PORGERA
JOINT VENTURE

ANNUAL ENVIRONMENT REPORT 2019

ISO 14001 Certified Environmental Management System

ERMCVS
CERTIFIED
ENVIRONMENTAL
MANAGEMENT
SYSTEM

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MANAGEMENT
SYSTEMS
067

ISO 14001 Certificate 489

Barrick Niugini Limited - Porgera Joint Venture

June 2020

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PAPUA NEW GUINEA

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Cover Photo: Lake Murray 2019

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CSIRO

James Versluis
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Porgera Joint Venture
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26 June 2020

Dear James,

Re: Porgera Joint Venture 2019 Annual Environment Report

Dr Graeme Batley and Dr Simon Apte reviewed a draft of the 2019 Porgera Joint Venture Annual Environment Report (AER) and provided detailed comments for consideration. Overall, the draft report was found to be technically sound and of high 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 comprehensive technical report.

Sincerely

Dr Simon Apte
Senior Principal Research Scientist

Dr Graeme Batley
Chief Research Scientist

EXECUTIVE SUMMARY

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

The PJV is owned by Barrick Gold (47.5%), Zijin Mining (47.5%) and Mineral Resources Enga (5%) and managed by Barrick (Niugini) Limited (BNL). 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 2039, with an annual production of approximately 500 koz of gold. The site employs 3,500 local, national and expatriate staff and contractors.

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.

A fundamental element of the PJV 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.

Since 1995, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's preeminent scientific organisation, have provided independent oversight of the PJV environmental monitoring program. CSIRO's role includes undertaking a review of PJV's AER, routine quality assurance audits of the PJV 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 PJV's results. The last audit was completed in 2019 and found that CSIRO and PJV results are consistent, confirming the high technical standard and accuracy of PJV's environmental monitoring program.

The objectives of this Annual Environment Report (AER) are to provide an assessment of the overall environmental performance of the operation throughout the previous calendar year and to assess historical trends in performance. The objectives of this report are aligned with those of the EMS and are to assess:

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

The first section of the AER 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.

Mine Operations and Environmental Aspects

The significant environmental aspects of the operation are 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.

The physical footprint and the quantity of ore and gold production in 2019 were comparable with the previous five years. Water and energy efficiencies also were comparable with previous years.

Tailings volumes were consistent with previous years and a significant proportion (14% by volume) was diverted from riverine disposal and used for cemented backfill in the underground mine.

Total suspended sediment (TSS) concentrations in tailings were comparable to previous years. Total alkalinity, total silver, dissolved and total cadmium, total chromium and copper, dissolved iron, dissolved and total nickel and dissolved and total zinc in tailings showed increased trends over the preceding ten-year period (2010-2019), while concentrations of other metals either remained unchanged or decreased.

Contact rainfall runoff from the site was typical of neutral mine drainage and exhibited elevated TSS and concentrations of dissolved cadmium, chromium and zinc. The volumes of mine contact water generated in 2019 were comparable to previous years.

Background Environmental Conditions

The Porgera Valley and downstream catchments experienced average annual rainfall during 2019. This, consequently, resulted in slightly above average river flows throughout the upper river within the highlands and the lower river along the Strickland floodplain, and average rates of dilution of mine-related inputs within the receiving aquatic ecosystem.

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 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.

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 2019, including water quality at compliance point at SG3 on the Strickland River.

Environmental Risk, Impact and Performance

Methodology

The methodology for risk and impact assessment developed by PJV 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

The risk assessment concluded that elevated electrical conductivity (EC), dissolved cadmium, copper and lead in tailings and contact runoff from the competent waste rock dumps, open pit and underground mines, posed a potential risk to aquatic ecosystems in the upper river between the mine and Wankipe on the Lagaip River, 116 km downstream of the mine. There was low risk to aquatic ecosystems downstream of Wankipe in the upper river and in the lower river, ORWBs and Lake Murray.

The proportion of mine-derived sediment at SG3 in 2019 was estimated to be 19%, which was consistent with recent years and with the long-term median of approximately 23%. Sediment inputs to the system did not result in mine-related sediment aggradation within the rivers or an increase to the median concentration of TSS within the rivers, and therefore posed low risk to the condition of the receiving environment.

There was low risk posed to human health by the operation's activities. However, it should be noted people who illegally accessed the tailings stream within the Porgera Special Mining Lease boundary were exposed to concentrations of dissolved cadmium, nickel and zinc which exceed the ANZG (2018) guidelines for recreational water quality.

The environmental impact assessment showed that in 2019 there was moderate mine-related environmental impact within the Porgera and Lagaip Rivers between the mine and Wasiba, located on the Lagaip River 96 km downstream. Environmental impact was detected in the form of elevated EC and dissolved copper concentrations in water, elevated weak acid extractable (WAE) concentrations of lead and zinc in benthic sediment, elevated cadmium, copper and lead concentrations in prawn abdomen at Wasiba, and a decline in the abundance and biomass of the mountain tandan fish (*N.equinus*) at Wasiba, compared to the reference site Ok Om. There was no mine-related environmental impact downstream of Wasiba, within the upper river from Wasiba to SG3 and throughout the lower river, ORWBs and Lake Murray regions. A summary of compliance, human health risk and environmental impact at each test site in 2019 is presented in Table E-1.

It should be noted that the concentrations of metals in fish flesh and prawn abdomen at all sites were below international food standards, indicating that they are safe for human consumption.

Furthermore, the downstream extent of impact, at Wasiba located 96 km downstream from the mine, lies well within the permitted mixing zone, which extends to SG3 on the Strickland River, 164 km downstream of the mine. Additionally, 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.

Table E-1 Summary of Compliance, Human Health Risk and Environmental Impact at test sites in 2019

Region	Site	Distance From the Mine (km)	Overall Condition			Comments
			Compliance	Human Health Risk	Environmental Impact	
Upper River	SG2	42	Compliant	Low Risk	Moderate Env Impact	Located within the permitted mixing and compensation zone.
	Wasiba	96	Compliant	Low Risk	Moderate Env Impact	
	Wankipe	116	Compliant	Low Risk	No Impact	
	SG3	164	Compliant	Low Risk	No Impact	End of the permitted mixing and compensation zone
Lower River	Bebelubi	310	Compliant	Low Risk	No Impact	
	SG4	360	Compliant	Low Risk	No Impact	
	SG5	550	Compliant	Low Risk	No Impact	
ORWBs	Kukufionga	510	Compliant	Low Risk	No Impact	
	Zongamange	560	Compliant	Low Risk	No Impact	
	Avu	575	Compliant	Low Risk	No Impact	
	Levame	600	Compliant	Low Risk	No Impact	
Lake Murray	SG6	570	Compliant	Low Risk	No Impact	
	Miwa	590	Compliant	Low Risk	No Impact	
	Pangoa	600	Compliant	Low Risk	No Impact	

Recommendations for Improvement

The recommendations are intended to improve the assessment methodology, communication of the findings to the many stakeholders and to improve the environmental performance of the operation and reduce environmental risk and impact.

Note that a number of the recommendations from the 2018 AER are still in progress and appear in the list below in addition to new recommendations raised from this year's AER.

Assessment Methodology and Communication of Findings

1. Continue to investigate options for increasing 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 AER.

3. Develop a PJV 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 PJV. It may be appropriate to adopt the CSIRO procedure for routine analysis.

Reduce Environmental Risk and Impact and Improve Performance

7. Continue to investigate options for reducing the concentrations of bioavailable metals and mass loads of metals in mine discharges.
8. 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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List of Abbreviations & Definitions

AEM: Assured Environmental Monitoring

AER: Annual Environment Report.

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.

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

The PJV is owned by Barrick Gold (47.5%), Zijin Mining (47.5%), which together forms Barrick Niugini Limited (BNL) (95%), and Mineral Resources Enga (5%), the operation is managed by BNL. 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 2039 with an annual production of approximately 500 koz of gold. The site employs 3,400 local, national and expatriate staff and contractors.

Figure 1-1 Location of Porgera operation

PJV has a number of unique economic, social and environmental aspects. The environmental aspects are managed in accordance with the site's Environmental Management System (EMS), which is certified to the ISO14001 international standard for EMS. The objectives of the EMS are to ensure methodical, consistent and effective control of the site's environmental aspects so as to ensure compliance with legal and other requirements, to mitigate potential environmental risks and to continually improve environmental performance.

A fundamental element of the EMS is the environmental monitoring and reporting program. The program provides feedback on the effectiveness of the EMS for achieving the stated objectives and therefore allows the operation to confirm which management techniques are working well, and more importantly, identify those which require attention to improve effectiveness.

The objectives of this Annual Environment Report (AER) are to provide an assessment of the overall environmental performance of the operation throughout the previous calendar year (2019), and to assess trends in historical performance. The objectives of this report are aligned with those of the EMS and are to assess:

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The first section of the AER describes background environmental conditions by quantifying the natural, non-mine related conditions and changes within the receiving 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.

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). 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 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.

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 – Present	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.

1.1.2 Mining operations overview

PJV mining operations consist of open cut and underground operations. Open pit mining is a hard rock operation developed using drill and blast, load and haul techniques. The design utilises 10 m benches, hydraulic face shovels and haul trucks to achieve a nominal material movement capacity in the order of 50 million tonnes per annum.

A particularly challenging aspect to development of the open pit is the inherent instability of the western wall as a result of the presence of brown mudstone and inflow of water to the pit from surrounding catchments. Although mining continues despite the ingress of mud, the on-going wall failure does pose a risk to workers' safety, equipment and inhibits access to and dilutes ore at the bottom of the open pit. A number of mitigation and stabilisation measures, known collectively as the west wall cutback, are being implemented to stabilise the west wall and prevent the ingress of mud and water to the pit. High grade ore is transported to the crusher and low-grade ore is transported to stockpiles for processing at a later date. Waste rock is classified into three categories, potential acid-forming (PAF), non-acid forming metal leaching (NAF-ML) and non-acid forming (NAF). Waste rock is managed to encapsulate the PAF waste and minimise the generation of metalliferous drainage from the waste rock dumps.

An underground mine was first operated from 1989 to 1997. The underground mining operation was recommenced in 2002 to extract underground reserves in the central and north zones. The original underground workings were subsequently maintained and developed to provide long-term drainage for the open pit, and to provide access for on-going exploration.

The underground mine is accessed by a portal adjacent to the open pit which facilitates mining of ore both from outside and beneath the open pit footprint. The underground mining method used is long-hole bench stoping. Ore is recovered by drilling and blasting while retreating along the strike for the full length of the stope. The broken ore is progressively mucked to trucks on the lower level using a combination of conventional, remote and tele-remote-control loader operations. Longer stopes are filled in stages with a combination of cemented and non-cemented fills to maintain hanging wall spans.

After mining, open stopes in strategic places are filled with unconsolidated waste rock and cement aggregate and a cement-tailings aggregate, produced from the paste plant, to create crown pillars. The underground mine generates approximately 1.2 million tonnes of ore per annum. Ore is transported to the crusher, while the majority of waste rock produced from the underground mine is used as backfill to support underground development, the small quantity of waste rock that is brought to the surface is stored in one of the competent waste rock dumps with waste from the open pit.

1.1.3 Processing operations overview

A flow sheet describing the ore processing operations is shown in Figure 1-2 and begins with run-of-mine ore being delivered by trucks to the crushing and grinding circuit, consisting of a gyratory rock crusher, secondary crusher and two SAG mills.

The SAG mills feed three cyclone packs, a portion of the underflow is sent to four Knelson concentrators to recover free gold, the Knelson concentrate is transferred to an Acacia reactor, an intensive leach reactor located in the gold room at Anawe. The remaining underflow is returned to the ball mills for re-grinding.

Overflow from the cyclone packs contains gold bound to sulfide which is not recoverable by gravity separation. This slurry is transferred via gravity to the Anawe plant site via twin 2 km long pipelines for further processing by flotation concentration, oxidation, Carbon In Pulp / Carbon In Leach (CIP/CIL), electrowinning and smelting.

The flotation circuit consists of rougher, cleaner, and scavenger banks producing a final concentrate of 14% sulfur and tailings. The flotation concentrate is combined with the Acacia reactor tailings and the mixture is reground to 92% passing 38 µm, pumped to a 35m diameter concentrate thickener and then to the concentrate storage tanks that provide approximately six days' worth of production buffer storage between flotation and the oxidation sections. The flotation tailings are sent to the tailings treatment circuit.

The oxidised concentrate is discharged from the autoclaves via a choke valve into a flash vessel that is equipped with a gas scrubber to control acidic emissions. The sulfuric acid produced in the autoclaves is washed from the oxidised concentrate via two wash thickeners, and the washed and thickened solids are pumped to the CIL circuit. The acidic wash water overflow from the thickener is sent to the tailings treatment circuit. In the CIL circuit activated carbon, slaked lime and sodium cyanide are added to facilitate a process known as cyanidation which results in the formation of gold cyanide complexes which are then adsorbed to the activated carbon. The concentrate is then transferred to the CIP circuit where excess activated carbon is added to adsorb any remaining gold cyanide complexes in the solution.

Next the concentrate is transferred to the elution circuit where the precious metals are stripped from the carbon. After stripping, the barren carbon is regenerated in a rotary kiln and then acid-washed prior to being returned to the CIP circuit. Gold and silver contained in the stripped solution are electro-won in three banks of electrowinning cells which produce concentrated, high density sludge. At regular intervals the sludge is washed from the cells, pressure filtered and retorted to remove any mercury. The residue containing gold and silver is mixed with a flux of borax, soda ash, nitre, and silica, and smelted in an induction furnace to produce bars of doré bullion that average about 80% gold. The mercury is condensed and disposed of to a licensed facility overseas. The CIP/CIL tailings are sent to the tailings treatment circuit.

Ore processing generates three effluent streams: flotation tailings from the flotation concentrator, acid wash from the wash thickeners downstream of the autoclaves, and CIP/CIL tailings from the cyanidation leach circuit. Treatment involves cyanide destruction and then neutralisation to reduce metal toxicity.

The CIP/CIL tailing is the only stream that contains cyanide, therefore these tails are sent to the cyanide destruction plant prior to being mixed with the other tailings streams for neutralisation. The cyanide destruction plant employs the International Nickel Companies (INCO) sulfur dioxide/air technology, which requires the addition of sodium metabisulfite, lime and copper sulfate and oxidises the cyanide to form less toxic cyanates. The concentration of cyanide is reduced from 80 – 100mg/L WAD-CN in the feed to <0.2 mg/L WAD-CN in the discharge. The detoxified CIP/CIL tailing is then sent to the tailings neutralisation circuit for further treatment.

Acid wash-water and flotation tailings do not contain cyanide and so are sent directly to the tailings neutralisation circuit. Here they are combined with the CIP/CIL tails and residual naturally occurring carbonates in the flotation tailings neutralise part of the acid and raise the pH of the tailings mixture to approximately 3.5. Slaked lime then is added to raise the pH and precipitate metals as hydroxides prior to discharge to the Porgera River. The target pH range for discharge is pH 6.3 – 9.5.

A portion (nominally 13%) of the treated tailings is diverted to the paste plant where it is filtered in rotary disc filters, mixed with cement and plasticiser then pumped via a steel pipeline into the underground mine to backfill mined stopes.

Lime for neutralisation purposes is produced from limestone quarried from a deposit 15km south of the mine. The limestone is processed in two vertical kilns which use either waste oil or diesel as fuel. Quicklime is stored in a silo and trucked to the Anawe plant site and transferred into one of two lime silos. The quicklime is slaked in a lime mill and stored in an agitated tank.

The pyrite concentrate plant is fed by a small portion of the high sulfur grade flotation concentrate from the first bank of flotation rougher cells and is pumped to the slurry filtration plant. The slurry is passed through a cyclone to remove fines which are returned to the concentrator for re-grinding and processing through the autoclaves. The coarse fraction from the cyclone is dewatered using a filter press and is then loaded into lined sea containers for export. The sea containers of pyrite concentrate are back-loaded onto trucks and transported by road to Lae Port for export to a refinery overseas.

Most of the water for the process plant is supplied by pipeline from the Waile Creek dam 20km south of the mine site and Aipulungu Creek located upstream of the Lime Plant. Additional water is delivered to the Tawisakale grinding circuit from the nearby Kogai Creek and FT07.

Electrical power is generated at Hides, 73 km south of the mine site using 9 gas turbines having a combined capacity of 72 MW and delivered to site via a 132 kV transmission line. This is supplemented by a 20 MW and 12 MW diesel power stations at the mine site.

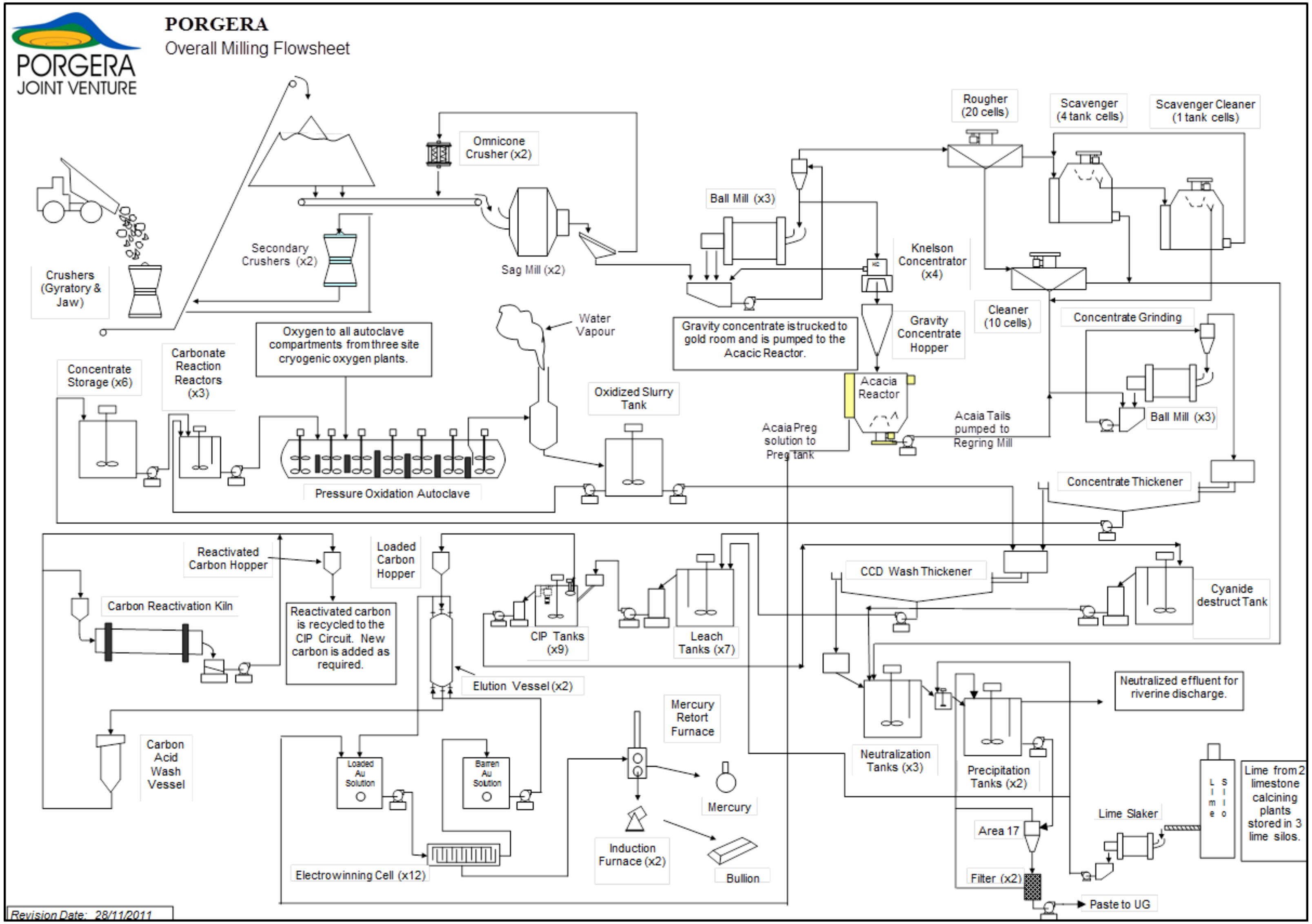


Figure 1-2 Process flow chart

2 AER METHODOLOGY

The PJV AER uses a risk-based framework for assessing the environmental compliance, risk, impact and performance of the Porgera mine operations. The report is structured in accordance with the following framework:

1. Identify the environmental aspects of the operation (Section 3.1).
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 5).
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 function based on the relationships between chemical, physical and biological functions within the environment.

Risk assessment based on physical and chemical parameters alone is typically less complicated, less time consuming and less costly 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 Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) nominate the following order of preference when establishing guideline TVs for physical and chemical indicators.

2.2.1 TVs derived from ecological effects data

For low-risk TVs, 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. This is defined the TV as 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. PJV 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 5. 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 current PJV 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.

Identification of PJV reference sites and an assessment of their suitability are presented in Table 3-3 and Table 3-4 respectively. A comparison of baseline and reference data is presented in Section 5. The assessment shows that the suitability of PJV 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. 80^{th}%ile or 20^{th}%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), being the test site median (TSM), with the TV. Statistically, the median represents the most robust descriptor of the test site data.

Inherent in the use of 80th%ile or 20th%ile values is the fact that monitoring data may 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. PJV has adopted Wilcoxon's test, a non-parametric rank 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 the AER is provided in Section 2.7.

2.2.3 Adopting TVs provided by guidelines

For physico-chemical stressors where ecological effects data, baseline data and reference site data are unavailable or unsuitable, and for toxicants, 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 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) are site specific and 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)*
Aquatic recreation	Water quality	ANZG (2018) Guidelines for recreational water quality and aesthetics WHO Drinking Water Guidelines *(2017)*

Risk	Indicator	Guideline
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)
Air quality	Emission quality	NSW Protection of the Environment Operations (Clean Air) Regulation 2010 (NSW 2010) Victoria State Environment Protection Policy (Air Quality Management) 2001 (VIC 2001)

2.2.4 Establishing locally-derived TVs by comparing baseline and reference site data with guidelines and adopting the most relevant

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 mine and non-mine related risk.

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 monthly data collected at the test site over the previous year (12 months) 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, PJV 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 metal are shown in Section 5.

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 clean 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 conservative 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 5.

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)

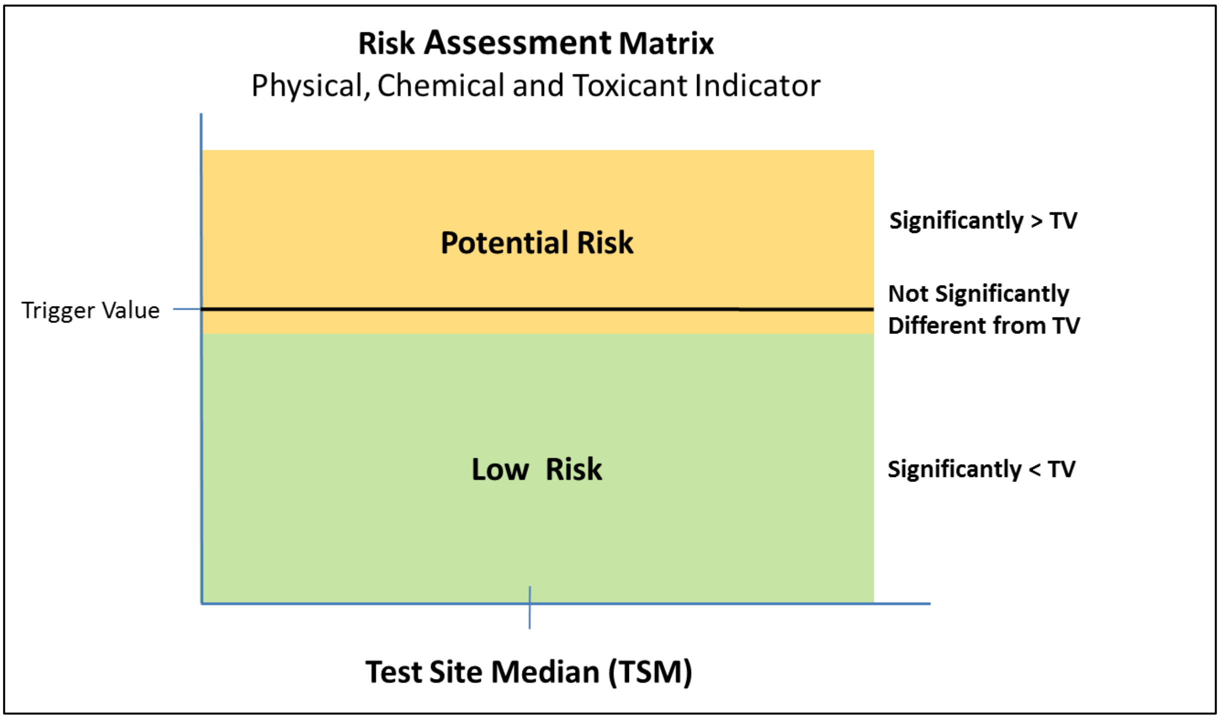


Figure 2-1 Risk assessment matrix – physical, chemical and toxicant indicators in water

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 80th% and 20th%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 80th% and 20th%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 5.

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 5.

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 80th%ile (full data set) - Regional reference 80th%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 20th%ile (full data set) - Regional reference 20th%ile (most recent 24 months data set), or - ANZG (2018) lower limit for upland rivers in tropical Australia

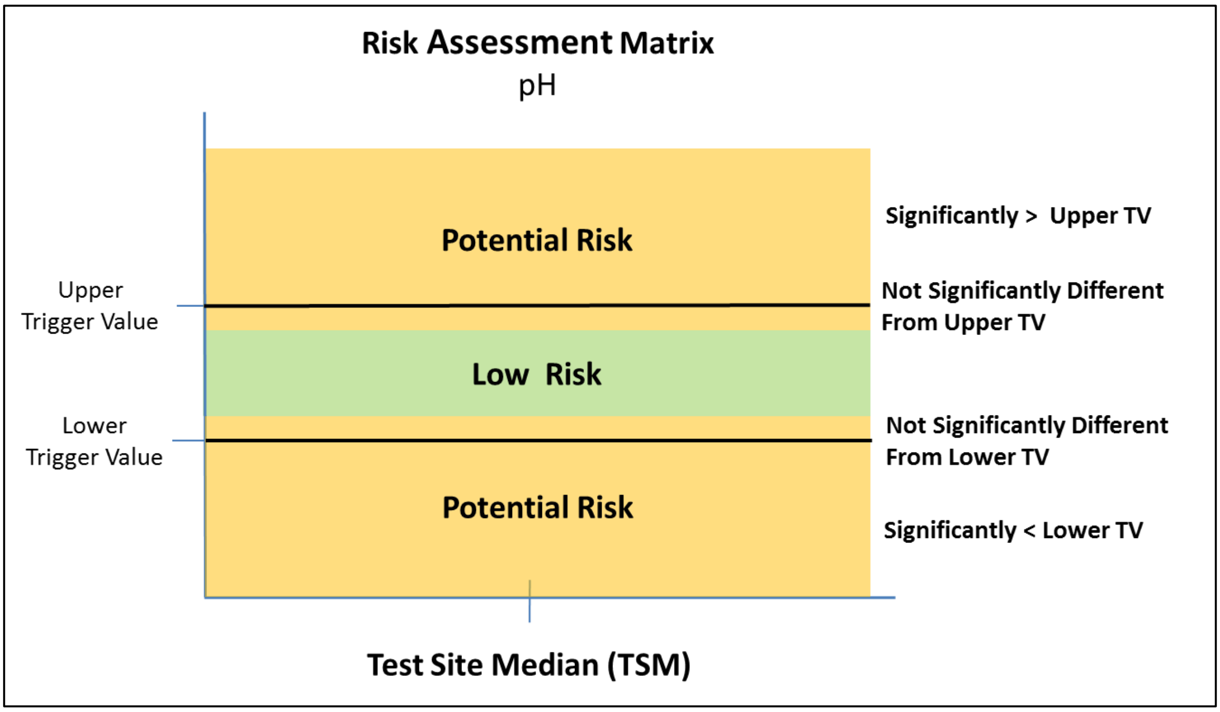


Figure 2-2 Risk assessment matrix – pH in water

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		
TSM significantly < Upper TV	Low Risk	
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 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)

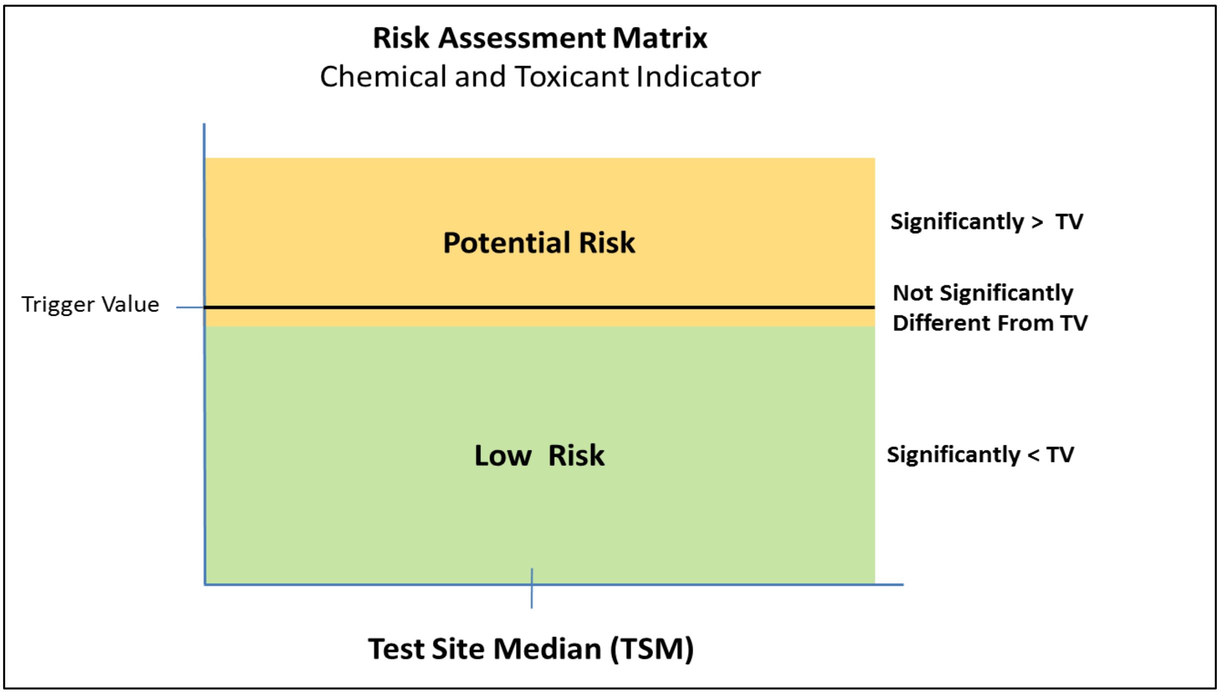


Figure 2-3 Risk assessment matrix – chemical and toxicant indicators in benthic sediment

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 conservative 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)

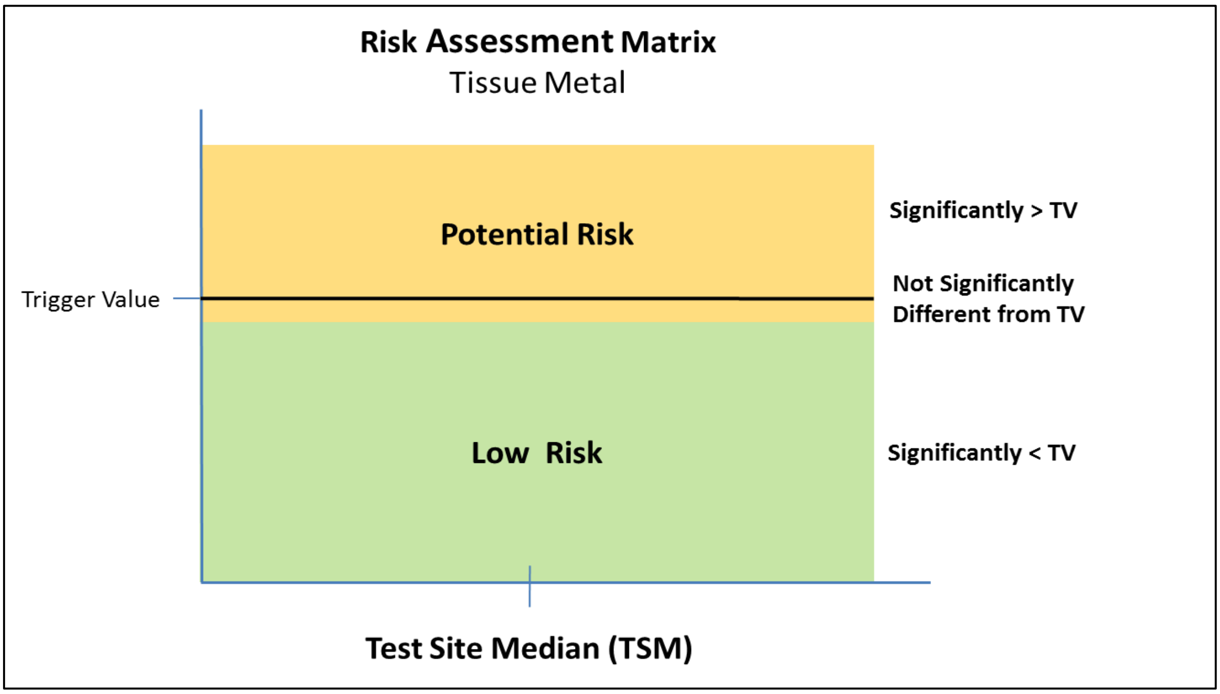


Figure 2-4 Risk assessment matrix – tissue metal concentrations

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 Drinking Water, Aquatic Recreation, Fish and Prawn Consumption, Air Quality

PJV has adopted the WHO Drinking Water Guidelines (WHO 2017) as the default risk assessment TVs for drinking water quality. The risk assessment is based on the comparison of guideline values with results of water quality sampling conducted at village water supplies around the special mining lease (SML). The results of the drinking water risk assessment are presented in Section 7.5.

Water-based activities involve contact with water, and in PJV'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. PJV 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 7.6.

Human consumption of fish and prawns has the potential to transfer toxicants from the flesh of the animal to humans. The PJV 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 7.7.

PNG has not enacted air quality legislation therefore PJV has adopted the NSW Protection of the Environment Operations (Clean Air) Regulation 2010 (NSW 2010) and the Victoria State Environment Protection Policy (Air Quality Management) 2001 (VIC 2001) as risk assessment TVs for emissions from stationary sources. The results of the air quality risk assessment are presented in Section 7.8.

A summary of guideline trigger values adopted for drinking water, water-based activities, fish and prawn consumption and air emissions 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	WHO Drinking Water Guidelines (2017)
Water-based activities: Water quality – receiving environment TSM	ANZG (2018) Guidelines for recreational water quality and aesthetics (Chapter 5) WHO Drinking Water Guidelines (2017)
Fish and prawn consumption: Tissue metals – fish and prawns TSM	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)
Air quality: Emissions at point source	NSW Protection of the Environment Operations (Clean Air) Regulation 2010 (NSW 2010) Victoria State Environment Protection Policy (Air Quality Management) 2001 (VIC 2001)

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

Risk	Assessment Result	Risk Rating	Action
Drinking water	TSM > WHO Drinking Water Guidelines	Potential risk	Conduct health risk assessment
	TSM ≤ WHO Drinking Water Guidelines	Low	NIL
Water-based activities	TSM > Recreation TV	Potential risk	Conduct health risk assessment
	TSM ≤ Recreation TV	Low	NIL
Fish and prawn consumption	TSM > Consumption TV	Potential risk	Conduct health risk assessment
	TSM ≤ Consumption TV	Low	NIL
Air quality – at emission point	TSM > Air Quality Guidelines	Potential risk	Monitor ambient air quality at sensitive receptor
	TSM ≤ Air Quality Guidelines	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, PJV 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 PJV monitoring program monitors fish and prawns on an annual basis using quarterly sampling, and macroinvertebrates on a two-yearly campaign basis.

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 previous years’ AERs, PJV has 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 PJV to reach accurate conclusions on ecological impacts, and thereby provide more confidence in the biology impact assessment within the AER. This work was completed and this new method of impact assessment is used in this AER and is referenced as WRM (2017).

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, PJV 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 current review is to enable PJV to reach accurate conclusions on ecological impacts, and thereby provide more confidence in the Biology Impact Assessment within the Annual Environmental Report (AER).

WRM (2018) found that the reference sites and test sites used in the PJV 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, represented by the 2019 mean of each indicator, could be compared, and to support a determination of whether impact had occurred. 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. 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 protective enough.

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 2017)

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 from 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 previous 24 months 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 previous 24 months (i.e. 2018 – 2019) data from Baia was also used. (WRM 2017)

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. 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 from upper river reference site Ok Om.
			N.equinus abundance *N.equinus* biomass	**Ok Om Reference** - Average of the most recent 24-months 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 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
	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
			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
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
	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

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 statistical significance at the risk assessment stage is 1-Sample Wilcoxon test with a probability threshold of $p = 0.05$. The Wilcoxon test is a non-parametric statistical hypothesis test used to determine if there is a significant difference between the test site median and the trigger value.

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 THE ENVIRONMENTAL MONITORING PROGRAM

The environmental monitoring program consists of sampling and measurement of physical, chemical and biological variables to quantify the operations environmental aspects and assess compliance, risk and impact. The monitoring program is detailed in the Porgera Environmental Monitoring, Auditing and Reporting Plan (ENV-SIT-STD-002) and associated Standard Operating Procedures. The spatial scope of the monitoring program is extensive, spanning from the mine site to SG5 on the lower Strickland River, approximately 560 river kilometres downstream from the mine.

Many of the monitoring locations are in remote areas and require the use of helicopters and boats to gain access. So while all efforts are taken to conduct the monitoring program to schedule, potential safety issues will sometimes prevent sampling from being undertaken, such as severe flooding, unsafe access, social unrest, or threats against PJV employees.

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 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
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

Environmental Aspect	Physical Parameters	Chemical & Toxicant Parameters	Biological Parameters
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 3-2 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 3-2 Receiving environment monitoring indicator parameters

Environmental Aspect	Physical	Chemical & Toxicant	Biological
Riverine tailings disposal	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
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 3-3. 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 3-4 gives an assessment of reference site suitability.

