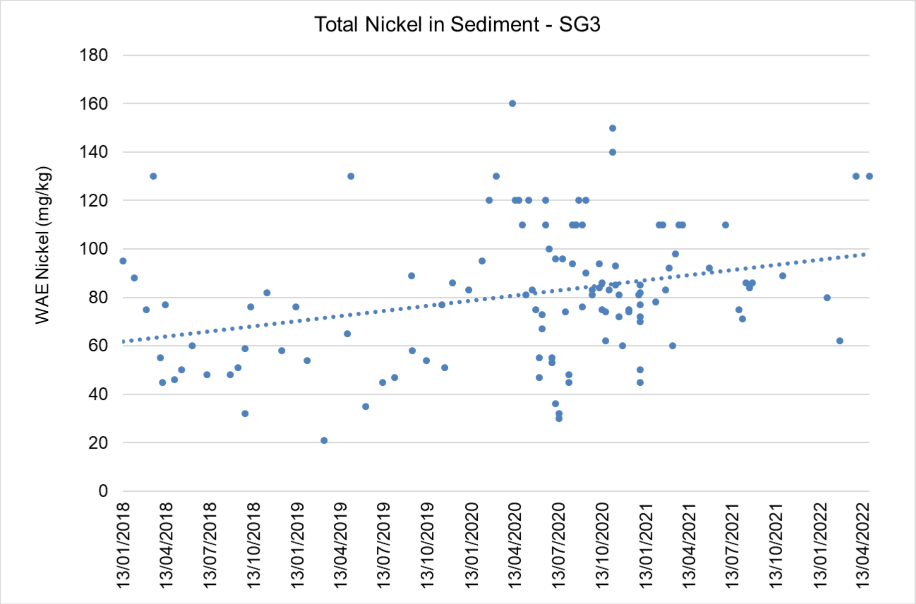


Figure 7-11 Total nickel in sediment at SG3 between January 2018 and May 2022

7.1.4.11 Lead (Pb)

The 2021-2022 mean concentrations of dissolved lead in water from all discharge sites were below the upper river TV, indicating low risk (Table 7-24). Historically, concentrations of dissolved lead in tailings have been low and posed a low risk (BNL, 2019).

The mean concentration of WAE lead in sediment from all discharge points except the lime plant, exceeded the upper river TV in 2021-2022, indicating potential risk (Table 7-25). Historically, sediment in tailings and erodible waste rock have exhibited elevated concentrations of WAE lead in sediment, indicating potential risk (BNL, 2019).

Within the receiving environment, the mean concentration of dissolved lead in water during 2021-2022 at all test sites was below the respective TVs, indicating low risk (Table 7-24). The 2021-2022 mean concentration of WAE lead in sediment at SG2 was greater than the upper river TV and at ORWB Avu, the 2021-2022 mean concentration of WAE lead in sediment was not significantly different from the TV, both indicating potential risk (Table 7-25). The mean concentration of WAE in sediment at all other test sites was below the respective TVs, indicating low risk (Table 7-25). In prawn abdomen at Wasiba, Wankipe and Bebelubi, the mean concentration of lead in 2021-2022 was not significantly different from the TV, indicating potential risk, and was below the TV for prawn abdomen and fish tissue at all other test sites, indicating low risk (Table 7-26).

Trend analysis showed that the concentration of dissolved lead in water at ORWB Zongamange and SG6 increased between 2013 and 2022 (Table 7-6 and Table 7-8), and either reduced or did not change over the same period at all other test sites (Table 7-4, Table 7-5, Table 7-6, Table 7-8). The concentration of WAE lead in sediment and lead in prawn abdomen and fish tissue at all test sites either reduced or did not change between 2013 and 2022 (Table 7-12, Table 7-13, Table 7-14, Table 7-16, Table 7-19, Table 7-20 and Table 7-22).

Overall, given the elevated concentrations of lead in sediment discharged from the mine and relatively low natural, non-mine related lead in sediment, WAE lead in sediment is considered to pose a potential risk at SG2, therefore the results of the initial risk assessment for WAE lead in sediment at SG2 are accepted and remain unchanged. The results of the risk assessment for WAE lead in sediment at Avu and lead in prawn abdomen at Wasiba, Wankipe and Bebelubi showed the 2021-2022 mean concentrations were less than but not significantly different from the TV, indicating potential risk. However, given the reduced lead inputs from the mine associated with the cessation of tailings discharge, the low risk posed by dissolved lead in water and WAE lead in sediment at these sites, and the results of the trend analysis which showed that concentrations of dissolved lead in water, WAE lead in sediment and lead in prawn abdomen and fish tissue either reduced or did not change between 2013 and 2022, the risk posed by lead at these sites is considered low.

Therefore, the result of the initial risk assessment for lead in sediment at Avu and prawn abdomen at Wasiba, Wankipe and Bebelubi have been revised from potential risk to low risk, the change is reflected in Table 7-25 and Table 7-26.

7.1.4.12 Selenium (Se)

The 2021-2022 mean concentrations of dissolved selenium in water discharged from the mine was below the upper river TV, indicating low risk (Table 7-24). Historically, tailings have exhibited elevated concentrations of dissolved selenium in water, however these remained below the upper rivers TV, indicating low risk (BNL, 2019).

In sediment discharged from the mine in 2021-2022, the mean concentration of WAE selenium was below the upper river TV, indicating low risk (Table 7-25Table 7-24). Historically, tailings discharge has exhibited low concentrations of WAE in sediment, indicating low risk (BNL, 2019).

Within the receiving environment, the 2021-2022 mean concentration of dissolved selenium in water was below the respective TVs at all test sites, indicating low risk (Table 7-24). In sediment, the mean concentration of WAE selenium was above the TV at all upper river test sites (SG2, Wasiba, Wankipe and SG3), and not significantly different from the TV at all lower river test sites (Bebelubi, SG4 and SG5), indicating potential risk (Table 7-25). The 2021-2022 mean concentration of WAE selenium in sediment at the ORWBs was below the TV, indicating low risk (Table 7-25). At Pangoa, Central Lake Murray the 2021-2022 mean concentration of WAE selenium in sediment was not significantly different from the TV, indicating potential risk, and at Miwa, Southern Lake Murray and SG6, the 2021-2022 mean was below the TV, indicating low risk (Table 7-25).

The tissue metal risk assessment showed the 2021-2022 mean concentration of selenium in prawn abdomen at Wasiba in the upper river and at Bebelubi and SG4 in the lower river, was not significantly different from the respective TVs, indicating potential risk (Table 7-26). The 2021-2022 mean concentration of selenium in prawn abdomen and fish tissue was below the respective TVs at all other sites, indicating low risk (Table 7-26).

Trend analysis shows that concentrations of selenium in water at all test sites either reduced or did not change between 2013 and 2022 (Table 7-4, Table 7-5, Table 7-6 and Table 7-8). Concentrations of

WAE selenium at all test sites except ORWB Levame either reduced or did not change between 2013 and 2022 and the concentration of selenium in prawn abdomen and fish tissue at all test sites did not change between 2013 and 2022 (Table 7-12, Table 7-13, Table 7-14, Table 7-16, Table 7-19, Table 7-20 and Table 7-22).

Overall, given the generally low concentrations of selenium in discharge from the mine, the presence of low natural selenium contributions from the reference sites and no increasing trends for selenium in water at all sites and in sediment, prawn abdomen and fish tissue at the majority of test sites, the risk posed by selenium to the environmental condition within the upper river, lower river, ORWBs and Lake Murray is considered low.

Therefore, the result of the initial risk assessment for selenium in sediment and prawn abdomen have been revised from potential risk to low risk, the change is reflected in Table 7-24, Table 7-25 and Table 7-26.

7.1.4.13 Zinc (Zn)

In 2021-2022, the concentration of dissolved zinc in water discharged from 28 Level, Kogai Culvert and Kogai Dump Toe was greater than the upper river TV, indicating potential risk (Table 7-24). Historically, the concentration of dissolved zinc in tailings has been greater than the upper river TV, also indicating potential risk (BNL, 2019).

In sediment discharged from the mine in 2021-2022, the mean concentration of WAE zinc in sediment discharged from 28 Level, Kogai Culvert, Kogai Dump Toe and Yakatabari Crk D/S 28 Level was greater than the upper river TV, indicating potential risk (Table 7-25). Historically, the concentration of WAE zinc in tailings has been greater than the upper river TV, also indicating potential risk (BNL, 2019).

Within the receiving environment, the concentration of dissolved zinc in water at lower river test sites Bebelubi and SG4, the 2021-2022 mean concentration of dissolved zinc was greater than the TV, indicating potential risk (Table 7-24). At all other test sites within the upper river, lower river, ORWBs and Lake Murray, the 2021-2022 median concentration of dissolved zinc was less than the TV, indicating low risk (Table 7-24).

The 2021-2022 mean concentration of WAE zinc in sediment at all test sites was below the respective TVs, indicating low risk (Table 7-25).

The tissue metal risk assessment showed that the 2021-2022 mean concentration of zinc was not significantly different from the TV in prawn abdomen at upper river test sites Wasiba and Wankipe, in prawn abdomen at lower river test site SG4 and Bebelubi and in fish flesh at Pangoa, Central Lake Murray and Miwa, Southern Lake Murray, indicating potential risk (Table 7-26). The 2021-2022 mean concentration of zinc in fish flesh at all upper river and lower river test sites were below the TV, indicating low risk (Table 7-26).

Trend analysis shows increasing concentrations of dissolved zinc in water at SG5 and Pangoa, Central Lake Murray between 2013 and 2022, concentrations of dissolved zinc in water at all other test sites either reduced or did not change between 2013 and 2022 (Table 7-4, Table 7-5, Table 7-6 and Table 7-8). Concentrations of WAE zinc in sediment and zinc in prawn abdomen and fish tissue either reduced or did not change at all test sites between 2013 and 2022 (Table 7-12, Table 7-13, Table 7-14, Table 7-16, Table 7-19, Table 7-20 and Table 7-22).

Overall, given the reduced discharge of zinc from the mine during care and maintenance, low concentrations of dissolved zinc in water and WAE zinc in sediment throughout the receiving environment, that for all cases where the tissue metal risk assessment indicated potential risk, the 2021-2022 mean was less than but not significantly different from the TV and trends for dissolved zinc in water, WAE zinc in sediment and zinc in prawn abdomen and fish tissue showing reducing or no change, the risk of zinc to receiving environment in 2021-2022 is considered low.

Therefore, the result of the initial risk assessment for selenium in sediment and prawn abdomen have been revised from potential risk to low risk, the change is reflected in Table 7-24, Table 7-25 and Table 7-26.

7.1.5 Metals speciation and toxicity

The risk assessment is based on dissolved metal concentrations in water, which best reflect the bioavailable metal concentrations that pose a risk of toxicity to aquatic organisms.

However, it is well known that dissolved metals as a direct exposure medium over-estimate bioavailability and potential toxicity. In order to understand the potential toxicity of the metals and risk to the ecosystem, in 2017 BNL commissioned CSIRO to undertake a study (Angel et al. 2018) to determine metal bioavailability by measuring the speciation of dissolved metals and applying highly sensitive bioassays which respond only to the bioavailable forms of metals. The study was repeated in 2019 (Angel et al. 2020) to again determine metal bioavailability by measuring the speciation of dissolved metals, the 2019 study did not include the use of sensitive bioassays.

The 2017 and 2019 study determined the concentrations of Chelex-labile Cd, Cu, Ni, Pb and Zn as a measure of the bioavailable form of these metals available for uptake by organisms from the dissolved phase, and the 2017 study also assessed metal toxicity to sensitive bacteria and algal species using bioassay techniques developed by CSIRO. The study design in 2017 and 2019 was based on the environmental monitoring sites of BNL. Water samples were collected from thirteen sites comprising mine site tailings, mine drainage waters, test sites and reference sites of the upper and lower sections of the Lagaip/Strickland River system. The study will be repeated every two years as part of CSIROs bi-annual independent audit of the BNL environmental monitoring program.

The key findings of the 2017 and 2019 studies were:

- The concentrations of dissolved metals in mine site waters and the river system generally were in the same range as those measured previously (Angel et al., 2015; 2017 and 2020) and in the PJV monitoring program, where concentrations decrease rapidly downstream of the mine.
- In the mine waters, cadmium, copper, nickel and zinc were generally mostly present in Chelex-labile (bioavailable) forms.
- For the Lagaip and Strickland River sites in 2019, there were no metal concentrations that exceeded ANZG (2018) default guideline values for 95% species protection.
- In the river water samples, a significant component of dissolved cadmium, nickel and copper was present as non-labile species (non-bioavailable), however, dissolved zinc was present mainly in a Chelex-labile (bioavailable) form. It may be possible that some complexation of zinc by natural organic matter occurs but this is not detected by the Chelex column method, and requires investigation using other less-aggressive speciation methods.
- Metal-related inhibition of bacterial respiration was observed only at SG2 and Wasiba. (Angel et al., 2017)
- Significant stimulation of bacterial respiration was observed in samples from SG3 and SG4. The cause of the observed respiratory stimulation is yet to be identified. (Angel et al., 2017)
- The only samples showing small (10% or lower) but significant algal growth inhibition were from Upper Lagaip, Baia, and Ok Om, which are reference sites that do not receive mine-related inputs. Further work is required to identify the causes of growth inhibition in these samples. (Angel et al., 2017)

7.2 Water-based Activities

Various water-based activities are undertaken by local communities downstream of the mine: gold panning, bathing, laundry, fishing and swimming. To assess the potential health risks to people contacting this water, the median pH and concentration of dissolved metals in tailings and at test sites downstream of the mine in the upper river were compared against the ANZG (2018) recreational water quality guideline values and the WHO Drinking Water Quality Guidelines (2017).

The results are presented in Table 7-28 and showed that concentrations of metals in water at all test sites downstream of the Porgera River, pH was within the upper and lower guideline values, and dissolved metal concentrations were below, and therefore compliant with, the respective guideline values indicating low risk to human health.

It should be noted that the median value for each indicator at the test site is compared with the guidelines value to remain consistent with the approach used in previous BNL Annual Environment Reports.

Exposure patterns differ greatly along the Porgera, Lagaip and Strickland rivers downstream of the mine. River use in the mountain section above the Strickland Gorge is primarily for gold panning, with little use for subsistence fishing. Occasional exposure occurs when people cross the river and when children play on the exposed sandbars, or other activities. Along the Lower Strickland and at Lake Murray, people regularly use the waterways as a transportation corridor, for subsistence fishing and harvesting of sago crops, washing of clothes and bathing. Although lowland communities have significantly greater exposure, the very low concentrations of metals mean that the overall risk of adverse health effects is low.

Table 7-28 Comparison of median receiving water quality concentrations with recreational exposure guideline values between November 2021 and May 2022 (µg/L except where shown)

Site	n	pH^	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
SG1	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SG2	1	7.7	0.04	0.83	0.05	0.27	0.2	8.3	0.05	1.3	0.1	0.2	2.7
Wasiba	24	8.2	0.01	0.77	0.05	0.25	0.61	5.2	0.05	0.69	0.1	0.2	2.0
Wankipe	24	8.2	0.01	0.76	0.05	0.19	0.58	4.7	0.05	0.65	0.1	0.2	1.6
SG3	35	8.1	0.01	0.68	0.05	0.24	0.61	6.1	0.05	0.67	0.1	0.2	1.7
ANZG (2018) Recreational WQG		**6.5 – 8.5**	**50**	**50**	**5**	**50**	**1,000**	**300**	**1.0**	**100**	**50**	**10**	**5,000**
WHO (2017) Drinking WQG		**6.5 – 8.5**	**NA**	**10**	**3**	**NA**	**2,000**	**NA**	**6.0**	**70**	**10**	**40**	**NA**

🟩	< Guideline = Low risk
🟨	≥ Guideline = Potential risk

^ standard units; NA = Not Applicable; NS = Not Sampled

7.3 Fish and Prawn Consumption

Median tissue metal concentrations in fish flesh and prawn abdomen are compared against relevant food standards in Table 7-29. The results show that all tissue metals at all locations were below the relevant food standard. Although dietary intake of fish and prawns differs greatly between the mountain and lowland sections of the river, the results show that tissue metals in fish flesh and prawn abdomen pose a low risk to human health.

Table 7-29 Risk assessment – median tissue metal results at upper and lower river and Lake Murray test sites in C&M compared against food standard showing which indicators pose low and potential risk (µg/g wet wt.)

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Wasiba	Fish Flesh	6	0.02	0.004	0.011	0.29	0.052	0.01	0.01	0.365	5.95
	Prawn Ab	6	0.017	0.003	0.032	4.15	0.01	0.01	0.01	0.625	14
Wankipe	Fish Flesh	6	0.013	0.004	0.02	0.21	0.051	0.011	0.01	0.25	4.5
	Prawn Ab	6	0.027	0.003	0.049	9.25	0.01	0.011	0.01	0.435	14
Bebelubi	Fish Flesh	6	0.01	0.003	0.022	0.081	0.037	0.013	0.01	0.11	2.3
	Prawn Ab	6	0.076	0.003	0.021	5.2	0.01	0.01	0.01	0.31	12.5
SG4	Fish Flesh	6	0.01	0.003	0.012	0.081	0.048	0.03	0.01	0.155	3.15
	Prawn Ab	6	0.058	0.003	0.031	6.35	0.01	0.01	0.01	0.305	11
Pangoa	Fish Flesh	2	0.034	0.003	0.013	0.097	0.275	0.011	0.01	0.335	2.85
Miwa	Fish flesh	3	0.014	0.003	0.031	0.13	0.01	0.18	0.01	0.26	3.5
Food Std	**Fish**		**2**	**0.05**	**1**	**2**	**0.5**	**NA**	**0.3**	**2**	**15**
	Prawn		**2**	**0.5**	**1**	**20**	**0.5**	**NA**	**0.5**	**1**	**40**

🟩	Compliant
🟧	Non-compliant

As – Food Standard Australia New Zealand 1.4.1 (ANZFS 2016)

Cd, Hg, Pb – European Food Safety Authority (EC 2006)

Cr – Hong Kong Food Adulteration (Metallic Contamination) Regulations (HK 1997)

Cu, Se, Zn – Food Standards Australia New Zealand GEL 90th%ile (FSANZ 2001)

NA – Not Applicable, Ab - Abdomen

8 IMPACT ASSESSMENT

The impact assessment was performed by firstly comparing the 2021 and 2022 replicate values for biological indicators on each sampling occasion at each test site against their respective TVs using a one sample t-test to test statistical significance. Where the 2021 or 2022 test site mean is significantly greater than or not significantly different from the TV, this indicates no impact has occurred. Where the 2021 or 2022 test site mean is significantly less than the TV, this indicates impact has occurred.

It should be noted that during the operational phase of the mine prior to C&M, replicated sampling was conducted quarterly at each site, with the overall mean of the four quarterly samples compared against the relevant guideline value. Because sampling under C&M was reduced to two occasions at each site, the approach was modified to compare the mean of each of the two sampling occasions against the relevant GV.

Secondly, the trend over time (2015 - 2022) was investigated for each indicator at both the test and reference site. Where significant downward (negative) trends are observed at the test sites and not at the reference sites, this indicates the potential for further reduction over time and serves as an early indication of where continued change may lead to future impact.

8.1 Upper River

8.1.1 *Macroinvertebrates*

Barrick Niugini Limited (BNL) undertake a comprehensive environmental monitoring program (EMP) of the riverine environment downstream of the Porgera mine in the central highlands of Papua New Guinea. The monitoring program developed by Porgera Joint Venture (PJV) is based on international guidelines (Australian and New Zealand guidelines for fresh and marine water quality; ANZG 2018) and advice received during consultation with external technical experts. The program includes assessment of changes to air, soil, river sediment, surface water, hydrology, prawns, fish and, more recently, aquatic macroinvertebrates. The macroinvertebrate component of the monitoring program was implemented in February 2022 (WRM, 2022), almost two years into the care and maintenance period, during which no disposal of tails to the river had occurred since April 2020. Previous rounds of monitoring macroinvertebrates were conducted in 2014, 2015, 2016 and 2019. A total of 10 sites were sampled for the 2022 study (out of a total of 15 that have been sampled previously for the EMP); four upper altitude (> 1000 m above sea level) reference sites (Aipulungu Creek, Kulapi Creek, Maiapam Creek and Pongema Creek) and one upper altitude test (exposed) site (Kogai Creek), two mid-altitude (400 – 1000 m above sea level) reference sites (Upper Lagaip River and Ok Om) and three mid-altitude test (exposed) sites (Wasiba, Wankipe and Ambi).

As part of the program, four metrics are calculated; number of species (species richness “S”), number of larval mayfly, stonefly and caddisfly species (Ephemeroptera, Plecoptera and Trichoptera richness; “EPT”), the SIGNAL2 biotic index for macroinvertebrates (developed for Australian river systems by Chessman 2003), and percent similarity of assemblages at test (exposed) sites to reference sites (Bray-Cutis similarity (%) measure). These metrics are used to determine an overall impact rating for each test site by applying a weight of evidence approach. Trigger values (also referred to as site-specific guideline values “SSGVs” – updated ANZG 2018 terminology) were derived by calculating the 20th percentile (20%ile) values for reference sites (separately for upper and mid-altitude regions) using the combined 2014-2022 reference dataset, which incorporates a degree of natural temporal variability. Median and mean values for test sites were then statistically compared against the SSGVs to derive impact scores. The median of each test site was compared against the SSGV as per ANZG (2018), but due to small sample size/low replication it was not valid to use a rank test to statistically test any difference, therefore a parametric t-test was used on the mean of test site data to test for significant differences from the SSGV.

Using the values of each of the four metrics to derive impact scores for each metric at each test site, the summed impact score across the four metrics for each site was then assigned to an Impact Rating Band to derive an overall Site Impact Rating for 2022, with comparisons against the same test sites sampled in the two previous sampling rounds, in 2016 and 2019 (Table E-1). The summed impact scores and Site Impact Ratings showed Kogai classified as high impact in 2016 and 2019, however, over the care and maintenance period, the rating has improved to medium impact in 2022. The most improved site over the care and maintenance period was Wasiba, with no impacts detected in 2022, whereas this site was classified as medium impact in 2016 and high impact in 2019. Wankipe also recorded no impacts in 2022, compared to a rating of low impact in 2019, and medium impact in 2016 (Table E-1). While a slight improvement was recorded at the furthest downstream test site Ambi, with a reduction of impact score from 12 in 2019 to 10 in 2022, it retained the previous classification as high impact. This was unexpected given the two sites upstream of Ambi had improved considerably. On further examination, it was considered that the "high impact" rating for Ambi in 2022 was not related to mine impacts. A rapid increase in water level was recorded on the morning of sampling at Ambi in February 2022, resulting in habitat only recently inundated and not yet colonised with fauna being sampled. As improvements in macroinvertebrate assemblage condition were observed at Wasiba and Wankipe, it is likely that assemblages at Ambi also would have improved, were it not for the rise in water level and samples being depauperate.

Overall, macroinvertebrate assemblages downstream of Porgera mine have undergone recovery since the previous 2019 study. The assessment method and indices selected through the development of this monitoring program are validated by the detection of "no adverse impacts" at Wasiba and Wankipe in 2022, which followed a two-year period of mine shut down, with no tails disposed to the river.

Table 8-1 Summed impact scores and overall site impact rating for each test site sampled in 2016, 2019 and 2022. Where a metric at a test site was not significantly different to the relevant SSGV, an impact score of zero (0) was assigned, where the metric was significantly less than the relevant SSGV, but the difference was < 10% decline an impact score of one (1) was assigned, and where the decline was > 10% from the relevant SSGV an impact score of three (3). The summed impact score is therefore the total impact scores for the four metrics at each test site. The impact rating for each site was derived by assigning the summed impact score for each site Impact Rating Bands, where a summed impact score of 0 = No Impact, 1 - 4 = Low Impact, 5 – 9 = Medium Impact, and >9 = High Impact.

Site	2016		2019		2022	
	Summed Impact Score	Site Impact Rating	Summed Impact Score	Site Impact Rating	Summed Impact Score	Site Impact Rating
KOGAI (Within SML6)	12	High	12	High	8	Medium
WASIBA	9	Medium	12	High	0	No impact
WANKIPE	9	Medium	4	Low	0	No impact
AMBI	9	Medium	12	High	10	High*

*Although Ambi returned an overall impact rating of "High" it is considered that this was due to the rapid increase in water level recorded on the morning of sampling in 2022, with sampling inadvertently being conducted in habitat only recently inundated and not yet colonised with fauna, therefore the rating does not reflect mine impact.

8.1.2 Fish

The impact assessment for fish in the upper river is based on the following indicators: total fish species abundance, total fish biomass, abundance of *N. equinus* and biomass of *N. equinus*. Data were collected using a standardised, replicated hook and line fishing method.

8.1.2.1 Comparison against fish impact assessment TVs

Results from the comparison of 2021 and 2022 test site means for fish impact indicators in the upper river against their respective TVs are provided in Table 8-2 and include the t-statistic and significance value (p) for each test.

<u>2021</u>

Results for both upper river test sites Wasiba and Wankipe showed that the 2021 test site means for *N. equinus* abundance were significantly less than the TVs, indicating adverse impact to this species in the upper river during 2021. At Wankipe, total abundance and *N. equinus* biomass were also significantly lower in 2021 compared to the TVs.

<u>2022</u>

Results for upper river test sites Wasiba and Wankipe showed that the 2022 test site means for total fish abundance and *N. equinus* abundance, and biomass and *N. equinus* biomass at Wasiba, were significantly less than the respective TVs, indicating adverse impact to fish populations and this species in the upper river during 2022.

Table 8-2 Results from one-sample t-tests testing for significant ($p < 0.05$) differences between average values for Wasiba and Wankipe for November 2021 and February 2022, and TVs derived from the previous 24 months for reference Ok Om. NS = not significantly different.

Test Site	Indicator Parameter	Test Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
WASIBA	Total Species Abundance - 2021	4.5	OK OM REFERENCE	3.6	9	-1.4	0.100	2021: NS. No adverse impact
	Total Species Abundance - 2022	2.9		4.2	9	13.2	<0.001	2022: Signif. < TV Adverse impact
	Total Biomass (g) - 2021	231.1		176.0	9	-1.1	0.144	2021: NS. No adverse impact
	Total Biomass (g) - 2022	174.8		223.3	9	3.2	0.005	2022: Signif. < TV Adverse impact
	N. equinus Abundance - 2021	1.1		2.4	9	2.2	0.028	2021: Signif. < TV Adverse impact
	N. equinus Abundance - 2022	0.4		3.2	9	12.6	<0.001	2022: Signif. < TV Adverse impact
	N. equinus Biomass (g) - 2021	88		136.4	9	0.8	0.208	2021: NS. No adverse impact
	N. equinus Biomass (g) - 2022	37.5		197.8	9	8.1	<0.001	2022: Signif. < TV Adverse impact
WANKIPE	Total Species Abundance - 2021	1.8	OK OM REFERENCE	3.6	9	4.4	<0.001	2021: Signif. < TV Adverse impact
	Total Species Abundance - 2022	2.6		4.2	9	4.4	<0.001	2022: Signif. < TV Adverse impact
	Total Biomass (g) - 2021	123.8		176.0	9	1.7	0.063	2021: NS. No adverse impact

Test Site	Indicator Parameter	Test Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
	Total Biomass (g) - 2022	212.3		223.3	9	0.2	0.439	2022: NS. No adverse impact
	N. equinus Abundance - 2021	0.8		2.4	9	3.7	0.003	2021: Signif. < TV Adverse impact
	N. equinus Abundance - 2022	1.6		3.2	9	2.9	0.008	2022: Signif. < TV Adverse impact
	N. equinus Biomass (g) - 2021	67.4		136.4	9	2.0	0.041	2021: Signif. < TV Adverse impact
	N. equinus Biomass (g) - 2022	158.9		197.8	9	0.5	0.317	2022: NS. No adverse impact

8.1.2.2 Trends for fish impact indicators

The results of Spearman rank correlation and linear regression analyses for fish indicators in the upper river are provided in Table 8-3, and time series plots for each site for all fish species combined, and for the dominant species *N. equinus*, are shown in Figure 8-1 and Figure 8-2. Note that the catch from consecutive days is shown in the plots but only the first day's catch was used for impact assessment due to the fishing-down effect of fishing on sequential days.

The analyses showed a statistically significant weak negative (i.e. decreasing) trend in *N. equinus* abundance and biomass at test site Wasiba, and in *N. equinus* biomass at test site Wankipe, between 2015 and 2022. These decreasing trends and the significantly low means described in Section 8.1.2.1, indicate adverse impact to *N. equinus* at Wasiba and Wankipe. No significant upward or downward trends were detected for any other indicators at the upper river test sites and reference site over the same period. Because only two sampling events were conducted under C&M, the trend lines are heavily influenced by prior sampling under operations, and data collected in 2021-22 do not appear appreciably higher or lower than data in previous recent years.

Table 8-3 Fish upper river - Spearman correlation coefficients (rho), linear regression coefficients (R) and associated significance values (p) for species abundance and biomass (g) parameters from hook and line catch for 2015 - 2022. NS = not significant.