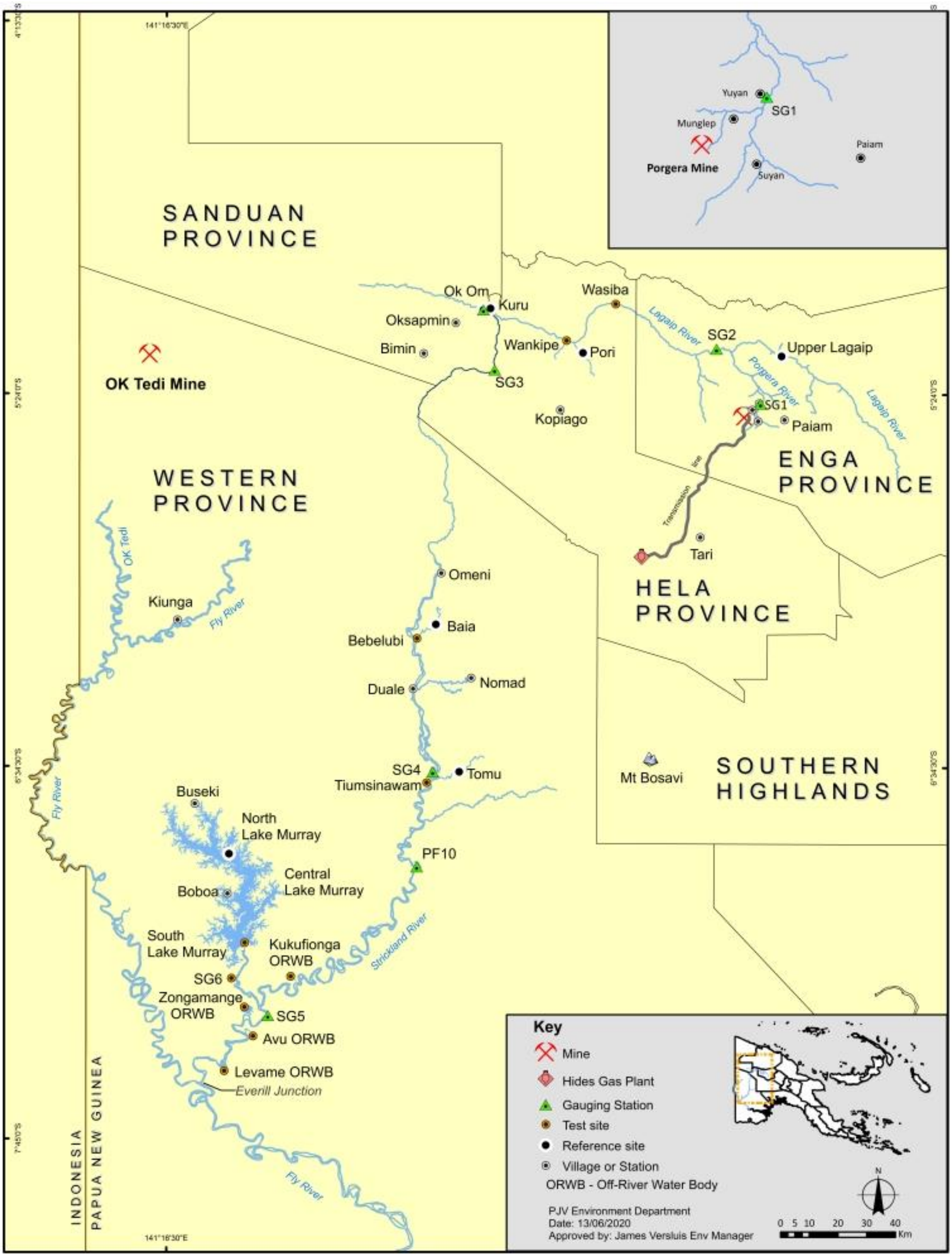


Figure 3-1 Receiving environment monitoring sites

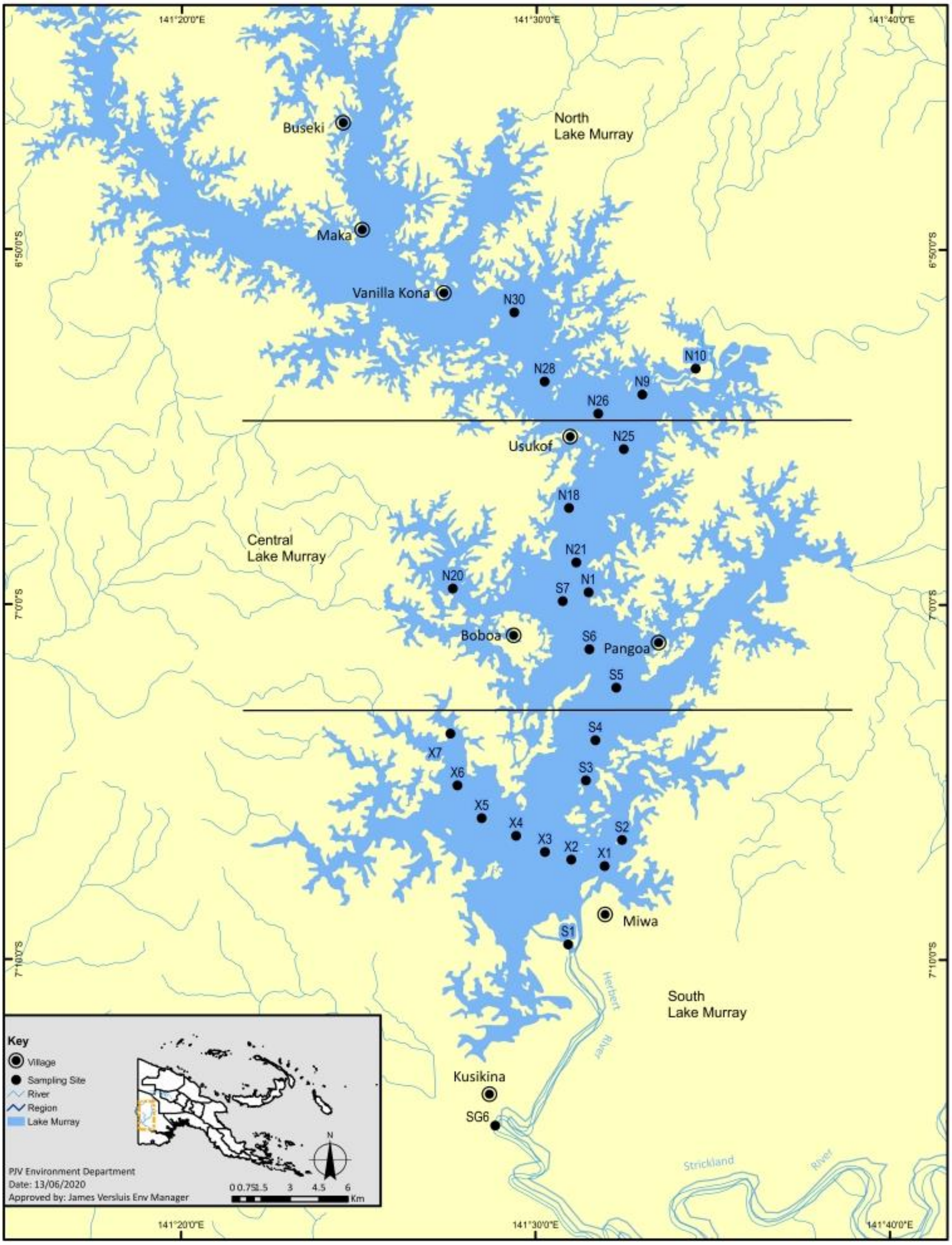


Figure 3-2 Lake Murray monitoring locations

Table 3-3 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]
Drinking Water	Villages surrounding Porgera Mine	NA[1]	NA[2]	NA[1]	NA[1]	NA[1]
Air Quality	Hides Power Station boundary Villages surrounding Porgera Mine	NA[1]	NA[2]	NA[1]	NA[1]	NA[1]

NAR – No appropriate reference site

NA[1] – Indicator not applied at monitoring site

NA[2] – Indicator at test sites compared against values derived from standards or guidelines not reference sites

Table 3-4 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

3.3.4 Schedule and execution

Compliance with the monitoring plan is summarised in Table 3-5, overall the monitoring schedule was executed to plan, with some exceptions due to access, safety and equipment damage. Compliance was measured by calculating the percentage of actual monitoring conducted against plan.

Table 3-5 Monitoring compliance to plan in 2019

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

3.3.5 QA & QC

PJV incorporates 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, 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
- Engaging CSIRO to perform external audits of the monitoring program and lab operations.

Some of the results from proficiency testing (PTA) samples fell outside the acceptable range, PJV 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 2021.

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

4 OPERATIONS AND ENVIRONMENTAL ASPECTS

This section provides a summary of key operational parameters and environmental aspects for 2019 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 2019

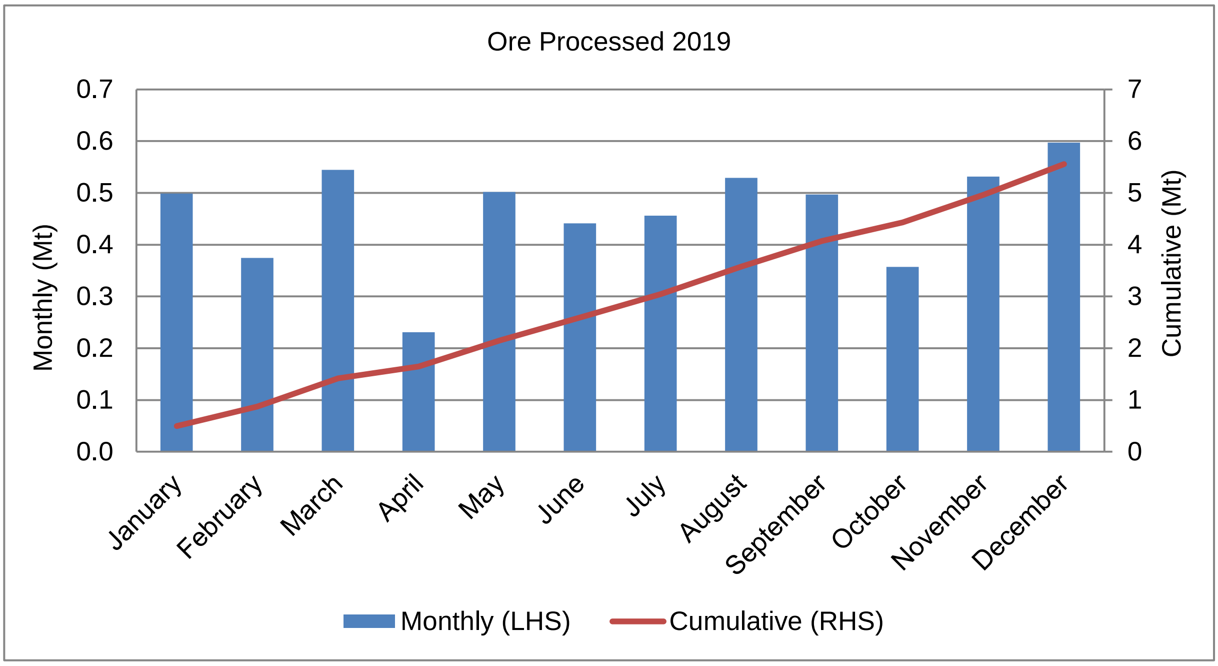
Operational and Environmental Aspects	2019	Life of Mine Total	Comments
Ore processed (Mt)	5.6	141.07	Above 2019 target.
Gold production (oz)	591,655	21,223,355	Above 2019 guidance.
Competent waste rock produced (Mt)	7.66	440.88	Consistent with previous years.
Incompetent waste rock produced – Anawe (Mt)	2.3	239.86	Consistent with previous years.
Incompetent waste rock produced – Anjolek (Mt)	10.7	252.45	Consistent with previous years.
Tailings to underground paste (% total tailings volume)	14	NA	On target.
Tailings discharged (Mt)	5.1	136.36	Consistent with previous years.
Total sediment discharged to river (Mt) (from tailings and erodible dumps)	14.4	NA	Consistent with previous years.
Sewage discharge (m^3)	226,349	NA	Consistent with previous years.
Mine contact rainfall runoff (Mm^3)	34.93	NA	Consistent with previous years.
Greenhouse gas and energy efficiency (kgCO2-e/t processed ore)	84	NA	1% increased emission rate compared to 2018, but downward trend maintained
Water use and efficiency (L/t processed ore)	5, 326	NA	8.6 % increase consumption compared to 2018
Area land disturbed (ha)	22	2,393	61% of total leased area is disturbed.
Area of disturbed land under rehab (ha)	0	240	10% of total disturbed land.

4.1 Production

4.1.1 Mining and processing operations

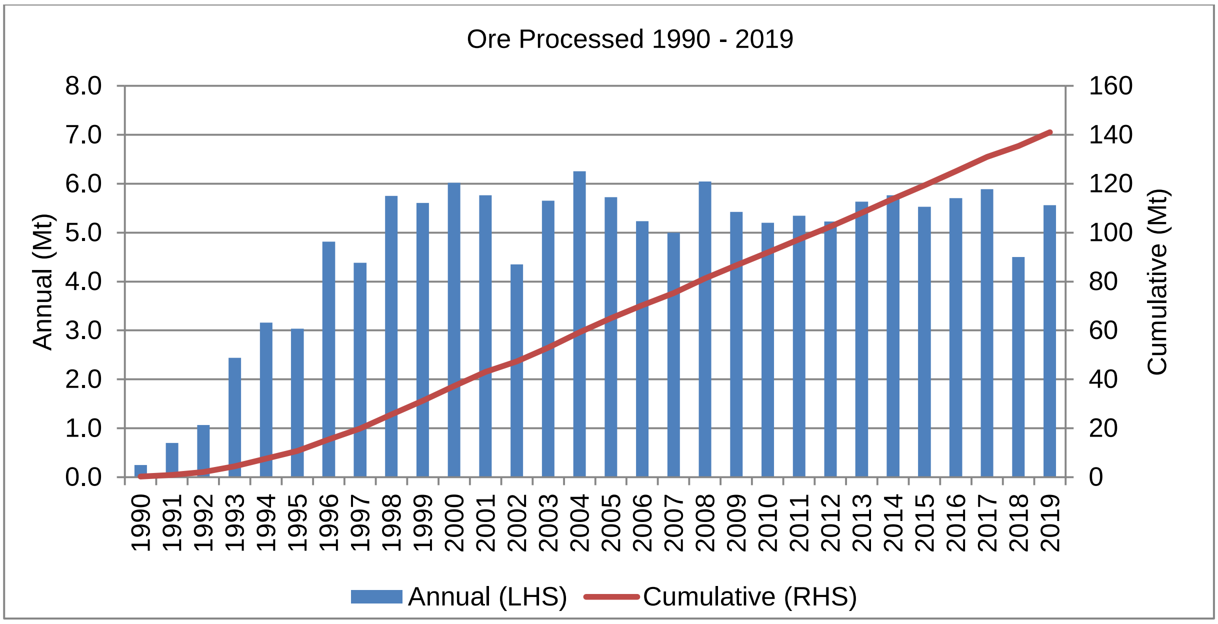
4.1.1.1 Total ore processed

The total quantity of ore processed in 2019 was 5.6 million tonnes (Mt). Figure 4-1 shows the monthly and cumulative quantities of ore processed in 2019. The cumulative quantity of ore processed from 1990 to 2019 was 141Mt and is shown in Figure 4-2.



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

Figure 4-1 Monthly and cumulative ore processed in 2019

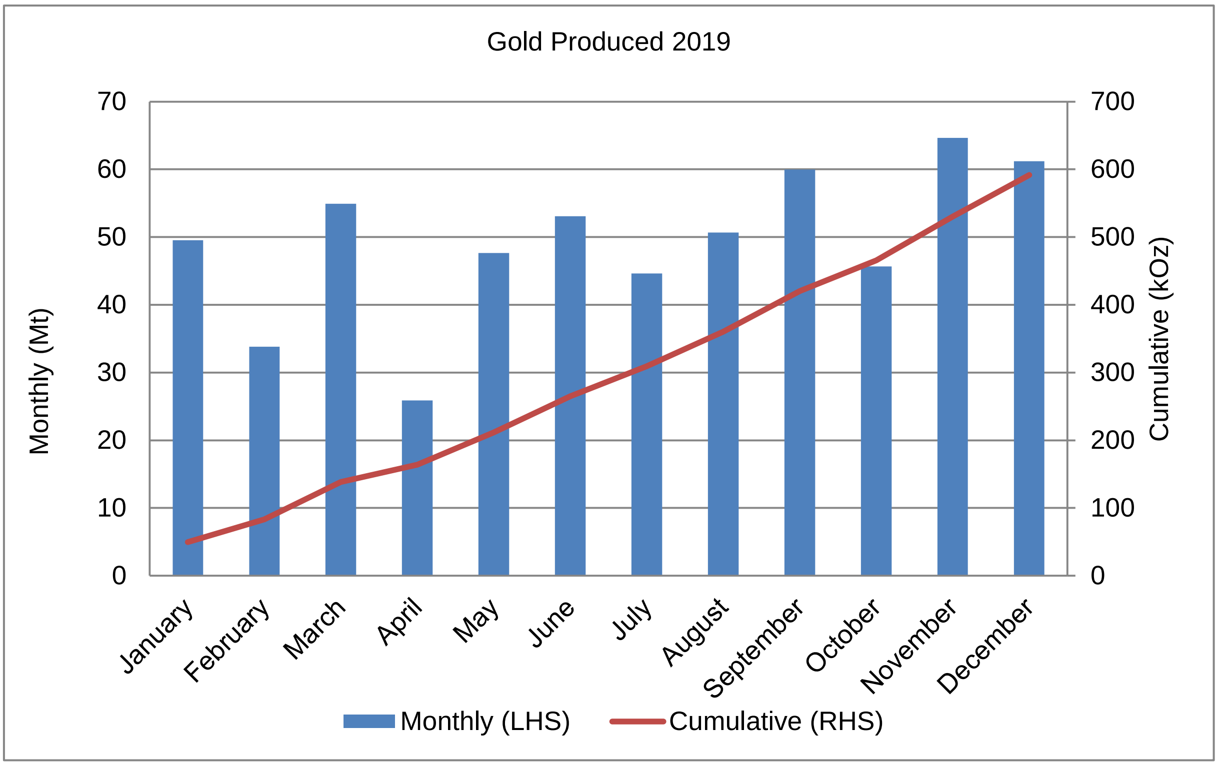


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-2 Yearly and cumulative ore processed 1990 - 2019

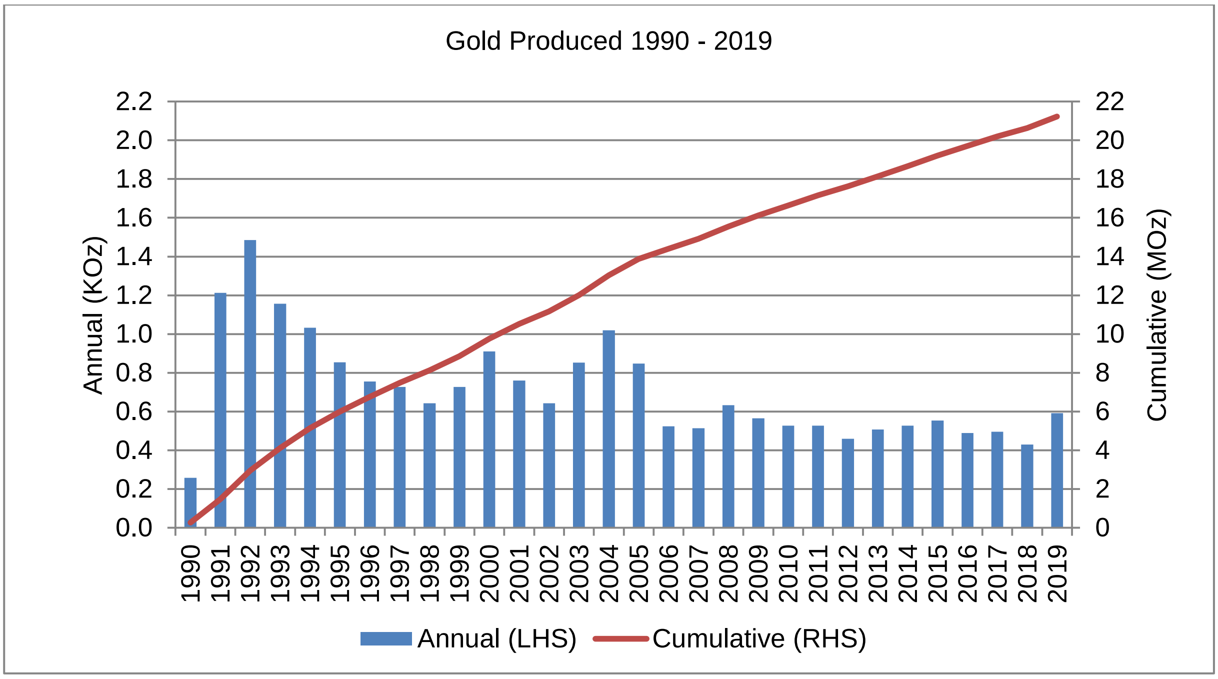
4.1.1.2 Gold production

Total gold production in 2019 was 592 koz. Figure 4-3 shows monthly and cumulative gold production during 2019. Total gold production from 1990 to 2019 was 21.2 million ounces. Figure 4-4 shows annual and cumulative gold production since operations began in 1990.



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

Figure 4-3 Monthly and cumulative gold production in 2019



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

Figure 4-4 Yearly and cumulative gold production 1990 – 2019

4.2 Water Use

Figure 4-5 shows water use efficiency between 2009 and 2019. Water use efficiency in 2019 was slightly higher than previous years, however the overall trend remains in a downward direction.

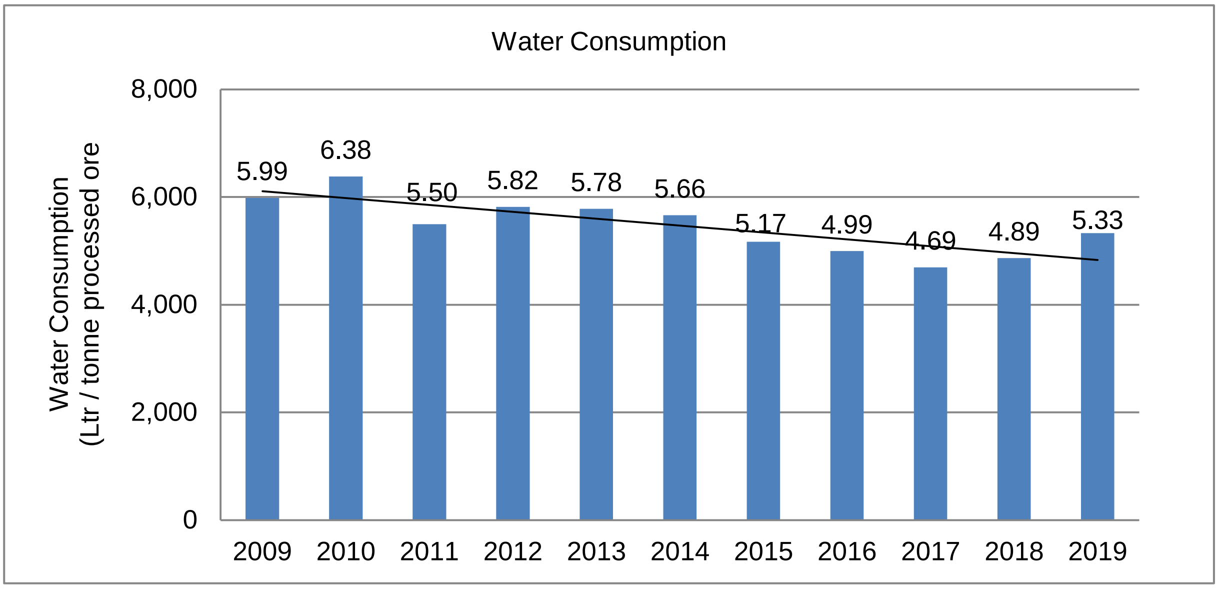


Figure 4-5 Water use efficiency 2009 - 2019

4.3 Land Disturbance

Porgera mine holds ten leases with a total area of 3,933ha as shown in Table 4-2 and Figure 4-6. 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 total area disturbed by mining and related activities as at 31 December 2019 was 2,393 ha, equating to 61% of the total leased areas. The total area of disturbance increased by 22 ha during 2019, comprising; 0.8 ha due to expansion of the erodible dumps, 16 ha due to expansion of the Kogai competent dump, 5ha due to construction of new Anjolek North dump at the Open Pit and 0.2 ha due to expansion of the Pangalita limestone quarry.

Table 4-2 Areas of cumulative land disturbance and reclamation to December 2019

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
Pangalita LMP	135	67	67.7	0

Lease	Total Lease Area (ha)	Total Disturbed Area (ha)	Undisturbed (ha)	Under Progressive Reclamation (ha)
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)**

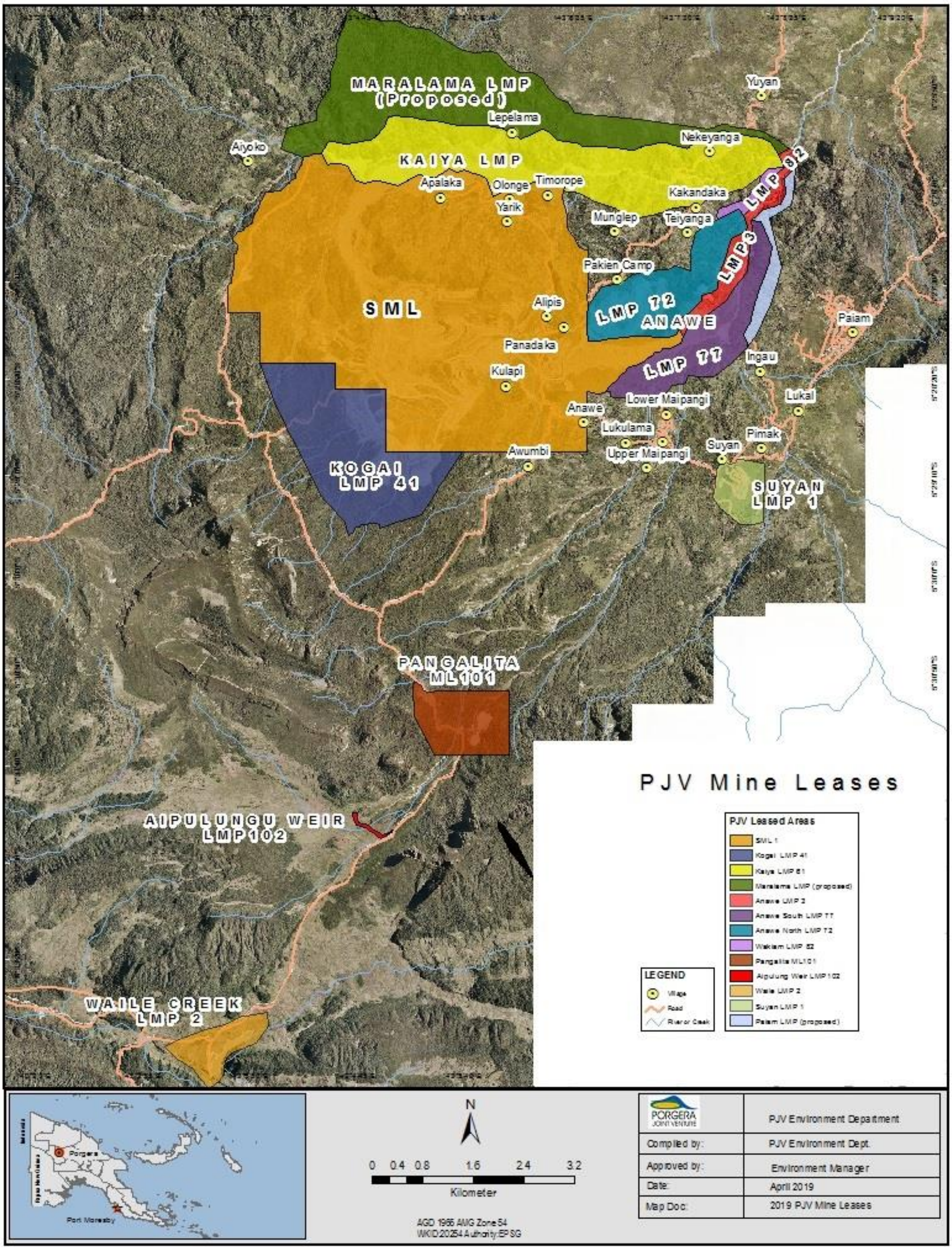


Figure 4-6 Boundaries of special mining lease and other leases for mining purposes

4.4 Waste Rock Production

The mine generates 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.

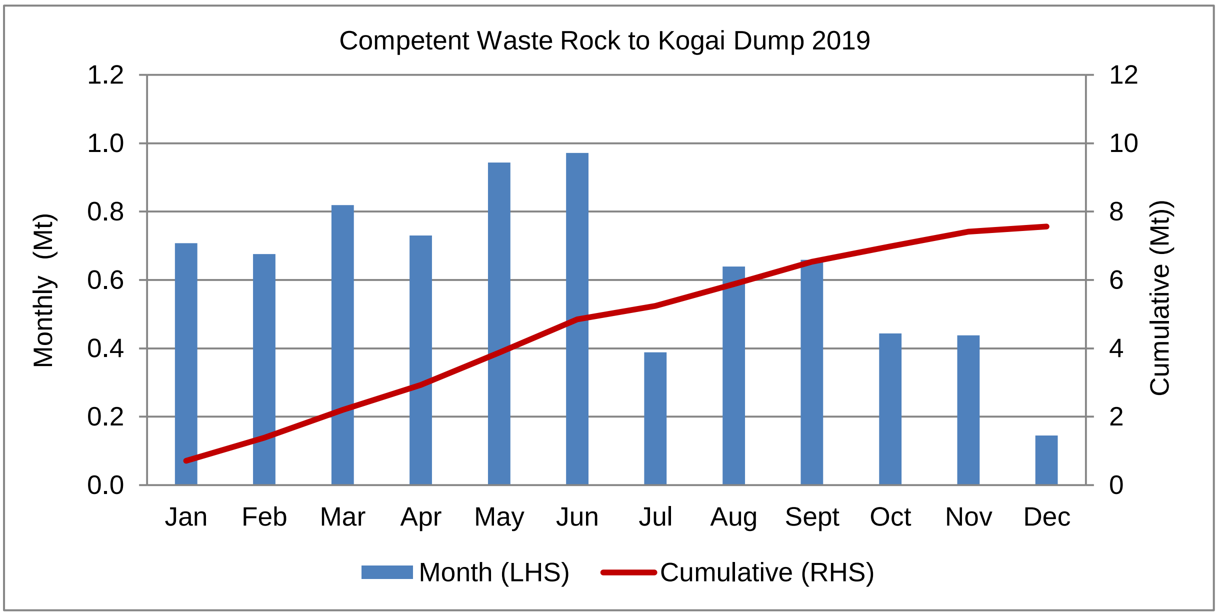
The mass of competent and incompetent waste rock mined between 1989 and 2019 and the corresponding disposal locations are presented in Table 4-3. The data show that to date, the quantity of competent waste rock placed at Kogai dump is approximately twice the total amount placed at Anawe North competent 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 – 2019

Waste Dump	Total Quantity (Mt)
Anawe North Competent	134.5
Kogai Competent	306.4
Competent Sub-Total	**440.9**
Anawe Erodible	239.9
Anjolek Erodible	252.5
Erodible Sub-Total	**492.4**
TOTAL	**933.3**

4.4.1 Kogai competent dump

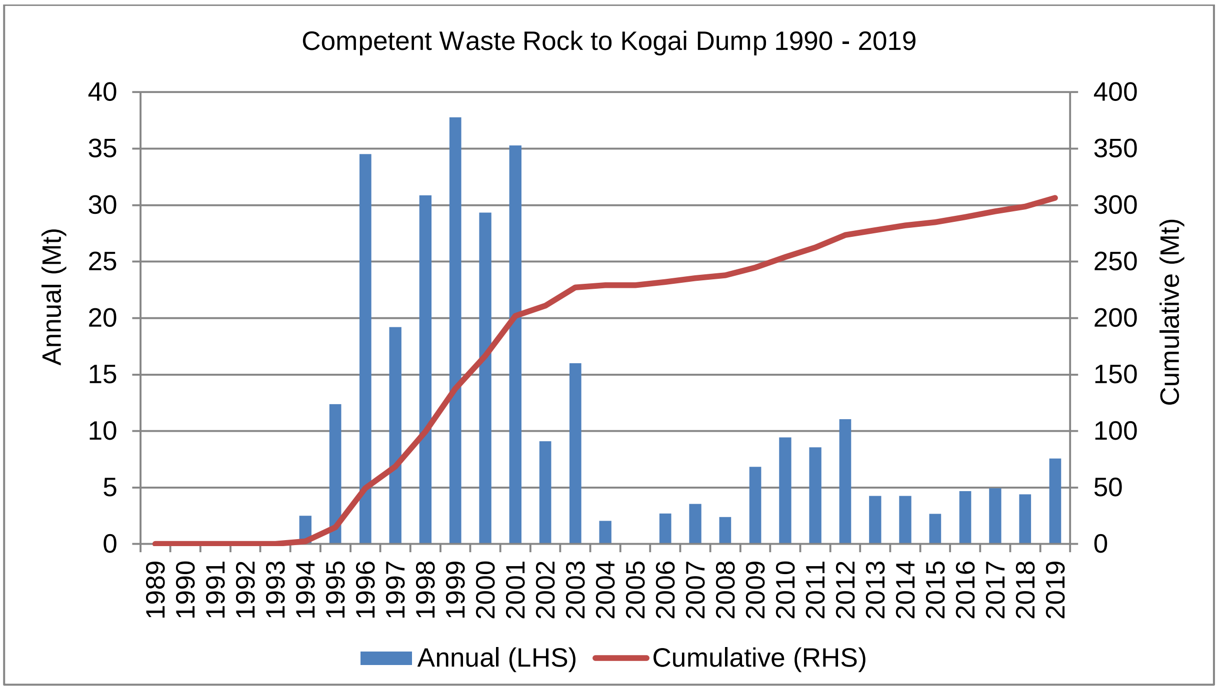
The total quantity of competent waste rock placed at the Kogai competent dump in 2019 was 7.6Mt as shown in Figure 4-7.



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

Figure 4-7 Monthly tonnages of competent waste rock placed at Kogai Dump in 2019

The total quantity of waste rock placed at Kogai competent dump since 1992 was 306Mt. Figure 4-8 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.

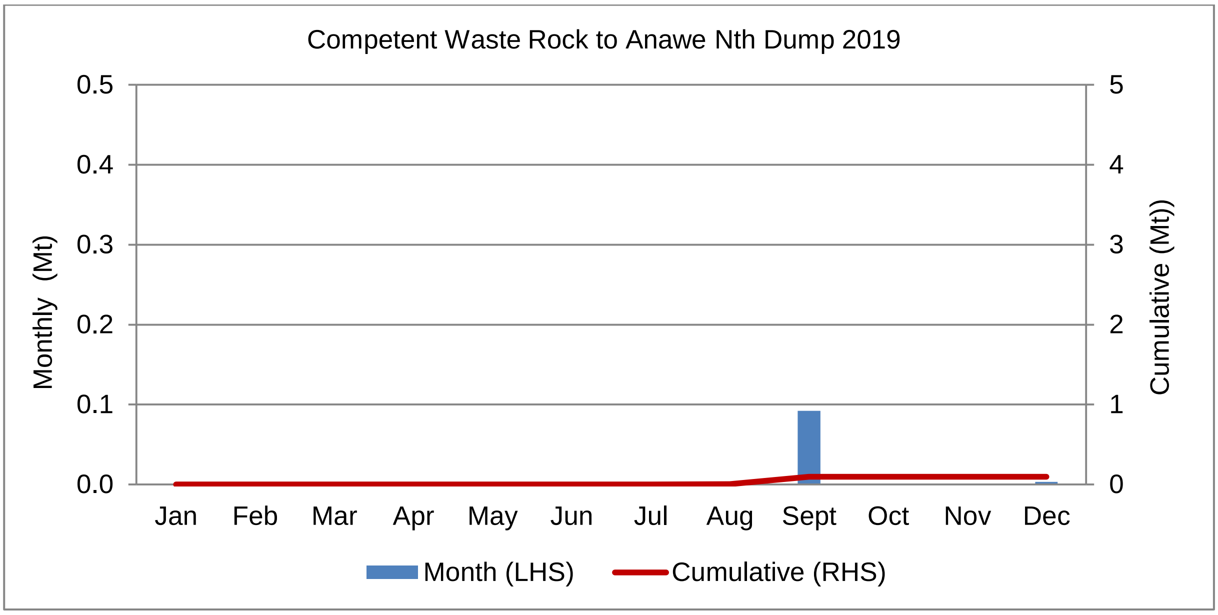


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-8 Yearly tonnages of competent waste rock placed at Kogai Dump 1989 – 2019

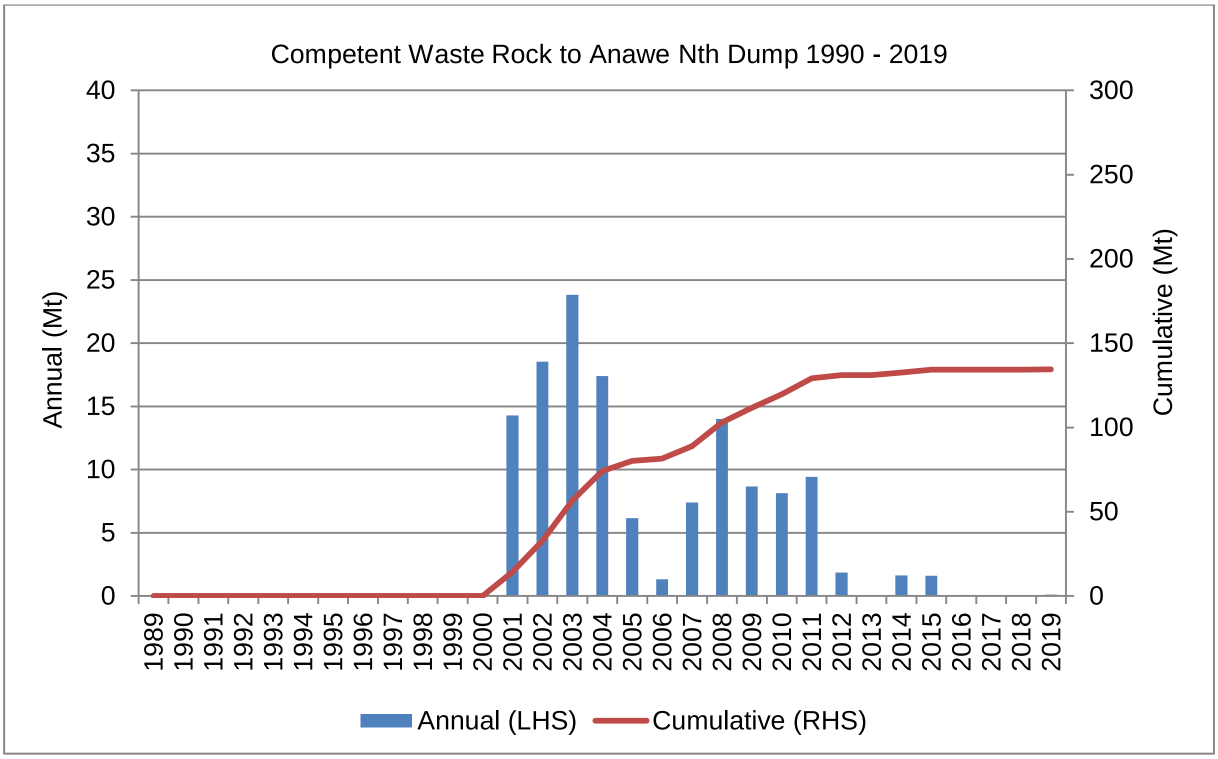
4.4.2 Anawe North competent dump

The Anawe North stable dump received 0.1Mt of competent waste rock in 2019 as shown in Figure 4-9. The total quantity of competent waste rock placed at Anawe North dump since construction began in 2001 was 134.5Mt. Figure 4-10 shows annual and cumulative quantities of competent waste rock placed at Anawe North.



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

Figure 4-9 Monthly tonnages of competent waste rock placed at Anawe North Dump in 2019



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

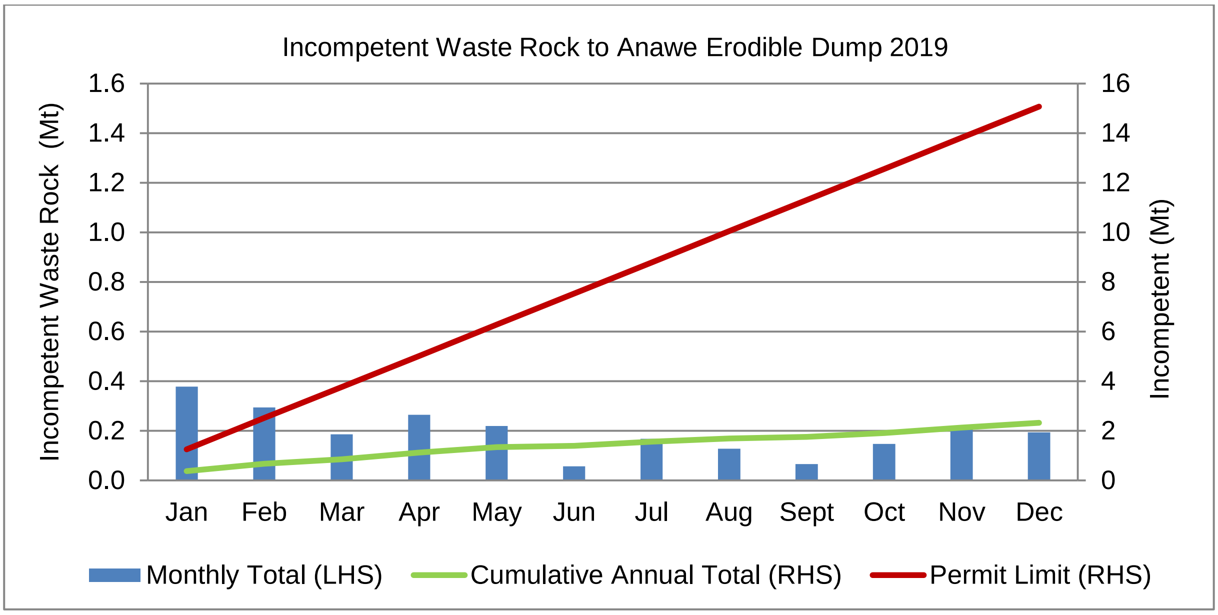
Figure 4-10 Yearly tonnages of competent waste rock placed at Anawe North Dump 2001-2019

4.5 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. The total quantities of incompetent waste rock placed during 2019 were slightly higher than the previous years due to increased mining of incompetent material from the open pit operational areas and west wall cutback.

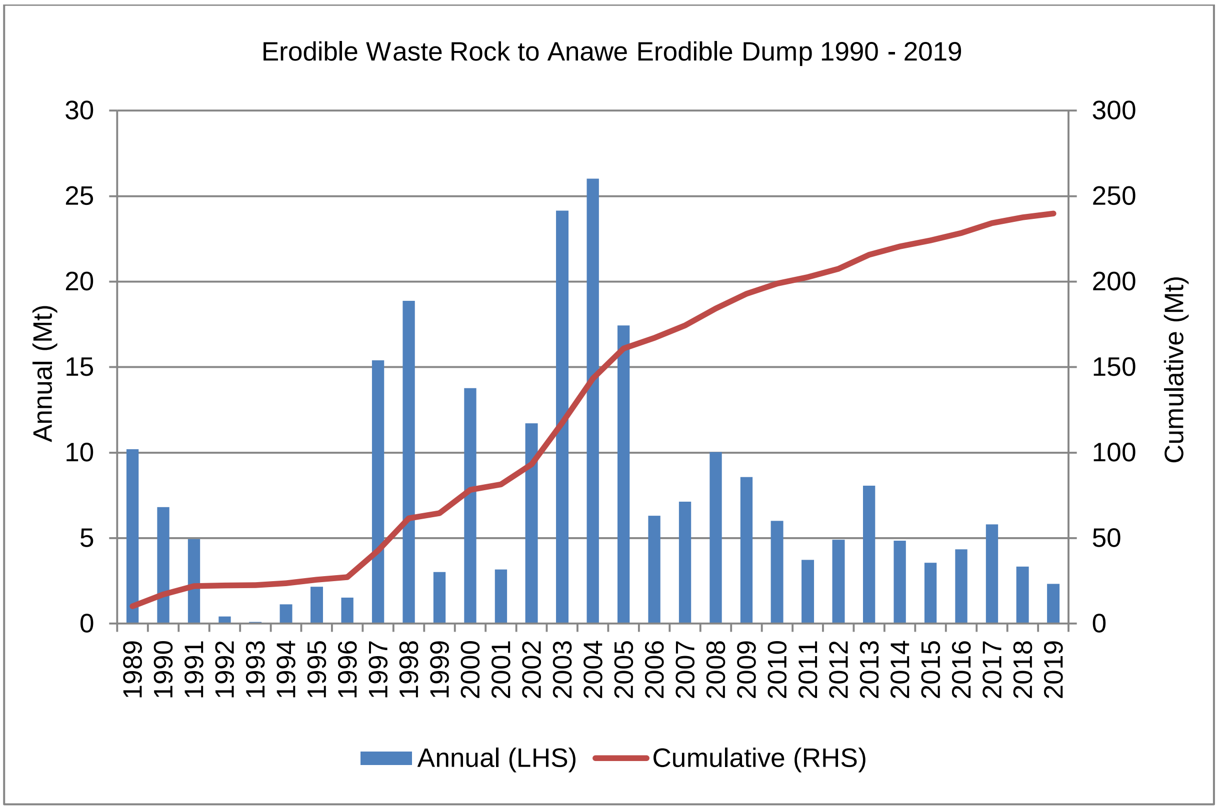
4.5.1 Anawe erodible dump

Monthly tonnages of incompetent waste rock disposed to Anawe erodible dump in 2019 are shown in Figure 4-11. A total of 2.3 Mt of incompetent waste rock was placed in Anawe during the year, the majority of which was mudstone material excavated from the bottom of the open pit. The quantity placed was 15% of the annual permit limit of 15.1Mt. Figure 4-12 shows the annual tonnages of incompetent waste rock placed in the Anawe dump since dumping began there in 1989. Figure 4-13 shows the cumulative surface area and volume of the dump since 2001.