Site		Indicator Parameter	n	Spearman Corr.		Linear Regress.		Trend
				Rho	p	R	p	
TEST	WASIBA 2015-2022	Total Species Abundance	21	0.227	0.321	0.265	0.263	NS
		Total Biomass (g)	21	0.092	0.691	0.072	0.756	NS
		N. equinus abundance	21	-0.137	0.161	-0.456	0.038	Signif. -ve
		N. equinus biomass (g)	21	-0.271	0.234	-0.451	0.040	Signif. -ve
	WANKIPE 2015-2022	Total Species Abundance	23	-0.168	0.443	-0.170	0.438	NS
		Total Biomass (g)	23	-0.392	0.064	-0.406	0.054	NS
		N. equinus abundance	23	-0.367	0.085	-0.357	0.094	NS
		N. equinus biomass (g)	23	-0.473	0.023	-0.438	0.036	Signif. -ve
REF.	OK OM 2015-2022	Total Species Abundance	21	0.167	0.496	0.164	0.477	NS
		Total Biomass (g)	21	0.082	0.724	0.084	0.717	NS
		N. equinus abundance	21	0.140	0.545	0.170	0.462	NS
		N. equinus biomass	21	0.039	0.867	0.061	0.792	NS

All Fish Species

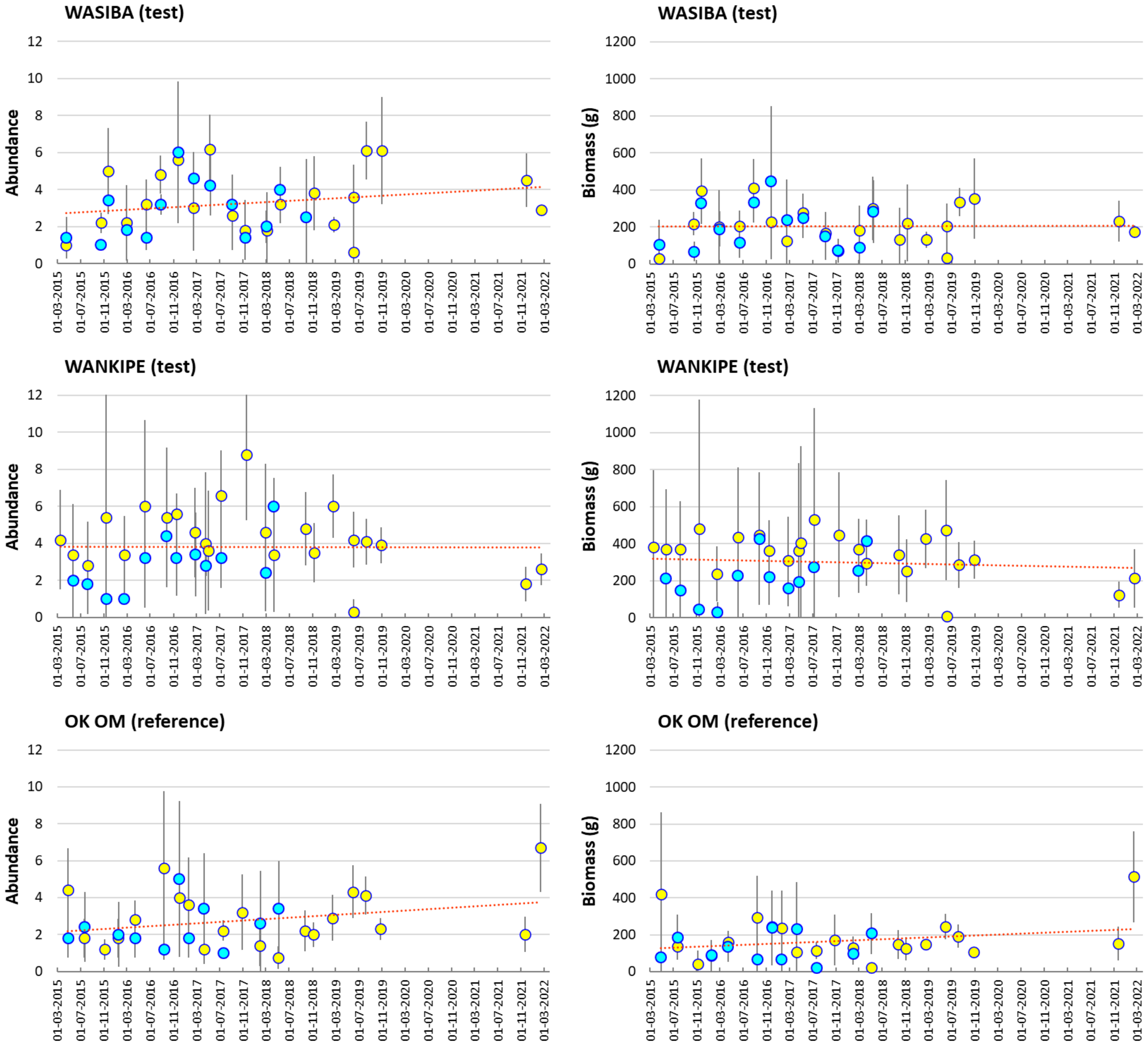


Figure 8-1 Time series plots of average (± 95% CIs) abundance and biomass (g) for combined fish species from replicate hook and line catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2022. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) was used for impact assessment.

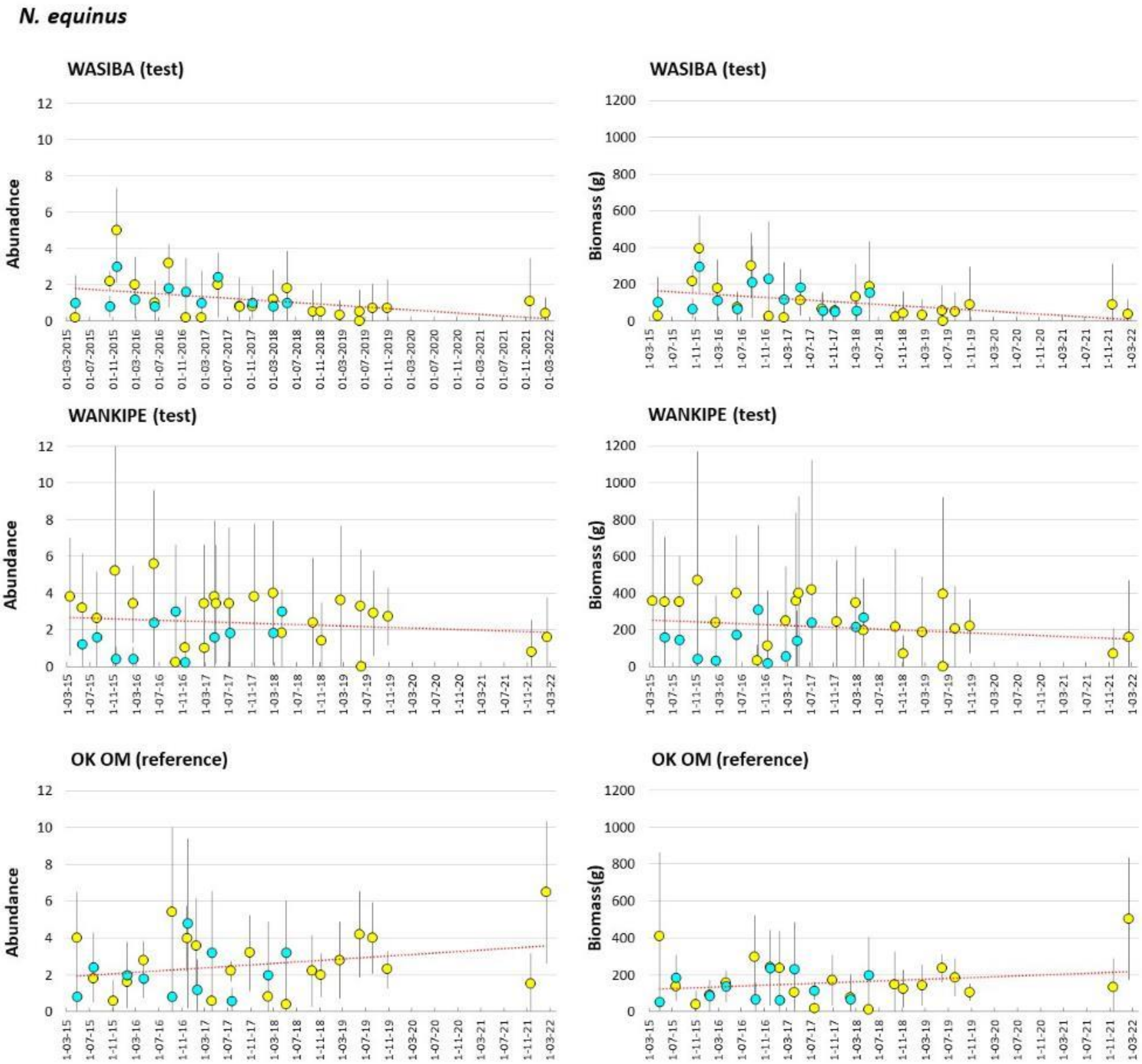


Figure 8-2 Time series plots of average (±95% CIs) abundance and biomass (g) of *Neosilurus equinus* in replicate hook and line catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2022. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) was used for impact assessment.

8.1.3 Prawns

The impact assessment for prawns in the upper river is based on the following indicators: total prawn species abundance, total prawn biomass, abundance of *M. handschini*, biomass of *M. handschini*, abundance of *M. lorentzi* and biomass of *M. lorentzi*. Data were collected using a standardised, replicated electro-seining method. Due to equipment malfunction in November 2021, sampling was only completed in February 2022.

8.1.3.1 Comparisons against prawn impact TVs

Results from the comparison of 2022 test site means for prawn impact indicators in the upper river against their respective TVs are provided in Table 8-4, and include the t-statistic and significance value (p) for each test.

Results for upper river test sites Wasiba and Wankipe showed that the 2022 test site means for most indicator parameters were not significantly different from their respective TVs, and therefore were not classified as adversely impacted. However, total prawn biomass at Wankipe in 2022 was significantly lower than the TV, and *M. lorentzi* abundance and biomass at both Wasiba and Wankipe were also significantly lower than the respective TVs. Therefore, these parameters were classified as adversely impacted.

Table 8-4 Results from one-sample t-tests testing for significant (p < 0.05) differences between average values for Wasiba and Wankipe for 2022, and TVs derived from the previous seven sampling events plus the 2022 event for reference Ok Om. NS = not significantly different.

Test Site	Indicator Parameter	2022 Test Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
WASIBA	Total Prawn Abundance	10.6	Ok Om Ref	7.2	4	1.13	0.161	NS. No adverse impact
	Total Prawn Biomass	38.4		30.6	4	0.75	0.247	NS. No adverse impact
	M. handschini Abundance	10.4		3.5	4	2.45	0.035	Signif. > TV. No adverse impact
	M. handschini Biomass	38		16.3	4	2.14	0.049	Signif. > TV. No adverse impact
	M. lorentzi Abundance	0.2		3.7	4	-17.62	<0.001	Signif. < TV Adverse impact
	M. lorentzi Biomass	0.4		14.2	4	-34.60	<0.001	Signif. < TV Adverse impact
WANKIPE	Total Prawn Abundance	5	Ok Om Ref	7.2	4	-1.05	0.177	Signif. > TV. No adverse impact
	Total Prawn Biomass	16		30.6	4	-2.25	0.044	Signif. < TV Adverse impact
	M. handschini Abundance	4.8		3.5	4	0.64	0.279	Signif. > TV. No adverse impact
	M. handschini Biomass	15.2		16.3	4	-0.18	0.433	NS. No adverse impact
	M. lorentzi Abundance	0.2		3.7	4	-17.62	<0.001	Signif. < TV Adverse impact
	M. lorentzi Biomass	0.8		14.2	4	-16.80	<0.001	Signif. < TV Adverse impact

8.1.3.2 Trends for prawn impact indicators

The results of Spearman rank correlation and linear regression analyses for prawn indicators in the upper river are provided in Table 8-5 and time series plots are shown in Figure 8-3, Figure 8-4 and Figure 8-5.

The analyses showed a statistically significant weak negative (i.e. decreasing) trend in abundance and biomass of *M. lorentzi* at test site Wasiba between 2015 and 2022. All other indicators at upper river test sites and reference site showed either significant positive (i.e. increasing) trends or no significant change over the same period. It should be noted that the impact assessment presented in Section 8 showed adverse impact to *M. lorentzi* abundance and biomass in 2022 at both Wasiba and Wankipe.

Table 8-5 Prawns upper river - Spearman rank correlation coefficients (rho) and associated significance values (p) for trends overtime in total prawn abundance and biomass (g) and in abundance and biomass of the dominant prawn species. Analyses were performed using average of replicate electro-seining catch averaged within each occasion in each year, 2015 - 2022 (NS = not significant).