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

Figure 4-11 Monthly tonnages of incompetent waste rock placed at Anawe Erodible Dump in 2019



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

Figure 4-12 Yearly tonnages of incompetent waste rock placed at Anawe Erodible Dump 1989-2019

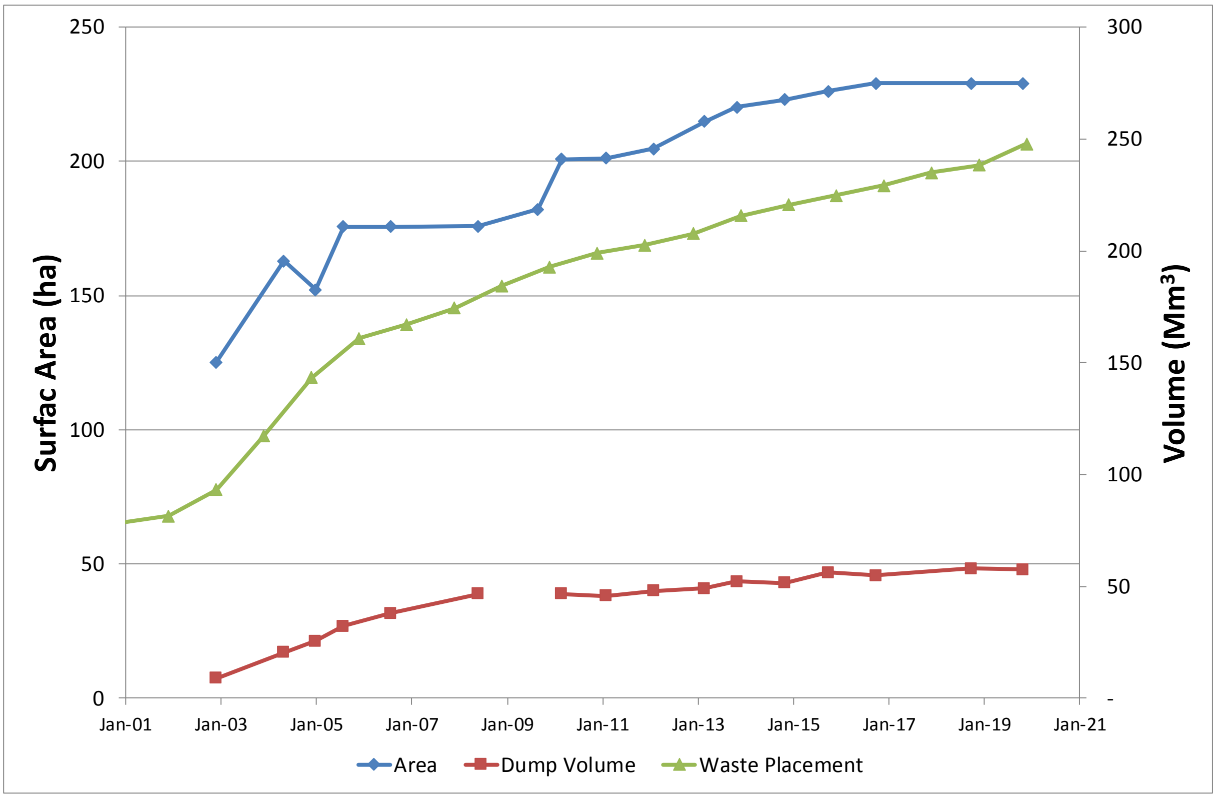
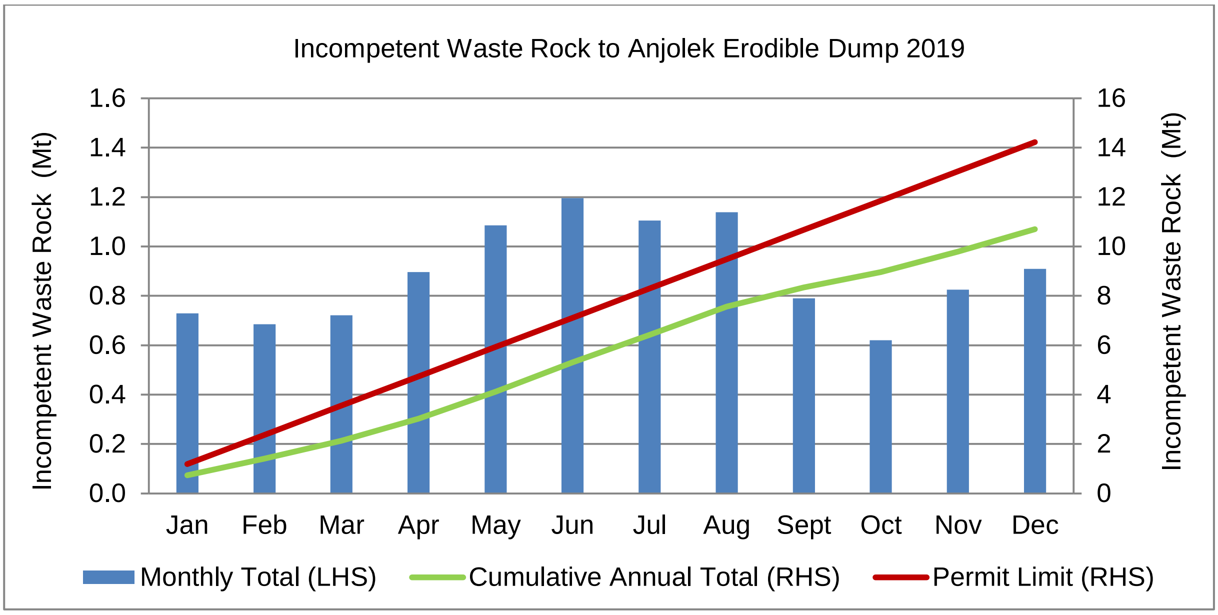


Figure 4-13 Area, volume of waste placed in the dump (Waste Placement) and volume of Anawe Erodible Dump based on LiDAR survey 2001-2019

4.5.1 Anjolek erodible dump

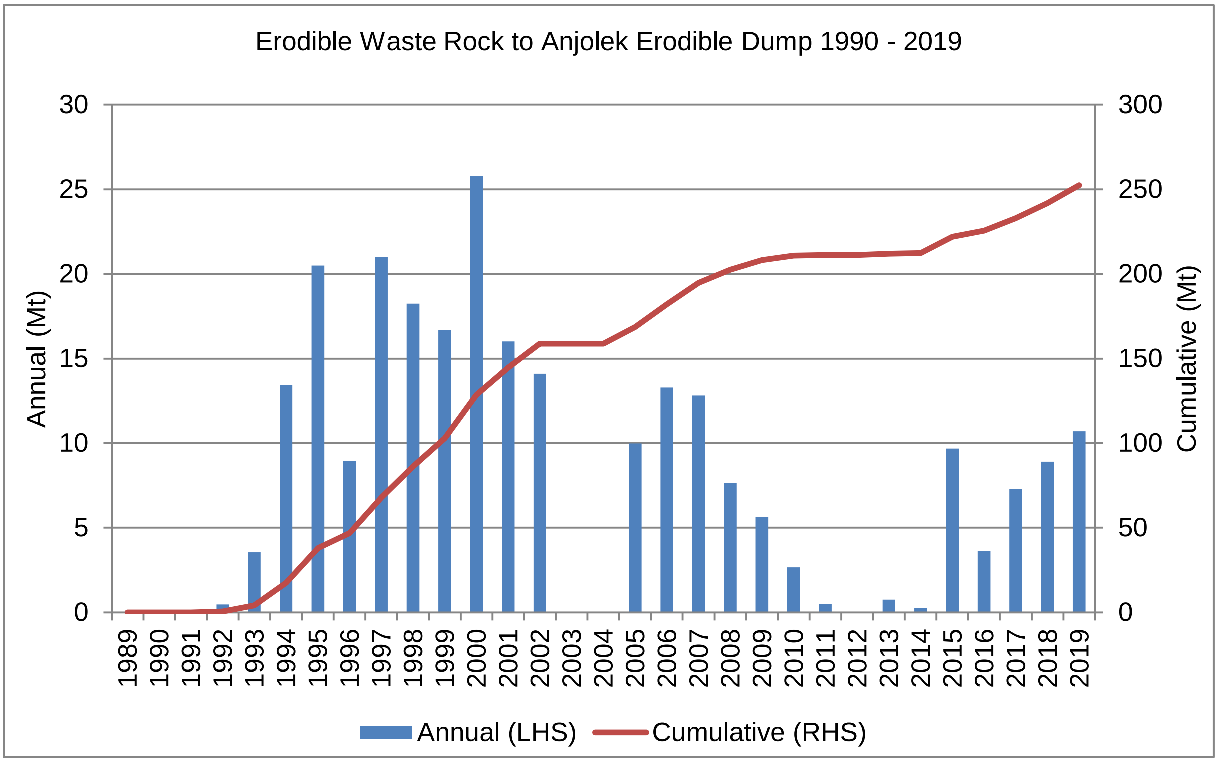
Figure 4-14 shows monthly tonnages of incompetent waste rock disposed to Anjolek erodible dump during 2019. A total of 10.7 Mt was placed during the year, the majority of which was mudstone from a cut-back of the west wall, Stage 5C of the open pit and soft waste rock from Stage 5A, which is pumped in slurry form through the Yarik portal to the lower section of the Anjolek erodible dump The volume discharged in 2019 was equivalent to 75% of the annual permit limit of 14.2Mt. The quantity dumped in 2019 was higher than 2018 due to an increase in mining from the west wall call cut-back, open pit mining expansion at Stage 5C.

Figure 4-15 shows the tonnage of incompetent waste rock placed in the Anjolek erodible dump since dumping began there in 1992. Figure 4-16 shows the cumulative surface area and volume of the dump since 2001.



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

Figure 4-14 Monthly tonnages of incompetent waste rock placed at Anjolek Erodible Dump in 2019



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

Figure 4-15 Yearly tonnages of incompetent waste rock placed at Anjolek Erodible Dump 1992-2019

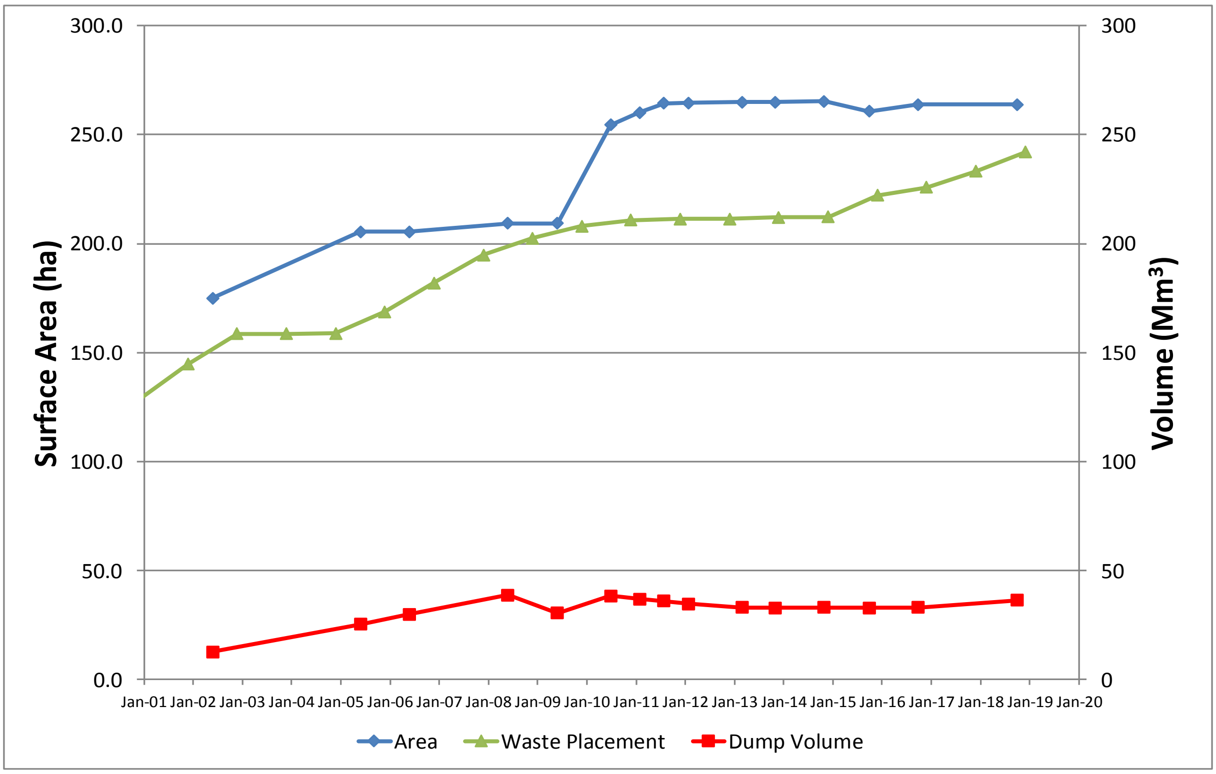


Figure 4-16 Area, volume of waste placed in the dump (Waste Placement) and volume of Anjolek Erodible Dump based on LiDAR survey 2001-2019

4.6 Status of the Erodible Dumps in 2019

An unmanned aerial vehicle (UAV) survey of the Anawe erodible dump was undertaken in November 2019. Due to access and weather conditions, the scheduled 2019 survey for Anjolek erodible dump could not be completed, so data from previous years surveys have been used.

Rates of waste dumping continued to be relatively low in a historical context. The total amount dumped to Anawe was 2.3Mt and Anjolek received 10.7Mt which is 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.

4.6.1 Anawe erodible dump

An aerial inspection undertaken in early 2020 showed that there had been relatively little change to the overall morphology of Anawe dump, an observation which aligns with survey data that indicate minimal change to both surface area and volume during the reporting period.

- Tip-heads and Upper Tract: Survey data show that the current dump surface is currently some 10-20 m below the level of the original ground topography (indicating historic scouring, Figure 4-17). The current dump surface begins to rise above the original ground surface at a location between the Maiapam Area and the Pongema River Fan – opposite to Anawe North Dump. In the Upper Tract, the 2019 surface is close to or just below the level of the 2018 surface, showing a degree of surface erosion in this zone.
- Maiapam Area (historical overspill area): Generally low and variable surface showing no trend of thickening. Yearly elevation contours show that the rate of change of thickness (i.e. surface erosion/lowering) is greatest in this zone.
- Confluence with Pongema River (including Pongema Fan). Thickening of the surface occurred in 2018 and the 2019 surface is at a similar elevation compared with that of 2018.

- Between the Pongema River Fan and the toe, both the 2018 and 2019 surfaces are at a similar elevation, above both the original ground topography (up to 50 m in places) and historic surface elevations. Although there has not been a substantial change since 2018, most of the increase in thickness in 2019 occurred in this zone. However, the coverage of vegetation in the Lower Tract suggests that the surface has been 'pushed up' from below rather than there being new material deposited on the surface.
- Toe area: Material is removed from the dump as it flows laterally into the Pongema River on the Southern Flank and by local runoff and tailings flows from the North Flank below Anawe North Dump. The toe continues to retreat in an upstream direction (of the order of tens of metres), indicating upstream progressing erosion. (Figure 4-18). It also indicates that the sediment transport capacity of the river at the toe now exceeds the rate of supply of sediment.

Figure 4-17 Upper Tract of Anawe Dump showing eroded surface

Figure 4-18 Anawe erodible dump toe

4.6.2 Anjolek erodible dump

Although no survey data were available for 2019, a flyover photographic survey was conducted in March 2020. In summary, observations suggested that there had been no substantial changes to the morphology of the dump since 2018, no significant valley wall landslips nor major changes of surface drainage patterns. The photographs suggest that:

- In the Upper Tract below the tip-head, the dump surface is at a relatively low elevation.
- Surface flows continue to incise (down-cut) into the dump. Figure 4-19 shows head-cuts (erosion fronts) on the surface of the dump, while the Kaiya River appears to be down-cutting.
- In 2018, the course of Anjolek Creek had changed to flow behind the Kaiya River Alluvial Fan. Photographs in 2020 indicated that flows in this new course had ceased.
- In late 2016, the Kaiya River reverted back to a former course that ran adjacent to the northern slopes, from a position that occupied a central course through the dump. The river appears to be continuing to follow that course and, although erosion of the northern slopes in the lower tract is continuing, there appears to have been no substantial change to those patterns of erosion.
- Inspection of the confluence of Kaiya River and Kogai Creek showed that there was no substantial sediment-related impact from upstream earthworks at Yarik Portal and no apparent morphological difference from 2018
- The toe area and runout zone to the Kaiya River showed little substantial change from 2018.
- Fresher dumped material appears to be ‘rafting’ down on top of the former surface (Figure 4-20

Figure 4-19 Anjolek Dump – lower Tract

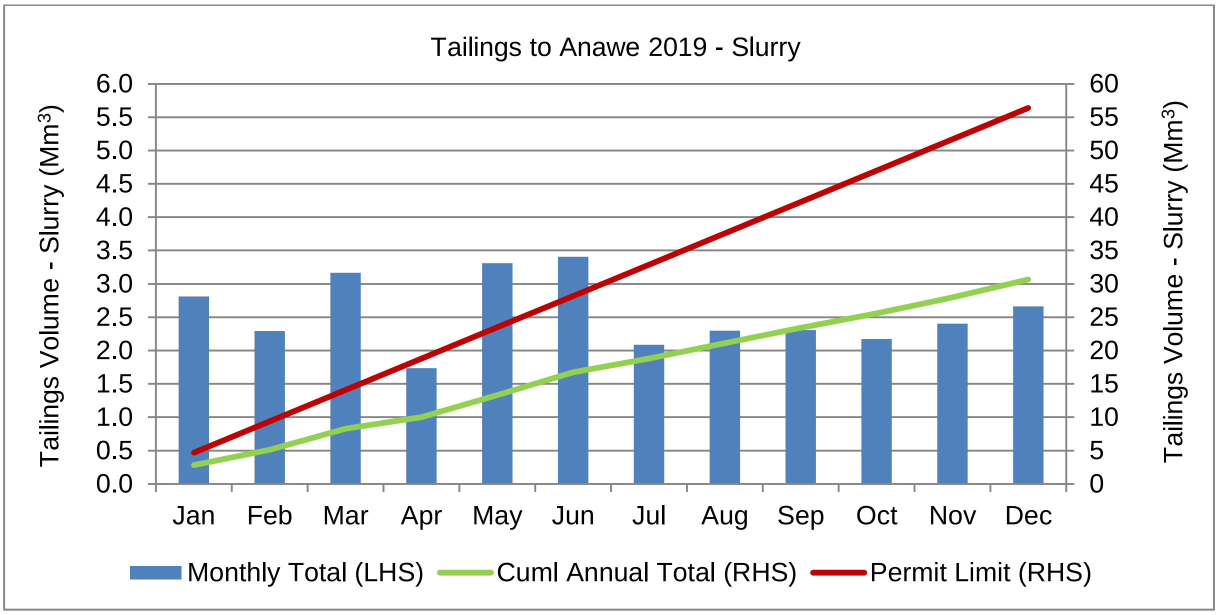
Figure 4-20 Dumped material ‘rafting’ downslope

4.7 Tailings Disposal

4.7.1 Riverine tailings disposal

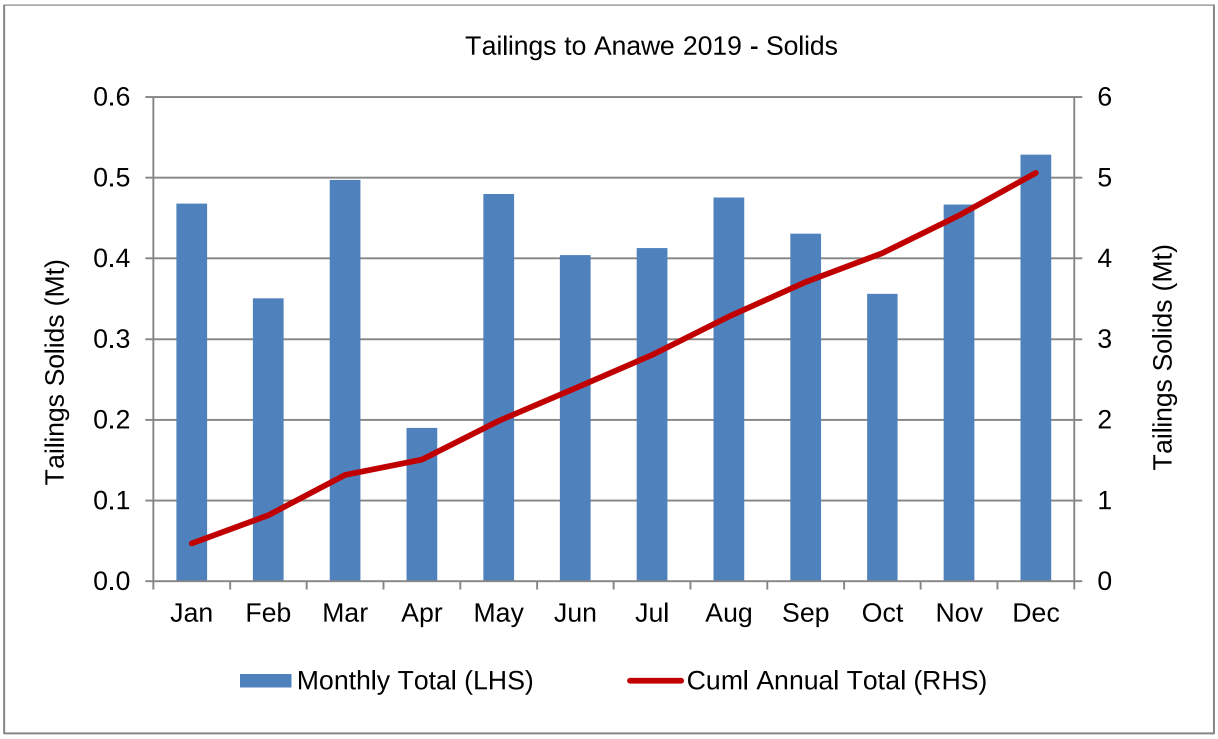
Monthly and cumulative volumes (Mm^3) of tailings slurry, the mixture of solids and water, discharged in 2019 are shown in Figure 4-21 and compared against the permit limits. The total volume of tailings slurry discharged in 2019 was 31 Mm^3 and is compliant with the environmental permit limit of 56.35 Mm^3.

The monthly and yearly mass (t) of tailings solids discharged are shown in Figure 4-22 and Figure 4-23 respectively. The mass discharged in 2019 was higher than the previous year but consistent with historical volumes, the total mass discharged since operations began was 136.4 Mt. The historical mass discharges are reported in tonnes for comparison with the erodible waste rock discharge mass.



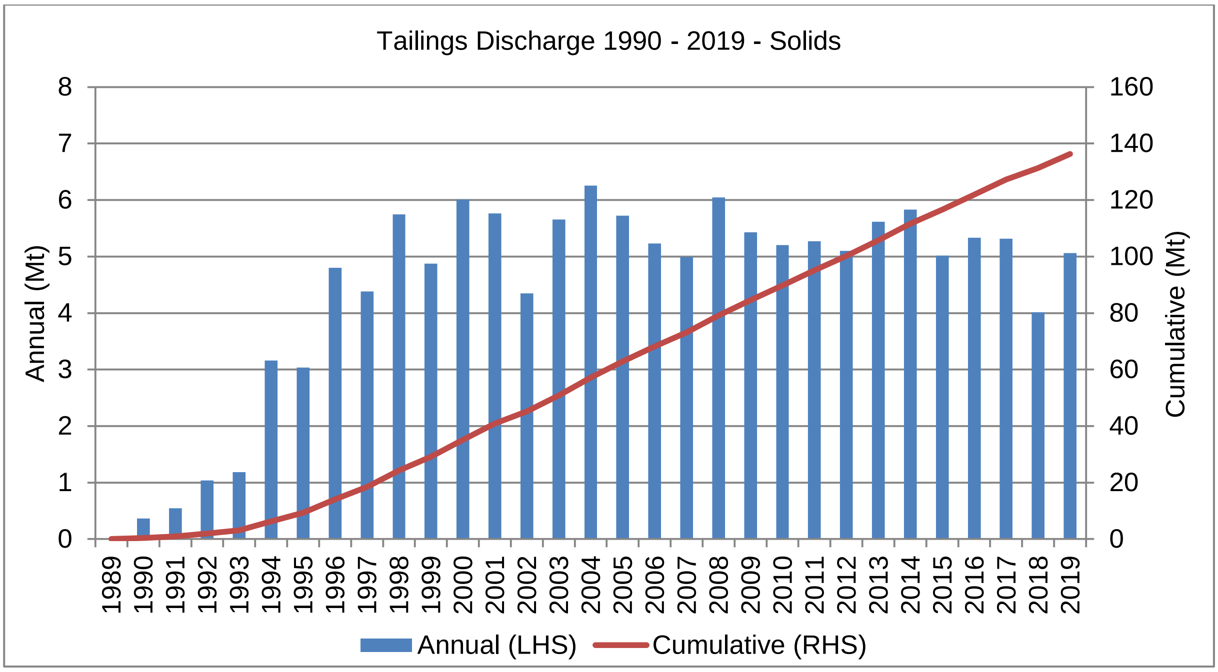
LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-21 Monthly and cumulative tailings slurry discharge volumes (Mm^3) 2019



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

Figure 4-22 Monthly and cumulative tailings discharge mass (Mt dry solids) 2019

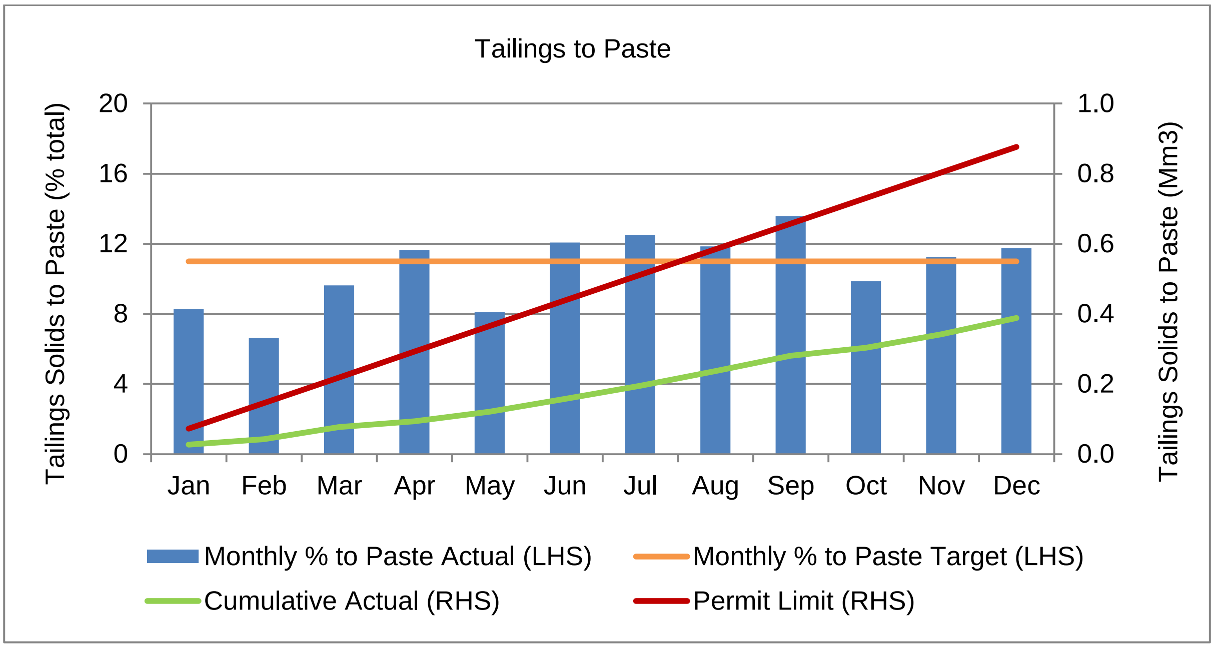


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-23 Annual and cumulative tailings discharge mass (Mt) (dry solids) (1990-2019)

4.7.2 Tailings used as underground mine backfill

The monthly and cumulative volumes of tailings diverted to the underground mine for use as paste backfill are shown in Figure 4-24 against the environmental permit limit. A total of 388,146 m^3 was diverted to paste in 2019, which is 14% of the total tailings volume produced. A total of 598,516 tonnes of tailings solids was diverted to paste, which is 11% of the total mass produced in 2019.



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

Figure 4-24 Tailings diverted to underground backfill in 2019

4.8 Tailings Quality

Contaminants of concern within the tailings discharge are cyanide (CN), total suspended solids (TSS) and metals. The quality of the discharge is influenced by the geochemistry of the ore, the gold extraction process and the tailings treatment circuit. Tailings treatment is managed to ensure compliance with internal site-developed requirements for pH and WAD-CN at the discharge point, permit requirements at the SG3 compliance monitoring station and to mitigate the risk of environmental impact within the receiving environment downstream from the point of discharge.

The slurry density, which influences the TSS concentration of the tailings, and the rate of discharge have remained relatively consistent throughout the history of the operation. The median TSS concentration in 2019 was slightly lower than in 2018. Monthly and annual TSS concentrations in the tailings discharge are shown in Figure 4-25 and Figure 4-26.

The pH of the tailings discharge is dictated by the geochemistry of the ore, the gold extraction process and by the addition of lime during tailings treatment. Controlling pH is critical for limiting the concentration of dissolved/bioavailable metals in the discharge. A range of metals within the discharge have the potential to impact the downstream environment if the treatment process is not managed appropriately to reduce their bioavailability. The metals are found naturally within the ore body and pass through the process plant with the tailings. A portion of the metals are dissolved during the pressure oxidation stage of the process plant, where pH reaches as low as pH 1. Adding lime raises the pH of the final combined tailings stream and precipitates the metals as solid forms such as hydroxides, which are less bioavailable. In addition, some metals will also adsorb to particulate matter as the pH increases, further reducing the bioavailable concentrations.

The PNG Government has not established compliance targets for tailings quality at the discharge point. PJV has therefore established its own end-of-pipe criterion for pH and WAD-CN, designed to mitigate human health and environmental risks.

Discharge pH for 2019 is shown in Figure 4-27, and the results from 2010 – 2019 are shown in Figure 4-28. The high level of compliance with the targets is attributable to the implementation in 2013 of greater process control in the form of a trigger-action-response plan (TARP) which facilitates proactive control and initiates corrective action in the event of pH excursion outside the target range throughout the process stream. Discharge pH for the period 1994 – 2019 is shown in Figure 4-29.

Cyanide concentrations within the tailings discharge are dictated by the amount of cyanide added to the circuit for gold extraction and the effectiveness of the cyanide destruction plant, which is part of the tailings treatment circuit. Weak Acid Dissociable Cyanide (WAD-CN) concentrations in the tailings discharge during 2019 were low and 100% in compliance with the internal site-developed end of pipe criterion of <0.5 mg/L. The monthly WAD-CN results for 2019 are shown in Figure 4-30. The performance achieved during 2019 has continued the trend of low WAD-CN concentrations demonstrated since the commissioning of the cyanide destruction plant in 2009. Similar to pH, the improved consistency achieved since 2013 is attributable to the implementation of greater process control in the form of a TARP for managing the operation of the treatment circuit.

Monthly concentrations for 2019 and annual concentrations between 2010 and 2019 are shown as box plots in Figure 4-33 to Figure 4-54 for all metals. An explanation of box plots is given in APPENDIX B. The concentration profile of metals in tailings changed between October and December. Higher concentrations of total metals were observed as a result of feeding primarily underground ore to the plant, as opposed to the usual blend of underground, open pit and stockpile ore. Underground ore exhibits higher mineralisation than ore from the open pit and stockpiles.

The 20th%ile, median and 80th%ile concentrations of total and dissolved metals in the tailings slurry during 2019 are shown in Table 4-4. A comparison of tailings quality against the upper river risk TVs provides an assessment of which stressors within the tailings discharge posed a potential risk to the downstream environment. The results showed that median EC and median concentrations of TSS, dissolved cadmium, copper, nickel and zinc were elevated in the tailings discharge compared with upper river trigger values and therefore posed a potential risk to the receiving environment. Moderate proportions of cadmium (4.3%), nickel (17%) and zinc (3.8%) were present in dissolved forms throughout 2019 as shown in Table 4-5.

Weak-Acid-Extractable (WAE) metals concentrations in tailings solids are presented in Table 4-6. The median concentrations of WAE arsenic, WAE cadmium, WAE copper, WAE mercury, WAE nickel, WAE lead, WAE selenium and WAE zinc were higher than the upper river TVs and therefore posed a potential risk to the receiving environment.

Table 4-4 Tailings slurry discharge quality 2019 (µg/L except where shown), sample count (n) = 48

Parameter	UpRiv TV	20th%ile	Median	80th%ile
pH^	6.0-8.2	6.4	6.6	6.8
EC#	228	2,930	3,900	4,426
WAD-CN*	NA	0.20	0.20	0.20
Sulfate*	NA	1,614	2,285	3,110
ALK-T**	NA	191	256	344
TSS*	2837	81,800	98,300	120,600
Hardness**	NA	3,289	3,614	4,031
Ag-D	0.05	0.01	0.01	0.02
Ag-T	NA	960	1,800	2,820
As-D	24	0.25	1.0	2.5

Parameter	UpRiv TV	20th%ile	Median	80th%ile
As-T	NA	12,400	22,000	30,000
Cd-D	0.34	17	32	48
Cd-T	NA	378	795	1,060
Cr-D	1.0	0.12	0.29	0.96
Cr-T	NA	5,780	8,950	13,000
Cu-D	1.4	6.5	17	36
Cu-T	NA	5,940	10,000	14,600
Fe-D	75	10	31	1,706
Fe-T	NA	2,686,000	4,415,000	6,186,000
Hg-D	0.60	0.07	0.12	0.35
Hg-T	NA	41	91	110
Ni-D	21	790	975	1,192
Ni-T	NA	3,220	5,350	7,260
Pb-D	7.3	0.10	0.10	0.21
Pb-T	NA	32,400	60,500	85,000
Se-D	11	1.0	1.5	4.3
Se-T	NA	100	100	106
Zn-D	20	2,970	6,580	11,100
Zn-T	NA	69,400	145,000	180,000
🟧	> 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 Percentage of total metals in tailings in dissolved form in 2019

	% Total in Dissolved Form 2019		
Parameter	**20th%ile**	**Median**	**80th%ile**
Ag-D	0.001	0.001	0.002
As-D	0.004	0.007	0.015
Cd-D	3.6	4.3	5.1
Cr-D	0.004	0.007	0.021
Cu-D	0.15	0.19	0.3
Fe-D	0.03	0.04	0.06
Hg-D	0.18	0.3	0.4
Ni-D	16	17	21
Pb-D	0.001	0.001	0.002
Se-D	1.2	1.7	2.5
Zn-D	3.8	3.8	6.4

D – Dissolved fraction

Table 4-6 Tailings solids discharge quality 2019 (mg/kg dry, whole fraction), sample count (n) = 48

Parameter	UpRiv TV	20th%ile	Median	80th%ile
Ag-TD	NA	11	17	27
Ag-WAE	1.0	0.46	0.73	2.1
As-TD	NA	160	200	246
As-WAE	20	32	50	106
Cd-TD	NA	5.8	7.4	10
Cd-WAE	1.5	3.8	5.2	7.5
Cr-TD	NA	72	83	98
Cr-WAE	80	23	27	34
Cu-TD	NA	83	97	120
Cu-WAE	65	79	89	110
Fe-TD	NA	37,600	42,300	51,600
Fe-WAE	NA	12,700	15,600	21,200
Hg-TD	NA	0.67	0.91	1.2
Hg-WAE	0.15	0.13	0.20	0.33
Ni-TD	NA	41	50	59
Ni-WAE	22	29	35	43
Pb-TD	NA	408	575	736
Pb-WAE	50	67	105	166
Se-TD	NA	0.70	0.87	1.3
Se-WAE	0.15	0.19	0.25	0.37
Zn-TD	NA	1,030	1,249	1,580
Zn-WAE	200	660	915	1,270
🟧	> UpRiv TV = Potential Risk			

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

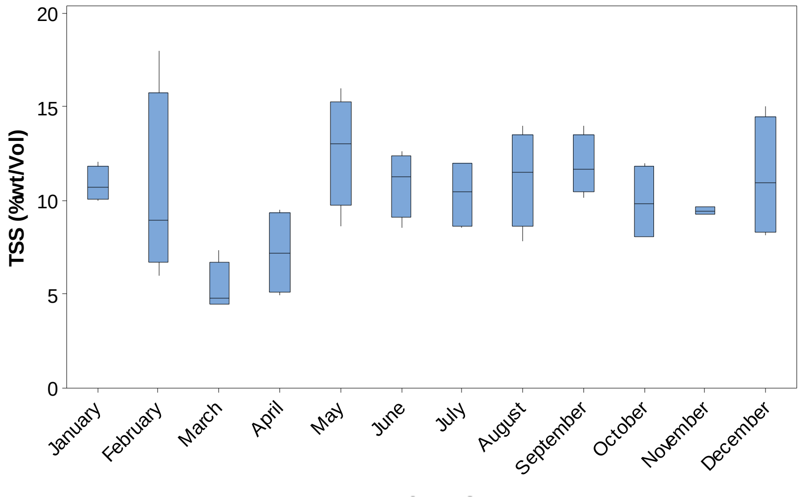


Figure 4-25 Monthly TSS in tailings discharge in 2019

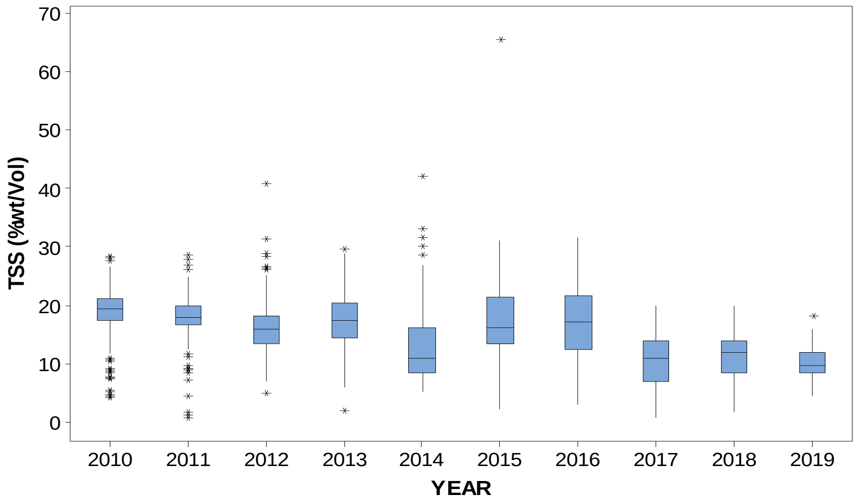


Figure 4-26 Annual TSS in tailings discharge 2010-2019

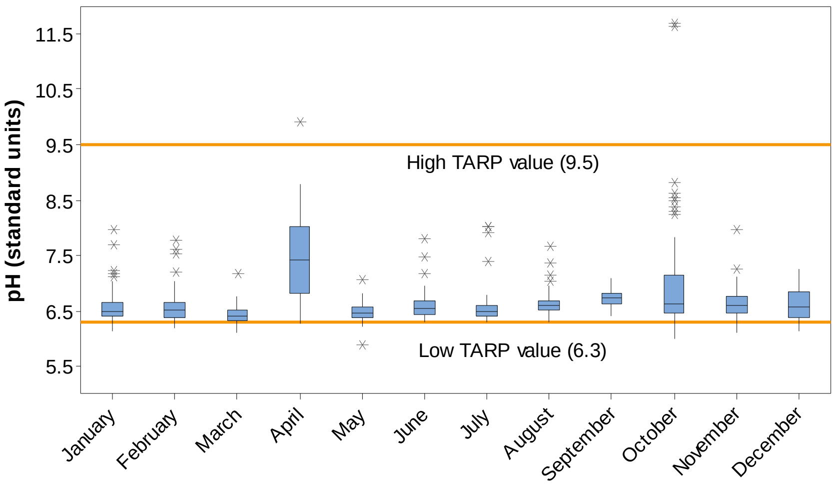
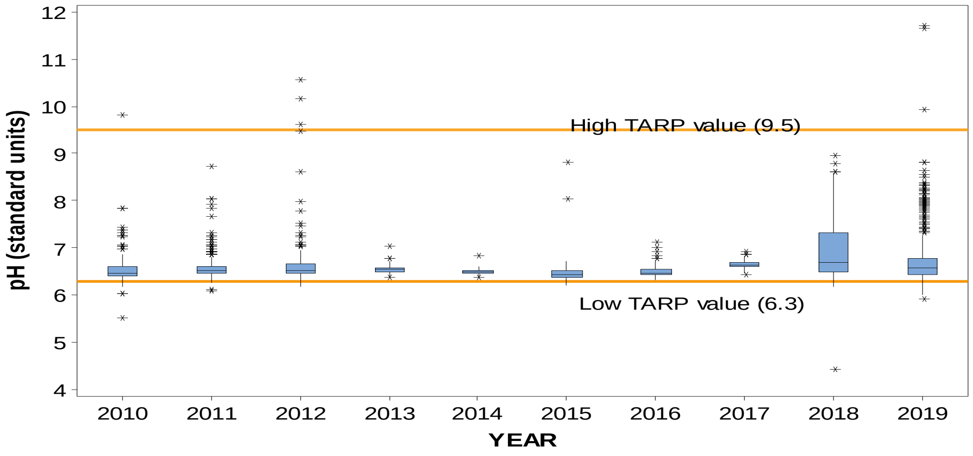