Site		**Parameter**	**n**	**Spearman Corr.**		**Linear Regress.**		**Trend**
				Rho	**p**	**R**	**p**	
Test	Wasiba 2015-2022	Total Prawn Abundance	23	-0.31	0.151	-0.34	0.114	NS
		Total Prawn Biomass	23	-0.03	0.886	0.04	0.860	NS
		M. handschini Abundance	23	0.37	0.084	0.33	0.125	NS
		M. handschini Biomass	23	0.61	0.002	0.54	0.008	Sig. +ve
		M. lorentzi Abundance	23	-0.59	0.003	-0.57	0.005	Sig. -ve
		M. lorentzi Biomass	23	-0.46	0.027	-0.38	0.069	Sig. -ve
Test	Wankipe 2015-2022	Total Prawn Abundance	23	0.32	0.136	0.32	0.140	NS
		Total Prawn Biomass	23	0.27	0.220	0.31	0.157	NS
		M. handschini Abundance	23	0.54	0.008	0.53	0.009	Sig. +ve
		M. handschini Biomass	23	0.58	0.004	0.58	0.003	Sig. +ve
		M. lorentzi Abundance	23	0.09	0.678	-0.05	0.816	NS
		M. lorentzi Biomass	23	-0.17	0.449	-0.18	0.416	NS
Ref	Ok Om 2015-2022	Total Prawn Abundance	21	0.16	0.537	0.13	0.584	NS
		Total Prawn Biomass	21	0.14	0.537	0.12	0.600	NS
		M. handschini Abundance	21	0.32	0.158	0.26	0.249	NS
		M. handschini Biomass	21	0.23	0.322	0.28	0.212	NS
		M. lorentzi Abundance	21	0.20	0.395	0.02	0.929	NS
		M. lorentzi Biomass	21	0.16	0.504	0.02	0.929	NS

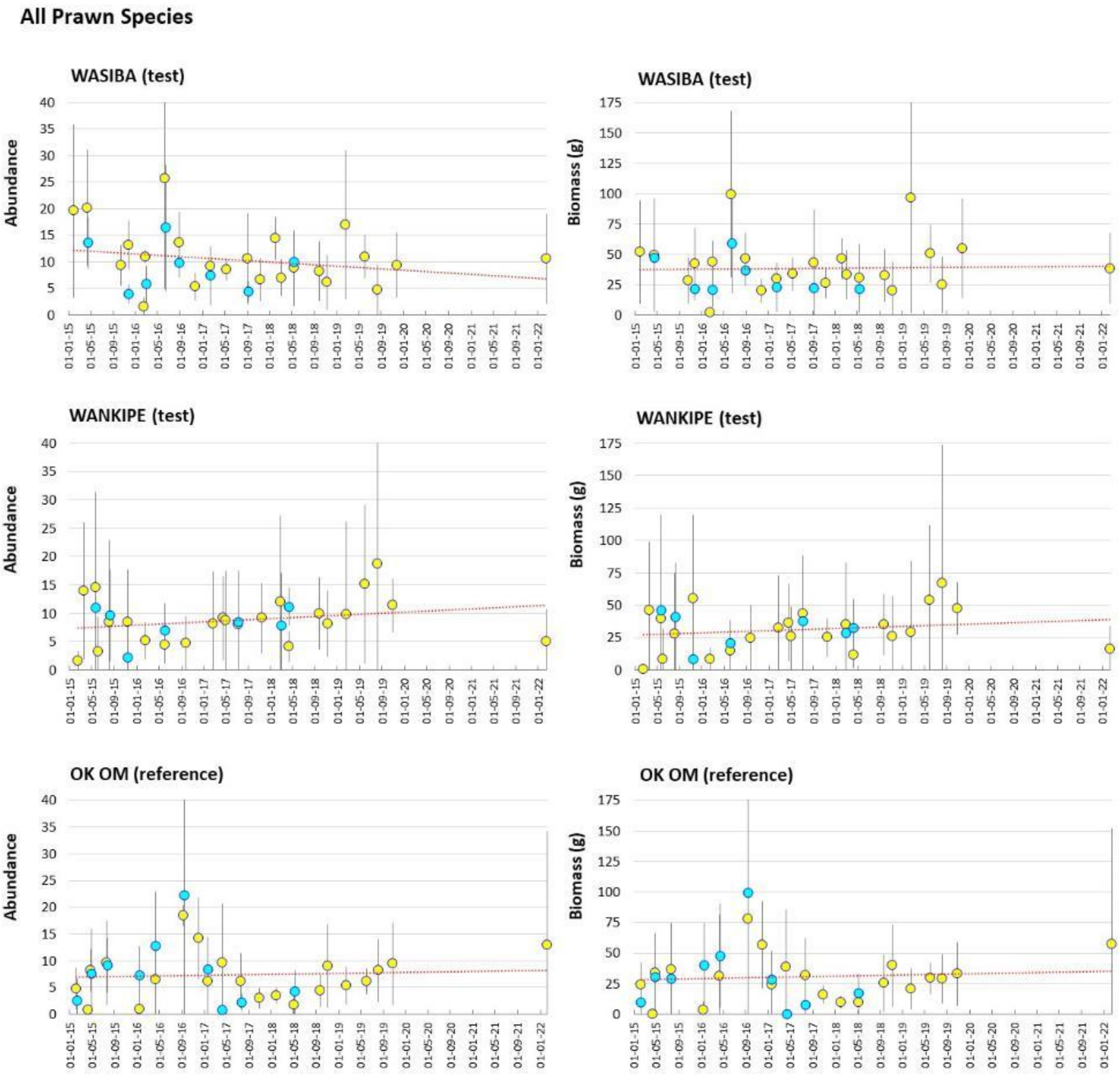


Figure 8-3 Time series plots of average (± 95% CIs) abundance and biomass (g) for combined prawn species from replicate electro-seining catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2022. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) was used for impact assessment.

M. handschini

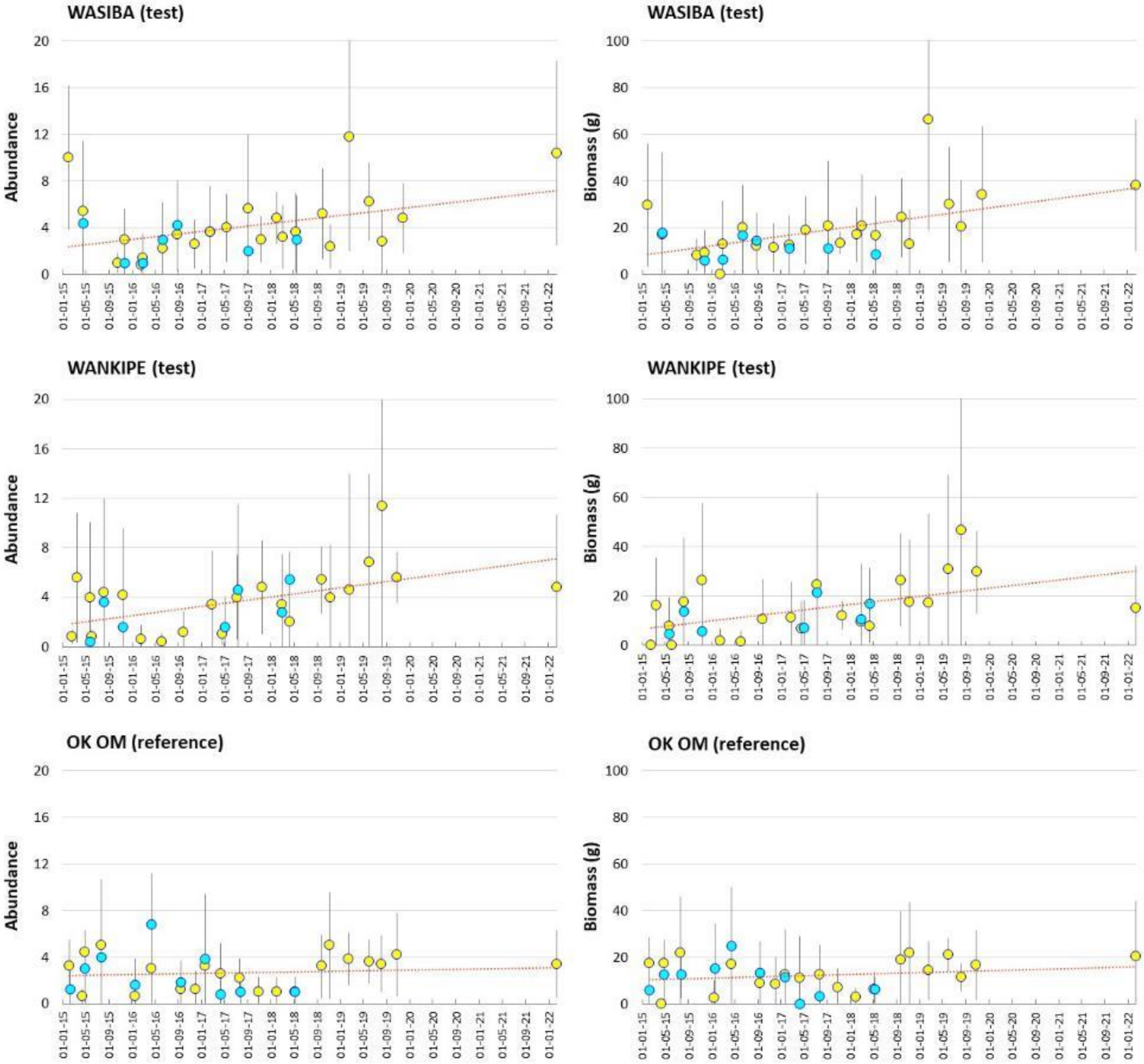


Figure 8-4 Time series plots of average (± 95% CIs) abundance and biomass (g) for *Macrobrachium handschini* in replicate electro-seining catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2022. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) was used for impact assessment.

M. lorentzi

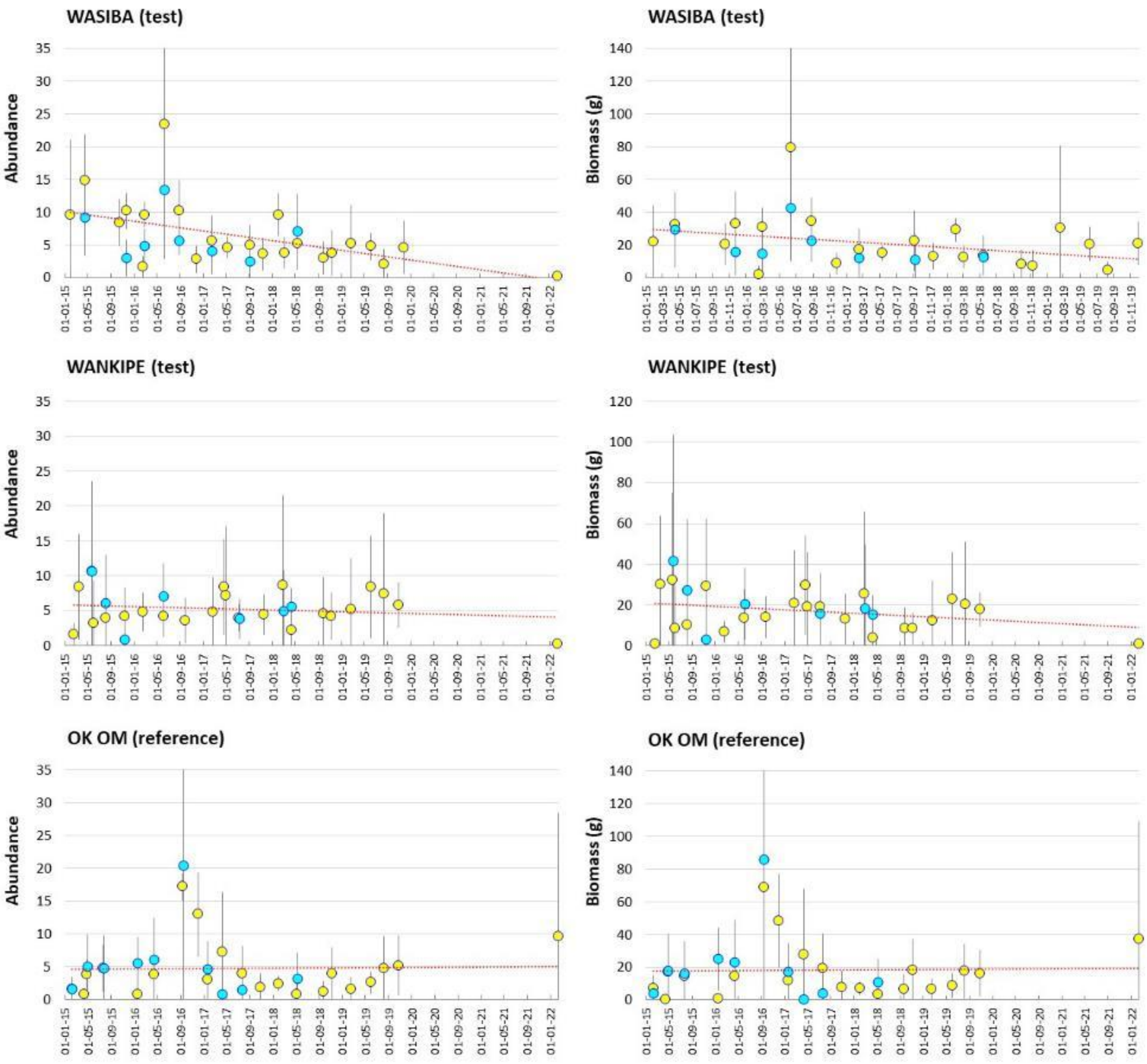


Figure 8-5 Time series plots of average (± 95% CIs) abundance and biomass (g) for *Macrobrachium lorentzi* in replicate electro-seining catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2022. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) was used for impact assessment.

8.2 Lower River

8.2.1 Fish

The impact assessment for fish in the lower river is based on the following indicators: total fish species richness, total fish species abundance and total fish biomass. Data were collected using a standardised, replicated gill net fishing method.

8.2.1.1 Comparison against fish impact TVs

Results from the comparison of 2020 - 2022 test site means for fish impact indicators in the lower river against their respective TVs are provided in Table 8-6 and include the t-statistic and significance value (p) for each test.

Results for lower river test site Bebelubi showed that the 2020 - 2022 test site means (n = 2 sampling events) for all indicators were not significantly different to, or significantly less than the respective TVs, indicating there was likely no impact to fish at Bebelubi during the care and maintenance period.

Results for lower river test site SG4 showed the 2020 - 2022 test site means (n = 2 sampling events) for species richness was not significantly different to, or significantly less than any of the TVs for species richness, indicating there was likely no impact to fish species richness at SG4 during the care and maintenance period.

The mean biomass at SG4 of 9.5kg was significantly less than the baseline mean (1989 – 1998) of 15.4kg. However, further analysis of the trends for each indicator showed statistically significant weak negative (i.e. decreasing) trends in abundance and biomass at test site SG4, but also in biomass at test site Bebelubi, and reference site Tomu. Additionally, water quality, sediment quality and tissue metal quality all indicate no potential risk at these sites. Therefore, the fact that declines in biomass were recorded at a reference site, as well as test sites, and in the absence of risk caused by water quality, sediment quality or tissue metals, indicates that the low biomass recorded at SG4 in the care and maintenance period is unlikely to be related to the operation of the Porgera Mine. This conclusion is further supported by WRM (2018) which performed an analysis of fishery yield versus artisanal fish consumptions by the local village populations. The results showed a significant increase in artisanal fish consumption since 2011 as a result of population growth, and based on census data, likely even greater increase in consumption since 2000 (and even more so since commencement of mining). Such increases in consumption could account for the observed declines in fish catch, especially at locations subjected to high fishing pressure as a result of localised population growth (WRM 2018).

Table 8-6 Results from one-sample t-tests testing for significant ($p < 0.05$) differences between average values for Bebelubi (n = 2 sampling events) and SG4 (n = 2 sampling events) for 2020 - 2022, and TVs derived from the previous 24 months for respective reference sites Baia and Tomu, and TVs derived from average and percentile values of baseline for Baia (2006-2008), Tomu (1999-2004) and SG4 (1989-1998). NS = not significantly different.