Figure 4-27 Monthly pH in tailings discharge in 2019



TARP - Trigger Action Response Plan

Figure 4-28 Annual pH in tailings discharge 2010-2019

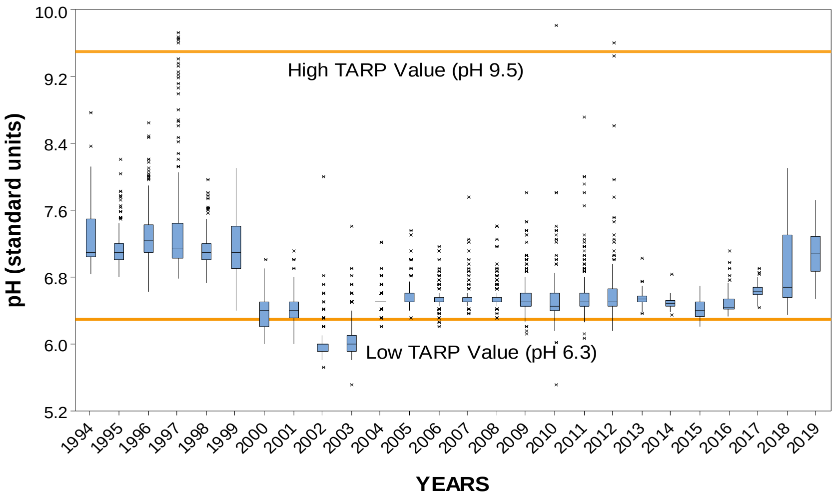


Figure 4-29 pH in tailings discharge 1994-2019

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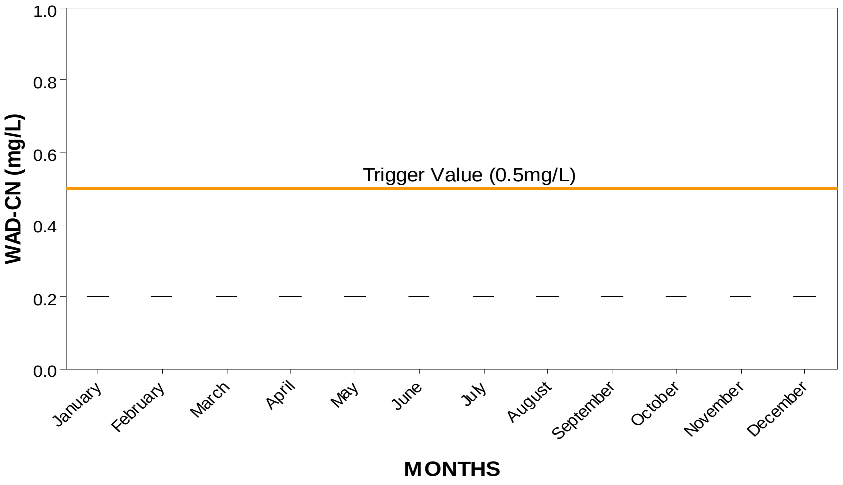

Figure 4-30 Monthly WAD-CN concentration in tailings discharge in 2019 (mg/L)

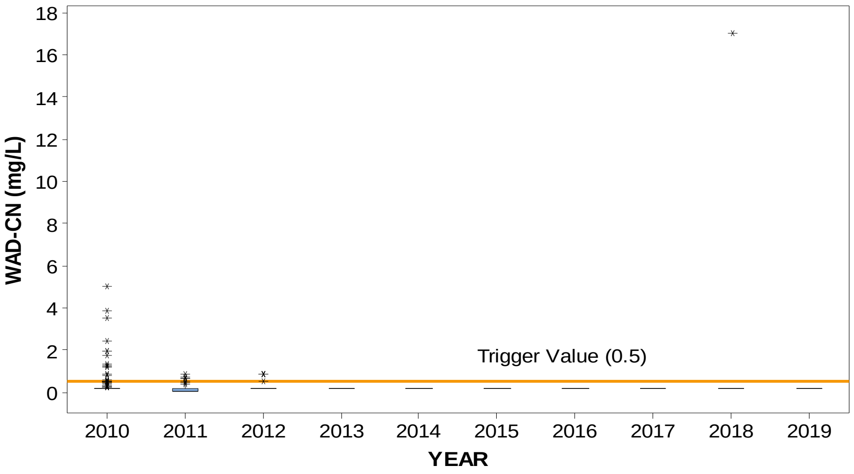

Figure 4-31 Annual WAD-CN concentration in tailings discharge 2010-2019 (mg/L)

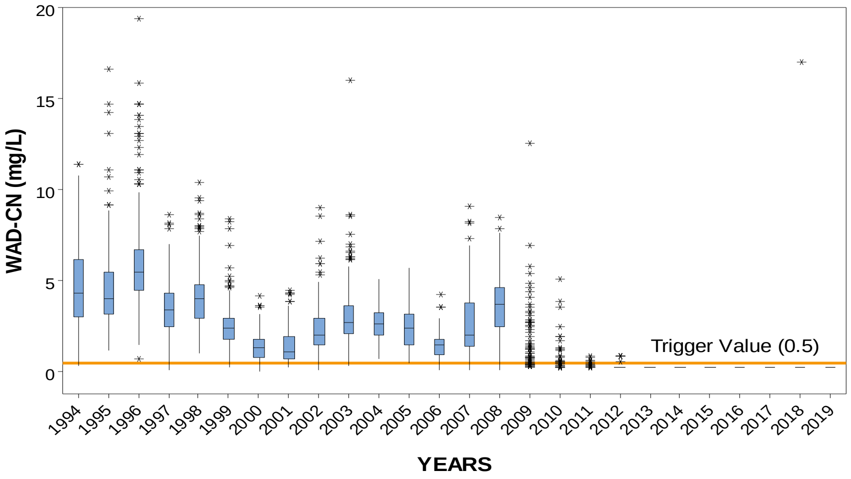

Figure 4-32 WAD-CN in tailings discharge 1994-2019

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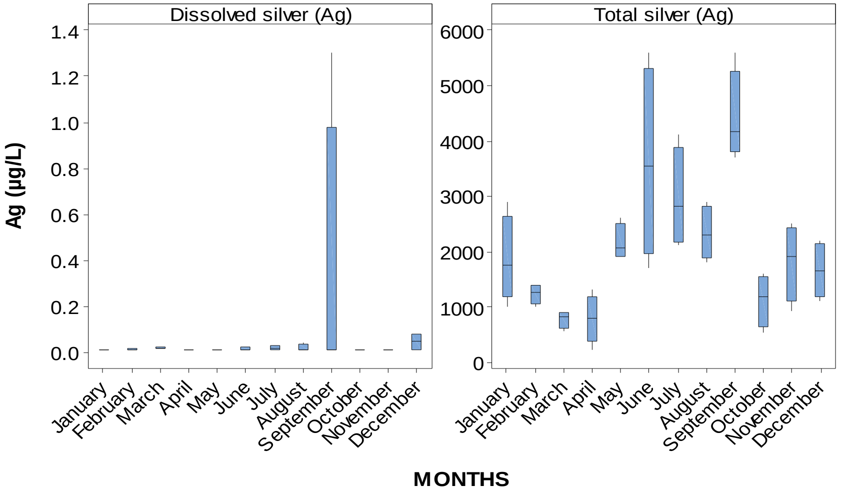


Figure 4-33 Monthly dissolved and total silver concentrations in tailings 2019 (µg/L)

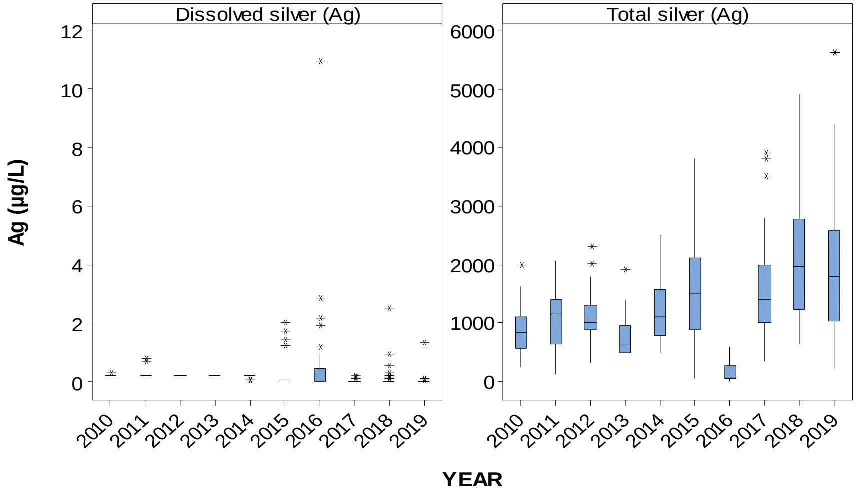


Figure 4-34 Annual dissolved and total silver concentrations in tailings 2010-2019 (µg/L)

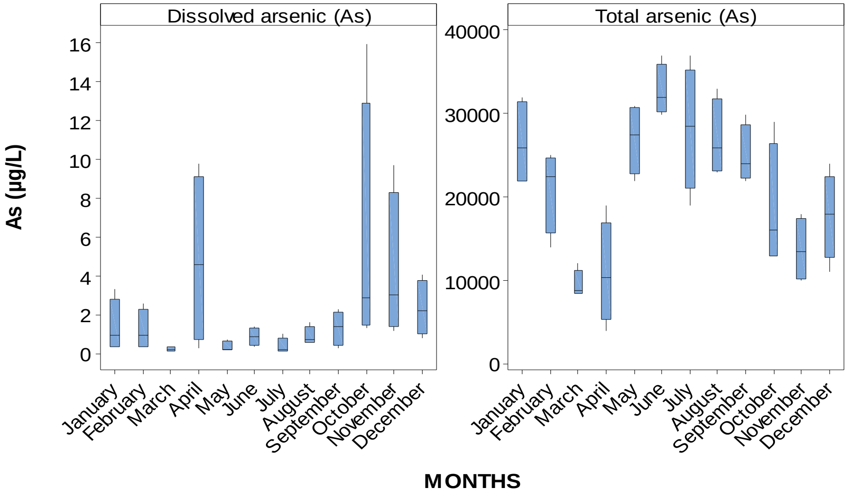


Figure 4-35 Monthly dissolved and total arsenic concentrations in tailings 2019 (µg/L)

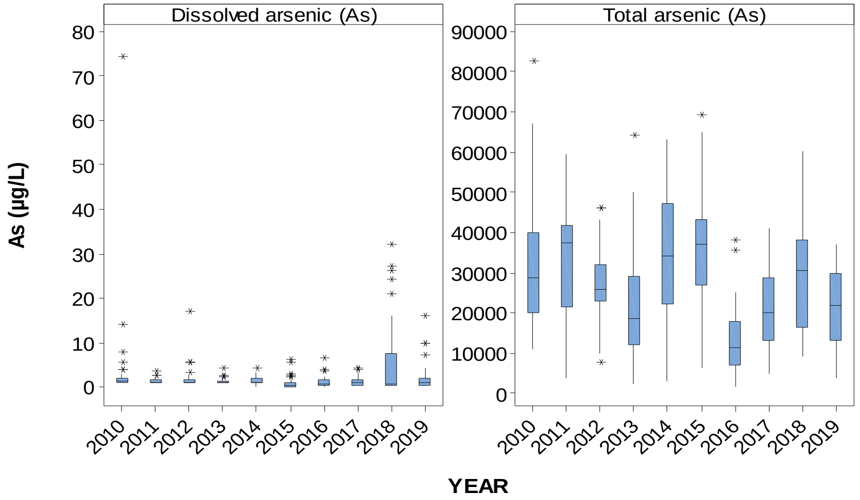


Figure 4-36 Annual dissolved and total arsenic concentrations in tailings 2010-2019 (µg/L)

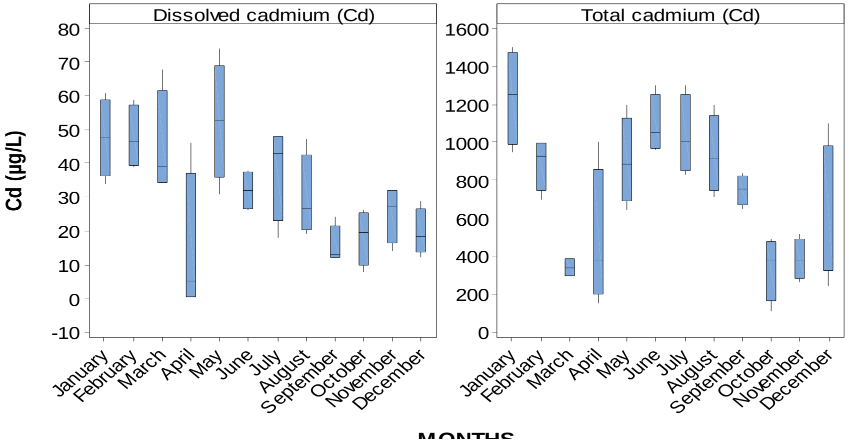


Figure 4-37 Monthly dissolved and total cadmium concentrations in tailings 2019 (µg/L)

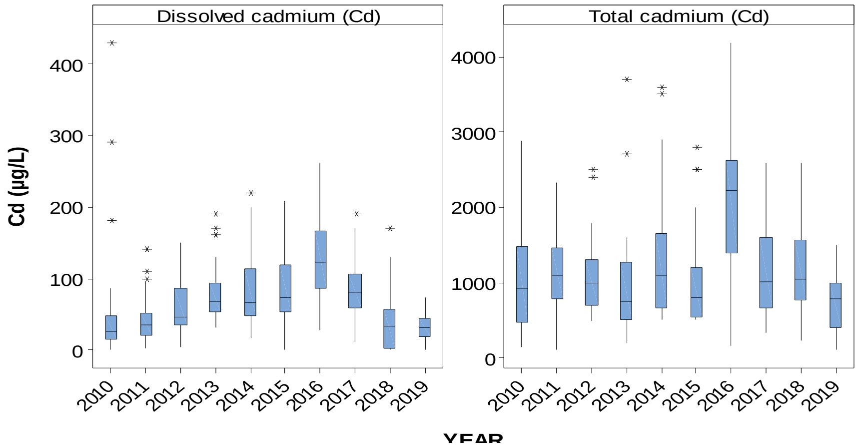


Figure 4-38 Annual dissolved and total cadmium concentrations in tailings 2010-2019 (µg/L)

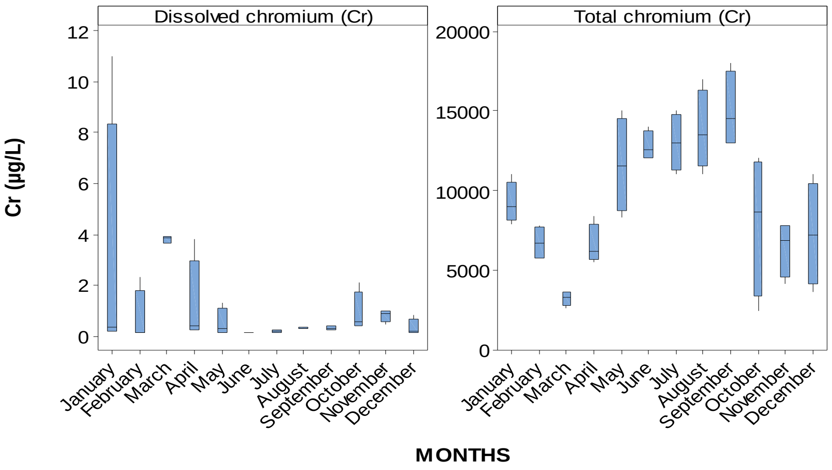


Figure 4-39 Monthly dissolved and total chromium concentrations in tailings 2019 (µg/L)

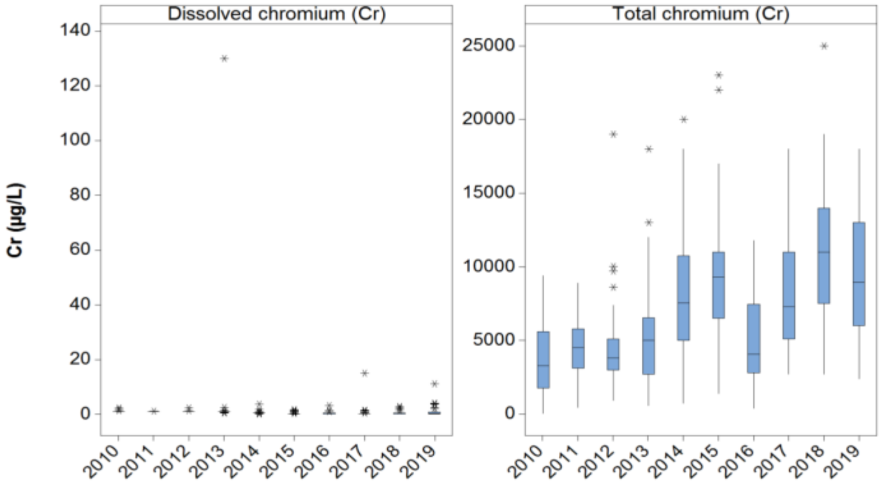


Figure 4-40 Annual dissolved and total chromium concentrations in tailings 2010- 2019 (µg/L)

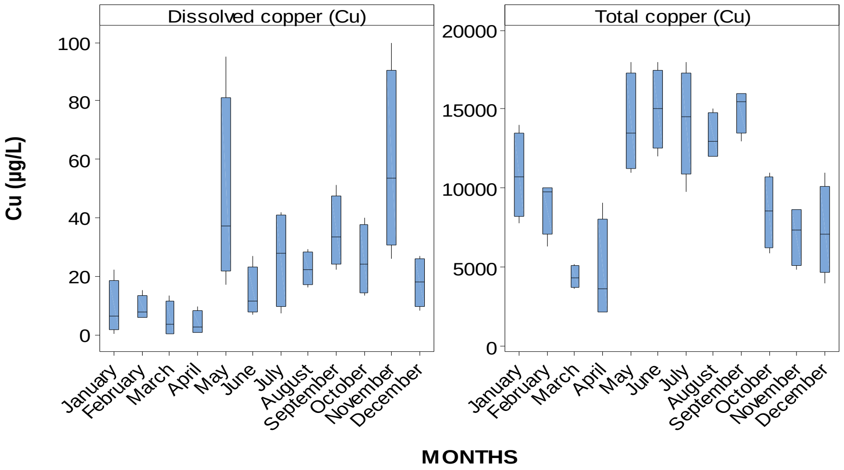


Figure 4-41 Monthly dissolved and total copper concentrations in tailings 2019 (µg/L)

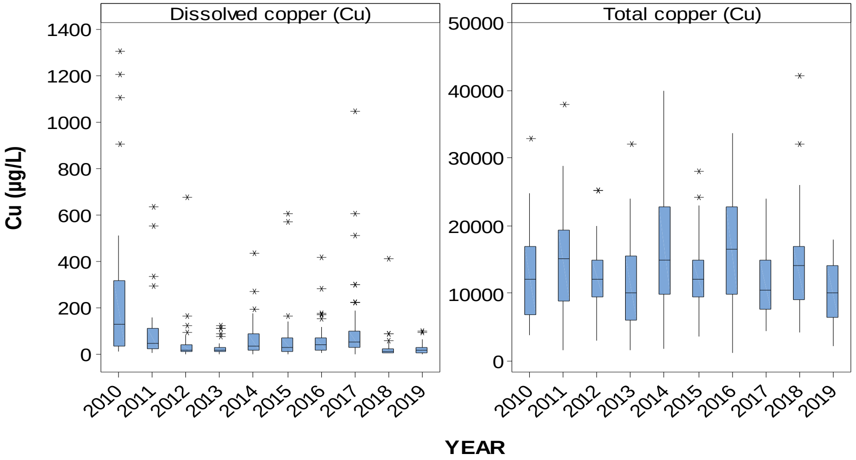


Figure 4-42 Annual dissolved and total copper concentrations in tailings 2010-2019 (µg/L)

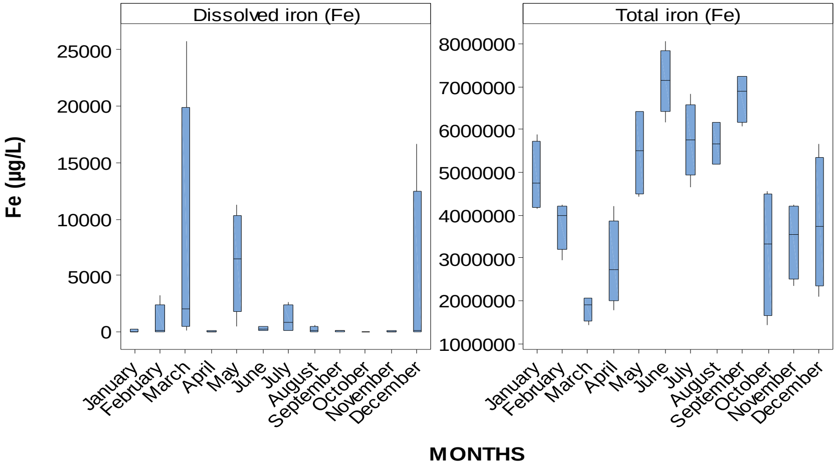


Figure 4-43 Monthly dissolved and total iron concentrations in tailings 2019 (µg/L)

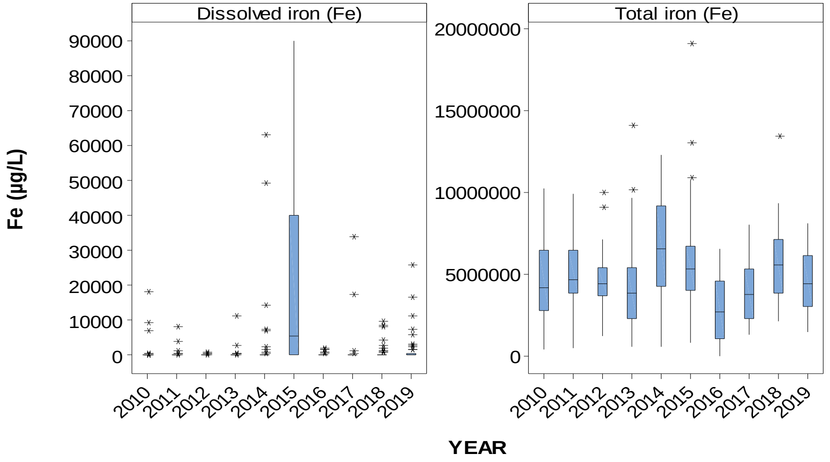


Figure 4-44 Annual dissolved and total iron concentrations in tailings 2010-2019 (µg/L)

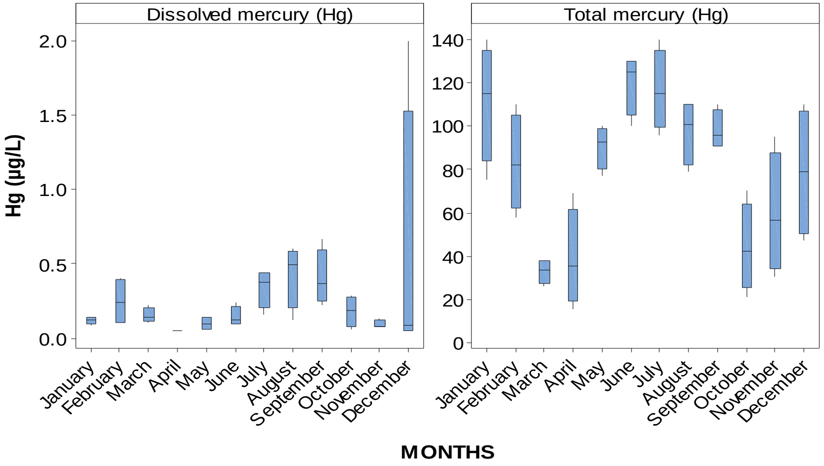


Figure 4-45 Monthly dissolved and total mercury concentrations in tailings 2019 (µg/L)

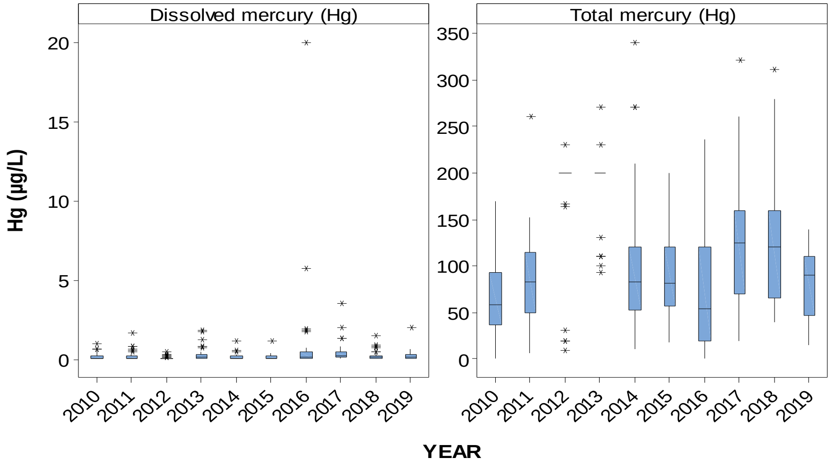
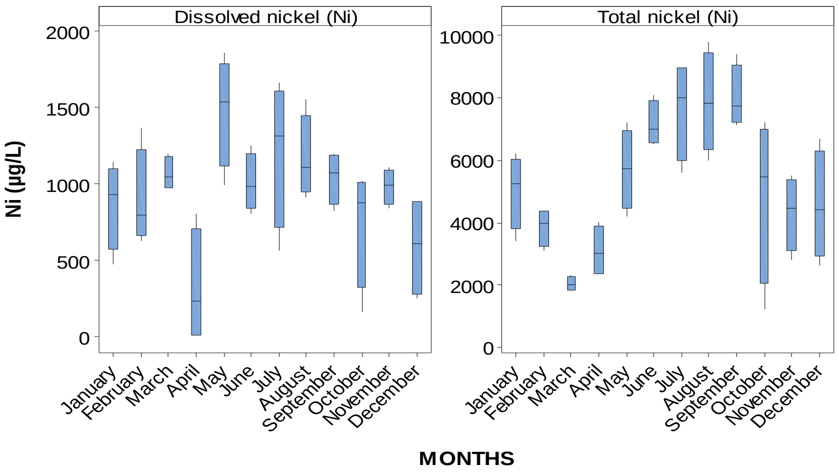


Figure 4-46 Annual dissolved and total mercury concentrations in tailings 2010-2019 (µg/L)



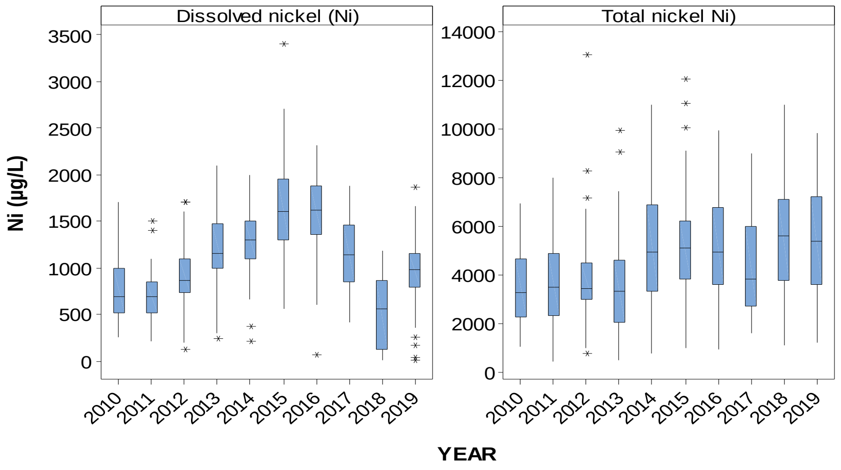
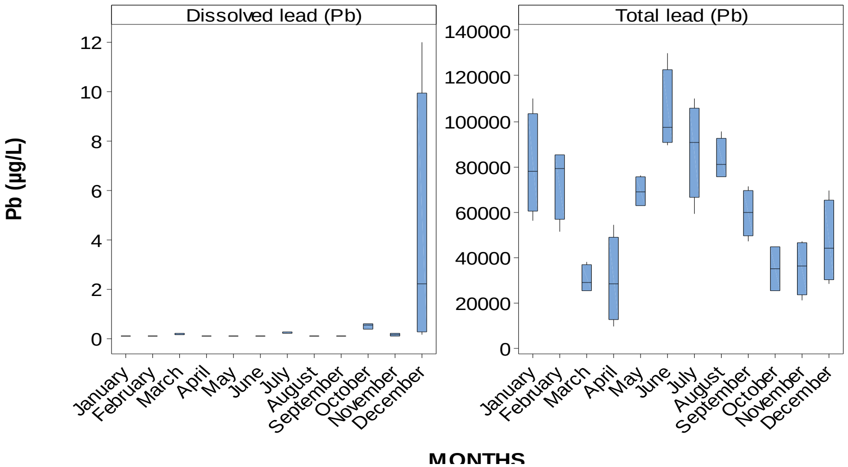


Figure 4-47 Monthly dissolved and total nickel concentrations in tailings 2019 (µg/L)

Figure 4-48 Annual dissolved and total nickel concentrations in tailings 2010-2019 (µg/L)



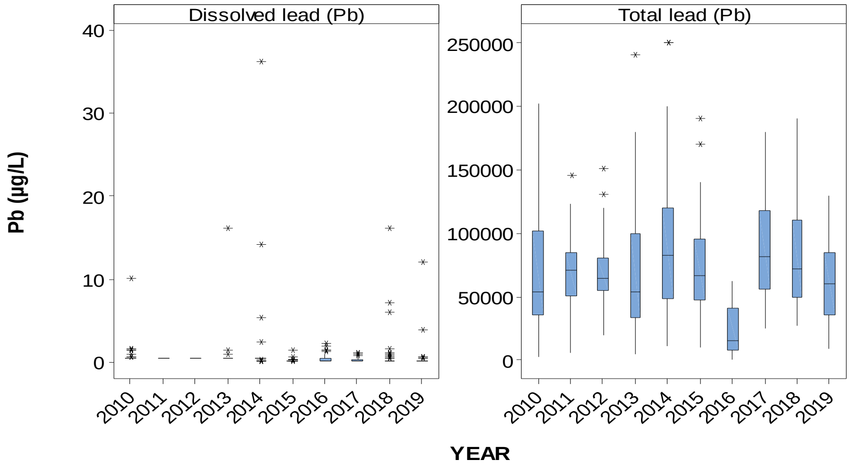


Figure 4-49 Monthly dissolved and total lead concentrations in tailings 2019 (µg/L)

Figure 4-50 Annual dissolved and total lead concentrations in tailings 2010-2019 (µg/L)

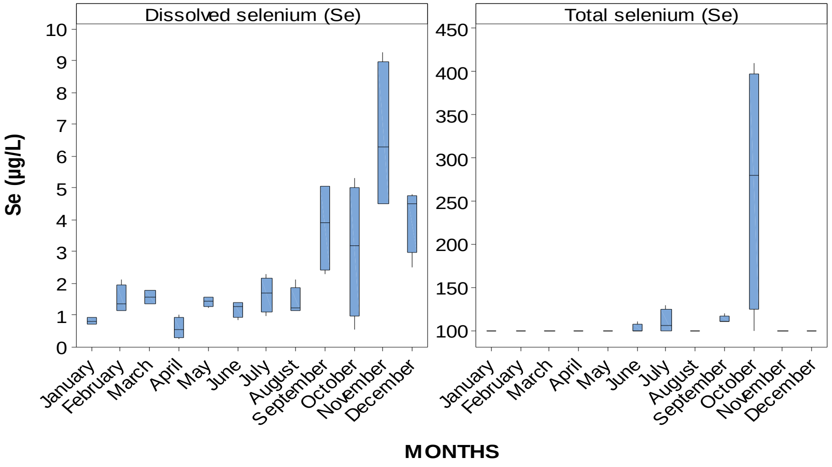


Figure 4-51 Monthly dissolved and total selenium concentration in tailings 2019 (µg/L)

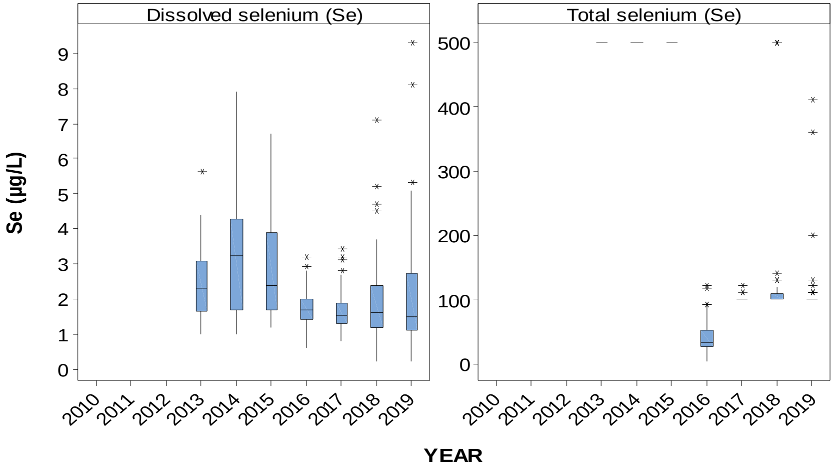


Figure 4-52 Annual dissolved and total selenium concentrations in tailings discharge 2010-2019 (µg/L)

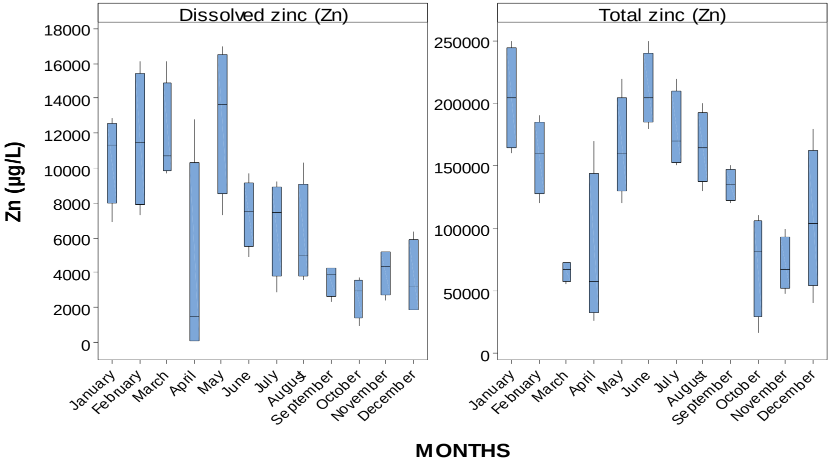


Figure 4-53 Monthly dissolved and total zinc concentrations in tailings 2019 (µg/L)

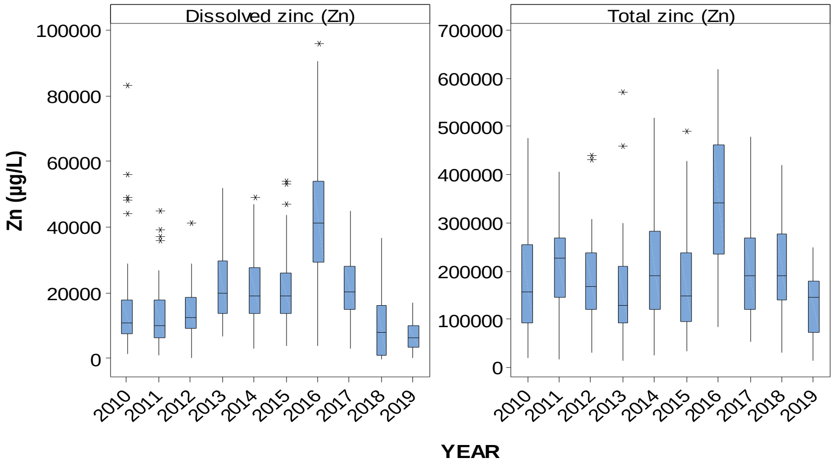


Figure 4-54 Annual dissolved and total zinc concentrations in tailings 2010-2019 (µg/L)

Statistical analysis of tailings quality trends tailings between 2010 and 2019 was performed using the Spearman Rank Test. The results are presented in Table 4-7 and show a statistically significant increase in pH, alkalinity and concentrations of total silver, total chromium, dissolved iron, dissolved and total nickel. The changes were due to changes in mineralogy and associated metals concentrations in ore being mined from the open pit and underground mines and ore stockpiles.

Table 4-7 Trends of tailings quality 2010 – 2019

Indicator	Spearman's rho	p-Value (p=0.05)	Trend (2010 – 2019)
pH	0.155	<0.001	Increased over time
EC	0.007	0.799	No change over time
WAD-CN	0.052	0.057	No change over time
Sulfate	-0.511	<0.001	Reduced over time
ALK-T	0.353	<0.001	Increased over time
TSS	-0.458	<0.001	Reduced over time
Hardness	-0.032	0.566	No change over time
Ag-D*	-0.750	<0.001	No change over time
Ag-T	0.315	<0.001	Increased over time
As-D*	-0.204	<0.001	No change over time
As-T	-0.207	<0.001	Reduced over time
Cd-D	0.056	0.223	No change over time
Cd-T	0.014	0.771	No change over time
Cr-D*	-0.593	<0.001	No change over time
Cr-T	0.483	<0.001	Increased over time
Cu-D	-0.275	<0.001	Reduced over time
Cu-T	-0.027	0.558	No change over time
Fe-D	0.267	<0.001	Increased over time
Fe-T	-0.017	0.717	No change over time
Hg-D	0.010	0.821	No change over time
Hg-T	-0.062	0.180	No change over time
Ni-D	0.121	0.009	Increased over time
Ni-T	0.303	<0.001	Increased over time
Pb-D*	-0.566	<0.001	No change over time
Pb-T	-0.040	0.390	No change over time
Se-D*	-0.297	<0.001	No change over time
Se-T*	-0.653	<0.001	No change over time
Zn-D	-0.044	0.342	No change over time
Zn-T	0.028	0.549	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.

D – Dissolved fraction, T – Total, LOR - Limit of Reporting

4.9 Sediment Contributions to the River System

Calculating the annual sediment budget for the Strickland River system and distinguishing between mine-derived and natural inputs is complex because it relies on a large number of factors that vary spatially and temporally across the numerous sub-catchments of the Porgera – Lagaip – Strickland River basins. These include rates of erosion and sediment delivery to the channel network, rainfall and corresponding river flow that influence rates of sediment transport and sediment deposition, and mine-related activity including incompetent waste rock and tailings discharge rates.

Acquiring the datasets required to develop an accurate sediment balance over such a large area on an annual basis is extremely challenging in practice and, ideally, would require simultaneous high-frequency (hourly) sampling throughout the length of the river.