Test Site	Indicator Parameter	2020 - 2022 Test Site Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
Bebelubi	Total Fish Richness	4.0	Baia Reference Mean of previous 24 months	3.5	1	0.50	0.352	NS.
	Total Fish Abundance	9.0		9.9	1	-0.22	0.431	NS.
	Total Fish Biomass (kg)	4.5		6.1	1	-0.68	0.310	NS.
	Total Fish Richness	4.0	Baia Baseline 80th%ile	3.0	1	1.00	0.250	NS.
	Total Fish Abundance	9.0		15.0	1	-1.50	0.187	NS.
	Total Fish Biomass (kg)	4.5		8.4	1	-1.61	0.177	NS.
SG4	Total Fish Richness	6.7	Tomu Reference Mean of previous 24 months	4.5	1	3.25	0.041	Signif. > TV.
	Total Fish Abundance	21.3		13.5	1	2.63	0.066	NS.
	Total Fish Biomass (kg)	9.5		7.6	1	1.01	0.209	NS.
	Total Fish Richness	6.7	Tomu Baseline Mean	5.2	1	2.20	0.079	NS.
	Total Fish Abundance	21.3		24.8	1	-1.09	0.195	NS.
	Total Fish Biomass (kg)	9.5	Tomu Baseline 20%ile	13.5	1	-2.18	0.080	NS.
	Total Fish Richness	6.7	SG4 Baseline	5.0	1	2.50	0.065	NS.

Test Site	**Indicator Parameter**	**2020 - 2022 Test Site Mean**	**TV Source**	**TV**	**t-Test**			**Level of Impact**
					df	**t-stat**	**p**	
	Total Fish Abundance	21.3	Mean	21.8	1	-0.15	0.448	NS.
	Total Fish Biomass (kg)	9.5		15.4	1	-3.22	0.042	Signif. < TV.

8.2.1.2 Trends for fish impact indicators

The results of Spearman correlation and linear regression analyses for fish indicators in the lower river are provided in The fact that declines in biomass were recorded at reference site Tomu, as well as test sites, suggests the cause is not mine related. In addition, declines in species richness and abundance were only observed at test site SG4, and not at test site Bebelubi closer to the mine. If the declines were entirely mine-related, then similar, if not stronger, trends would be expected at Bebelubi. The absence of a strong mine-related signal in sediment and water metal concentrations and TSS levels in surface water at these sites (see Risk Assessment Section 7) provides further weight to the argument that the mine is not the sole factor influencing fish populations. As discussed above, it is possible the declines observed reflect the combined indirect effects of PJV's presence in the region, which may aid communities to have access to more effective fishing methods (through access to income, nets and boats), as well as local fishing pressure and population pressure, rather than direct mine impacts. Analysis of fishery yield versus artisanal consumption (WRM 2018) indicates a significant increase in artisanal consumption since 2011 as a result of population growth, and based on census data, likely even greater increase in consumption since 2000 (and even more so since commencement of mining). For example, census data between 2000 and 2011 showed a 42% increase in population size for the lower Strickland/Lake Murray area, and between 2011 and 2018 an estimated further increase of 23%. Assuming no major change in individual daily consumption rates, this is a significant increase in consumption through population growth alone, and indicates that a higher percentage of fishery yield is being consumed. Such increases in consumption could account for the observed declines in fish catch, especially at locations subjected to high fishing pressure as a result of localised population growth (WRM 2018). It is also noteworthy that only two sampling events were conducted under C&M, and therefore the trend lines are heavily influenced by prior sampling under operations, and data collected in 2021-22 do not appear appreciably higher or lower than data in previous recent years.

Table 8-7, and time series plots for each site are shown in Figure 8-6 and Figure 8-7.

The analyses showed statistically significant weak negative (i.e. decreasing) trends in abundance and biomass at test site SG4, and in biomass at test site Bebelubi, and reference site Tomu.

The fact that declines in biomass were recorded at reference site Tomu, as well as test sites, suggests the cause is not mine related. In addition, declines in species richness and abundance were only observed at test site SG4, and not at test site Bebelubi closer to the mine. If the declines were entirely mine-related, then similar, if not stronger, trends would be expected at Bebelubi. The absence of a strong mine-related signal in sediment and water metal concentrations and TSS levels in surface water at these sites (see Risk Assessment Section 7) provides further weight to the argument that the mine is not the sole factor influencing fish populations. As discussed above, it is possible the declines observed reflect the combined indirect effects of PJV's presence in the region, which may aid communities to have access to more effective fishing methods (through access to income, nets and boats), as well as local fishing pressure and population pressure, rather than direct mine impacts. Analysis of fishery yield versus artisanal consumption (WRM 2018) indicates a significant increase in artisanal consumption since 2011 as a result of population growth, and based on census data, likely even greater increase in consumption since 2000 (and even more so since commencement of mining). For example, census data between 2000 and 2011 showed a 42% increase in population size for the lower Strickland/Lake Murray area, and between 2011 and 2018 an estimated further increase of 23%. Assuming no major change in individual daily consumption rates, this is a significant increase in consumption through population growth alone, and indicates that a higher percentage of fishery yield is being consumed. Such increases in consumption could account for the observed declines in fish catch, especially at locations subjected to high fishing pressure as a result of localised population growth (WRM 2018). It is also noteworthy that only two sampling events were conducted under C&M, and therefore the trend lines are heavily influenced by prior sampling under operations, and data collected in 2021-22 do not appear appreciably higher or lower than data in previous recent years.

Table 8-7 Fish lower rivers - Spearman rank correlation coefficients (rho), linear regression coefficients (R) and associated significance values (p) for trends in species richness, abundance and biomass (kg) over time from gill net catch for all years. Only data from replicate net #1 were used. NS = not significant.

Site		**Indicator Parameter**	**n**	**Spearman Corr.**		**Linear Regress.**		**Trend**
				Rho	**p**	**R**	**p**	
Test	Bebelubi 2006-2019	Total Fish Richness	48	0.088	0.552	0.070	0.639	NS.
		Total Fish Abundance	48	-0.251	0.085	-0.285	0.050	NS.
		Total Fish Biomass (kg)	48	-0.262	0.072	-0.385	0.023	Signif. -ve
	SG4 1989-2019	Total Fish Richness	97	-0.171	0.094	-0.186	0.068	NS.
		Total Fish Abundance	97	-0.162	0.114	-0.236	0.020	Signif. -ve
		Total Fish Biomass (kg)	97	-0.357	<0.01	-0.344	0.001	Signif. -ve
Ref	Baia 2006-2019	Total Fish Richness	46	-0.119	0.432	-0.021	0.889	NS.
		Total Fish Abundance	46	-0.166	0.272	-0.193	0.200	NS.
		Total Fish Biomass (kg)	46	-0.287	0.053	-0.245	0.101	NS.
	Tomu 1996-2019	Total Fish Richness	89	-0.113	0.293	-0.095	0.374	NS
		Total Fish Abundance	89	-0.112	0.296	-0.209	0.050	NS
		Total Fish Biomass (kg)	89	-0.240	0.024	-0.333	0.001	Signif. -ve

All Fish Species

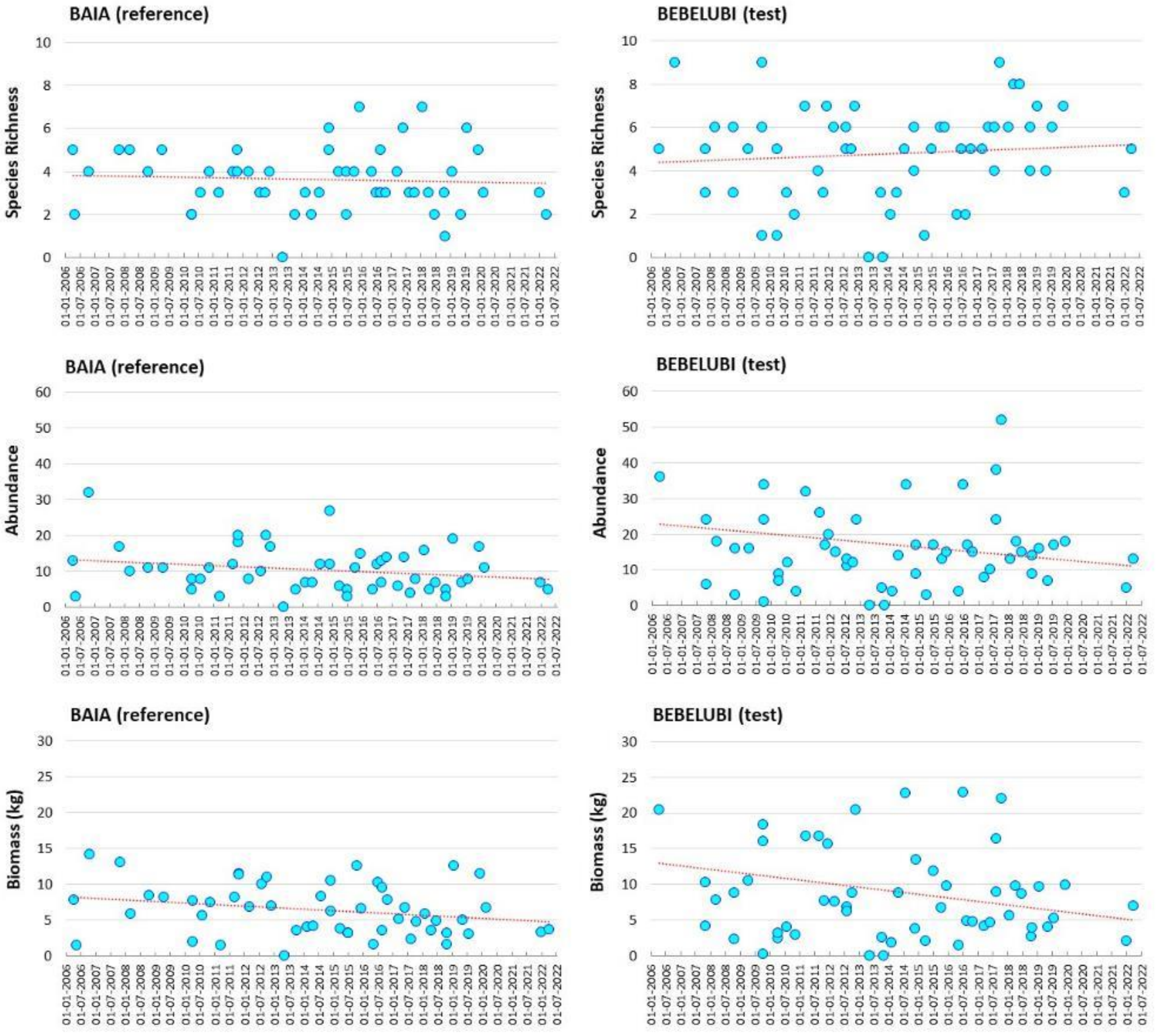


Figure 8-6 Time series plots of species richness, abundance and biomass (kg) from replicate net set #1 gill net catch at paired monitoring sites Bebelubi and Baia, 2006 - 2022. Linear trend lines are shown in red. Data from consecutive days sampling are included in the plots, but only data from the first day sampling were used for impact assessment.

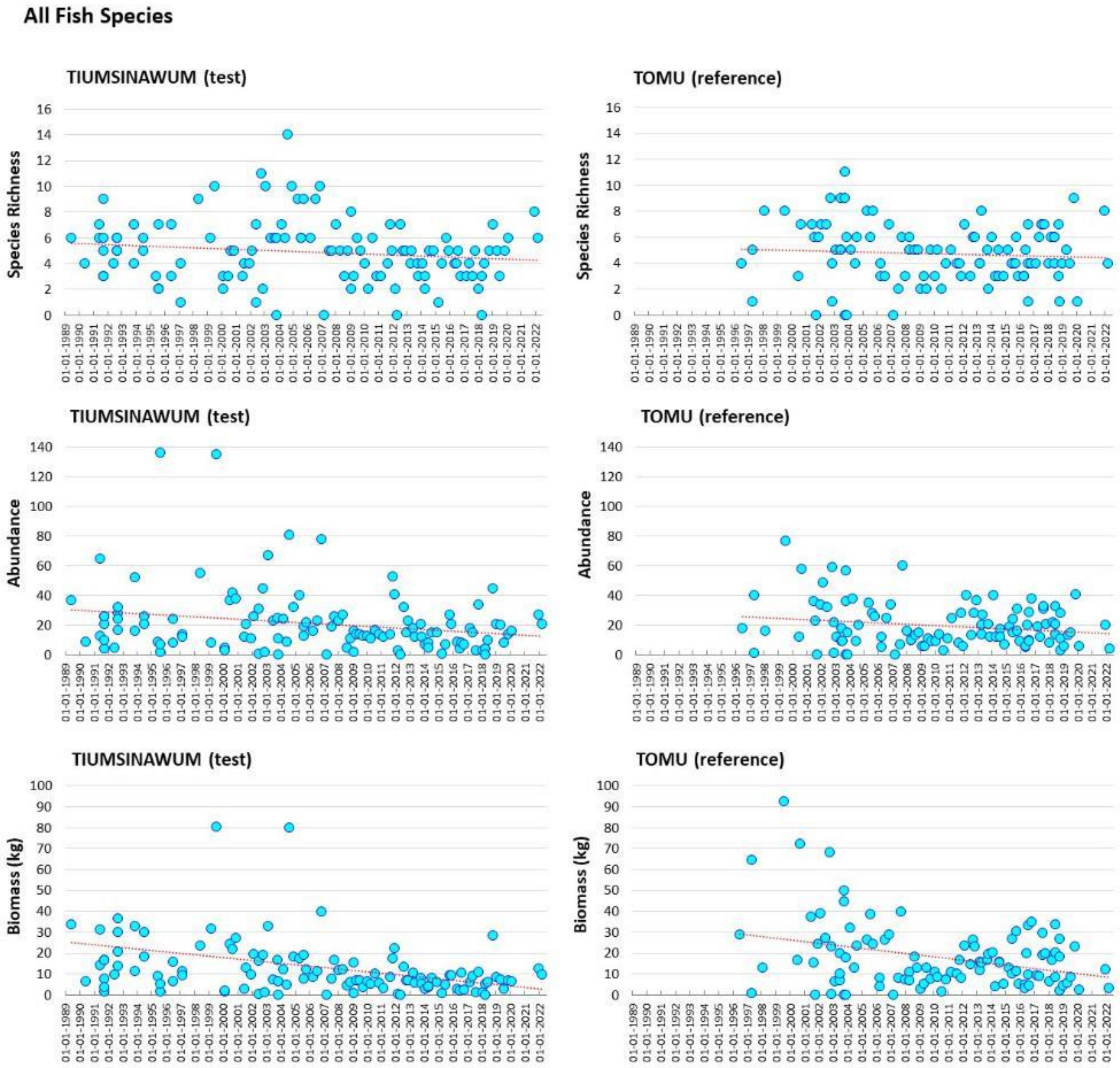


Figure 8-7 Time series plots of species richness, abundance and biomass (kg) from replicate net set #1 gill net catch at paired monitoring sites SG4 and Tomu, 1989 - 2022. Linear trend lines for average values shown in red. Data from consecutive days sampling are included in the plots, but only data from the first day sampling were used for impact assessment.

8.3 Lake Murray

The impact assessment for fish in Lake Murray is based on the following indicators: total fish species richness, total fish abundance and total fish biomass. Data were collected using a standardised, replicated gill net fishing method.