The PJV method for calculating the annual sediment budget is to use a multiple lines-of-evidence approach using the best available datasets for that year, and relevant historical data. In addition, the 30-year documented history of the dynamics of the erodible waste rock dumps and the associated response of the river system are drawn upon to inform the annual assessment. This approach is considered adequate for impact assessment purposes. In summary, the key data elements that inform the annual review of sediment delivery and transport are:

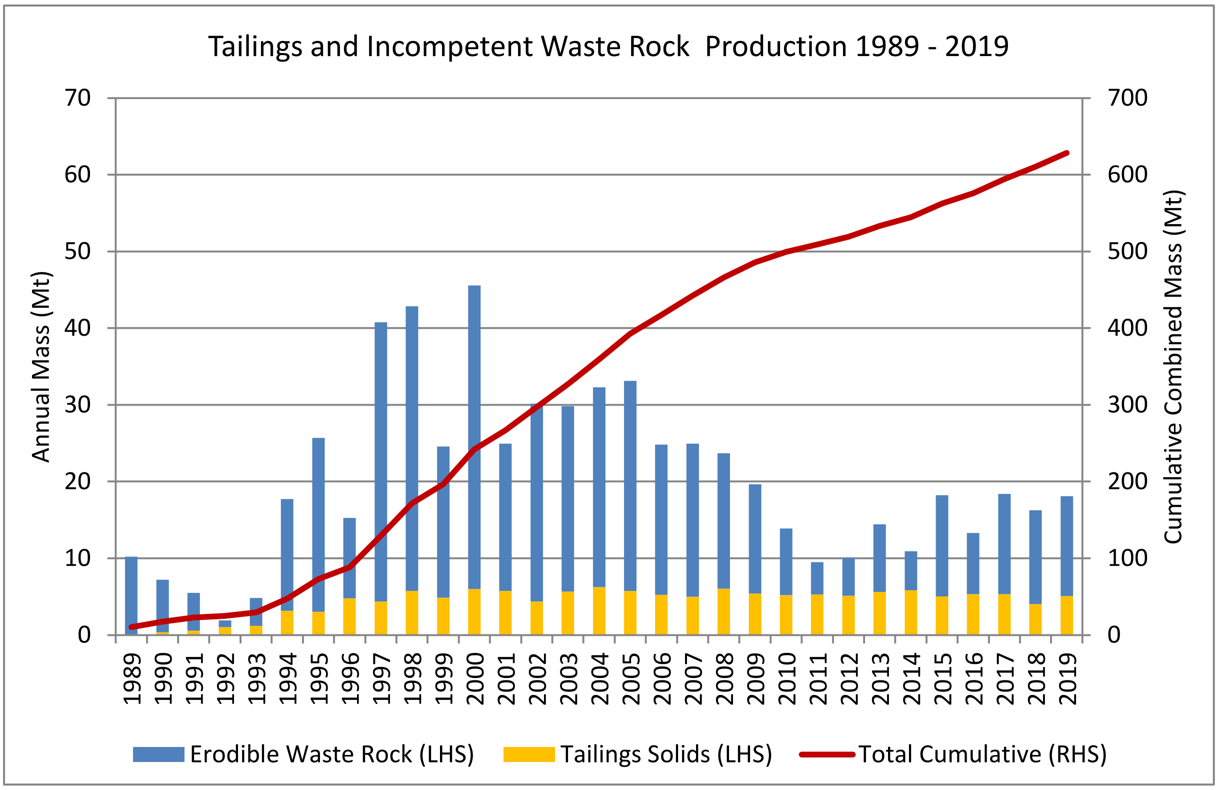
- Discharge of sediment from the toes of the erodible dumps. This is largely controlled by the fluvial action of the Kaiya River (Anjolek erodible waste rock dump) and Pongema River (Anawe erodible waste rock dump), but is also influenced by existing dump morphology, rainfall and flow rates and land sliding activity along valley walls. The loss of sediments from the dumps is best calculated from a mass-balance by using UAV survey which is typically undertaken on an annual basis. A long history of survey data and targeted studies indicate that the export of sediment from the erodible waste rock dumps does not vary greatly on a year to year basis and is limited by the sediment transport capacity of the Pongema and Kaiya Rivers.
- Tailings discharge. This is relatively constant from year to year. A small proportion of tailings are assumed to be retained within the tract of Anawe erodible waste rock dump.
- TSS and flow data. The best available data are derived from the monthly compliance sampling at SG3 and are sufficient to provide a defensible estimate of TSS load at that point in the river.
- Historical datasets including particle size distributions, TSS concentration and flow, observational data on dump behaviour, observations on river impacts and recovery during periods of operational shutdown or low waste placement rates. It should be noted PJV plan to undertake a study to update the data presented in Table 4-9, and this is included in the recommendations of this report.
- Results from targeted studies such as mine sediment tracing which allow independent estimates of the proportion of mine-derived sediment present at specific points in the river.
- Expert review to ensure the results for a particular year are realistic and defensible.

As discussed previously, the volume of mine-derived waste exported to the downstream river system does not vary greatly from year to year as the tailings discharge rate is relatively constant, and the removal of waste from the erodible waste rock dump toes is limited by rainfall and the transport capacity of the Kaiya and Pongema Rivers.

The quantity of incompetent waste rock placed in the erodible dumps over the period of mine operation and the quantity of tailings produced by the mine are summarised in Table 4-8. Figure 4-55 presents the yearly and cumulative quantity of incompetent waste rock and tailings produced by the mine.

Table 4-8 Summary of incompetent waste rock and tailings disposal tonnages in 2019 and 1989 - 2019

Discharge Location	Total for 2019 (Mt)	Total 1989 – 2019 (Mt)
Anawe erodible dump	2.3	240
Anjolek erodible dump	10.7	252
Tailings discharge (dry solids)	5.1	136
TOTAL	**18.1**	**629**



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

Figure 4-55 Production of incompetent rock and tailings 1989-2019

These figures, however, do not represent the amount of sediment contributed to the river system each year from the tailings and erodible dumps.

The tailings are discharged across the Anawe erodible dump and as a result a small fraction of the tailings solids settles along the body of the dump and is not transported into the river system.

A minor proportion of sediment contribution from the erodible dumps occurs via surface erosion and failure across the body of dumps driven by the creeks and minor drainage pathways which traverse the body of the dump. The predominant mechanism contributing sediment to the river system from the erodible dumps is erosion and failure of dump material where the toes of the dumps are intersected by higher flowing rivers (specifically the Pongema River and Kaiya River). Sediment eroded in this way is entrained in the river flows and transported downstream. The dominant factors for each of these mechanisms are rainfall, river flow rate and particle size distribution of the dumped material, rather than the volume of material being dumped at the head of the dump.

The volume of sediment contributed to the river system each year is estimated based on the historical estimates of particle size distribution and an annual survey of the erodible dumps which measures changes to dump surface area and volume.

A summary of the various estimates of particle size distribution for the combined Anawe and Anjolek dump toes is presented in Table 4-9 which also shows the adopted size distribution used for the purposes of sediment transport calculations.

It was assumed that 5% of all tailings discharged are trapped and stored in the dump and that, of the tailings leaving the dump, a further 5% is lost to long-term storage (bed and bars) between the dump toe and SG3. While these are arbitrary figures and difficult to verify, they are considered reasonable based on professional judgement.

Table 4-9 Estimates of particle size distribution of material sampled at erodible dump toe

Reference	Silt (%)	Sand (%)	Gravel (%)
1. CSIRO review (1995)	58	27	15
2. PJV 1995 samples (average)	30	30	40
3. Anawe toe 1997 samples (average)	5	35	60
4. Black Sed. Accelerated Weathering Tests	72	20	8
5. Davies et al. (2002)	76	11	13
Mean (1, 2, 4 and 5)	**59**	**22**	**19**

Long-term survey data (2002-2019) and mass-balance calculations for the dumps were used to indicate that approximately 60-70% of erodible waste rock input has been lost downstream as a long-term average. More recent survey data, as of 2019 (Anawe) and 2018 (Anjolek), indicate that the amount of material exported downstream since 2010, expressed as a percentage of the amount of material dumped, was approximately 75% for Anawe and 108% for Anjolek. This partly reflects the lower rates of dumping in recent years, while there has still been consistent erosion of material from the dumps by river flows. The data also indicate that over the long term, the rate of erosion at Anjolek has exceeded the rate of sediment accumulation.

The data analysis described above is based on a simple mass balance which reconciles the year-to-year volume change to each dump, and the amount of waste placed at the tip-heads. This method does not necessarily account for the amount of sediment from landslides that may account for dump volume change, or basal lowering or scouring of colluvium at the base of the dumps. Also, it is possible that some landslide inputs may discharge directly downstream as sediment load and would not be accounted for in the mass balance.

Estimates of the rates of sediment loss from the dumps are summarised in Table 4-10 which also shows that the estimated average annual load of sediment that is transported downstream is 9.4 Mt/y based on survey data since 2010. This appears to be a reasonable estimate and compares well with the estimated suspended load at SG1 of approximately 10 Mt/y, based on historical measured flow and TSS data.

Table 4-10 Summary of long-term dump mass balance from survey data

Dump	Proportion of total dumped material released based on long term survey data since 2002 (%)	Median downstream transport rate since 2002 (Mt/y) (Total mass exported downstream from survey data divided by number of years between survey)	Downstream transport rate since 2010 (Mt/y) and percentage of dumped material released (%)
Anjolek	57	3.0	4.4 (108%)
Anawe	64	5.8	5.0 (75%)
Total	**NA**	**8.8**	**9.4**

Based on the figures above, Table 4-11 presents estimates of suspended sediment discharge from the SML for both tailings and waste rock in 2019, based on the most recent survey data for Anawe in late 2019, and 2018 survey data for Anjolek. It should be noted that a level of inherent uncertainty exists within the survey data on a year to year basis due to the large area of the dump, difficult terrain in which the survey is conducted and changes to survey equipment and personnel from year to year. Therefore, to account for this uncertainty, the sediment discharge rate from the erodible dumps is based on the average volume change recorded since 2010.

Table 4-11 Estimate of sediment discharge from erodible dumps and tailings during 2019

Source	Total Sediment Discharged from Dumps (Mt/y)	Suspended Sediment Component (Mt/y)	Assumptions
Erodible dumps	9.4	5.5	Assumes 59% (silt fraction) travels as suspended load
Tailings	5.03 (5.3 x 0.95)	4.8 (5.03 x 0.95)	Assumes 95% of tailings is transported to the river system and 5% remains stored in Anawe dump
TOTAL 2019	**14.4**	**10.3**	

4.10 Other Discharges to Water

4.10.1 Treated sewage effluent

The total volume of treated sewage effluent discharged from the five treatment plants that service the mine site and accommodation camps are shown in Figure 4-56 and confirms that discharge volumes from all STPs were within the respective environment permit limits.

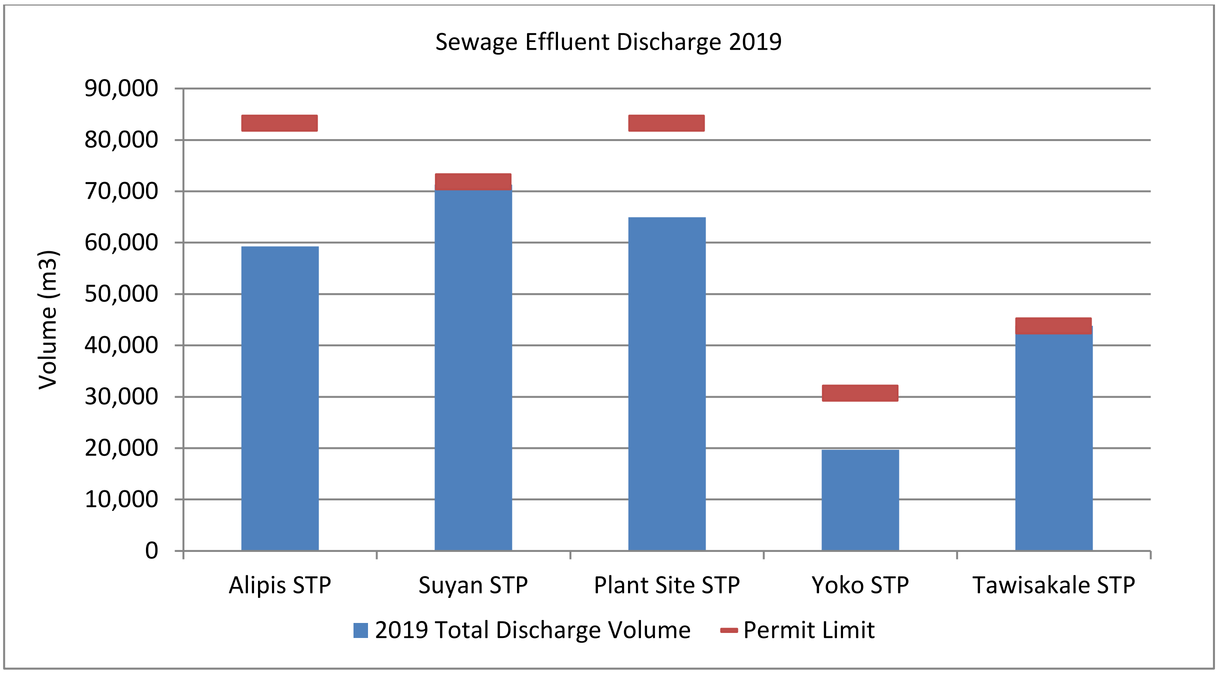


Figure 4-56 Total annual discharge volumes of treated sewage for 2019

The quality of the discharge from each STP is monitored for TSS, BOD_5 and faecal coliforms. The results of monitoring in 2019 are shown in Figure 4-57 to Figure 4-59 respectively. Operation of the sewage treatment plants consistently achieved compliance with the TSS criterion of 30 mg/L throughout the year except for four short-term excursions slightly above the permit limit at Alipis, Yoko and Suyan STPs. All plants achieved compliance with the BOD_5 and faecal coliform criteria throughout the year.

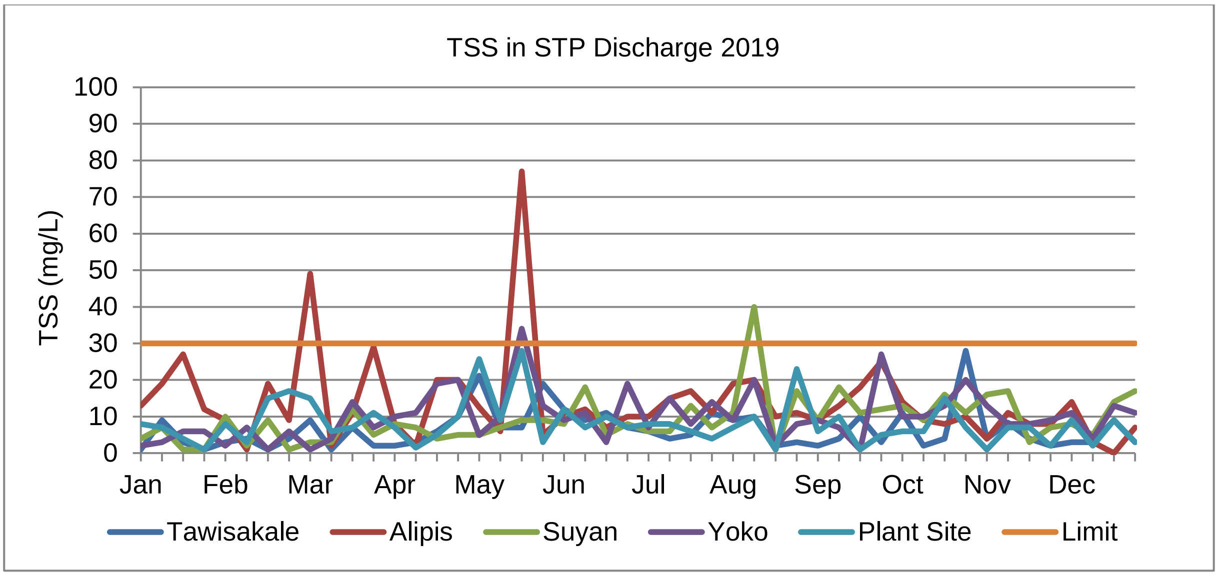


Figure 4-57 Average monthly TSS concentration in treated sewage discharge in 2019

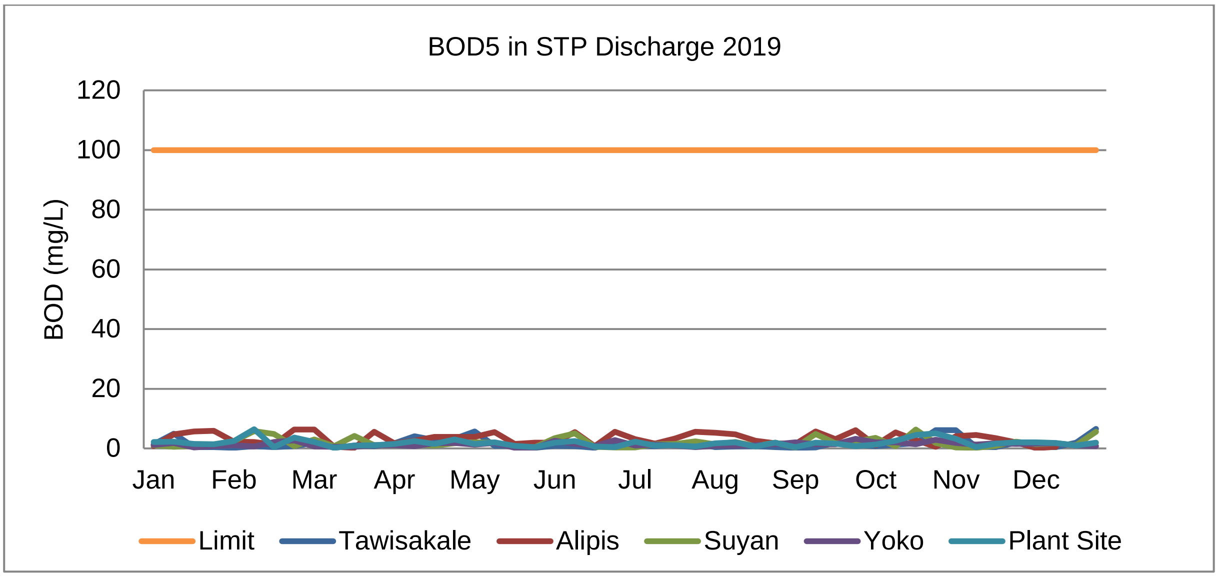


Figure 4-58 Average monthly BOD$_5$ concentration in treated sewage discharge in 2019

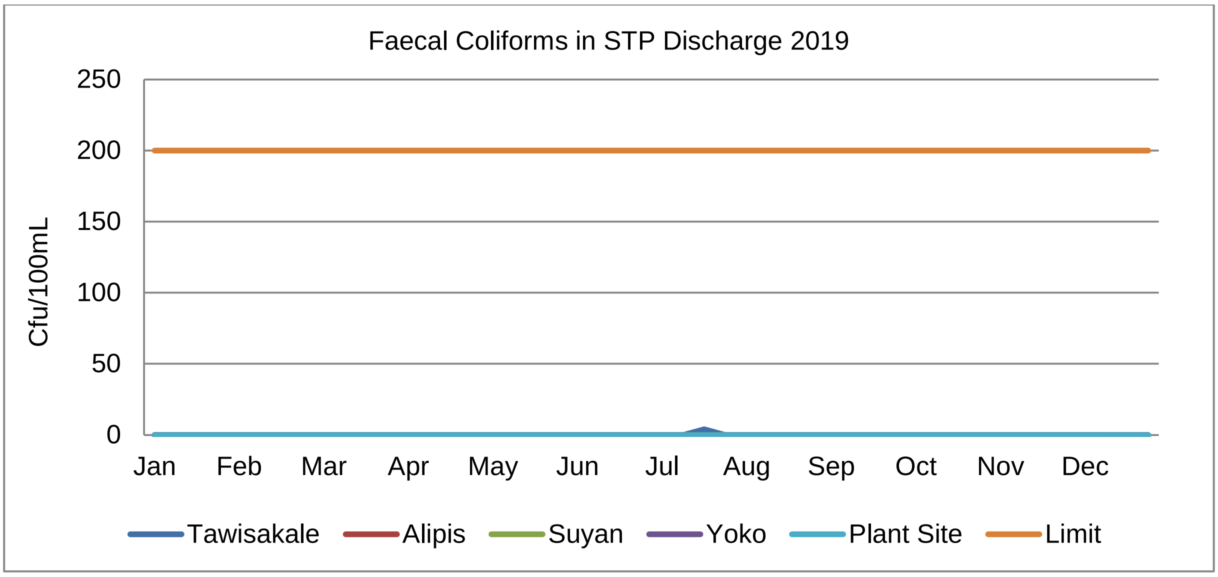


Figure 4-59 Average monthly faecal coliform count in treated sewage discharge 2019

4.10.2 Oil/water separator effluent

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

Figure 4-60 shows monthly average hydrocarbon concentrations from oil-water separators and a local creek, compared against the internal site-developed target of 30 mg/L.

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.

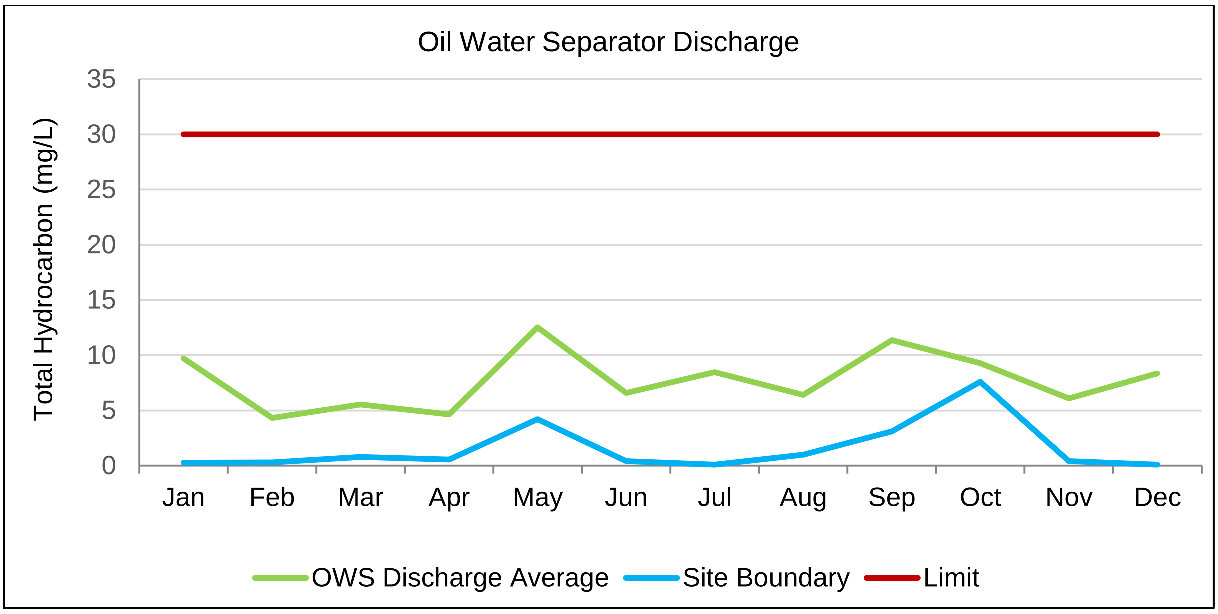


Figure 4-60 Average monthly total hydrocarbon concentrations in oil-water separator discharges in 2019

4.10.1 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.

4.10.1.1 Contact runoff volumes

Table 4-12 shows the estimated volume of contact runoff from land disturbed by mining operations. It is impractical to measure runoff volumes and these have been estimated from rainfall and catchment areas. The total volume of contact run-off increased during the year compared to the previous year as a result of improvement made to the discharge calculations but the volume remained well below the permit limit.

Table 4-12 Estimated volumes of contact runoff from mine lease areas 2019

Location		Total Rainfall run off 2019 (Mm^3)	Permit Limit (Mm^3/y)
Starter Dump A (SDA) (DP3)		0.8	1.8
Civil crusher to Kogai Creek (DP4)		0.05	0.1
Kogai waste dump to Kogai Creek (DP5)		21.6	1,680
Open Pit and UG Mine drainage tunnel to Kogai Creek (DP6)		8.9	12.1
Anawe stable dump to Wendoko Creek (DP7)		3.6	4.5
Runoff from Hides to a tributary of the Tagari River (DP16)		0.04	0.1
	TOTAL	**34.9**	**1,700**

4.10.1.2 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 4-13 identifies the land uses within the contributing catchment for each monitoring site and the locations of the sites are shown in Figure 4-61.

Table 4-13 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
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
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
Wendoko Creek downstream of Anawe Nth stable dump	Competent waste rock dump
Yakatabari Creek downstream of 28 Level discharge	Underground mine Workshops Sewage treatment plant Hydrocarbons substance storage
Yunarilama/Yarik portal	Open cut mine Underground mine

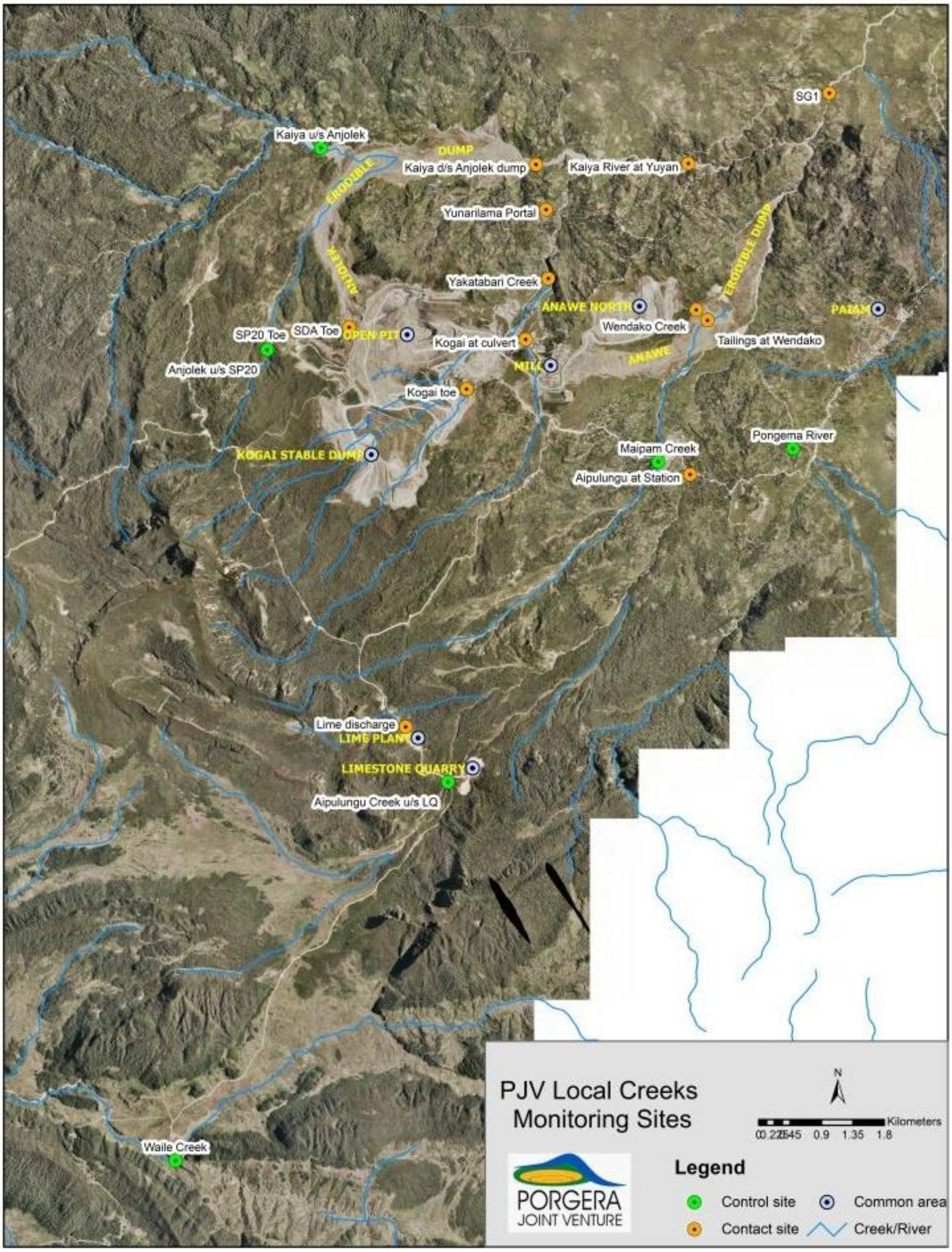


Figure 4-61 Mine contact runoff sampling location

Annual median values from monthly monitoring conducted in 2019 at mine contact runoff sites are shown in Table 4-14, amber highlight indicates values that exceeded or were not significantly different from the upper river TV. Samples were not collected from SDA Toe during 2019 due to community and security issues. Electrical conductivity of water discharged from all contact runoff sites exceeded upper river TV. Runoff from Kogai Stable Dump Toe and Wendoko Creek downstream of Anawe Nth, which receives runoff from competent waste rock dumps, exhibited elevated concentrations of dissolved cadmium, chromium and zinc. The water quality at these sites is typical of neutral mine drainage and indicates that oxidation/reduction and neutralisation are occurring within the waste rocks dumps 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 and dissolved chromium and copper. 28 Level exhibited elevated dissolved chromium and zinc and Yunarilama at Portal, which discharged from underground mine, exhibited elevated TSS and dissolved silver.

A summary of trends of water quality parameters between 2010 and 2019 in contact runoff is presented in Table 4-15. Details of the statistical analysis are shown in APPENDIX C. 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 at SDA Toe, Kogai Culvert, and Lime Plant. These sites also showed trends of increasing concentrations of total metals, indicating the presence of mine-derived mineralised sediment.

The median concentrations of WAE metals and total metals in sediment in runoff from the mine areas are shown in Table 4-16. Of note are elevated cadmium, WAE lead and WAE 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 4-14 Contact water quality 2019 median concentrations (µg/L except where shown)

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	7.6	NS	7.9	7.8	7.7	11.7	7.8	7.5	7.6
EC#	228	717	NS	274	815	1,750	1,157	2,130	635	1,900
WAD-CN*	NA	0.20	NS	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Sulfate*	NA	174	NS	58	340	800	3.0	1,070	142	700
ALK-T**	NA	131	NS	85	149	239	461	165	121	140
TSS*	2,837	67	NS	2,500	620	99	97	10	1,700	11,500
Hardness**	NA	376	NS	95	439	980	250	1,198	292	403
Ag-D	0.05	0.01	NS	0.02	0.01	0.01	0.01	0.01	0.01	0.01[1]
Ag-T	NA	0.27	NS	1.3	3.5	0.27	0.01	0.07	20	23
As-D	24	3.1	NS	1.1	1.6	0.89	0.13	0.87	9.0	2.2
As-T	NA	18	NS	42	54	4.9	0.66	1.3	105	240
Cd-D	0.34	0.07	NS	0.1	0.15[1]	0.91	0.05	1.1	0.05	0.06
Cd-T	NA	0.32	NS	2	5.2	2.0	0.051	1.0	7.4	12
Cr-D	1.0	0.48[1]	NS	0.47[1]	0.28	0.32[1]	3.6	0.31	0.82[1]	0.67
Cr-T	NA	1.3	NS	68	34	2.6	13	0.12	68	410
Cu-D	1.4	0.54	NS	1.0	1.1[1]	0.62	0.80[1]	0.45	1.1	0.4
Cu-T	NA	2.2	NS	62	50	4.6	5.8	0.41	110	245
Fe-D	75	33	NS	13	12	10	5.4	6.9	15	13
Fe-T	NA	2,040	NS	91,900	35,100	2,570	1,940	200	54,900	231,000
Hg-D	0.60	0.05	NS	0.10	0.06	0.05	0.05	0.05	0.06	0.06
Hg-T	NA	0.05	NS	0.27	0.34	0.07	0.05	0.05	1.4	2.3
Ni-D	21	3.1	NS	0.9	1.3	2.2	0.50	1.6	1.3	2.1
Ni-T	NA	5.3	NS	73	31	4.3	2.4	1.7	63	255
Pb-D	7.3	0.46	NS	0.38	1.1	1.3	0.14	0.13	0.78	0.35
Pb-T	NA	8.9	NS	220	320	35	0.81	0.4	805	1,075
Se-D	11	0.20	NS	0.45	0.20	0.21	0.2	0.39	0.20	1.1
Se-T	NA	0.20	NS	1.9	0.69	0.30	0.2	0.41	1.1	6.3
Zn-D	20	27	NS	6.2	16[1]	170	1.8	370	4.1	5.5
Zn-T	NA	93	NS	520	800	290	10	345	1,470	2,675
🟧	> 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 2019, [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 is found to be not statistically significantly different from the TV

Table 4-15 Trends of water quality contact runoff 2010 - 2019 (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 4-16 Contact Sediment Quality 2019 median values (mg/kg dry, whole fraction)

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	1.0	NS	0.15	1.1	0.62	0.05	0.35	1.9	0.13
Ag-TD	NA	14	NS	1.4	9.6	6.3	0.05	1.1	7.5	1.5
As-WAE	20	20	NS	4.8	12	9.9	0.43	6.1	14	5.2
As-TD	NA	250	NS	59	130	170	1.9	57	104	52
Cd-WAE	1.5	2.2	NS	0.8	2.2	2.2	0.24	1.1	1.9	0.6
Cd-TD	NA	4.7	NS	2.7	5.6	10	0.3	2.6	6.1	2.8
Cr-WAE	80	9.0	NS	7.1	6.5	6.1	8.3	5.2	11	6.3
Cr-TD	NA	49	NS	22	32	45	14	21	71	23
Cu-WAE	65	14	NS	6.5	12	8.3	1.6	8.3	23	5.1
Cu-TD	NA	65	NS	35	48	78	3.3	26	78	33
Hg-WAE	0.15	0.01	NS	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Hg-TD	NA	0.82	NS	0.24	0.38	0.52	0.01	0.09	0.7	0.15
Ni-WAE	22	21	NS	11	8.9	8.6	1.9	7.2	14	8.5
Ni-TD	NA	51	NS	36	32	41	3.8	26	52	32
Pb-WAE	50	430	NS	110	270	420	1.8	54	285	95
Pb-TD	NA	500	NS	400	210	480	2.0	90	380	145
Se-WAE	0.15	0.14	NS	0.17	0.17	0.15	0.1	0.14	0.13	0.20
Se-TD	NA	0.77	NS	0.77	0.84	0.92	0.1	0.71	0.59	0.92
Zn-WAE	200	550	NS	170	440	340	11	200	395	129
Zn-TD	NA	1,520	NS	550	1,130	1,880	22	510	1,420	565

🟧 > UpRiv TV = Potential Risk

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

4.11 Point Source Emissions to Air

PJV monitors emissions from stationary sources at the mine site, the Lime Plant and at Hides Power Station every two years, the most recent sampling was performed in 2019. Papua New Guinea does not have legislation for controlling emissions to air so PJV has voluntarily set a target of complying with the relevant Australian Standards, which are the NSW Protection of the Environment Operations (Clean Air) Regulation 2010 and the Victoria State Environment Protection Policy (Air Quality Management) 2001. A comparison of results against the standards is presented in Section 7.8.

4.12 Greenhouse Gas and Energy

Figure 4-62 presents information on the average annual rate of carbon dioxide equivalents (CO_2-e) emissions per tonne of ore processed. The Porgera annual CO_2-e emission rate is higher than at other gold mining operations because of the high energy requirement for the pressure oxidation processing of ore in autoclaves. GHG emission increased by 1% in 2019 compared to 2018 due to use of the extra diesel generators onsite to generate power to support the mine's operations.

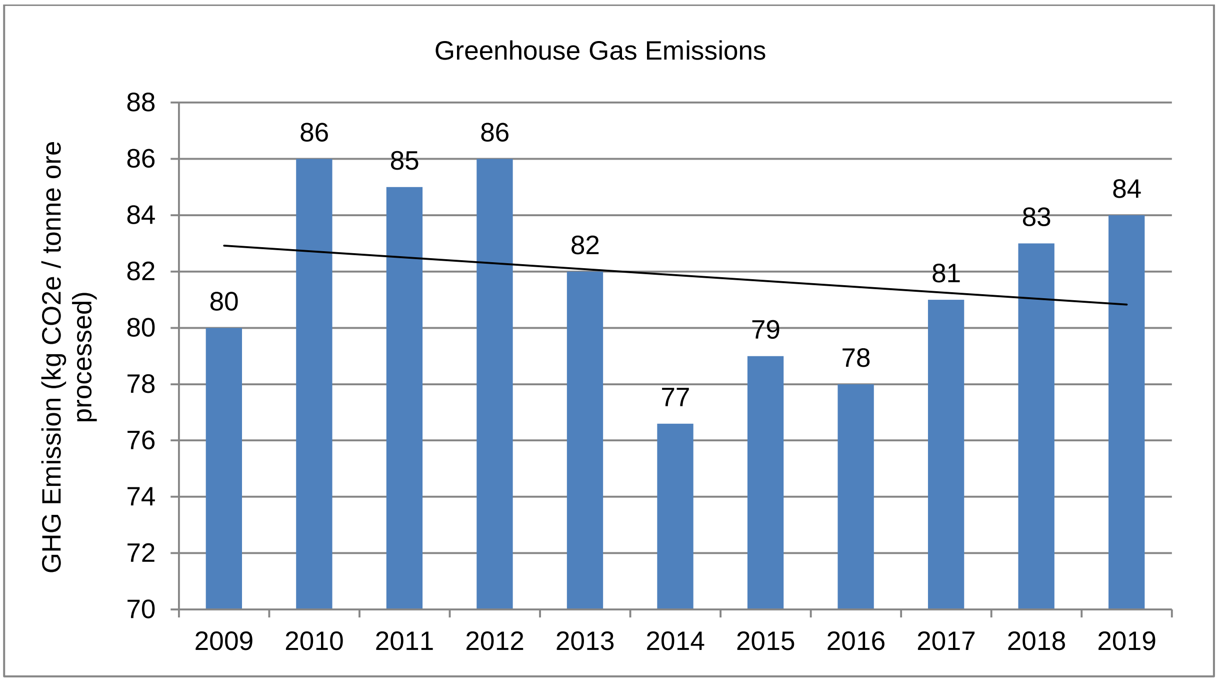


Figure 4-62 Energy efficiency 2009 – 2019

4.13 Non-mineralised Waste

Non-mineralised waste is all waste produced by the operation other than waste rock and tailings. Porgera has developed a Waste Management Plan that describes the methods for waste segregation, reuse, recycling or treatment for safe disposal. Figure 4-63 shows the proportion by volume of each type of waste produced at the mine site. Waste oil made up 26% of the non-mineralised waste in 2019, 100% of which is re-used as fuel for heating the lime kiln. Sewage Treatment Plant sludge is disposed of by land application at a reclaimed area of Kogai Waste Rock Dump. Scrap paper is shredded and used as mulch for hydroseeding in land reclamation. Scrap steel is disposed at an industrial landfill on Kogai Waste Rock Dump, while other high value metals and alloys are stored for sale to a recycling contractor. Combustible wastes are disposed by incineration at 1100°C and remaining materials are disposed to a landfill.

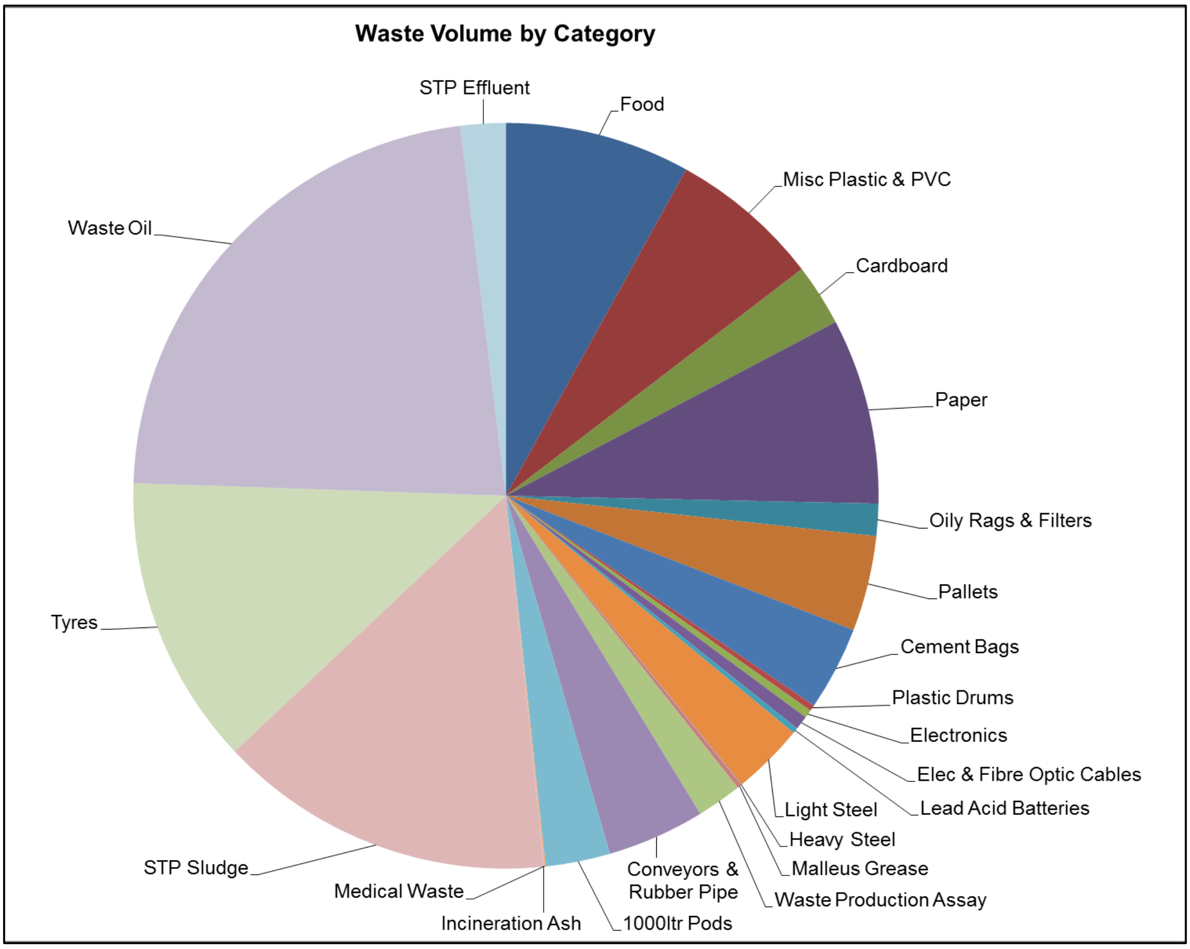


Figure 4-63 Non-mineralised waste production proportions by volume

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 AER is to determine how much change has occurred within the environment at reference sites adjacent to, but not affected by, the mine as opposed to change at sites downstream of the Porgera Mine (test sites). And also then, to determine how much of that change is caused by factors not related to the mining operation, and how much is caused by factors that are related to the mining operation.

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. 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 during 2019;
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 2019 and during 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, impact and performance assessments.

5.1 Climate

5.1.1 Strickland River catchment rainfall

Annual rainfall at stations in the upper, middle and lower Strickland River catchments is shown in Figure 5-1.

The upper catchment can broadly be described as the reach of river extending from the mine site down to SG2, the middle extends from SG2 down to SG3, and the lower from SG3 past SG5 (near Lake Murray) to the confluence with the Fly River.

In general terms, rainfall in 2019 was approximately 4.4% above the long-term mean in the upper reach, 3.4% below average in the middle reach (SG2, Ok Om and SG3) and 2.1% below average in the lower reach (SG4, SG5).