8.3.1 Fish

8.3.1.1 Comparison against fish impact TVs

Results from the comparison of 2022 test site means for fish impact indicators in Lake Murray against their respective TVs are provided in Table 8-6 and include the t-statistic and significance value (p) for each test.

Results for lower lake test site Miwa showed the 2022 test site mean for species richness was not significantly different to, or significantly less than any of the TVs for species richness, indicating no impact to fish species richness at Miwa during 2022. Biomass was significantly less than the TV based on the average of Miwa baseline data (i.e. 1989-2006), but were not significantly different to, or significantly less than the other TVs for Miwa. On a weight of evidence approach, it was therefore concluded that there was no impact to fish abundance and biomass at Miwa.

Results for mid-lake test site Pangoa showed that the 2022 test site means for fish abundance were not significantly different to, or significantly less than the respective TVs. Fish biomass was significantly less than both the Miwa 24 month mean TV and the TV based on the average of Maka baseline data. As there were only two replicate samples conducted, both of which recorded four species each, the one-sample t-tests for differences in species richness compared to the TVs were not able to return a result. As mean fish abundance was higher than the TVs (though not significantly so, due to insufficient replication available for the t-test), but biomass was lower, this may indicate large fish were not as common at Pangoa in 2022 compared to Maka baseline (2001-2006). This indicates a potential difference in fishing pressure between sites and/or over time, and is unlikely to be directly mine-related.

Table 8-8 Results from one-sample t-tests testing for significant ($p < 0.05$) differences between average values for Miwa and Pangoa for 2022 and TVs derived from the previous 24 months for reference site Maka, and TVs derived 20th percentile values of baseline for Maka (2001-2006) and Miwa (1989-2000). NS = not significantly different.

Test Site	Indicator Parameter	2022 Test Site Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
Miwa	Total Fish Richness	6	Maka Reference Mean of previous 24 months	5	2	1.73	0.113	NS.
	Total Fish Abundance	20		10.9	2	2.09	0.086	NS.
	Total Fish Biomass (kg)	24.9		20.9	2	0.49	0.335	NS.
	Total Fish Richness	6	Maka Baseline 20%ile	1.9	2	7.10	0.010	Signif > TV.
	Total Fish Abundance	20		4.8	2	3.49	0.037	Signif > TV.
	Total Fish Biomass (kg)	24.9		19.7	2	0.64	0.293	NS.
	Total Fish Richness	6	Miwa Baseline Mean	3.8	2	3.81	0.031	Signif. > TV.
	Total Fish Abundance	20		19.4	2	0.138	0.452	NS.
	Total Fish Biomass (kg)	24.9		66.7	2	-5.14	0.018	Signif. < TV.

Test Site	Indicator Parameter	2022 Test Site Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
Pangoa	Total Fish Richness	4	Maka Reference Mean of previous 24 months	5	1	-	-	Insufficient variation for test.
	Total Fish Abundance	19		9.9	1	0.68	0.311	NS.
	Total Fish Biomass (kg)	6.4		17.5	1	-15.76	0.020	Signif. < TV.
	Total Fish Richness	4	Maka Baseline 20th%ile	1.9	1	-	-	Insufficient variation for test.
	Total Fish Abundance	19		4.8	1	1.18	0.223	NS.
	Total Fish Biomass (kg)	6.4		19.7	1	-14.43	0.022	Signif. < TV.

8.3.1.2 *Trends for fish impact indicators*

The results of Spearman correlation and linear regression analyses for fish indicators in Lake Murray are provided in Table 8-9, and time series plots for each site are shown in Figure 8-8 and Figure 8-9.

The analyses showed statistically significant weak negative (i.e. decreasing) trends in species biomass at test site Pangoa (mid lake), and in biomass at reference site Maka (upper lake). There were no significant trends in indicator parameters at test site Miwa (lower lake). The fact that declines were recorded at the reference site Maka as well as test site Pangoa, and in the absence of any risk indicated by water quality, sediment quality or tissue metals, the results suggests that the cause is not mine-related.

Table 8-9 Fish Lake Murray - Spearman rank correlation coefficients (rho), linear regression coefficients (R) and associated significance values (p) for trends in average species richness, abundance and biomass (kg) over time from replicate gill net catch for all years. NS = not significant.

Site		Indicator Parameter	n	Spearman Corr.		Linear Regress.		Trend
				Rho	p	R	p	
Test	Miwa 1989-2022	Total Fish Richness	47	0.120	0.423	0.111	0.456	NS
		Total Fish Abundance	47	0.014	0.927	-0.107	0.475	NS
		Total Fish Biomass (kg)	47	-0.089	0.551	-0.156	0.294	NS
	Pangoa 1992-2022	Total Fish Richness	39	-0.031	0.850	-0.131	0.427	NS
		Total Fish Abundance	39	-0.076	0.645	-0.060	0.716	NS
		Total Fish Biomass (kg)	39	-0.352	0.028	-0.199	0.225	Signif. -ve
Ref	Maka 1993-2022	Total Fish Richness	32	-0.200	0.273	-0.164	0.369	NS
		Total Fish Abundance	32	-0.290	0.107	-0.325	0.070	NS
		Total Fish Biomass (kg)	32	-0.422	0.016	-0.386	0.029	Signif. -ve

All Fish Species

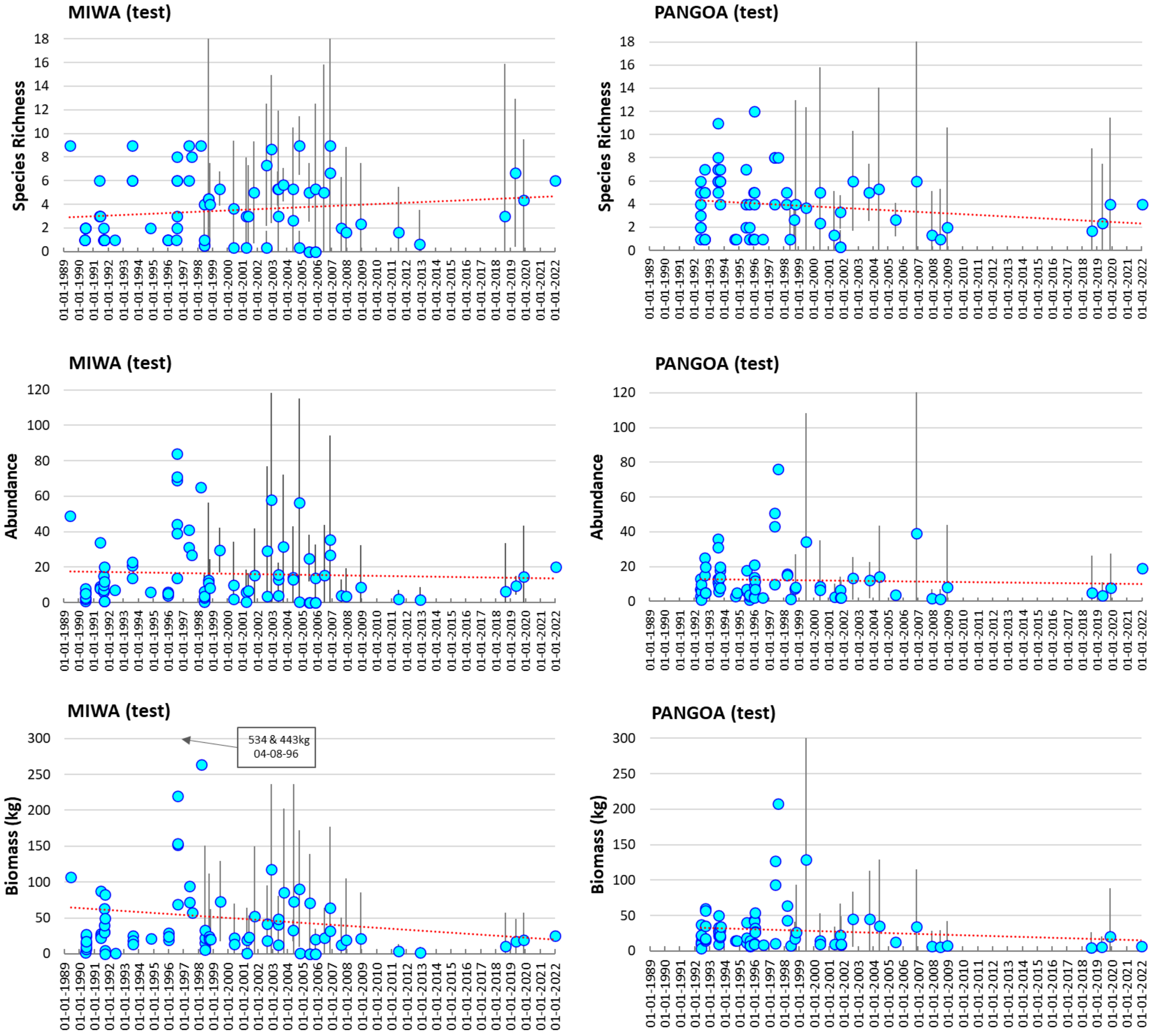


Figure 8-8 Time series plots of average (±95%CIs) species richness, abundance and biomass (kg) from replicate gill net catch at Lake Murray test sites Miwa and Pangoa, 1989 - 2022. Linear trend lines are shown in red. Data from consecutive days sampling are included in the plots, but only data from the first day sampling were used for impact assessment.

All Fish Species

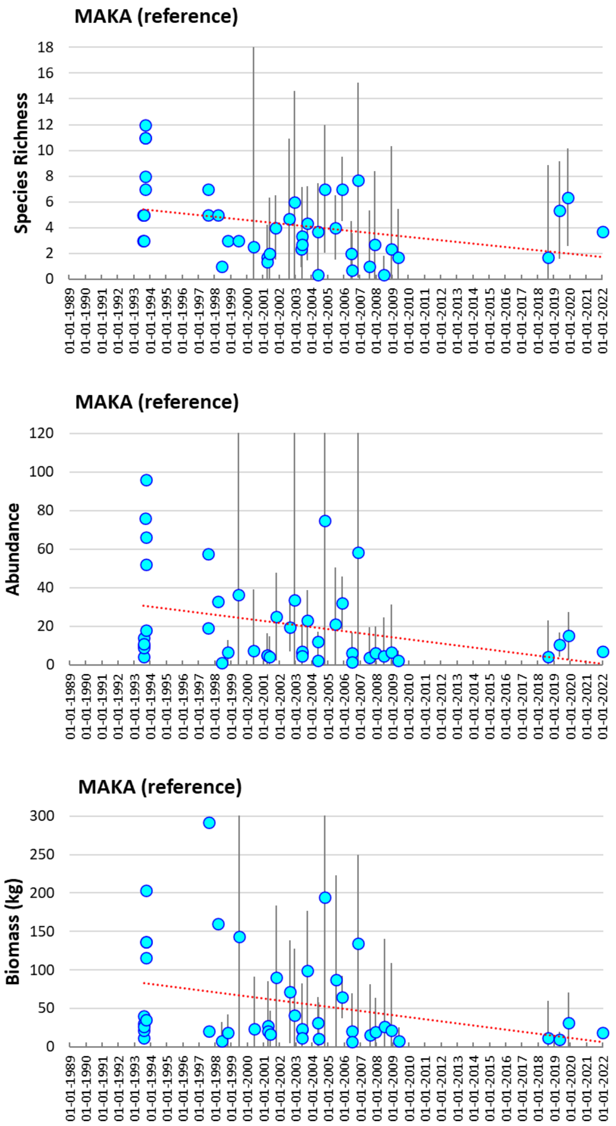


Figure 8-9 Time series plots of average (±95%CIs) species richness, abundance and biomass (kg) from replicate gill net catch at Lake Murray reference site Maka, 1989 - 2022. Linear trend lines are shown in red. Data from consecutive days sampling are included in the plots, but only data from the first day sampling were used for impact assessment.

9 CONCLUSIONS AND OVERALL ASSESSMENT

The Porgera Mine is a large-scale open cut and underground gold mine that operated consistently between 1990 and April 2020, at which time the operation was placed into care and maintenance while BNL continues to negotiate an extension of the Porgera SML with the PNG Government and other project stakeholders.

Upon entering C&M, mining and processing activities ceased and the size of the workforce was reduced significantly. A care and maintenance team was established with the purpose of maintaining the site in a safe and stable condition in accordance with the PJV Care and Maintenance Environmental, Security, Health and Safety Plan, which was reviewed and approved by the PNG Government.

The environmental aspects of the operation are managed through the implementation of the site's EMS, which has been certified to the ISO 14001 standard since 2012. The objectives of the EMS are to consistently achieve compliance with legal obligations, mitigate risk and continually improve performance. The BNL environmental monitoring program provides data and information upon which to measure the ability of the EMS to achieve its objectives. Upon entering C&M, the EMS and environmental monitoring program were adjusted to align with the change of activities.

The monitoring program has continually evolved, benefiting from improvements to scientific knowledge, sampling and data analysis techniques and environmental management practices. The results of the program are used each year to produce the Porgera Annual Environment Report, which is a comprehensive assessment of the operation's environmental performance and is submitted to the PNG CEPA each year.

Monitoring continued during C&M, although modified to suit the change of activities and practical limitations imposed by resource constraints and COVID 19 controls. This report is based on the AER framework and, using data collected during the operational and C&M phases of the operation, presents a comprehensive assessment of environmental performance through the C&M phase.

Since 1995 the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's preeminent scientific organisation, have provided independent oversight of the Porgera Mine environmental monitoring program. CSIRO's role includes undertaking review of the AER, routine quality assurance audits of the BNL environmental monitoring program and environmental laboratory operations and technical studies to improve the understanding of the behaviour of metals within the receiving environment. CSIRO audits include independent sampling and analysis of water, sediment and fish and prawn tissue to cross-check BNL's results. The last audit was completed in 2019 and found that CSIRO and BNL's results are consistent, confirming the high technical standard and accuracy of BNL's environmental monitoring program.

Consistent with the EMS, the purpose of the C&M Environment Report is to assess compliance, risk, impact and performance of the operation during the C&M phase. The assessment is based on the use of environmental indicators at discharge points and potentially impacted (test) sites within the receiving environment downstream of the mine. The data at the test sites are assessed against compliance limits dictated by the site's environmental permits; trigger values that act as benchmarks of risk and historical data to assess performance trends. Where possible, the comparison is supported by statistical analysis to provide added confidence in the results.

The operational footprint during C&M remained unchanged from April 2020 when the site was placed into C&M, there have been no expansion to disturbance footprints through mining and no reclamation of disturbed land through rehabilitation activities during the C&M phase.

The quantity of inputs from the site to the receiving environment during the C&M phase reduced significantly, owing to the cessation of riverine tailings disposal, and significant reduction in erodible waste rock disposal. This resulted in a reduction of sediment and metals discharged to the river system compared to the operational phase. Contact runoff, containing sediment and metals, continued to be discharged from the site as a result of rainfall runoff and dewatering activities, with volumes and quantities being generally consistent with recent years.