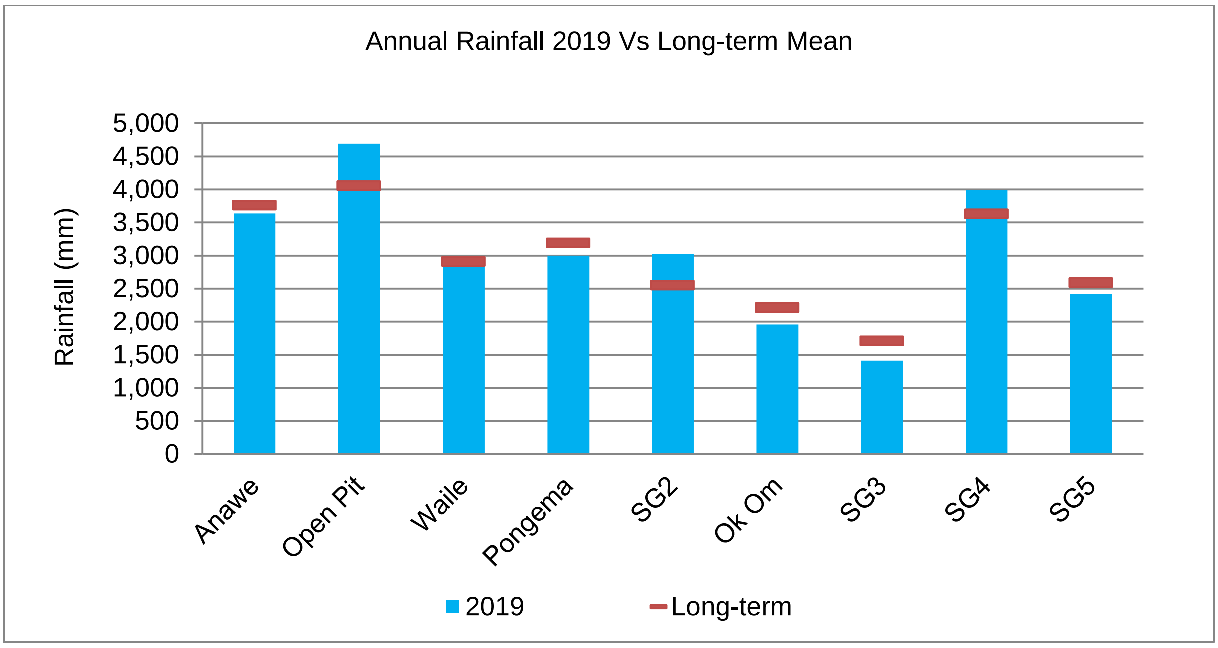


Figure 5-1 Comparison of annual rainfall (2019 data versus long-term mean) at sites in the Porgera – Lagaip-Strickland Catchment

5.1.2 Hydrological context

In the context of longer-term rainfall trends, Figure 5-2 shows the rainfall pattern of recent years at Anawe, the station with the longest period of record, plotted with the Pacific Decadal Oscillation (PDO). The PDO is a pattern of Pacific climate variability that shifts phases on at least inter-decadal time scale, usually about 20 to 30 years. The plotted lines represent the cumulative deviation of each year's rainfall total and PDO value from the overall mean of the dataset. To interpret the graph, a downward sloping line represents 'below-average' years, while an upward sloping line represents 'above average years'. This demonstrates that since 1997, rainfall was notably higher than the period 1974-1997 suggesting decadal scale variability. Statistically, the Mann-Kendall test run on the series of annual totals showed a significant increasing trend ($p<0.05$) while a Student's t-test for pre and post-2010 periods showed that annual rainfall totals for the period 2010-2019 were significantly higher than for the period 1974-2009 ($p<0.05$).

Figure 5-3 presents the PDO index and Anawe rainfall expressed as a ten-year moving average in order to identify trends more clearly. The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of latitude 20°N. During a 'warm' or 'positive' phase, the west Pacific becomes cool and part of the eastern ocean warms; during a 'cool' or 'negative' phase, the opposite pattern occurs. The PDO is strongly related to El Nino Southern Oscillation (ENSO) episodes but operating over much longer timescales. Negative ENSO events generally mean low rainfall for PNG, however, the Porgera rainfall also appears inversely correlated with the PDO on a decadal scale, although both indices are correlated with Anawe rainfall on a 10-year moving average basis. Although detailed analysis of rainfall trends is not the focus of this section, the analysis serves to highlight that rainfall (and, by inference, river flow and sediment transport) varies over both long and short-term timescales. An El Nino event is defined when the ENSO falls below -8, the average ENSO value in 2019 was -7.8 and is currently considered to be in a neutral phase.

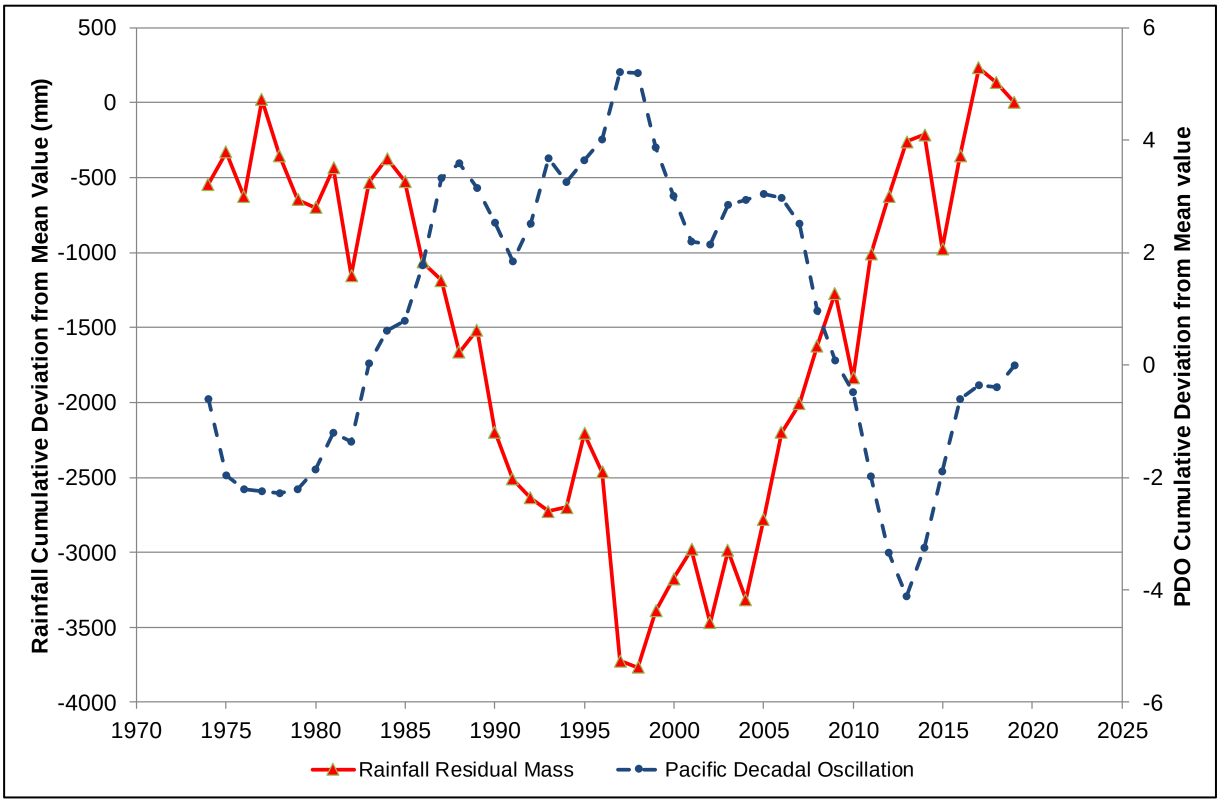


Figure 5-2 Residual mass plots Anawe rainfall station data

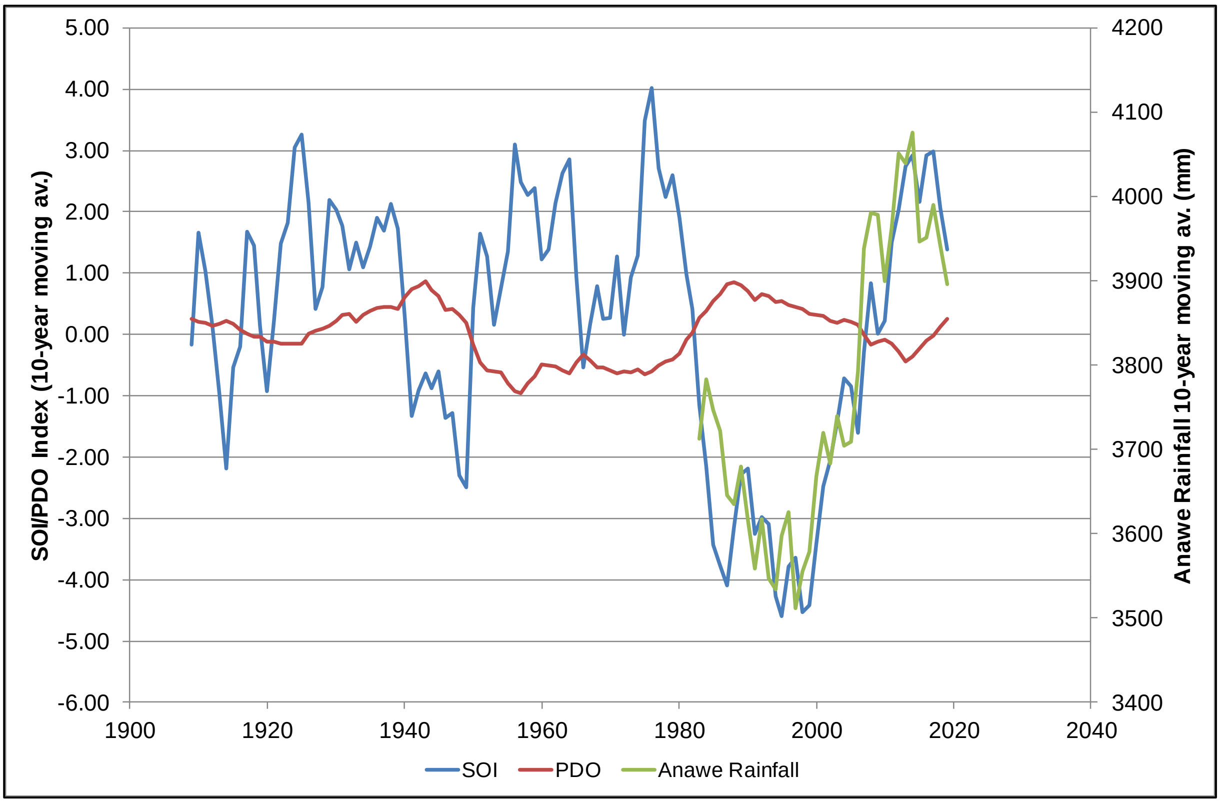


Figure 5-3 Anawe rainfall, SOI and PDO indices on 10-y moving average

5.1.3 Rainfall summaries

5.1.3.1 Anawe plant site

Meteorological data are measured continuously at Anawe Plant site. The parameters monitored are rainfall, temperature, humidity, evaporation, wind vectors, barometric pressure and solar radiation. Due to the influence of the surrounding mountains there is minimal seasonal variability in climate throughout the year at Porgera. Table 5-1 provides a summary of the meteorological data collected during the year.

Table 5-1 Summary of meteorological data recorded at Anawe Plant site during 2019

Parameter	Yearly total	Daily max	Daily min	Daily mean	Long-term daily mean
Rainfall (mm)	3,628	65.5	0.0	9.9	10.2
Max/Min Temp. (^{o}C)	-	27	13	-	-
Mean Daily Temp.(^{o}C)	-	27	13	17.5	16
Sunshine (h)	1,122	9.5	0.0	3.3	4.0
Evaporation (mm)	1,031	8.8	0.8	2.9	2.9
Wind run (km)	11,915	95	17	35	46

Figure 5-4 shows monthly total rainfall at Anawe in 2019 against long-term monthly means. Annual rainfall in 2019 was 3,628 mm on 314 wet days against a long-term mean annual total of 3,766 mm. The historical rainfall at Anawe is shown in Figure 5-5. The highest annual rainfall recorded at Anawe was 4,594 mm in 2011.

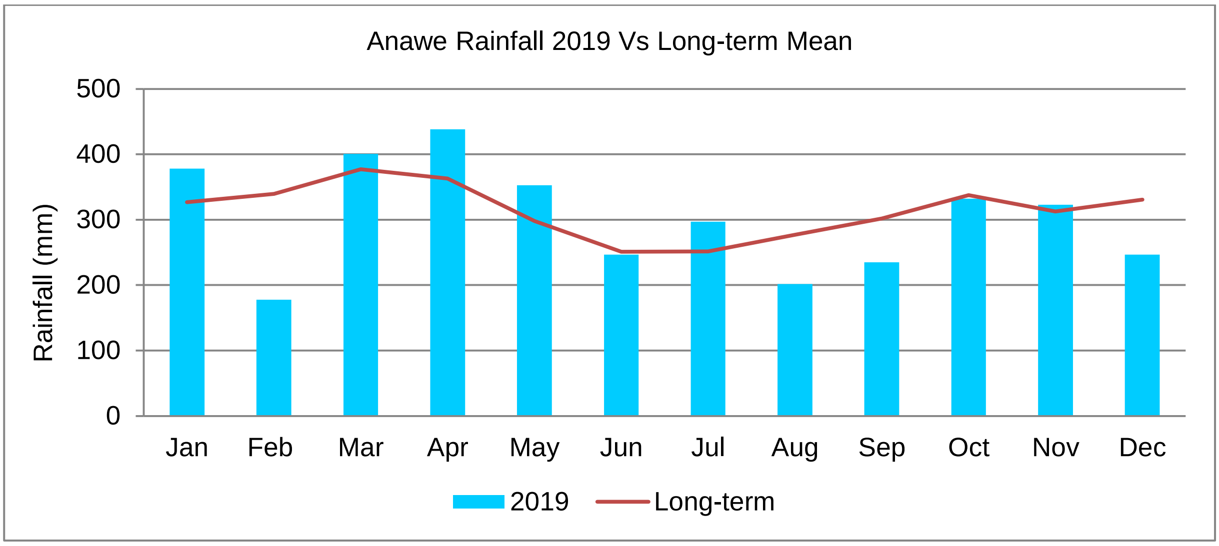


Figure 5-4 Monthly rainfall at Anawe Plant site during 2019 compared to long-term monthly means

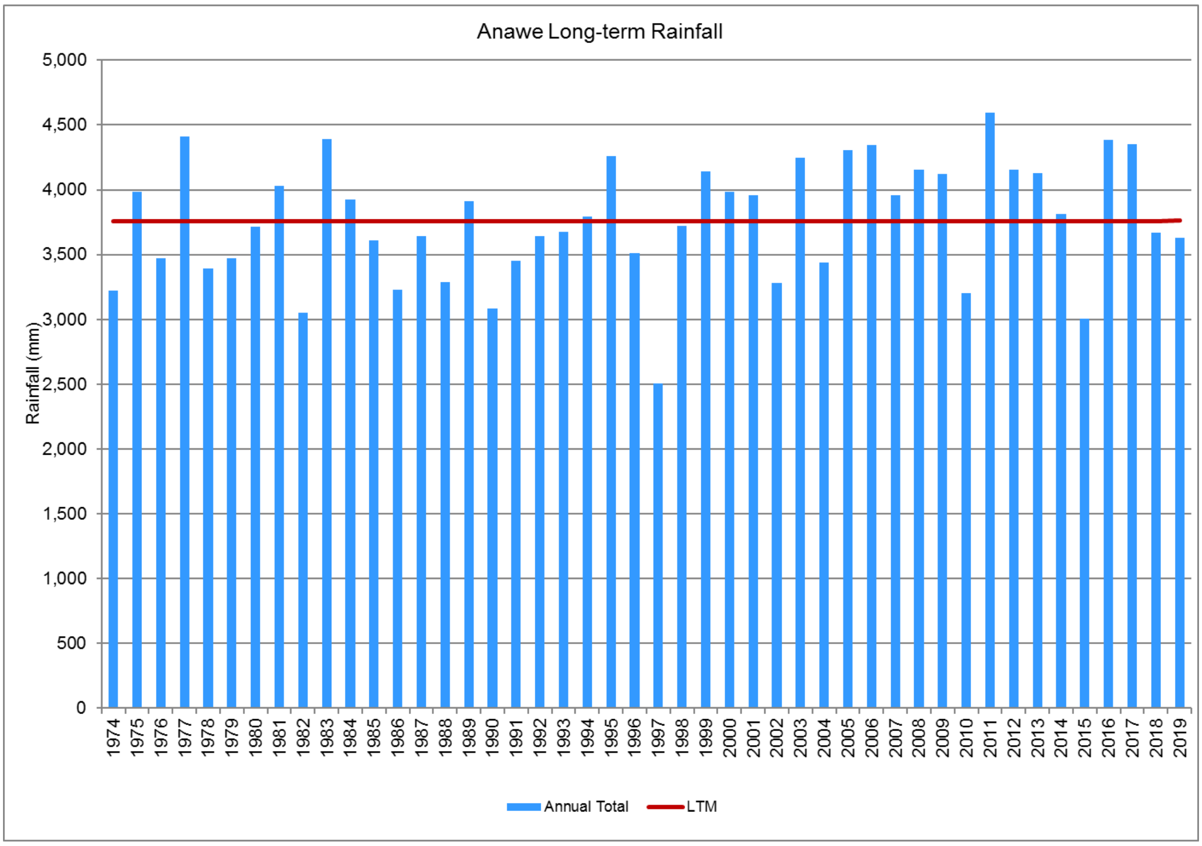


Figure 5-5 Comparison of annual total rainfall at Anawe Plant site with long-term mean (LTM) 1974 - 2019

5.1.3.2 Open pit

Figure 5-6 shows total monthly rainfall at the Open Pit during the year against long-term monthly means. Annual rainfall was 4,622 mm on 318 wet days. The long-term mean annual total was 4,057 mm. Figure 5-7 shows the historical annual totals.

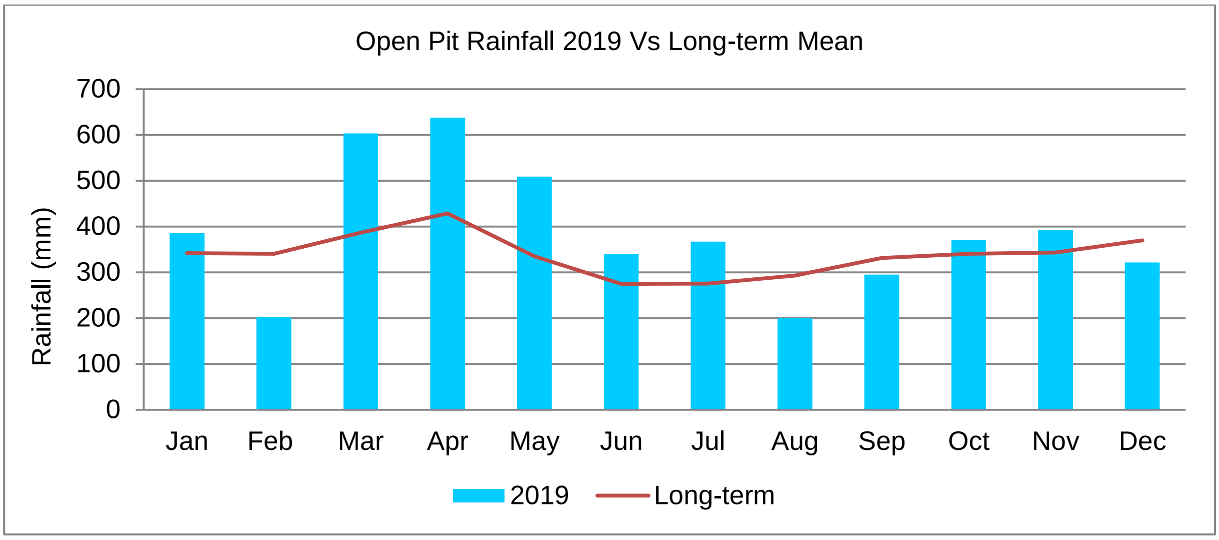


Figure 5-6 Rainfall at the Open Pit during 2019 compared to long-term monthly means

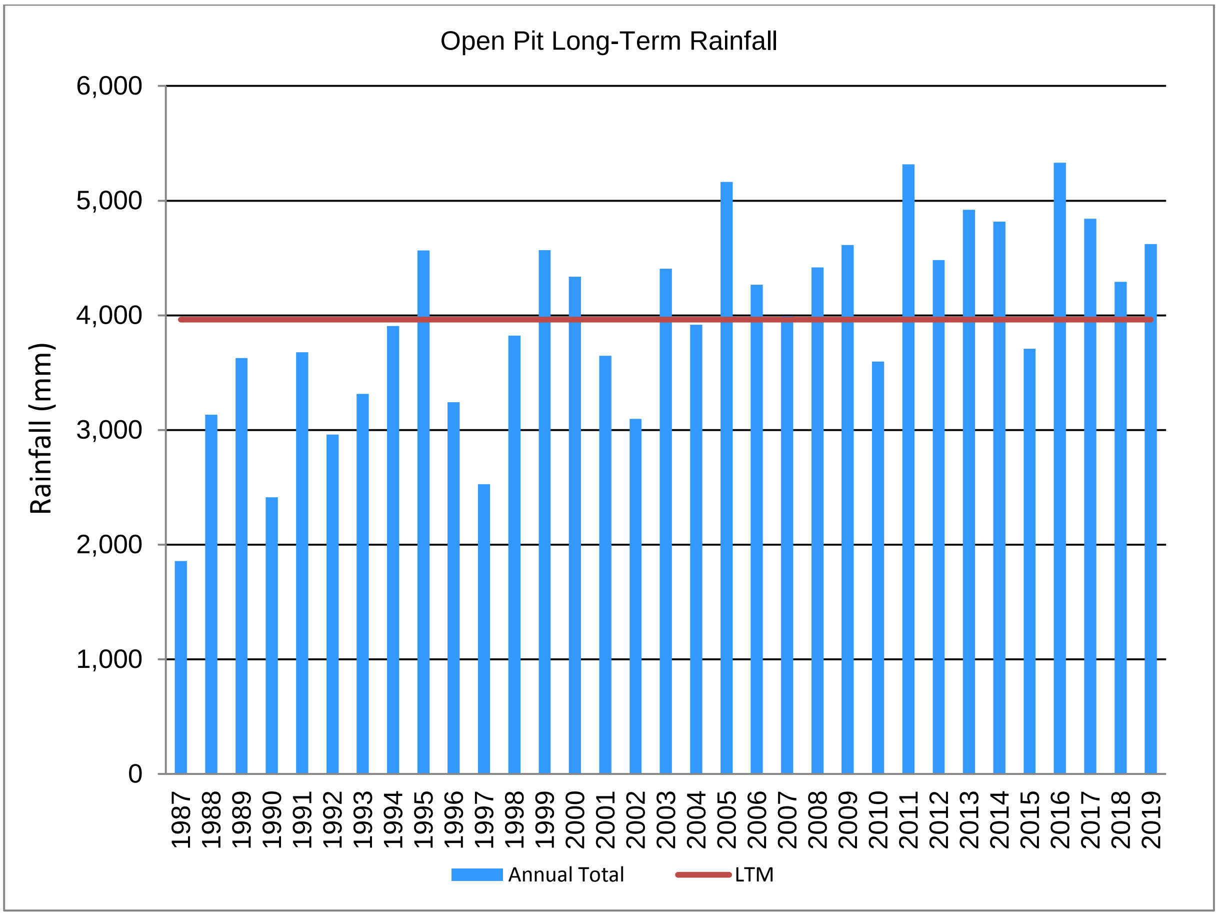


Figure 5-7 Comparison of annual total rainfall at Open Pit site with long-term mean (LTM) 1987–2019

5.1.3.3 Other Sites

Total annual rainfall for 2019, the number of wet days in 2019 and the long-term mean annual total rainfall at Waile Creek, Pongema, SG2. Ok Om, SG3, SG4 and SG5 are shown in Table 5-2 and Figure 5-8 to Figure 5-14.

Table 5-2 Other Rainfall Site Summary

Site	2019 Annual Total Rainfall (mm)	Wet Days in 2019	Long-term Mean Total Annual Rainfall (mm)
Waile Creek	3,133	318	2,907
Pongema	3,163	321	3,200
SG2	3,026	291	2,555
Ok Om	1,961	238	2,216
SG3	1,412	227	1,850
SG4	4,.038	257	4,038
SG5	2,422	217	2,497

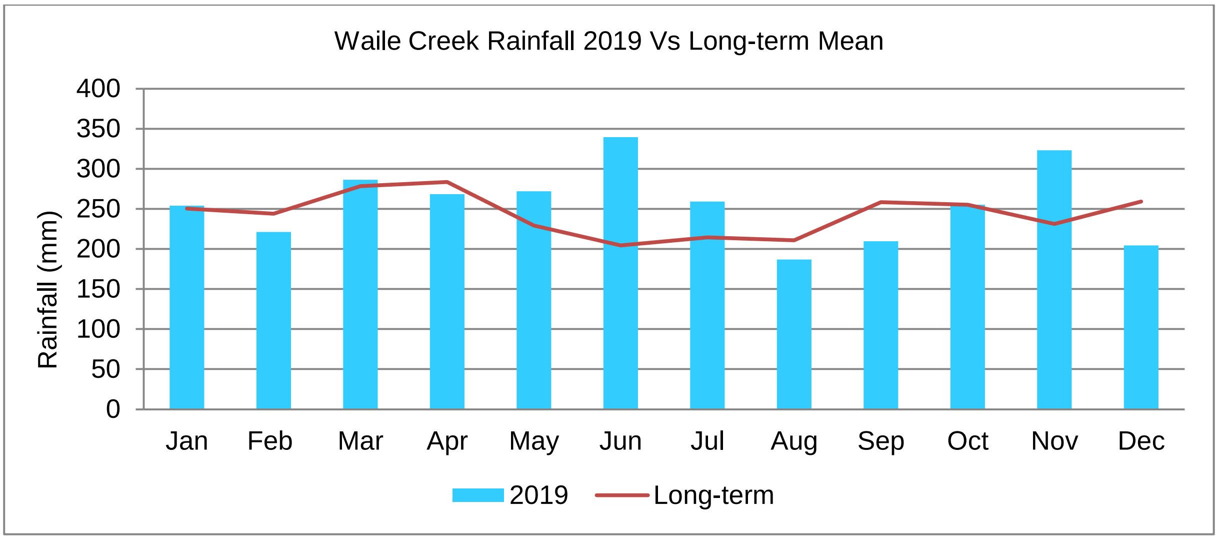


Figure 5-8 Rainfall at Waile Dam during 2019 compared to long-term monthly means

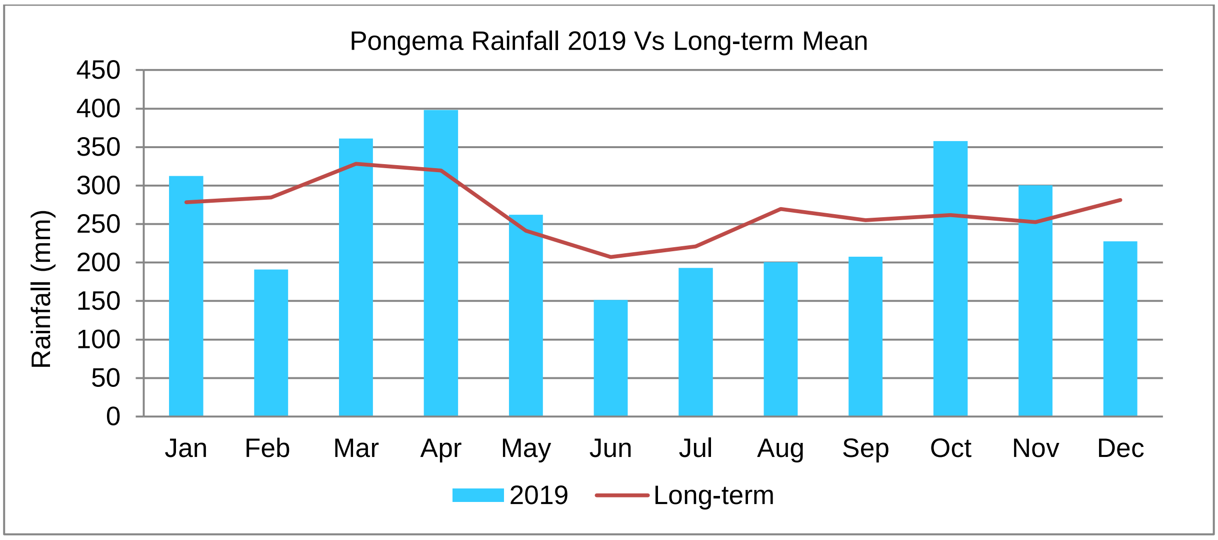


Figure 5-9 Rainfall at Suyan Camp during 2019 compared to long-term monthly means

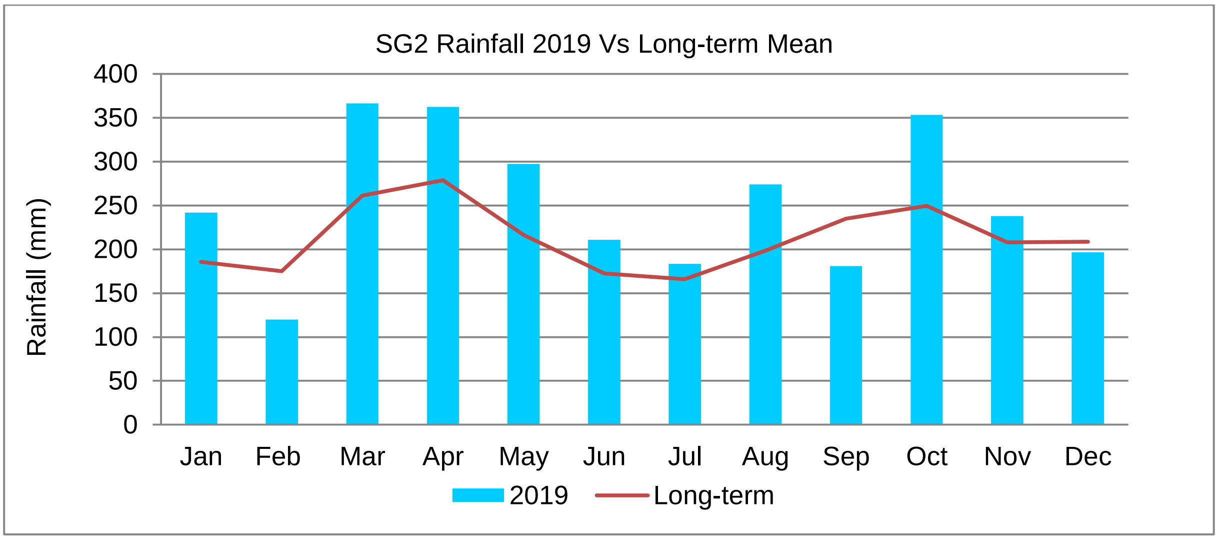


Figure 5-10 Rainfall at SG2 during 2019 compared to long-term monthly means

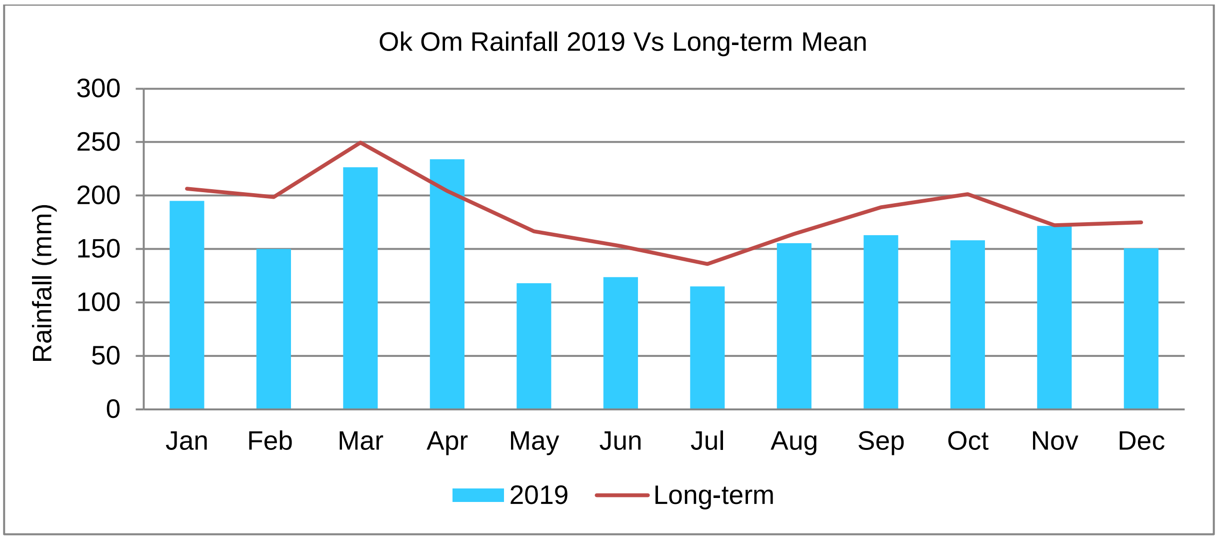


Figure 5-11 Rainfall at Ok Om During 2019 compared to long-term monthly means

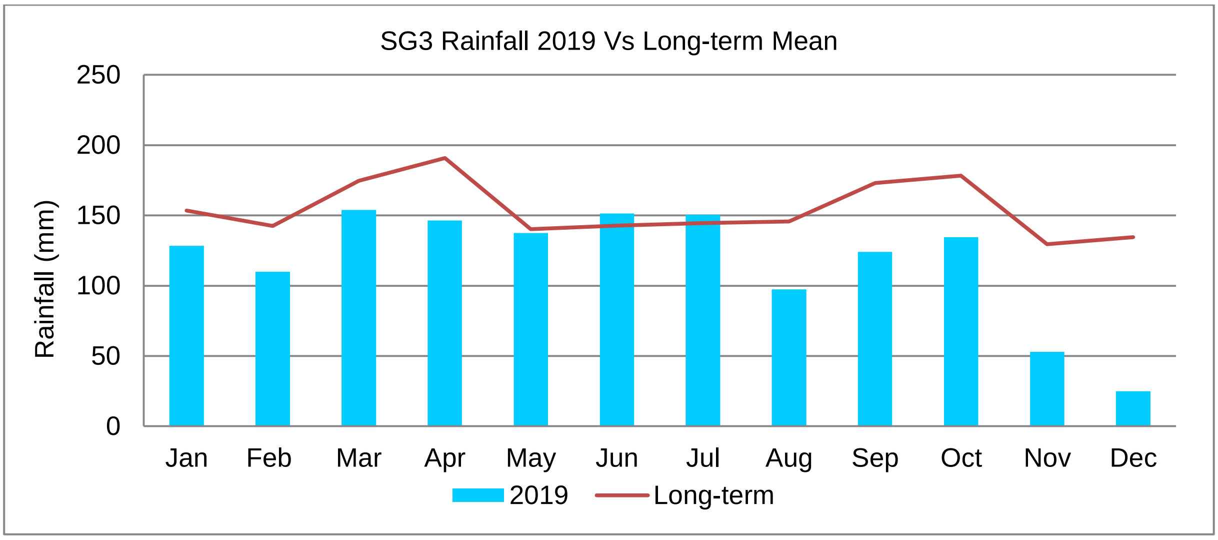


Figure 5-12 Rainfall at SG3 during 2019 compared to long-term monthly means

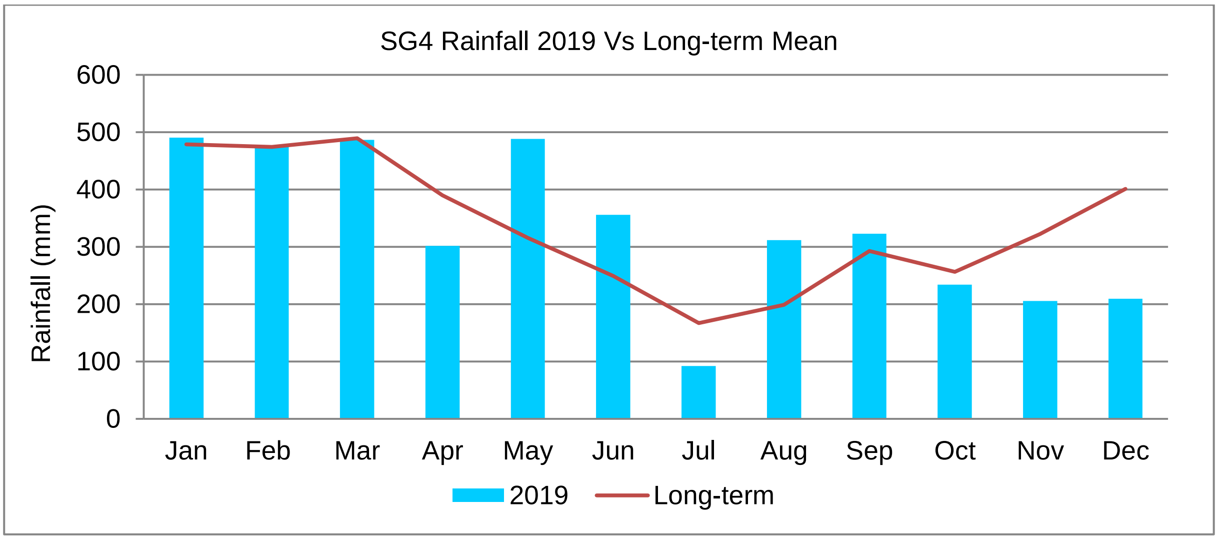


Figure 5-13 Rainfall at SG4 during 2019 compared to long-term monthly means

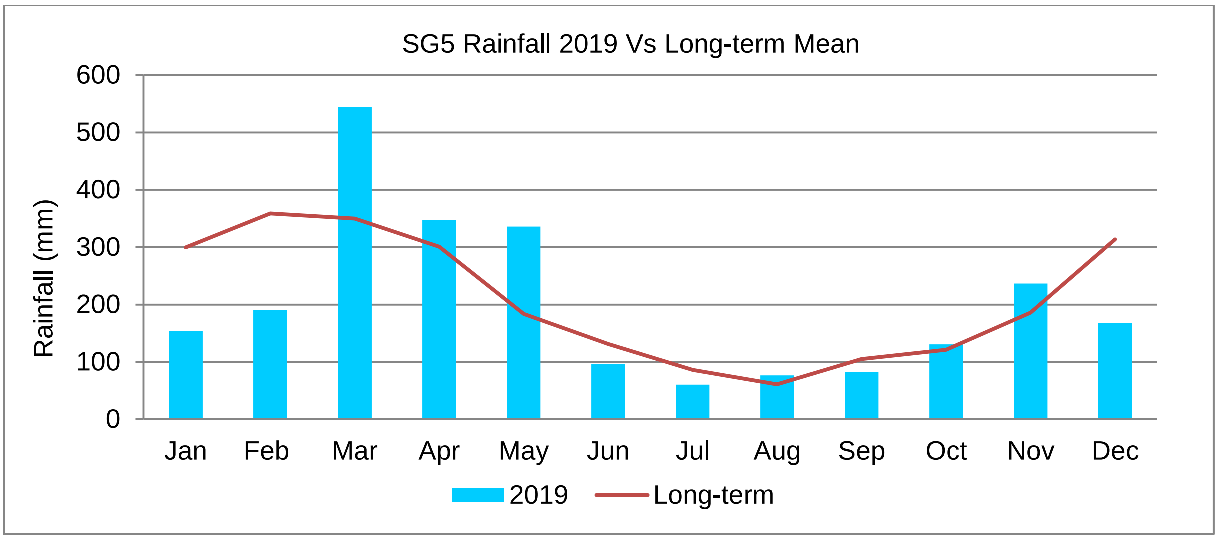


Figure 5-14 Rainfall at SG5 during 2019 compared to long-term monthly means

5.2 Hydrology

5.2.1 Strickland River Catchment

The river systems downstream of, and potentially impacted by, the mine are the Porgera, Lagaip and Strickland Rivers. From a hydrological perspective, these can be broadly grouped into three regions of interest; upper catchment (Porgera Valley), middle catchment (SG2 to SG3) and lower catchment (SG3 to lowlands / floodplain). The Ok Om monitoring site is a reference site and therefore not influenced by the mine.

In general, flows were estimated to be average in the upper catchment sites of Kogai at SAG Mill and Kogai at the culvert. In the middle region at SG2, flows were 23% above average, while flows at SG4 were 13% above average and at SG5 in the lower region flows were 17% above average.

A summary of annual river flow data is shown in Table 5-3, total annual river flow volumes at SG2, SG3, SG4 and SG5 from 1999 – 2019 are shown in Figure 5-15.