Natural environmental conditions in 2021-2022 were characterised by approximately average rainfall totals at the mine site and at all other monitoring sites within the receiving environment.

Given that inputs from the mine have been significantly reduced during C&M compared to the operational phase, the behaviour of mine inputs within the receiving aquatic ecosystem are largely dictated by the natural flow rates and sediment loadings of rivers, which in turn are related to rainfall. Average rainfall results in moderate natural flows and sediment loads to the system.

Baseline water quality in the upper and lower rivers and in Lake Murray indicated that naturally elevated background concentrations of some physical and chemical toxicants were present downstream of the mine prior to operations commencing. Water quality data from reference sites showed low concentrations of metals were being contributed from catchments within the upper and lower rivers and northern Lake Murray that are not influenced by the mine.

Similarly, baseline benthic sediment quality in the upper and lower rivers and in Lake Murray indicated that naturally elevated background concentrations of some metals were present downstream of the mine prior to operations commencing, which is expected in a naturally mineralised catchment that hosts the Porgera ore body. Sediment quality data from reference sites showed that low concentrations of most metals were being contributed from catchments within the upper and lower rivers and northern Lake Murray that are not influenced by the PJV mine.

Baseline and reference fish tissue and prawn abdomen metal concentrations reflected low baseline and reference metal concentrations in water and sediment.

The C&M Environment Report assessment was performed by assessing compliance against the conditions of the environmental permits and by applying a weight of evidence approach to assessing human health risk and environmental impact based on a range of environmental indicators. It should be noted that the C&M Environment Report assessment applies to sites downstream of SG1 on the Porgera River, as SG1 was not included as a monitoring site in the approved C&M Monitoring Plan due to security concerns, therefore any assessment could not be performed at this location.

For the purposes of this C&M Environment Report, the receiving environment is divided into four (4) regions. The upper river section of the receiving environment extends from the mine to SG3 on the Strickland River, 164 km downstream of the mine. This zone also constitutes the permitted mixing zone as defined by the PNG Government environmental permits and is also the zone in which compensation for environmental impact is paid to communities living along the river.

The lower river extends from SG3 on the Strickland River, to the junction of the Strickland and Fly Rivers, approximately 600 km downstream of the mine. The off-river water bodies (ORWBs) are a number of ox-bow lakes that lie adjacent to the lower section of the Strickland River, between 510 km and 600 km from the mine. And finally, Lake Murray, a large freshwater lake which is connected to the lower section of the Strickland River via the Mamboi breakthrough and Herbert River, approximately 550 km downstream of the mine. Typically, water flows from Lake Murray into the Strickland River, however when the water level within the river is higher than that of the lake, the direction of flow will reverse and water will flow from the Strickland River into the southern and central regions of Lake Murray.

Due to the mine being in care and maintenance, this has resulted in reduced activities and considerably lower inputs from the mine, especially the cessation of tailings discharge and significantly reduced placement of erodible waste rock. Although the AERs during operations demonstrated continued compliance and expected influence as per the Environmental Impact Assessment (NSR 1990), the monitoring during care and maintenance expectedly demonstrated that the overall condition of the receiving environment has improved and, in some instances, returned to background conditions.

In summary, monitoring of the environmental conditions within the Lagaip River, Strickland River and Lake Murray during the maintenance period has shown that:

- Water quality condition throughout the Lagaip River, Strickland River and Lake Murray continued to comply with the environmental permit limits and was assessed as 'low risk' (Table E-1).
- Sediment quality condition throughout the most of the Lagaip River, Strickland River and Lake Murray was assessed as 'low risk' (Table 9-1). The exception was at monitoring site SG2 which is the first downstream monitoring site located on Lagaip River, where the concentration of weak-acid extractable (WAE) lead in sediments remained elevated resulting in a 'potential risk' rating (Table 9-1). Lead concentrations did however show a reduction compared with the operational phase.
- Macroinvertebrate populations within the Lagaip River and Upper Strickland River showed no sign of mine-related impacts, aligned to reference conditions during care and maintenance as a result of improved water and sediment quality.
- Fish and prawn populations within the Lagaip River and Upper Strickland River, within the permitted mixing zone, did show signs of mine-related impact which were observed during and attributable to the operational phase of the mine.

  Although water and sediment quality and macroinvertebrate populations have recovered during care and maintenance, fish and prawn populations are expected to take longer to recover due to the slower rate of population growth through reproduction and migration for these species compared to macroinvertebrates.
- Fish populations downstream of the mixing zone within the Lower Strickland River and Lake Murray showed no mine-related impacts, which is consistent with the conditions observed at these sites during the operational phase of the mine.
- Although impact was observed in fish and prawn populations in the Lagaip River and Upper Strickland River, the concentrations of metals in fish flesh and prawn abdomen were below international food standards, indicating that they are safe for human consumption.
- The degree of impact detected is consistent with the predictions made prior to mining operations commencing in 1990 and compensation for environmental impact is paid to landowners living along the river within the permitted mixing zone, in accordance with the 1996 Ministerial Determination.

A summary of compliance, human health risk and environmental impact at each test site in C&M is presented in Table 9-1. The compliance assessment showed that from January 2021 – May 2022 the site remained in full compliance with the conditions of its environmental permits. The human health risk assessment showed that the risk to human health posed by the operation of the Porgera Mine between November 2021 and May 2022, downstream of SG1, was low which is consistent with the results during the operational phase.

Table 9-1 Summary of Compliance, Human Health Risk and Environmental Impact at test sites in 2021 - 2022

Region	Site	Distance From the Mine (km)	Compliance	Human Health	Environmental			
					Water	Sediment	Macro-invertebrates	Fish & Prawns
Upper River	SG2	42	Compliant	Low Risk	Low Risk	Potential Risk	NA	NA
	Wasiba	96	Compliant	Low Risk	Low Risk	Low Risk	No Impact	Moderate Impact
	Wankipe	116	Compliant	Low Risk	Low Risk	Low Risk	No Impact	Moderate Impact
	SG3*	164	Compliant	Low Risk	Low Risk	Low Risk	No Impact	NA
Lower River	Bebelubi	310	Compliant	Low Risk	Low Risk	Low Risk	NA	No Impact
	SG4	360						No Impact
	SG5	550						NA
ORWBs	Kuku-fionga	510	Compliant	Low Risk	Low Risk	Low Risk	NA	NA
	Zonga-mange	560						
	Avu	575						
	Levame	600						
Lake Murray	SG6	570	Compliant	Low Risk	Low Risk	Low Risk	NA	NA
	Miwa	590						No Impact
	Pangoa	600						No Impact

SG3* Located at the end of the permitted and compensated mixing zone boundary

WAE = Weak acid extractable

10 RECOMMENDATIONS

The recommendations are intended to improve the assessment methodology, communication of the findings to stakeholders and with a view towards continued environmental performance (including further reduction of environmental risk and impact).

Note that a number of the recommendations from the 2019 Annual Environment Report are still in progress and appear in the list below in addition to new recommendations raised from this C&M Environment Report.

Assessment Methodology and Communication of Findings

1. Review the frequency of TSS sampling in the upper and lower river, Lake Murray and ORWB reference and test sites.
2. Deliver a summary presentation of the report methodology and findings to the Conservation and Environmental Protection Authority to support delivery of the C&M Environment Report.
3. Develop a Porgera Mine Environment Report Card to present a summary of the findings of the report and make the report card available in hard copy and via the PJV website.
4. Undertake a study to update the particle size information for the erodible dumps, used in the sediment mass balance calculations.
5. Conduct a critical review to investigate the major ions present in the system, which contribute to elevated EC, and their impacts on aquatic life. This work should also investigate options for development of a site-specific EC trigger value.
6. Review the analytical procedure used for the determination of WAE metals. The CSIRO 2019 ultratrace study reported much lower WAE metal concentrations in benthic sediments from the main river than typically reported by BNL. It may be appropriate to adopt the CSIRO procedure for routine analysis.
7. Engage CSIRO to visit Porgera and conduct a quality review of the BNL environmental monitoring program. As a minimum, the review shall include training and competency, sample collection, sample handling and dispatch, laboratory analytical methods, data management and internal quality assurance and quality control systems. The review shall also include the collection and analysis of water, sediment and tissue metal samples by CSIRO for comparison against BNL results.
8. Undertake a specific investigation into the behaviour of mine derived sediment and contaminants of concern in the Lower Strickland floodplain.

Reduce Environmental Risk and Impact and Improve Performance

9. Continue to investigate options for reducing the concentrations of bioavailable metals and mass loads of metals in mine discharges.
10. Investigate the metal uptake pathway by which prawns and fish are accumulating mine derived metals to understand the influence of particulate metals and metals bound to organic matter.

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APPENDIX A. QA & QC – CHEMISTRY AND BIOLOGY

Collection of environmental monitoring data is performed by the PJV Environment Department. The team consists of seven staff during the C&M period and includes trained environmental scientists, chemists, engineers, biologists, hydrologists and technicians.

Water samples are analysed for alkalinity, pH, conductivity, total suspended solids, sulfate, chloride, WAD-CN, total hydrocarbons and coliforms by PJV staff at the onsite environmental chemistry laboratory. All other analysis of water, sediment and fish and prawn tissue during care and maintenance was performed by the National Measurement Institute (NMI) in Sydney which is a NATA-accredited laboratory.

Quality assurance and quality control (QA & QC) measures for water, sediment and tissue metals are performed to ensure the results of the monitoring program are accurate, representative and defendable. The QA & QC measures associated with the Porgera Environmental Monitoring and Reporting program are discussed in the following sections.

Training and Competency

The training and competency system is aimed at achieving consistent application of techniques for sampling, analysis, data management and reporting that are consistent with industry best practice.

Each task associated with the monitoring and reporting program is outlined in a Standard Operating Procedure (SOP). Each staff member is then trained to conduct the task in accordance with the SOP, and then assessed to confirm competence.

QA & QC Sampling and Laboratory Results

The sampling schedule includes the collection of QA & QC samples for the purpose of validating that the monitoring results are accurate and representative. The QA & QC samples, their purpose, collection frequency and performance criteria are shown in Table A-1.

Upon receiving the results from the laboratory, the results are screened to ensure the QA & QC results are within acceptable limits prior to being transferred to the database.

Water and Sediment

The QA & QC samples for water and sediment, their purpose, collection frequency and performance criteria are shown in Table A-1. It should be noted that the acceptance criteria applied to field duplicate samples of ±44% aligns with the criteria applied by NMI to the internal laboratory samples, and when combined with the acceptance criteria applied to the field blanks, is considered acceptable for supporting a robust QA program.

Table A-1 QA & QC Samples – Water and Sediment Quality

QA & QC Sample	Purpose	Sample rate	Acceptance Criteria
Combined field, method and transport blank (water only)	Test for contamination during field work, sample preparation and transport. Test for accuracy of laboratory analytical method.	1 blank per sample batch	≤2 x LOR for each analyte
Field duplicate	Test repeatability of laboratory analytical method.	1 duplicate for every 8 samples (minimum 1 per batch)	±44% of primary sample
NMI lab duplicate	Test repeatability of laboratory analytical method.	1 duplicate per sample batch	±44% of primary sample
NMI lab control sample	Test influence of sample preparation and analysis on recovery.	1 control per sample batch	75% – 120% recovery
NMI matrix spike	Test influence of sample preparation and analysis on recovery.	1 spiked sample per sample batch	75% – 120% recovery

The results of QA & QC samples from water quality sampling at SG3 between November 2021 and May 2022 as shown in Table A-2 indicated good performance for all of QA & QC samples across all parameters.

Table A-2 2022 Water quality QA & QC sample results SG3

	% Within Acceptable Criteria												
Sample Type	**Ag-D**	**As-D**	**Cd-D**	**Cr-D**	**Cu-D**	**Hg-D**	**Ni-D**	**Pb-D**	**Se-D**	**Zn-D**	**pH**	**EC**	**WAD-CN**
Combined Blank	100	92	90	100	100	100	92	92	100	100	NA	92	100
CRM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	100	NA
Field Duplicate	96	100	100	92	100	100	100	100	96	96	92	100	100
NMI Duplicate	100	100	100	100	100	100	100	100	100	100	NA	NA	NA
NMI Lab Control Sample	100	100	100	100	100	100	100	100	100	100	NA	NA	NA
NMI Matrix Spike	100	100	100	100	100	100	100	100	100	100	NA	NA	NA

D = Dissolved fraction

The results of QA & QC samples from sediment quality sampling at SG3 between November 2021 and May 2022 shown in Table A-3 indicated good performance of all samples for all parameters.

Table A-3 2022 Sediment quality QA & QC sample results SG3

	% Within Acceptable Criteria									
Sample Type	**Ag - WAE**	**As - WAE**	**Cd - WAE**	**Cr - WAE**	**Cu - WAE**	**Hg - WAE**	**Ni - WAE**	**Pb - WAE**	**Se - WAE**	**Zn - WAE**
Field Duplicate	100	100	96	92	100	96	93	96	100	100
NMI Duplicate	100	100	100	92	100	91	100	100	100	100
NMI Matrix Spike	100	91	100	100	100	100	100	100	91	100
NMI Blank	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NMI LCS	100	100	100	100	100	100	100	100	100	92

WAE = Weak-Acid Extractable

In addition to the routine QA & QC samples, PJV also participated in eight proficiency test rounds in 2021 and 2022 run by Proficiency Testing Australia. The inter-laboratory testing program provides an independent assessment of the analytical methods used within the PJV Environmental Chemistry Laboratory.

The proficiency testing results are summarised in Table A-4. The results show that a number of PTA results obtained by the PJV environment laboratory did not fall within the acceptable range of the test. Each time a parameter falls outside the acceptable range, an internal investigation is commenced to identify the cause.