Table 5-3 Summary of flows in m^3/s for riverine stations in 2019

Station	Days lost 2019	Flow (m^3/s)		
		2019 Mean	2019 Min	Long-term Mean
Kogai @ Culvert	0	1.5	0.2	1.6
Lagaip @ SG2	0	274	156	220
Ok Om	0	181	67	143
Strickland @ SG3	0	792	367	761
Strickland @ SG4	0	2258	1,240	2,566
Strickland @ SG5	0	3,370	2,091	2,889

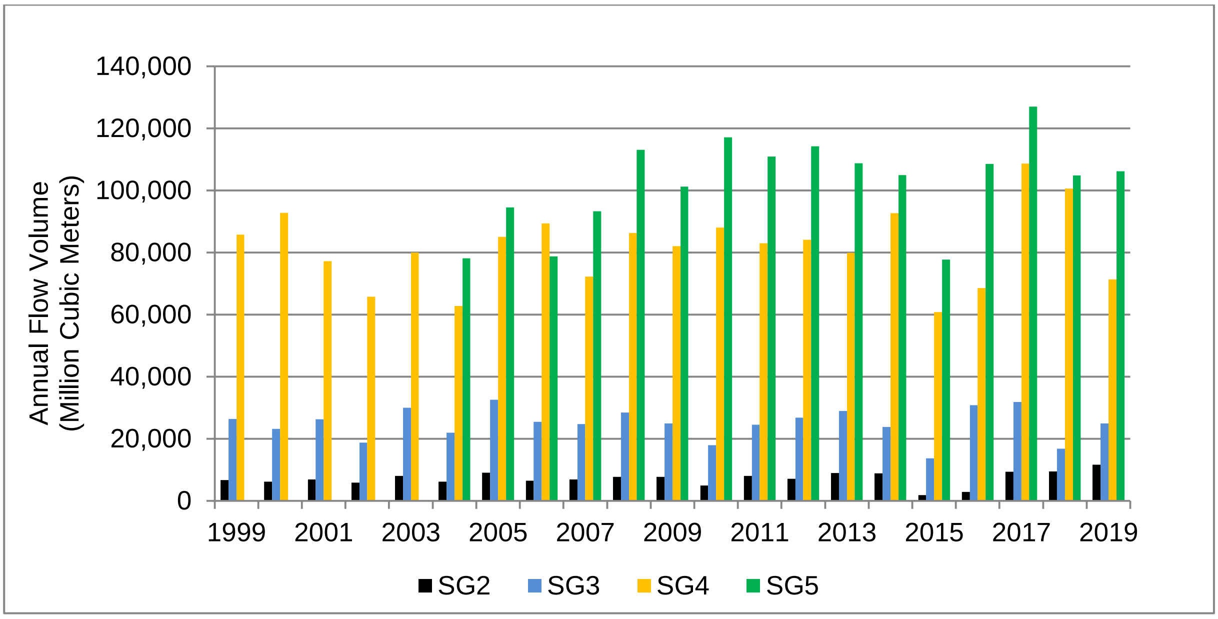


Figure 5-15 Total annual flow volumes for the main river gauging stations in 2019

5.2.2 SG3

Figure 5-16 shows the daily total flows for the year at SG3 while Figure 5-7 shows total monthly flows compared to long-term monthly averages. The total flow volume for 2019 at SG3 of 25,000 GL was approximately 14% above the long-term average of 21,908 GL. April had the highest monthly flow with 3,081 GL while December had the lowest with 983 GL, which is consistent with the rainfall pattern, shown in Figure 5-12.

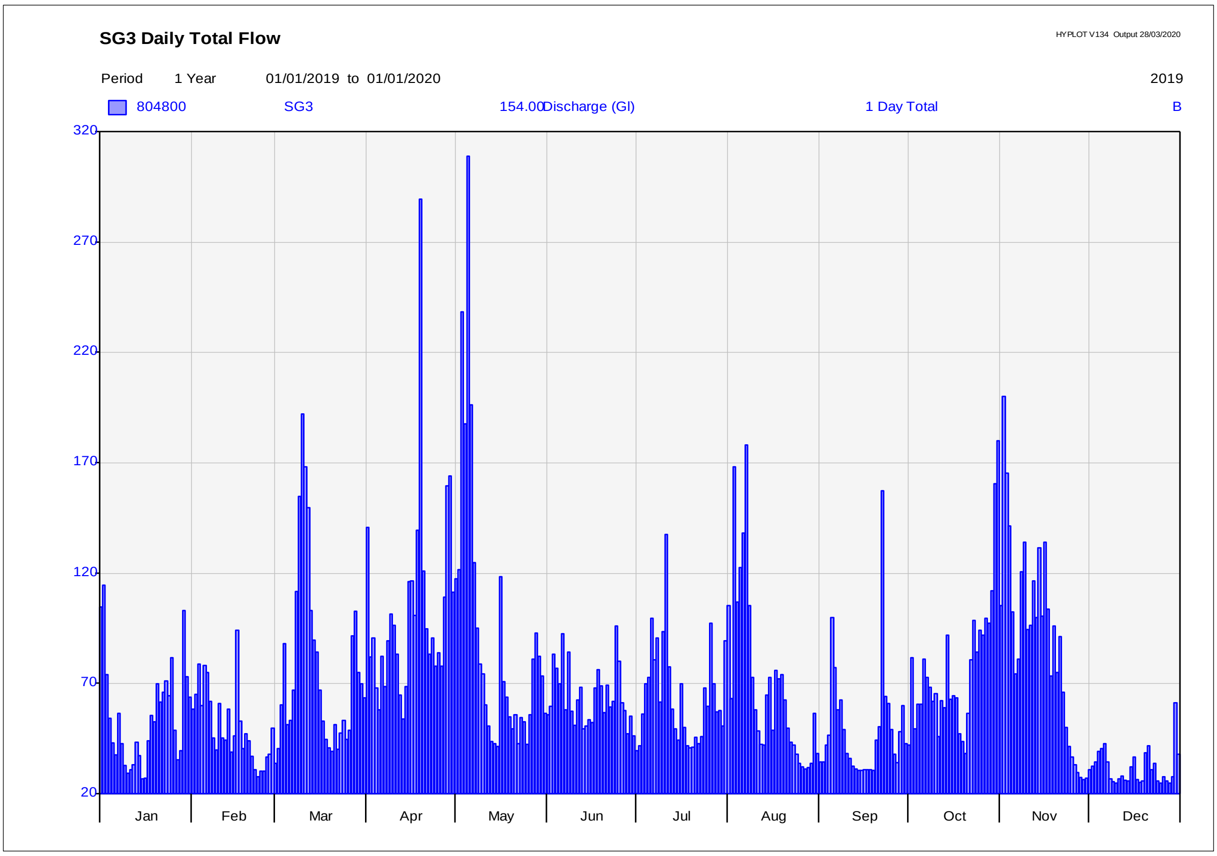


Figure 5-16 Total daily flow (GL) at SG3 for 2019

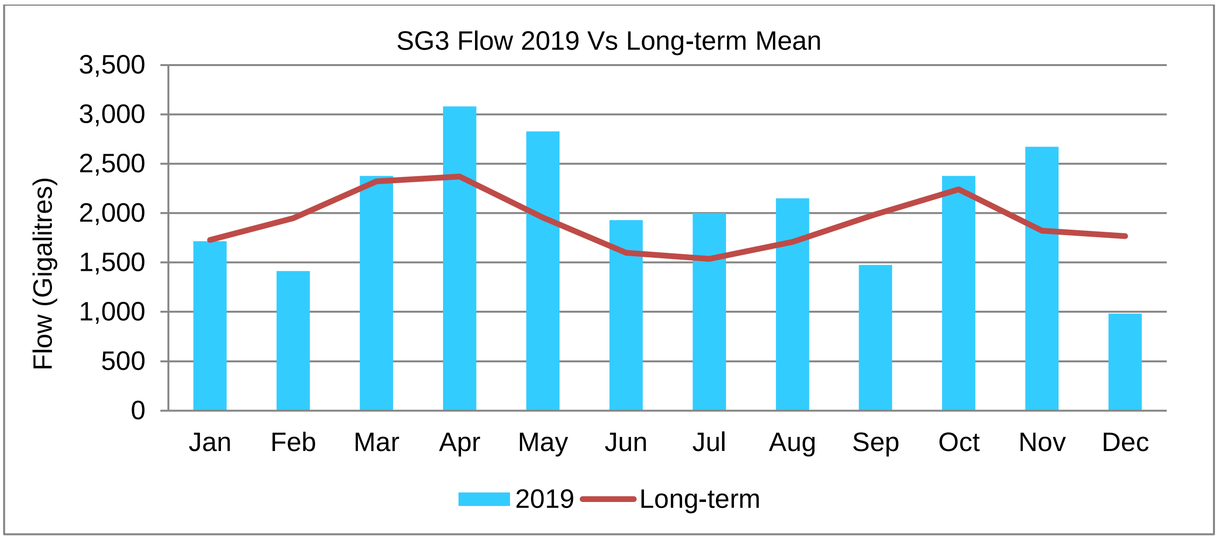


Figure 5-17 Total monthly flow (GL) at SG3 during 2019 compared to long-term monthly means

5.3 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), from reference sites during the previous 24-months and the guideline values for 95% species protection from ANZG (2018).

In accordance with Section 2.3 of this report, the data are compared and the highest value for each parameter is then adopted as the 2019 TV for use in the water 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.

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 concentrations include bioavailable, non-bioavailable and particle-bound metals and are therefore likely to overestimate potential toxicity.

5.3.1 Local reference sites

Local sites comprise the small highland creeks within the Porgera River catchment that are not affected by the mining operation. Rainfall runoff from these creeks joins with discharge from the mine to form the Porgera River, and so the quality of water in these creeks is important for providing the full context of inputs that influence downstream water quality.

The site names are presented in Table 5-4 and median water quality data for 2019 are presented in Table 5-5 and shown in Figure 5-18 to Figure 5-47. The long-term trends from 2010-2019 are shown in Table 5-6 and as median data in Figure 5-18 to Figure 5-47.

Table 5-4 Local reference site monitoring locations

Site Type	Site Name
Local sites	Aipulungu US - Aipulungu River upstream of lime plant and quarry
	Waile Dam
	Kaiya River US – Kaiya River upstream of Anjolek erodible dump
	Pongema River

Water quality in local creeks is dominated by the surrounding limestone geology and relatively low level of development within the catchments. The pH is alkaline and typical of limestone geology, TSS is generally low but has the potential to become elevated during high rainfall periods due to landslides and erosion within the steep valley catchment, and particularly in the Kaiya River US and Aipulungu River US. Concentrations of dissolved metals generally were low; however, background concentrations of chromium, copper, iron, nickel, lead and zinc were at detectable levels throughout the historical record. Electrical conductivity at Pongema exceeded the upper river TV, shown in Table 5-5, elevated concentrations of some total metals were present throughout the record at some sites. The Kaiya River upstream (u/s) Anjolek Dump was not sampled in 2019 due to security concerns.

A summary of the trends between 2010 and 2019 is shown in Table 5-6, and details of the statistical analysis for long-term trends are provided in Appendix C. The analysis showed that dissolved zinc at Aipulungu US, Waile Creek Dam and Kaiya River US have increased over time. This is consistent with a reducing trend in pH at each of the sites. Graphical representation of dissolved and total zinc and pH data from each site showing increasing and decreasing trends respectively is presented in Figure 5-48.

Table 5-5 Local reference site water quality 2019 median values (µg/L except where shown)

Parameter	UpRivs TV	Aipulungu US	Waile Dam	Kaiya Riv US	Pongema
pH^	6.0-8.2	8.0	7.9	NS	8.0
EC$^{\#}$	228	205	152	NS	241
WAD-CN*	NA	0.20	0.20	NS	0.20
Sulfate*	NA	3.0	2.0	NS	2.5
ALK-T**	NA	101	82	NS	125
Hardness**	NA	101	74	NS	126
TSS*	2837	23	6.0	NS	39
Ag-D	0.05	0.01	0.01	NS	0.01
Ag-T	NA	0.01	0.01	NS	0.02
As-D	24	0.17	0.13	NS	0.22
As-T	NA	0.25	0.19	NS	0.45
Cd-D	0.34	0.05	0.05	NS	0.05
Cd-T	NA	0.05	0.05	NS	0.05
Cr-D	1.0	0.41	0.29	NS	0.70
Cr-T	NA	0.35	0.24	NS	2.6
Cu-D	1.4	0.69	0.57	NS	0.74
Cu-T	NA	0.93	0.53	NS	1.2
Fe-D	75	22	53	NS	16
Fe-T	NA	150	140	NS	1030
Hg-D	0.60	0.05	0.05	NS	0.05
Hg-T	NA	0.05	0.05	NS	0.05

Parameter	UpRivs TV	Aipulungu US	Waile Dam	Kaiya Riv US	Pongema
Ni-D	21	0.50	0.50	NS	0.50
Ni-T	NA	0.52	0.50	NS	1.5
Pb-D	7.3	0.11	0.12	NS	0.13
Pb-T	NA	0.12	0.10	NS	0.84
Se-D	11	0.20	0.20	NS	0.20
Se-T	NA	0.20	0.20	NS	0.20
Zn-D	20	3.8	2.5	NS	2.3
Zn-T	NA	3.6	1.9	NS	7.6
🟧	> UpRiv TV				

^std units, $^{\#}$µS/cm, * mg/L, **mg $CaCO_3$/L, D = Dissolved fraction, T = Total, NS – Not sampled