Table A-4 Proficiency testing results 2021 and 2022

Date	Round	Analyte	Units	Lab result	MU	Median	NORM IQR	CV (%)	n	z-score
Feb-21	272	Chloride	mg/L	142	NA	140.0	6.9	4.9	26	0.29
		Chloride	mg/L	78.9	NA	74.45	6.15	8.3	26	0.72
Mar-21	274	Weak Acid Dissociable Cyanide	mg/L	0.064	NA	0.1575	0.0208	13.2	14	-4.50
		Weak Acid Dissociable Cyanide	mg/L	0.253	NA	0.2615	0.0259	9.9	14	-0.33
May-21	276	Sulfate	mg/L	9.5	NA	10.80	0.8	7.6	33	-1.59
		Sulfate	mg/L	121	NA	151	6.7	4.4	33	-4.50
		Conductivity	µS/cm	636	NA	660	12.6	1.9	48	-1.9
		Conductivity	µS/cm	1518	NA	1565	22.2	1.4	48	-2.11
		pH - potable	SU	7.51	NA	7.59	0.104	1.4	49	-0.77
		pH - potable	SU	7.06	NA	7.10	0.052	0.7	49	-0.77
		pH - standard	SU	7.53	NA	7.47	0.044	0.6	49	1.35
		Turbidity standard	NTU	5.10	NA	4.89	0.335	6.9	36	0.63
		Colour standard	Pt/Co	17	NA	13.0	3.0	22.8	25	1.35
Jun-21	278	Total Recoverable Oil and Grease	mg/L	66.5	NA	69.6	12.95	18.6	27	-0.24
		Total Recoverable Oil and Grease	mg/L	40.7	NA	87.65	16.30	18.6	27	-2.88
Jul-21	279	Total Solids	mg/L	280	NA	251.5	19.6	7.8	20	1.45
		Total Solids	mg/L	630	NA	634.0	31.1	4.9	21	-0.13
		Total Suspended Solids	mg/L	38.0	NA	36.7	3.60	9.8	36	0.36

Date	Round	Analyte	Units	Lab result	MU	Median	NORM IQR	CV (%)	n	z-score
		Total Suspended Solids	mg/L	53.0	NA	43.4	6.89	15.9	37	1.39
Aug-21	282	Alkalinity	mg/L	49.4	NA	53.8	4.4	8.1	31	-1.01
		Chloride	mg/L	124	NA	107	3.0	2.8	30	5.73
		Conductivity	mg/L	513	NA	506	10.0	2	36	0.7
		Sulphate	mg/L	17	NA	18.2	1.5	8.3	27	-0.79
		Totals Solids	mg/L	240	NA	320	23.5	7.4	18	-3.4
Oct-21	284	Sulphate - Potable	mg/L	16.0	NA	19.5	1.9	9.9	21	-1.82
		Sulphate - Potable	mg/L	78	NA	123	8.52	6.9	21	-5.28
		Conductivity - Potable	µS/cm	617	NA	796.5	61.2	7.7	38	-2.94
		Conductivity - Potable	µS/cm	1618	NA	1652	53.7	3.3	38	-0.63
		pH -Potable	SU	6.23	NA	6.94	0.059	0.9	41	-11.97
		pH -Potable	SU	6.86	NA	7.24	0.052	0.7	41	-7.32
		pH -Standard	SU	7.27	NA	7.15	0.052	0.7	40	2.31
		Color -Standard	Pt/Co	4.55	NA	3.98	0.4	10.1	22	1.42
Nov-21	285	Total Biochemical Oxygen Demand	mg/L	61	NA	41.75	5.06	12.1	20	3.80
		Total Biochemical Oxygen Demand	mg/L	35	NA	22.00	5.49	24.9	19	2.37
Nov-21	285	Total Recoverable Oil and Grease	mg/L	5.6	NA	55.7	15.27	27.4	18	-4.84
		Total Recoverable Oil and Grease	mg/L	6.0	NA	89.15	30.73	34.5	17	-5.01
Feb-22	288	Chloride	mg/L	95.4	NA	90.0	2.82	3.1	27	1.92
		Chloride	mg/L	69.1	NA	62.4	4.84	7.8	26	1.39
May-22	292	Sulfate	mg/L	10	NA	10.20	0.46	4.5	26	-0.21
		Sulfate	mg/L	15.3	NA	15.9	0.37	2.3	26	-0.41
		Conductivity	µS/cm	802	NA	798	16.3	2.0	41	0.25
		Conductivity	µS/cm	216	NA	271	6.70	2.5	41	-8.24
		pH - potable	SU	6.71	NA	6.75	0.044	0.7	45	-0.90
		pH - potable	SU	7.15	NA	7.19	0.052	0.7	45	-0.77
		pH - standard	SU	7.51	NA	7.45	0.037	0.5	45	1.62
		Turbidity - potable	NTU	5.89	NA	5.275	0.95	18.1	26	0.65
		Turbidity - potable	NTU	6.44	NA	6.38	0.79	12.4	26	0.08
		Turbidity standard	NTU	9.79	NA	9.35	0.44	4.7	27	1.00
		Colour standard	Pt/Co	8.0	NA	12.0	3.0	24.7	17	-1.35
🟩	🟩	Within acceptable range of results								
🟧	🟧	Outlier – value lies outside acceptable range of results.								

MU - Measurement Uncertainty, NORM IQR - Normalized Interquartile Range, CV - Coefficient of Variation, Z - score - statistical measurement of a score's relationship to the mean.

Tissue Metals

The QA & QC samples for tissue metal, their purpose, collection frequency and performance criteria are shown in Table A-5. It should be noted that the acceptance criteria applied to field duplicate samples of ±44% aligns with the criteria applied by NMI to the internal lab samples, and when combined with the acceptance criteria applied to the field blanks, is considered acceptable for supporting a robust QA program.

Table A-5 QA & QC samples – tissue metals

QA&QC Sample	Purpose	Sample rate	Acceptance Criteria
Field reference sample (Fish flesh of known concentration)	Test for contamination during field work, sample preparation and transport. Test for accuracy of laboratory analytical method.	1 blank per sample batch (as per sampling monitoring schedule)	±44% of known concentration.
Field duplicate	Test repeatability of laboratory analytical method.	1 duplicate for every 8 samples (minimum 1 per batch)	±44% of primary sample
NMI blank	Test for contamination during sample analysis. Test for accuracy of laboratory analytical method.	1 blank per sample batch	≤LOR for each analyte
NMI duplicate	Test repeatability of laboratory analytical method.	Minimum 1 blank per sample batch	±44% of primary sample
NMI lab control sample	Test influence of sample preparation and analysis on recovery.	Minimum 1 blank per sample batch	75 – 120% recovery
NMI matrix spike	Test influence of sample preparation and analysis on recovery.	Minimum 1 blank per sample batch	75 – 120% recovery

The results of QA & QC samples from tissue metal sampling in 2021 and 2022 are shown in Table A-6 and indicate good performance for the majority of QA & QC samples across the majority of parameters. The exceptions are the performance of Arsenic and Cadmium in the field reference samples. An increased focus of compliance to SOPs and training and competency is expected to improve accuracy and will facilitate a more timely investigation of non-compliant QA & QC results.

Table A-6 2022 Tissue metal QA & QC sample results

	% Within Acceptable Criteria									
	n	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**
Field Duplicate	7	100	100	100	86	100	100	100	86	86
Field Reference Sample	7	50	50	86	100	86	100	100	100	86
NMI Duplicate	5	100	100	100	100	100	100	100	100	100
NMI Lab Control Sample	5	100	100	100	100	100	100	100	100	100
NMI Matrix Spike	5	100	100	100	100	100	100	100	100	100

Discussion

The QA & QC program is designed to provide accurate, representative and defendable results. It includes a training and competency program to ensure the correct procedures are defined and complied with, and it includes a sampling program to provide evidence to validate that the results are accurate and representative.

The results show that overall the QA & QC program provides a reasonable level of confidence that the results as reported are accurate and representative. A number of opportunities for improvement have been identified, and the review of SOPs, training and competency and timely investigation of poor QA & QC performance will be ongoing throughout 2022

APPENDIX B. BOX PLOTS EXPLAINED

Box plots are used throughout the AER to visually present a range of statistical information for a given dataset and to allow visual comparison of statistical information between a number of datasets.

The features of a boxplot are defined below and shown in Figure B-1.

Median: The median (middle quartile) marks the mid-point of the data and is shown by the line that divides the box into two parts. Half the values are greater than or equal to this value and half are less.

Inter-quartile range (IQR): The middle "box" represents the middle 50% of values for the dataset. The range of values from lower to upper quartile is referred to as the inter-quartile range. The middle 50% of values fall within the inter-quartile range.

Upper quartile: Seventy-five percent of the values within the dataset are lower than the upper quartile.

Lower quartile: Twenty-five percent of the values within the dataset are lower than the lower quartile.

Whiskers: The upper and lower whiskers represent scores outside the middle 50%. Whiskers often (but not always) stretch over a wider range of scores than the middle quartile groups.

Outlier: Values within the dataset that statistically do not fall within the IQR, outliers can be treated as a high or low value that is significantly different from the IQR of values within the dataset.

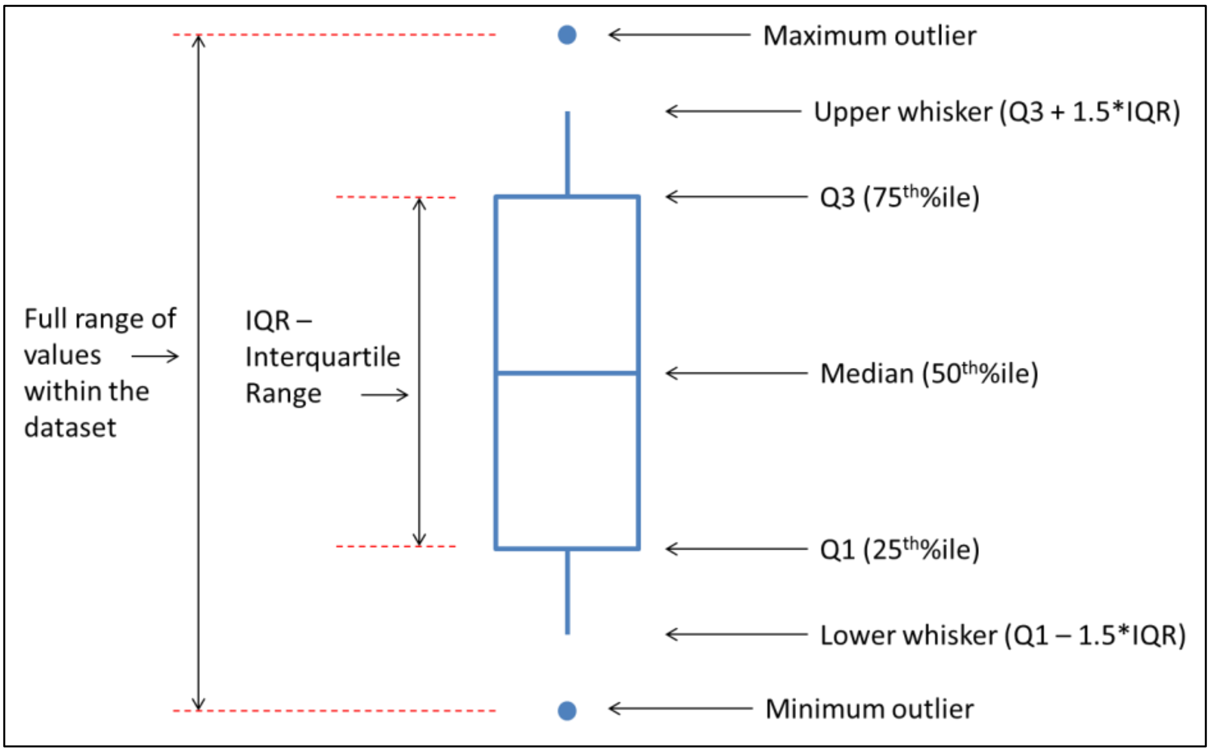

Figure B-1 Box Plot Explained

Interpreting box plots between two datasets and against a trigger value is shown in Figure B-2 and described below.

SITE A:

The median value for the indicator at Site A falls below the trigger value, as do all of the values, with the exception of an outlier. This indicates that the median is likely to be statistically significantly less than the trigger value, to be confirmed by Wilcoxon's test, and indicating low risk. The distance between the median and Q3 is the same as the distance between the median and Q1, indicating the data are normally distributed and therefore there are as many values between the median and Q3 as there are between the median and Q1.

SITE B:

The median value for the indicator at Site B falls below the trigger value, as do all of the values. This indicates that the median is likely to be statistically significantly less than the trigger value, to be confirmed by Wilcoxon's test, and indicating low risk. The distance between the median and Q3 is larger than that between the median and Q1, indicating the data are not normally distributed and skewed towards Q3, meaning more values were recorded between the median and Q3, than between the median and Q1.

COMPARING BETWEEN SITES:

The median and IQR at Site A are higher than Site B, indicating that values for the indicator are higher at Site A than at Site B for the particular dataset.

The IQR for Site A is larger than for Site B, indicating a wider range of values were recorded at Site A than at Site B for the particular dataset.

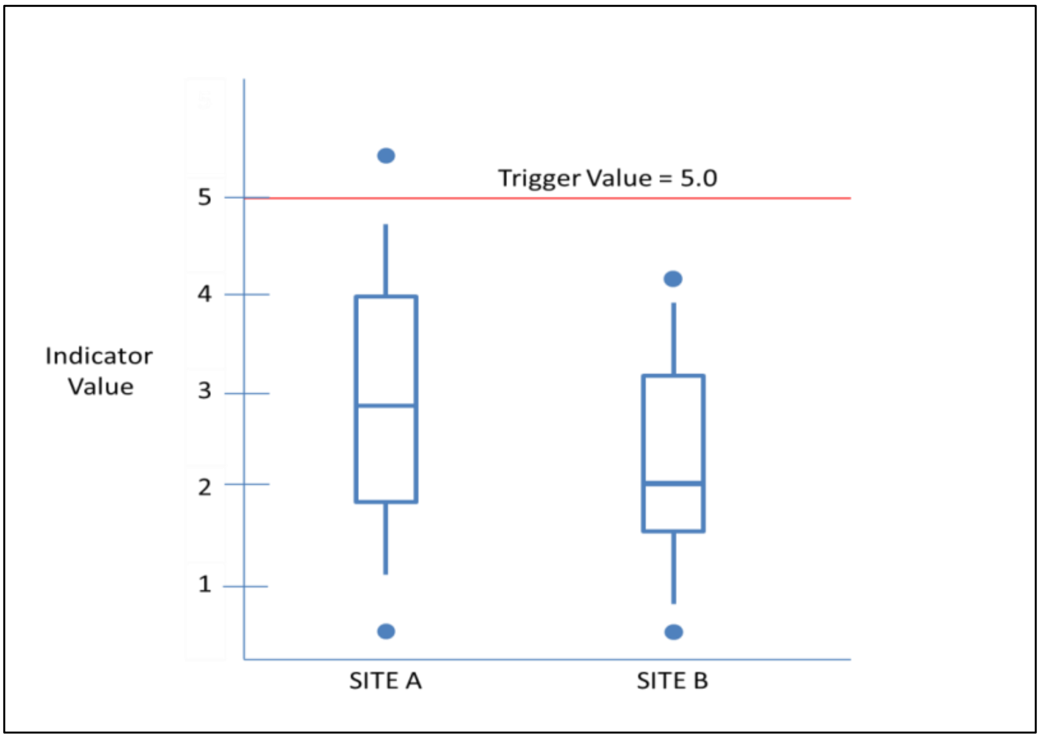

Figure B-1 Comparing box plots between sites and against trigger values