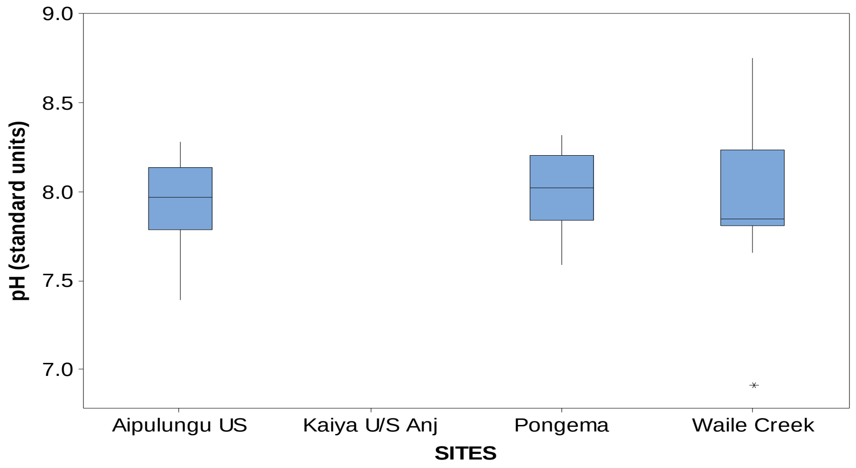


Figure 5-18 pH in local creek runoff 2019

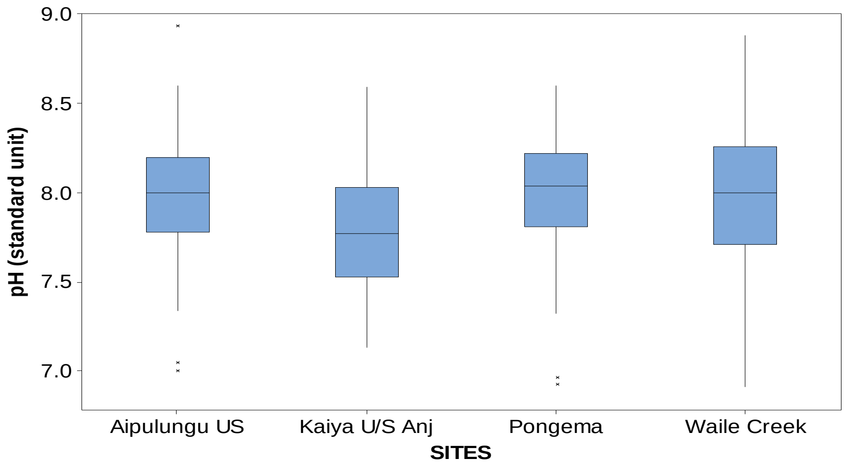


Figure 5-19 pH in local creek runoff 2010-2019

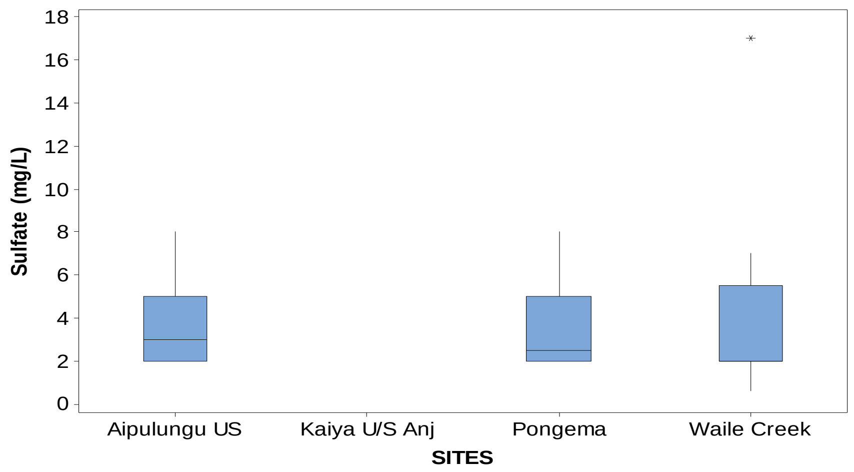


Figure 5-20 Sulfate in local creek runoff 2019

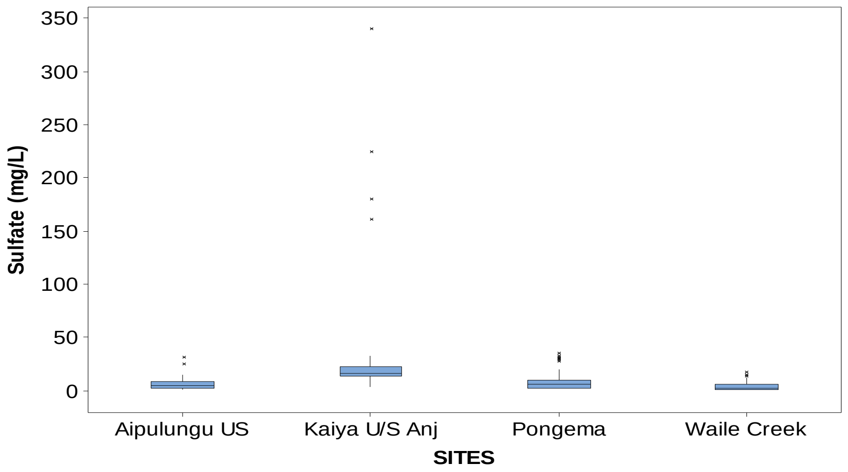


Figure 5-21 Sulfate in local creek runoff 2010-2019

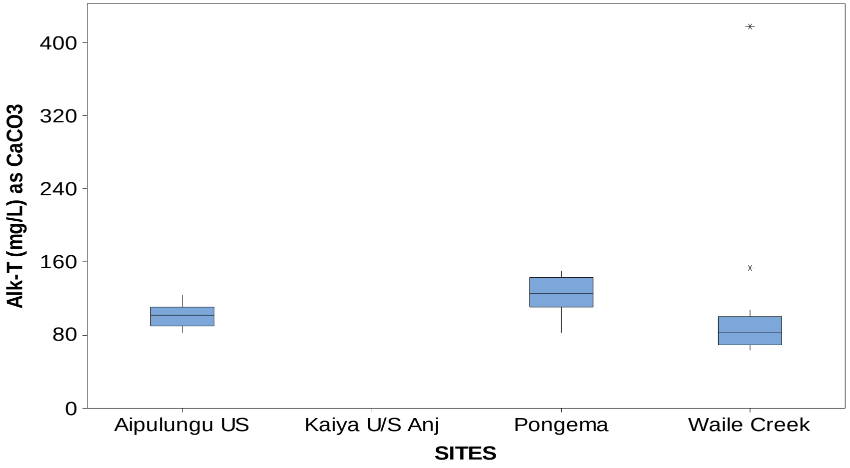


Figure 5-22 Alkalinity in local creek runoff 2019

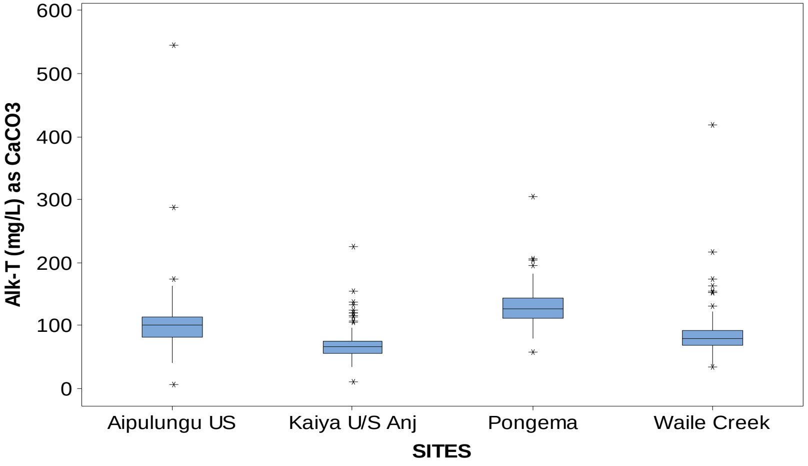


Figure 5-23 Alkalinity in local creek runoff 2010-2019

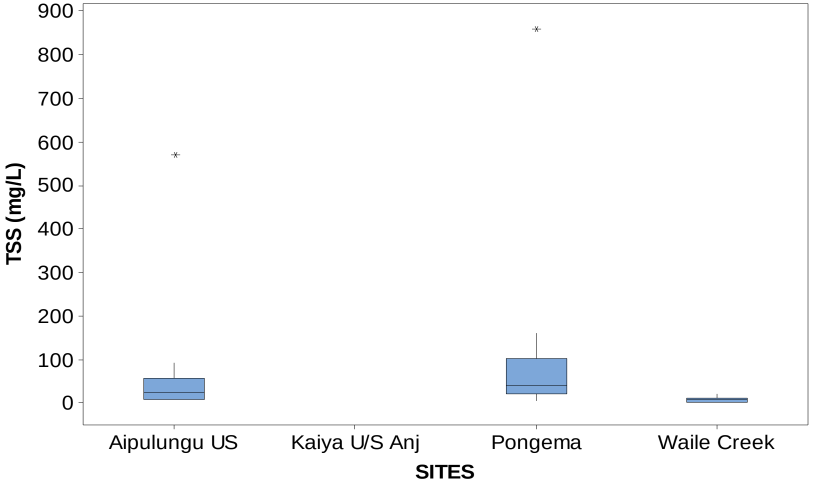


Figure 5-24 TSS in local creek runoff 2019

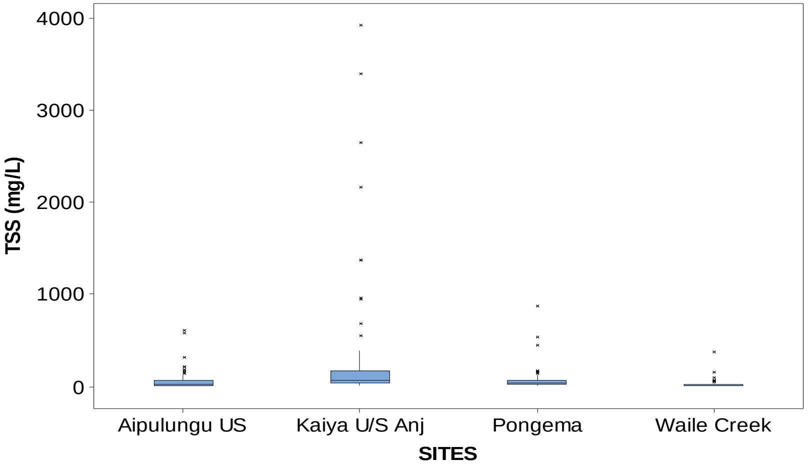


Figure 5-25 TSS in local creek runoff 2010-2019

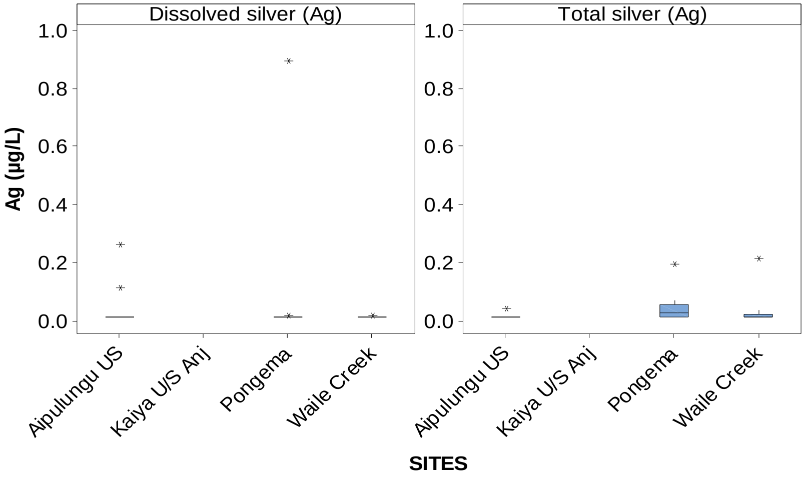


Figure 5-26 Dissolved and total silver in local creek runoff 2019

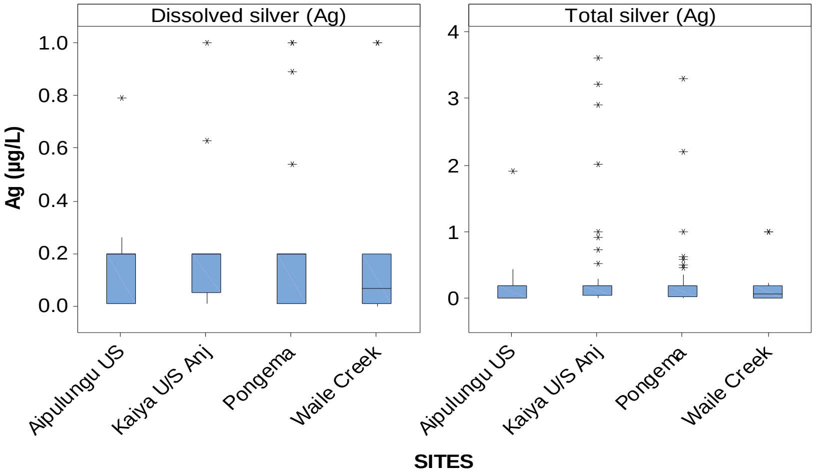


Figure 5-27 Dissolved and total silver in local creek runoff 2010-2019

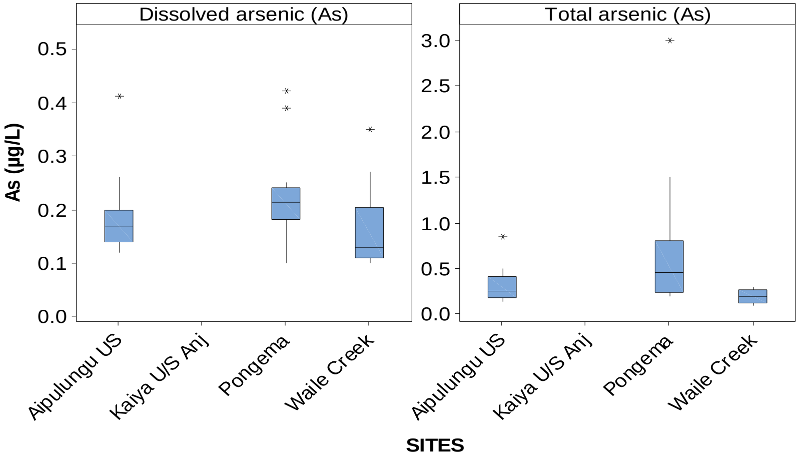


Figure 5-28 Dissolved and total arsenic in local creek runoff 2019

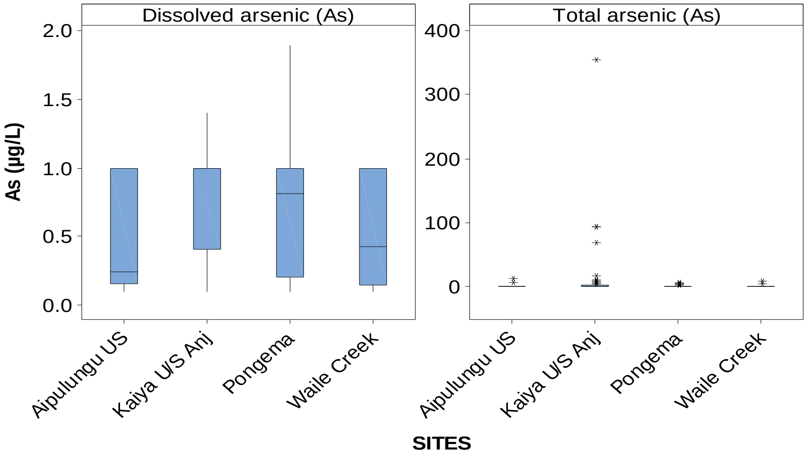


Figure 5-29 Dissolved and total arsenic in local creek runoff 2010-2019

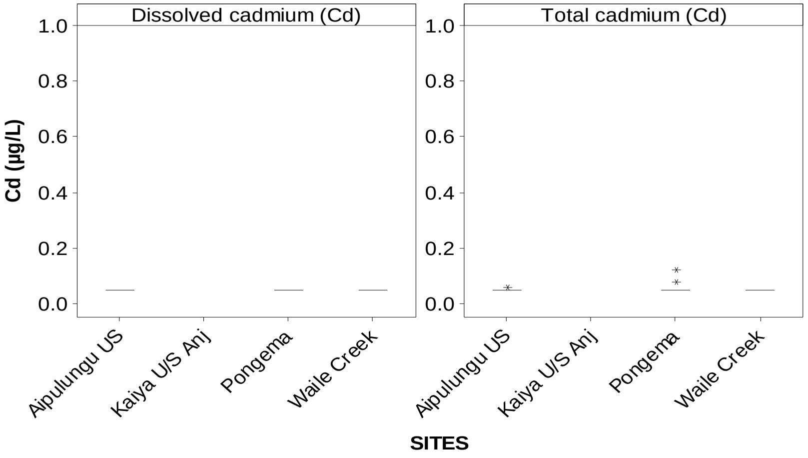


Figure 5-30 Dissolved and total cadmium in local creek runoff 2019

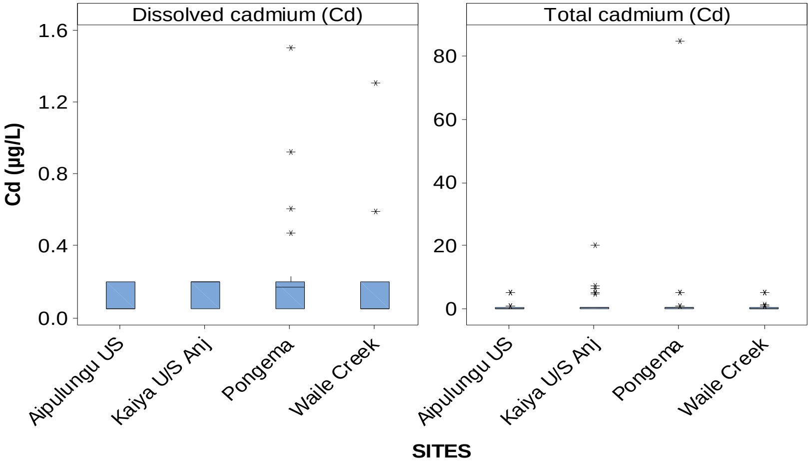


Figure 5-31 Dissolved and total cadmium in local creek runoff 2010-2019

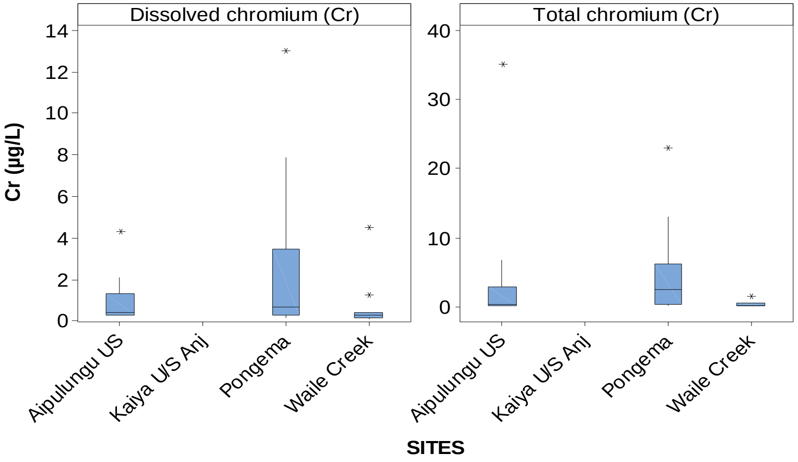


Figure 5-32 Dissolved and total chromium in local creek runoff 2019

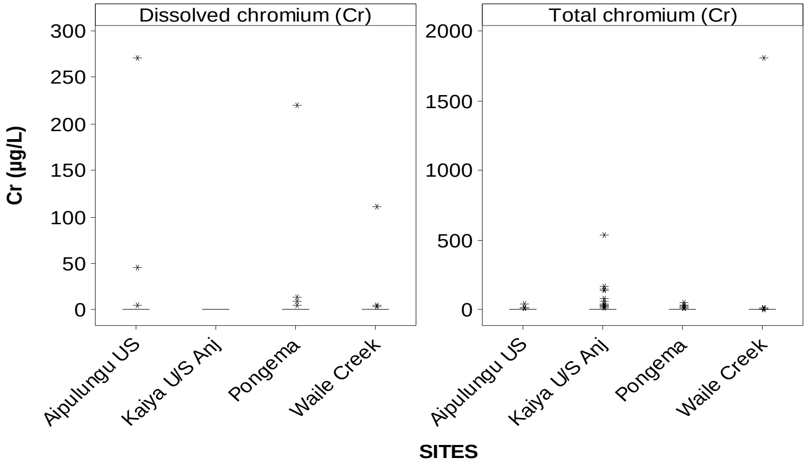


Figure 5-33 Dissolved and total chromium in local creek runoff 2010-2019

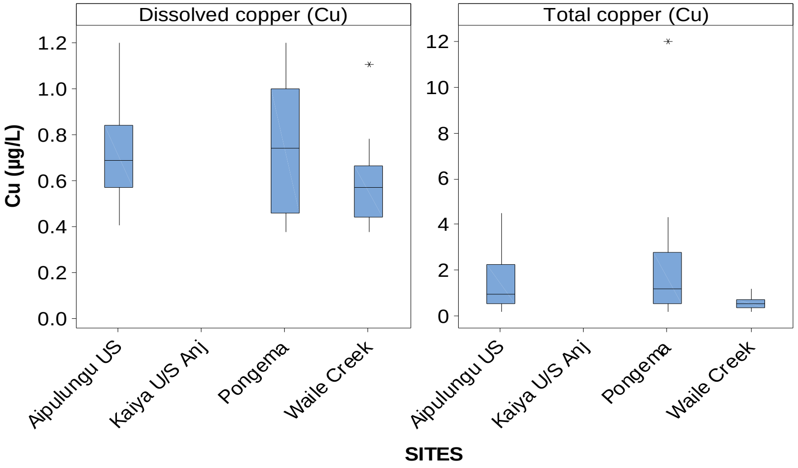


Figure 5-34 Dissolved and total copper in local creek runoff 2019

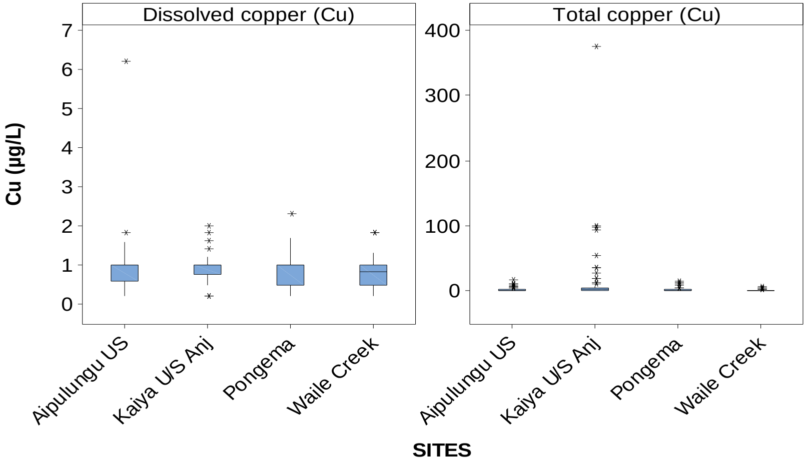


Figure 5-35 Dissolved and total copper in local creek runoff 2010-2019

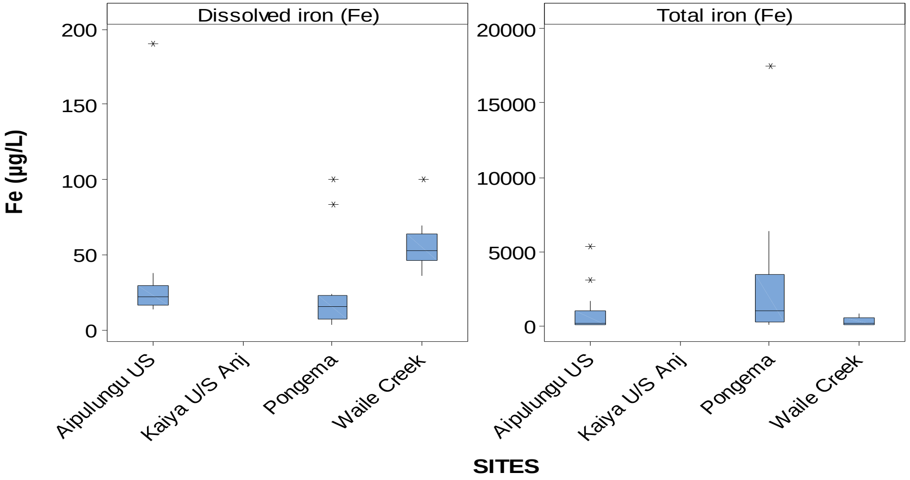


Figure 5-36 Dissolved and total iron in local creek runoff 2019

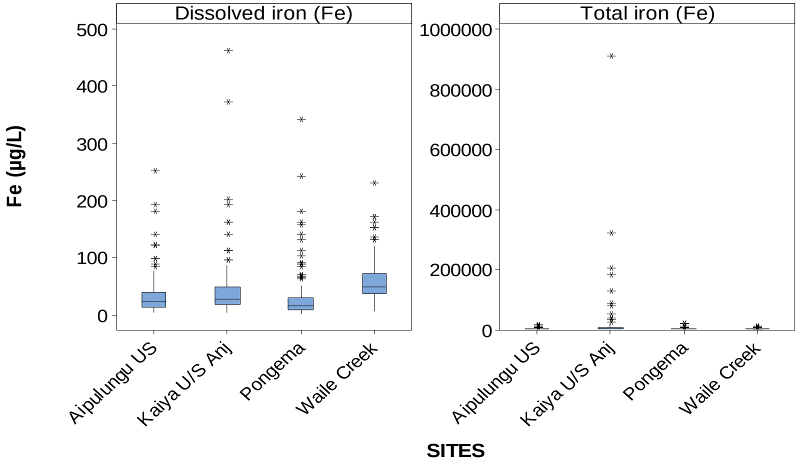


Figure 5-37 Dissolved and total iron in local creek runoff 2010-2019

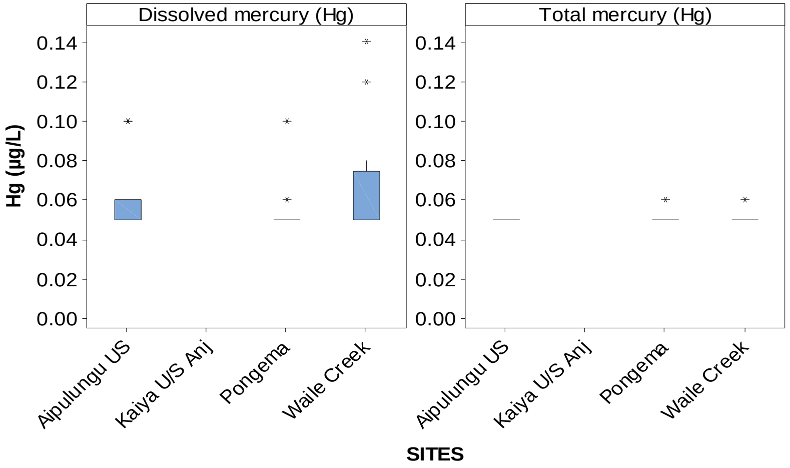


Figure 5-38 Dissolved and total mercury in local creek runoff 2019

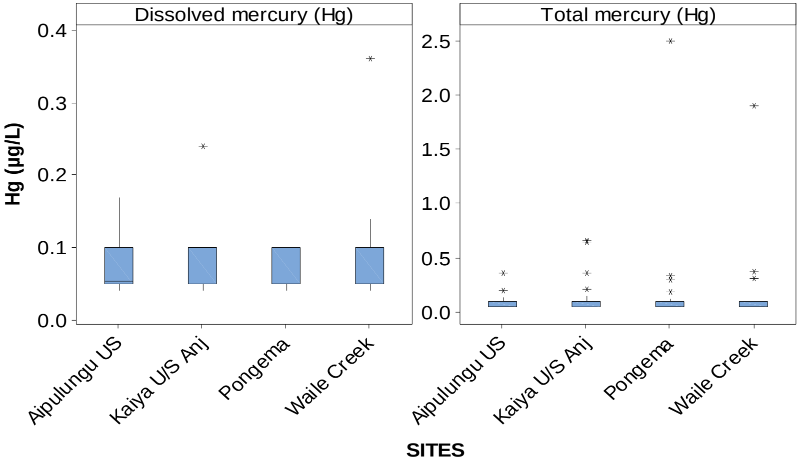


Figure 5-39 Dissolved and total mercury in local creek runoff 2010-2019

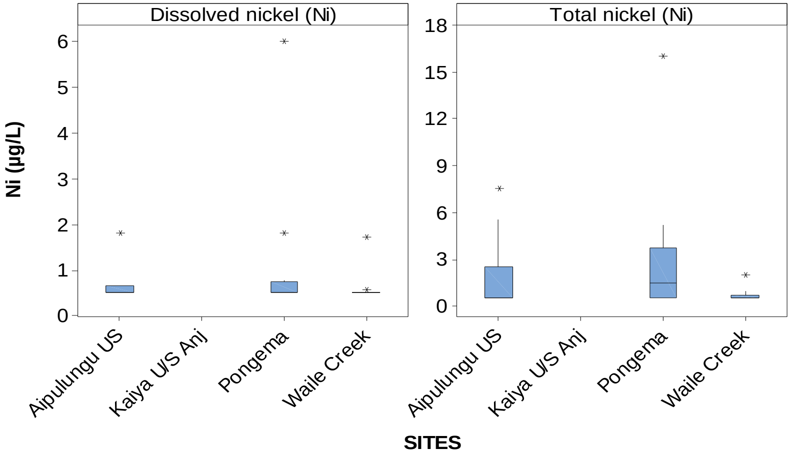


Figure 5-40 Dissolved and total nickel in local creek runoff 2019

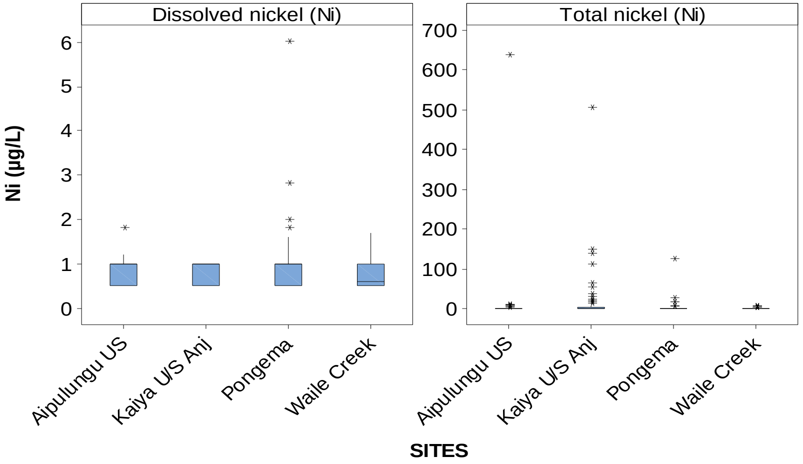


Figure 5-41 Dissolved and total nickel in local creek runoff 2010-2019

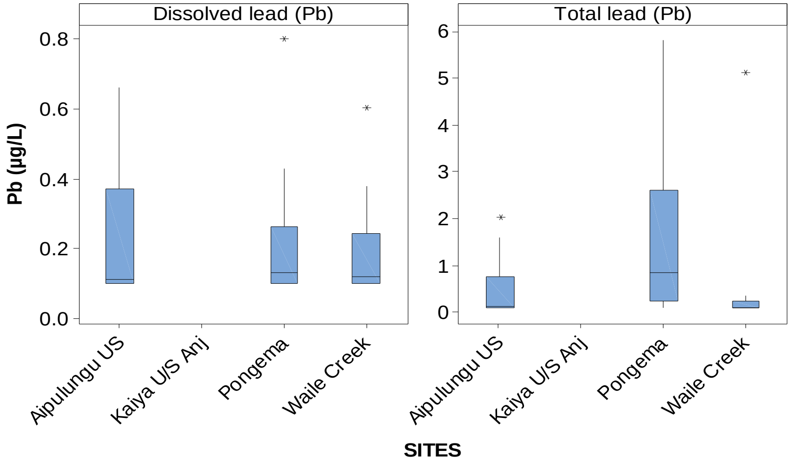


Figure 5-42 Dissolved and total lead in local creek runoff 2019

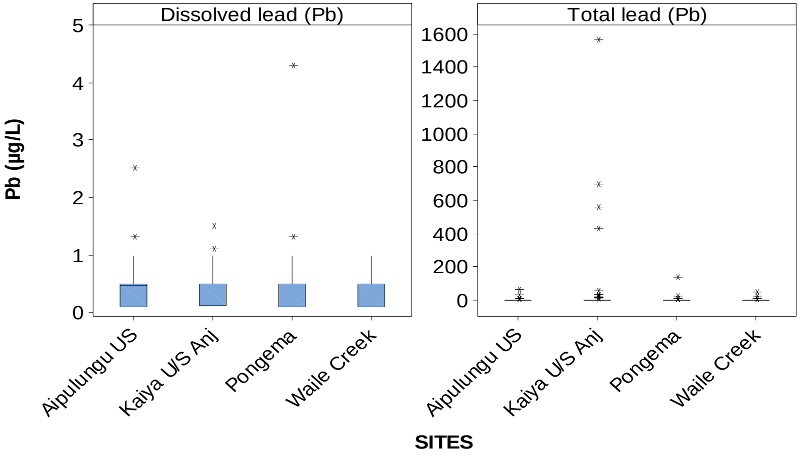


Figure 5-43 Dissolved and total lead in local creek runoff 2010-2019

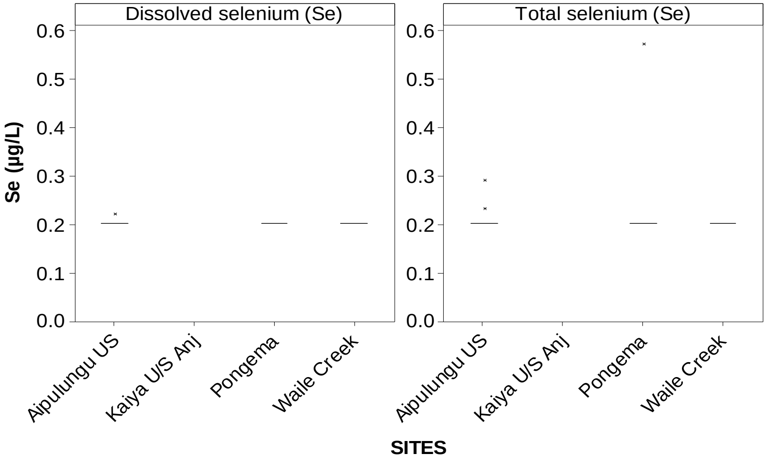


Figure 5-44 Dissolved and total selenium in local creek runoff 2019

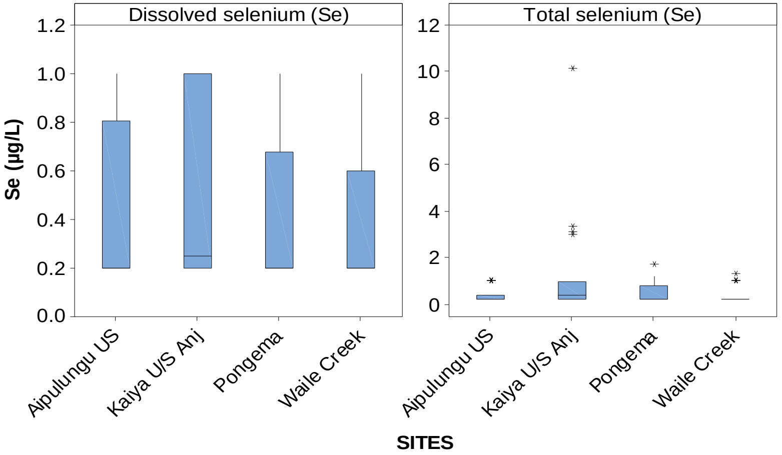


Figure 5-45 Dissolved and total selenium in local creek runoff 2010-2019

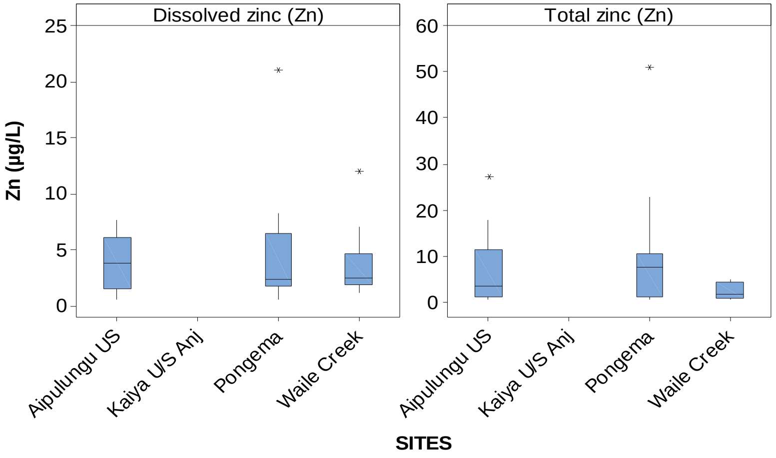


Figure 5-46 Dissolved and total zinc in local creek runoff 2019

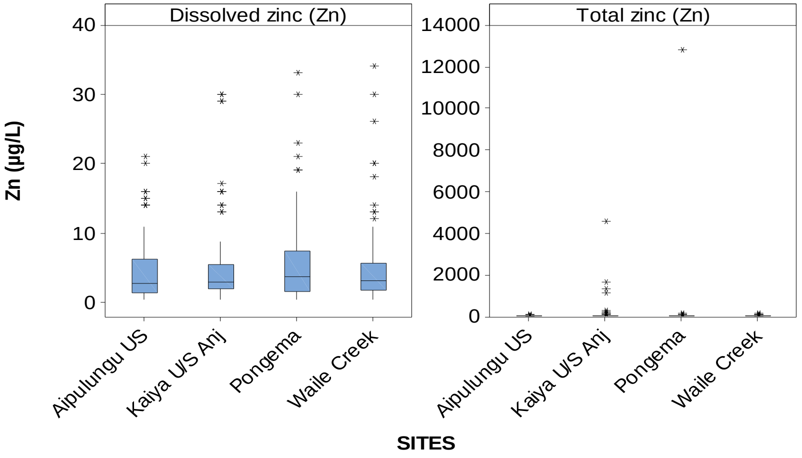


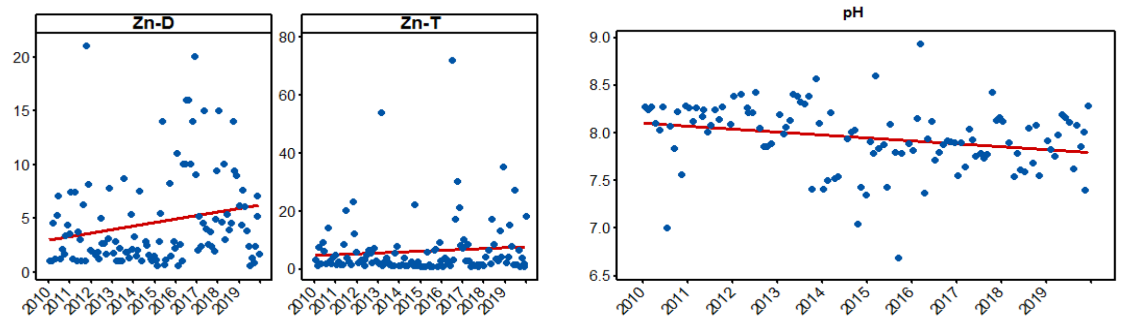
Figure 5-47 Dissolved and total zinc in local creek runoff 2010-2019

Table 5-6 Trends of water quality in local creek runoff reference sites 2010-2019 as tested by Spearman Rank Correlation

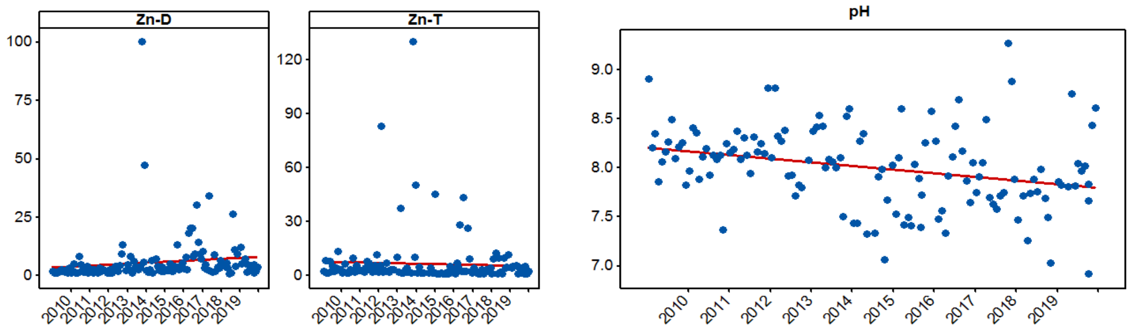
Parameter	Aipulungu US	Waile Creek	Kaiya Riv US	Pongema
pH^	🟩	🟩	🟩	🟩
EC$^{\#}$	🟩	🟩	🟩	🟩
WAD-CN*	🟩	🟩	🟩	🟩
Sulfate*	🟩	🟩	🟩	🟩
ALK-T**	🟩	🟩	🟩	🟩
TSS*	🟩	🟩	🟩	🟩
Hardness**	🟩	🟧	🟩	🟩
Ag-D	🟩	🟩	🟩	🟩
Ag-T	🟩	🟩	🟩	🟩
As-D	🟩	🟩	🟩	🟩
As-T	🟩	🟩	🟩	🟩
Cd-D	🟩	🟩	🟩	🟩
Cd-T	🟩	🟩	🟩	🟩
Cr-D	🟩	🟩	🟩	🟩
Cr-T	🟩	🟩	🟩	🟩
Cu-D	🟩	🟩	🟩	🟩
Cu-T	🟩	🟩	🟩	🟩
Fe-D	🟩	🟩	🟩	🟩
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

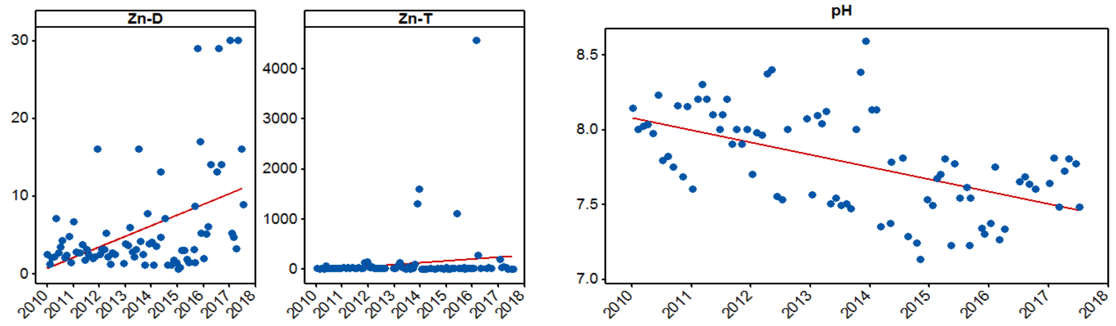
^std units, $^{\#}$µS/cm * mg/L, **mg $CaCO_3$/L, D = Dissolved fraction, T = Total



Aipulungu U/S Lime Plant - Dissolved and total zinc and pH 2010 - 2019



Waile Dam - Dissolved and total zinc and pH 2010 - 2019



Kaiya U/S Anj Dump - Dissolved and total zinc and pH 2010 - 2017

Figure 5-48 Trend analysis Local reference sites (scatter plot of all data from 2010 – 2019 with linear trend line)

5.3.2 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), from reference sites during the previous 24 months and from ANZG (2018).

In accordance with Section 2.3 of this report, the data are compared and the highest is then adopted as the 2019 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 5-7.

Reference site data used for comparison is 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, elevated EC, occasionally elevated TSS and the presence of arsenic, chromium, copper, iron, nickel, lead and zinc.

Analysis of trends between 2010 and 2019 indicate that most parameters remained constant at the reference sites, the exception being TSS, dissolved iron and zinc which showed an increasing trend and a concurrent decrease in pH. Trend analysis results are shown in Table 5-8 and graphical representation of dissolved and total zinc and pH data from each site showing increasing and decreasing trends respectively are presented in Figure 5-49.

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 2019 TV were from the following sources:

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

Table 5-7 Summarised water quality for upper 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 TV for 95% species protection provided for comparison (µg/L except where indicated)

Parameter	UpRiv Ref 24 month (n=107)			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	7.7	7.9	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	6.0-8.1
EC#	137	191	228	168	180	190	178	185	226	176	188	204	170	185	202	NA	228
Sulfate*	6.0	11	25	10	12	16	18	21	31	28	30	34	15	22	32		
Alk-T**	54	81	108	110	117	122	110	150	263	96	106	124	106	117	169		
TSS*	71	280	904	222	401	2496	258	1462	4874	743	1428	2663	258	1188	2837	NA	2,837
Hardness**	55	78	103	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	0.038	0.09	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
As-D	0.37	0.48	0.65	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	0.77	2.4	8.8	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	0.34***	0.34
Cd-T	0.05	0.05	0.071	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	0.24	0.42	0.80	ND	ND	ND	133	133	133	ND	ND	ND	0.5	0.5	0.5	1.0	1.0
Cr-T	1.4	10	28	ND	ND	ND	0.5	0.5	0.5	ND	ND	ND	133	133	133		
Cu-D	0.31	0.54	1.0	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	1.2	7.5	23	5.2	15	66	8.8	41	146	7.4	36	68	7	29	82		
Fe-D	8.7	18	49	75	75	75	57	75	75	75	75	75	75	75	75	NA	75
Fe-T*	1.4	9.0	36	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	0.065	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	0.50	0.50	0.70	13	15	15	5.7	9.1	15	11	15.7	23	10	15	21	18***	21
Ni-T	1.5	12	32	16	16	16	20	20	179	10	12	94	12	20	90		
Pb-D	0.1	0.10	0.22	0.30	0.30	0.64	0.26	0.30	0.38	0.3	0.3	1.3	0.3	0.3	1.0	7.3***	7.3
Pb-T	0.68	4.0	17	4.36	12	160	6.1	18	139	3.6	23	59	4.4	19	82		
Se-D	0.20	0.20	0.2	ND	ND	ND	0.07	0.07	0.07	ND	ND	ND	0.07	0.07	0.07	11	11
Se-T	0.20	0.24	0.54	ND	ND	ND	0.25	0.25	0.25	ND	ND	ND	0.25	0.25	0.25		
Zn-D	1.8	3.7	7.7	0.18	0.2	0.42	0.28	0.40	0.64	0.8	4.3	25	0.48	1.4	20	13***	20
Zn-T	5.5	23	80	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

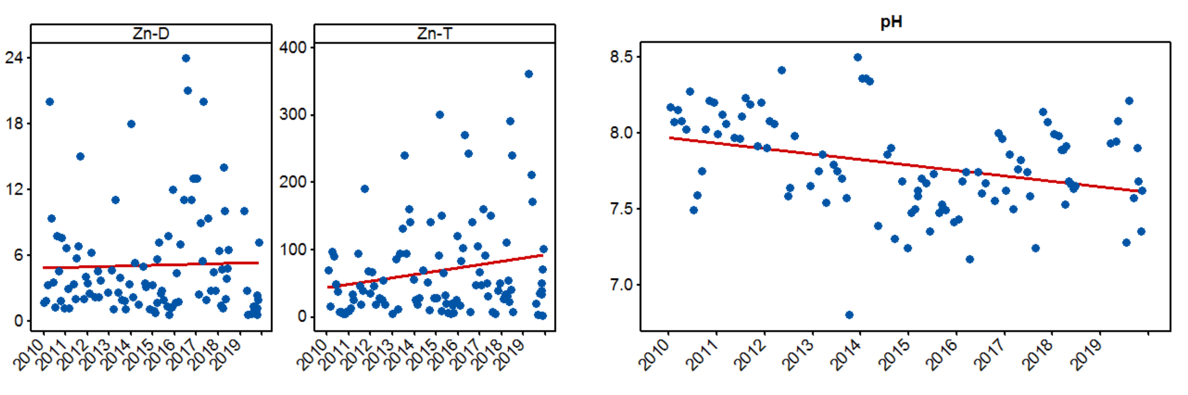
Baseline data were collected from the test sites prior to mine operations commencing

Table 5-8 Trends for water quality at upper river reference sites 2010-2019 as determined by Spearman Rank correlation against time

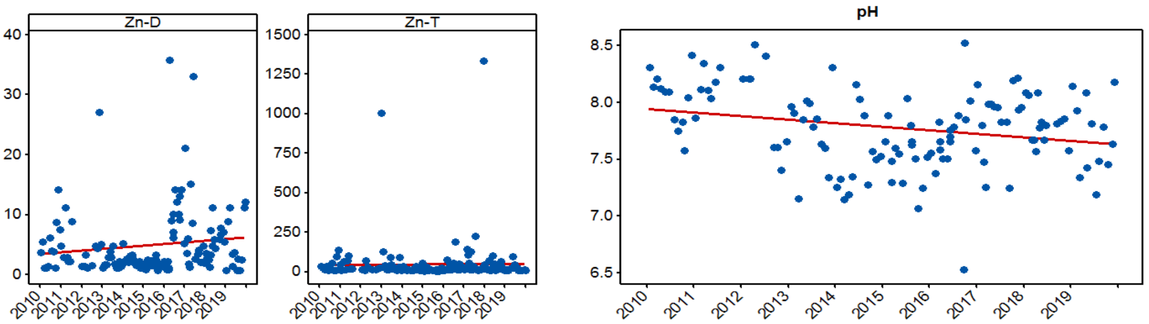
Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2010 – 2019)
Upper River Ref (Trend of all data from 2010 - 2019)	pH	-0.183	<0.001	Reduced over time
	EC	-0.091	0.045	Reduced over time
	TSS	0.090	0.046	Increased over time
	Ag-D*	-0.892	0.589	No change over time
	Ag-T	-0.636	0.046	Reduced over time
	As-D*	-0.712	0.019	No change over time
	As-T	0.026	0.624	No change over time
	Cd-D*	-0.824	<0.001	No change over time
	Cd-T	-0.644	<0.001	Reduced over time
	Cr-D*	-0.526	<0.001	No change over time
	Cr-T	0.029	0.567	No change over time
	Cu-D*	-0.543	<0.001	No change over time
	Cu-T	0.014	<0.001	No change over time
	Fe-D	0.160	<0.001	Increased over time
	Fe-T	0.028	0.527	No change over time
	Hg-D*	-0.553	<0.001	No change over time
	Hg-T	-0.483	0.762	Reduced over time
	Ni-D*	-0.629	<0.001	No change over time
	Ni-T	0.017	0.529	No change over time
	Pb-D*	-0.624	<0.001	No change over time
	Pb-T	0.012	<0.001	No change over time
	Se-D*	-0.682	<0.001	No change over time
	Se-T*	-0.363	0.708	No change over time
	Zn-D	0.143	<0.001	Increased over time
	Zn-T	0.060	0.783	No change over time

D - Dissolved fraction, T - Total fraction

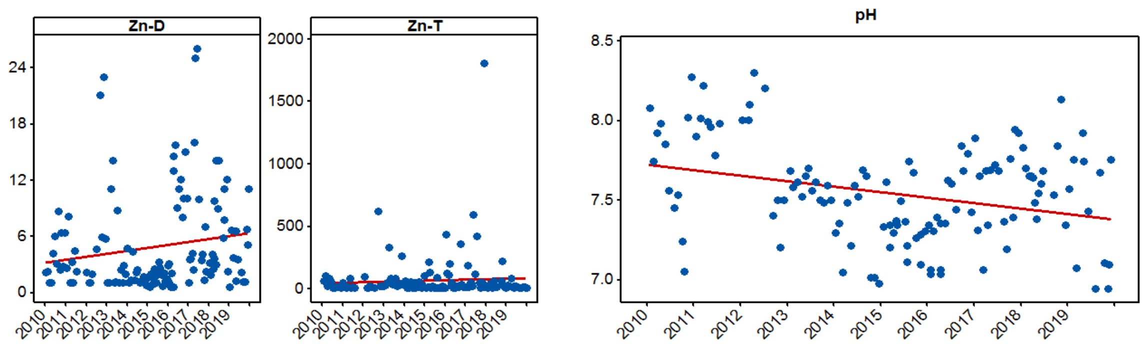
* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate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



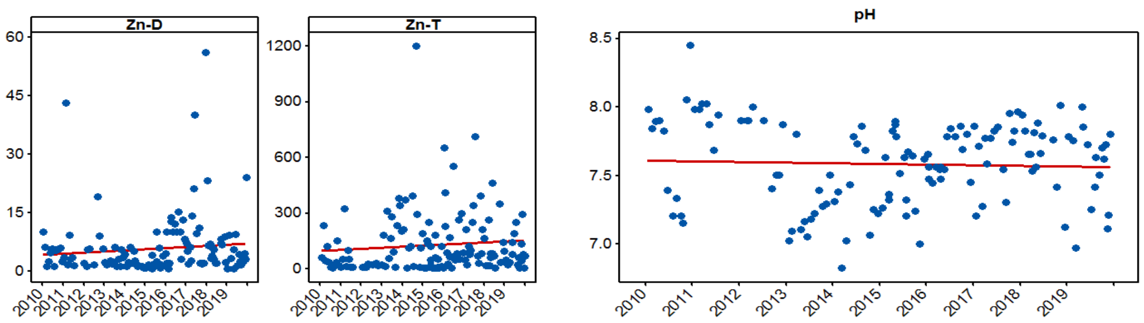
Upper Lagaip dissolved and total zinc concentrations (µg/L) and pH 2010 - 2019 (Ref site)



Pori dissolved and total zinc concentrations (µg/L) and pH 2010 - 2019 (Ref site)



Kuru dissolved and total zinc concentrations (µg/L) and pH 2010 - 2019 (Ref site)



Ok Om dissolved and total zinc concentrations (µg/L) and pH 2010 - 2019 (Ref site)

Figure 5-49 Trend analysis Upper River reference sites water quality (scatter plot of all data from 2010 – 2019 with linear trend line)

5.3.1 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 reference sites during the previous 24-months and from ANZG (2018).

In accordance with Section 2.3 of this report, the data are compared and the highest is then adopted as the 2019 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 5-9.

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 slightly alkaline pH, elevated EC, occasionally elevated TSS and the presence of arsenic, chromium, copper, iron, nickel, lead and zinc. Analysis of trends between 2010 and 2019 indicated that most parameters remained constant at the reference sites, with the exception of EC and dissolved zinc, which showed an increasing trend at both sites. pH showed a decreasing trend at Baia. Trend analysis results are shown in Table 5-10 and graphical representation of dissolved and total zinc and pH data from each site showing trends is presented in Figure 5-50.

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 2019 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 5-9 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 TV for 95% species protection provided for comparison (µg/L except where indicated)

Parameter	**LwRiv Ref 24 Month (n=22)**			**Baseline LwRiv (n=36)**			**ANZG (2018) 95%**	**LwRiv & ORWB TV**
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
pH^	6.9	7.3	7.7	7.8	8.0	8.1	6.0-8.0	6.0-8.1
EC$^{\#}$	75	170	186	140	150	170	250	186
Sulfate*	1.2	3.0	6.0	10	15	18		
ALK-T**	35	68	74	83	93	101		
TSS*	15	98	858	326	638	983	NA	983
Hardness**	18	58	94	ND	ND	ND		
Ag-D	0.01	0.01	0.01	ND	ND	ND	0.05	0.05
Ag-T	0.01	0.01	0.06	ND	ND	ND		
As-D	0.10	0.68	0.94	0.60	0.70	0.80	24	24
As-T	0.18	1.9	9.1	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	0.25	0.60	0.90	1.0		
Cr-D	0.20	0.33	0.51	0.50	0.50	0.50	1.0	1.0
Cr-T	0.78	5.7	37	18	34	46		
Cu-D	0.39	0.60	0.94	0.50	0.85	1.4	1.4	1.4
Cu-T	1.1	5.2	24	8.0	18	26		
Fe-D	5.8	15	28	0.64	75	75	NA	75
Fe-T*	0.80	5.5	30	17	37	49		
Hg-D	0.05	0.05	0.06	ND	ND	ND	0.60	0.60
Hg-T	0.05	0.05	0.14	0.10	0.10	0.10		
Ni-D	0.50	0.50	0.68	3.6	10	15	11	15
Ni-T	0.79	5.3	37	10	23	24		
Pb-D	0.10	0.10	0.21	0.30	0.50	0.70	3.4	3.4
Pb-T	0.35	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	0.33	0.20	0.20	0.50		
Zn-D	1.1	4.0	6.8	0.50	1.0	2.9	8.0	8.0
Zn-T	3.4	12.0	64	28	68	94		

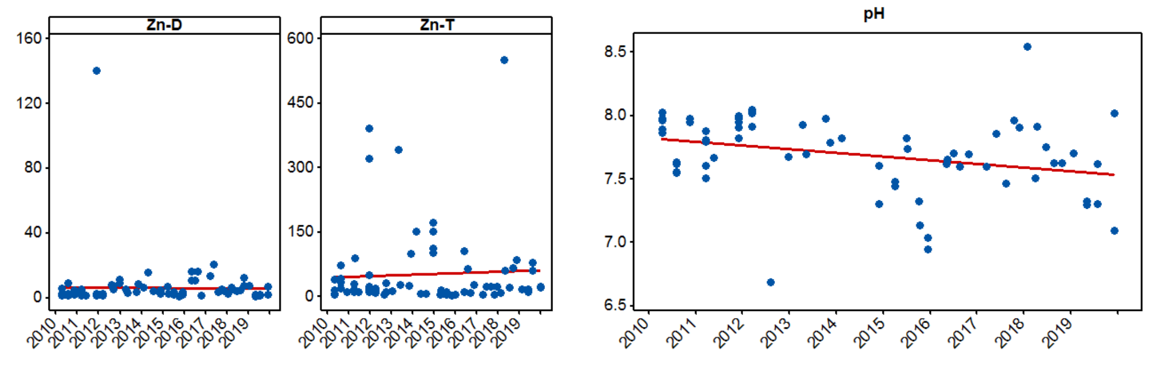
^ std units, $^{\#}$µS/cm, *mg/L, **mg CaCO3/L, D – Dissolved fraction, T – Total fraction, NA – Not applicable, ND – Not determined

Table 5-10 Trends for water quality at lower river reference sites 2010-2019 as determined by Spearman Rank correlation against time

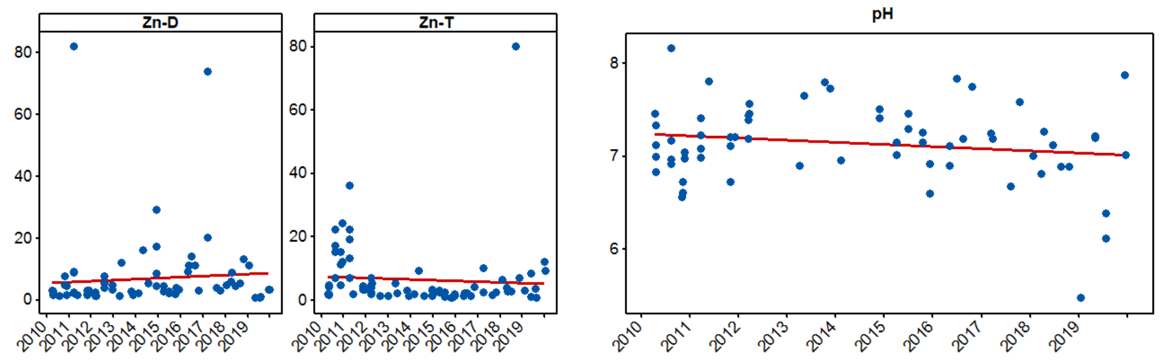
Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2010 – 2019)
Lower River Ref (Trend of all data from 2010 - 2019)	pH	-0.148	0.082	No change over time
	EC	0.261	0.002	Increased over time
	TSS	-0.074	0.392	No change over time
	Ag-D*	-0.874	<0.001	No change over time
	Ag-T*	-0.673	<0.001	No change over time
	As-D*	-0.674	<0.001	No change over time
	As-T*	-0.163	0.045	No change over time
	Cd-D*	-0.824	<0.001	No change over time
	Cd-T*	-0.546	<0.001	No change over time
	Cr-D*	-0.644	<0.001	No change over time
	Cr-T	0.011	0.895	No change over time
	Cu-D*	-0.616	<0.001	No change over time
	Cu-T	-0.108	0.185	No change over time
	Fe-D	-0.230	0.004	Reduced over time
	Fe-T	-0.074	0.362	No change over time
	Hg-D*	-0.663	<0.001	No change over time
	Hg-T*	-0.496	<0.001	No change over time
	Ni-D*	-0.691	<0.001	No change over time
	Ni-T	-0.091	0.266	No change over time
	Pb-D*	-0.696	<0.001	No change over time
	Pb-T	-0.098	0.231	No change over time
	Se-D*	-0.762	<0.001	No change over time
	Se-T*	-0.589	<0.001	No change over time
	Zn-D	0.261	0.001	Increased over time
	Zn-T	-0.063	0.439	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.



Baia dissolved and total zinc concentrations (µg/L) and pH 2010 - 2019 (Ref site)



Tomu dissolved and total zinc concentrations (µg/L) and pH 2010 - 2019 (Ref site)

Figure 5-50 Trend analysis Lower River reference sites water quality (scatter plot of all data from 2010 – 2019 with linear trend line)

5.3.2 Lake Murray

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

In accordance with Section 2.3 of this report, the data are compared and the highest is then adopted as the 2019 TV for use in the water quality risk assessment presented in Section 7. Data summaries and presentation of water quality TVs for the lower river are presented Table 5-11.

Reference data were generated from the North Lake Murray region. Reference sites exhibited slightly 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 2010 and 2019 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 5-12 and graphical representation of dissolved and total zinc and pH data from each site showing increasing trends is presented in Figure 5-51.

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 2019 TV were from the following sources.

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

Table 5-11 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 TV for 95% species protection provided for comparison (µg/L except where indicated)

Parameter	**NORTHERN LAKE MURRAY (n=20)**			**Lake Murray (LM1) Baseline (n=10)**			**Lake Murray (LM2) Baseline (n=10)**			**Lake Murray LM1 and LM2 Baseline (n=20)**			**ANZG (2018) 95%**	**LMY TV**
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
pH^	5.0	6.7	7.3	6.3	6.4	6.4	6.3	6.4	6.6	6.3	6.4	6.6	6.0-8.0	5.0-8.0
EC$^{\#}$	14	16	21	15	15	15.5	15	15	15.5	15	15	15.5	NA	21
Sulfate*	0.8	1.7	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
ALK-T**	6.3	10	12	7.7	8.1	8.8	7.9	8.1	8.5	7.8	8.1	8.7		
TSS*	2.0	2.0	13	6.0	7.0	9.0	4.6	6.0	8.2	5.4	6.5	9.0	NA	13
Hardness**	5.0	6.0	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	0.05	0.05
Ag-T	0.01	0.01	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND		
As-D	0.12	0.14	0.15	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	24	24
As-T	0.17	0.20	0.21	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
Cd-D	0.05	0.05	0.05	0.1	0.2	0.80	0.1	0.1	0.64	0.1	0.1	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	0.7	1.4	4.8		
Cr-D	0.16	0.25	0.38	0.1	0.1	0.44	0.1	0.1	0.2	0.1	0.1	0.40	1.0	1.0
Cr-T	0.24	0.31	0.43	0.1	0.1	0.4	0.1	0.25	1.3	0.1	0.15	0.6		
Cu-D	0.31	0.36	0.58	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	1.4	1.4
Cu-T	0.32	0.49	0.70	0.26	0.4	0.8	0.1	0.3	0.52	0.1	0.3	0.7		
Fe-D	56	77	182	138	255	342	166	230	324	148	250	340	NA	340
Fe-T	476	845	1068	762	1005	1072	898	945	1024	898	980	1072		
Hg-D	0.05	0.06	0.09	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.60	0.60
Hg-T	0.05	0.05	0.06	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3		
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	11	11
Ni-T	0.50	0.50	0.57	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
Pb-D	0.10	0.10	0.25	0.2	0.2	0.7	0.2	0.2	0.62	0.2	0.2	0.7	3.4	3.4
Pb-T	0.10	0.14	0.22	0.5	1.0	1.9	0.4	0.8	1.4	0.38	0.9	1.7		
Se-D	0.20	0.20	0.20	0.7	0.8	0.9	0.7	0.7	0.8	0.7	0.7	0.9	11	11
Se-T	0.20	0.20	0.20	0.9	0.9	0.9	0.7	0.8	1.0	0.7	0.9	1.0		
Zn-D	1.7	5.3	8.1	0.05	0.05	0.14	0.05	0.5	1.0	0.05	0.08	0.8	8.0	8.1
Zn-T	3.5	3.7	6.3	1.2	2	2.7	1.3	2	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

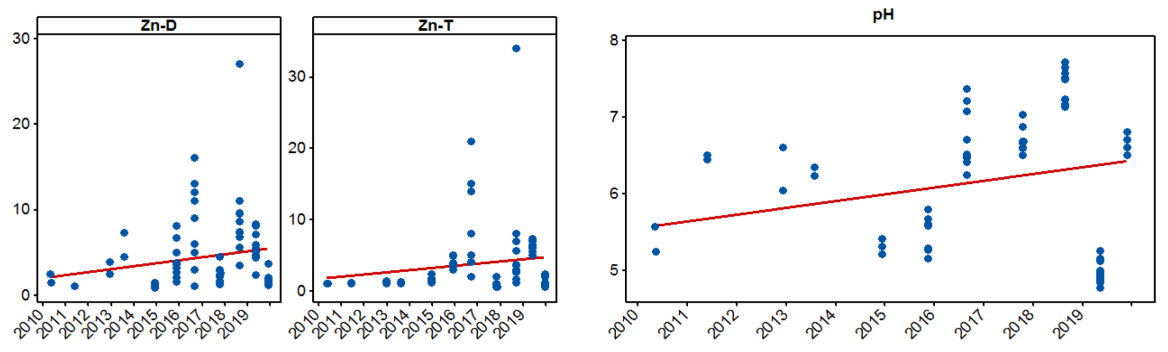
Baseline data were collected from the test sites prior to mine operations commencing

Table 5-12 Trends for water quality in Lake Murray 2010 - 2019 as determined using Spearman Rank Correlation against time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2010 – 2019)
Lake Murray Ref (Trend of all data from 2010 - 2019)	pH	0.290	0.010	Increased over time
	EC	-0.190	0.096	No change over time
	TSS	-0.526	<0.001	Reduced over time
	Ag-D*	-0.671	<0.001	Reduced over time
	Ag-T*	-0.771	<0.001	Reduced over time
	As-D*	-0.644	<0.001	Reduced over time
	As-T*	-0.710	<0.001	Reduced over time
	Cd-D*	-0.529	<0.001	Reduced over time
	Cd-T*	-0.717	<0.001	Reduced over time
	Cr-D*	-0.209	0.066	No change over time
	Cr-T*	-0.717	<0.001	Reduced over time
	Cu-D*	-0.529	<0.001	Reduced over time
	Cu-T*	-0.628	<0.001	Reduced over time
	Fe-D*	-0.202	0.076	No change over time
	Fe-T*	-0.221	0.052	No change over time
	Hg-D*	-0.222	0.051	No change over time
	Hg-T*	-0.198	0.082	No change over time
	Ni-D*	-0.625	<0.001	Reduced over time
	Ni-T*	-0.666	<0.001	Reduced over time
	Pb-D*	0.007	0.949	No change over time
	Pb-T*	-0.677	<0.001	Reduced over time
	Se-D*	-0.287	0.015	Reduced over time
	Se-T*	-0.653	<0.001	Reduced over time
	Zn-D	0.252	0.026	Increased over time
	Zn-T	0.101	0.377	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.



North Lake Murray dissolved and total zinc concentrations (µg/L) and pH 2010 – 2019 (Ref site)

Figure 5-51 Trend analysis Lake Murray water quality (scatter plot of all data from 2010 – 2019 with linear trend line)

5.4 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), from reference sites during the previous 24 months 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 2019 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 the total digest (TD). The WAE concentrations best represent the concentration of metals that are bioavailable and therefore have potential to cause toxicity. Concentrations of total digestible metals include weakly and strongly bound sediment metals and over estimate the fraction likely to become readily bioavailable, and therefore likely overestimate potential toxicity.

5.4.1 Local reference sites

Local sites comprise the small highland creeks within the Porgera River catchment that are not affected by the mining operation. As is the case for water at these sites, sediment from these creeks mixes with the discharge from the mine to form the Porgera River, and so the quality of sediment within these creeks is important for assessing the full context of inputs that influence downstream environmental conditions. Sediment monitoring began at local sites in 2015, and the results are presented in Table 5-13.

Sediment quality within local creeks is dominated by the surrounding limestone geology and relatively low level of development within the catchments. The WAE and TD concentrations for all metals were comparable to other regional reference sites, indicating that the local creeks do not contribute significant amounts of metals in sediment to the river system downstream of the mine. Sampling was not performed at Kaiya US during 2019 due to security concerns.

Table 5-13 Local sites sediment quality 2019 (mg/kg dry, whole fraction)

Parameter	Aipulungu US			Kaiya US			Pongema		
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile
Ag-WAE	0.06	0.061	0.069	NS	NS	NS	0.05	0.05	0.069
Ag-TD	0.11	0.12	0.12	NS	NS	NS	0.054	0.059	0.061
As-WAE	1.1	1.1	1.2	NS	NS	NS	0.90	1.0	1.0
As-TD	2.4	2.5	3.0	NS	NS	NS	3.2	4.3	4.6
Cd-WAE	0.12	0.12	0.12	NS	NS	NS	0.10	0.12	0.14
Cd-TD	0.13	0.14	0.14	NS	NS	NS	0.14	0.15	0.16
Cr-WAE	6.2	8.3	12	NS	NS	NS	4.7	5.1	6.4
Cr-TD	25	27	28	NS	NS	NS	15	17	23
Cu-WAE	8.3	8.9	9.3	NS	NS	NS	2.5	2.9	3.1
Cu-TD	12	12	15	NS	NS	NS	5.3	6.8	8.4
Hg-WAE	0.01	0.01	0.01	NS	NS	NS	0.01	0.01	0.01
Hg-TD	0.03	0.03	0.03	NS	NS	NS	0.02	0.02	0.02
Ni-WAE	7.4	9.5	14	NS	NS	NS	3.8	4.2	4.7
Ni-TD	21	22	22	NS	NS	NS	9.7	13	15

Parameter	Aipulungu US			Kaiya US			Pongema		
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile
Pb-WAE	4.1	4.3	4.4	NS	NS	NS	2.9	3.6	4.5
Pb-TD	5.6	6.2	6.2	NS	NS	NS	3.3	4.3	5.4
Se-WAE	0.15	0.18	0.26	NS	NS	NS	0.11	0.12	0.12
Se-TD	0.42	0.44	0.65	NS	NS	NS	0.24	0.3	0.35
Zn-WAE	34	47	51	NS	NS	NS	15	18	19
Zn-TD	61	68	70	NS	NS	NS	31	36	47

WAE - Weak acid extractable, TD - Total digest, NS – Not sampled

5.4.2 Upper River

This section presents sediment quality data collected from test sites prior to mining operations commencing (baseline data), from reference sites during the previous 24 months 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 2019 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 2010 and 2019 for TD metals and between 2013 and 2019 for WAE metals shows increasing concentrations of WAE arsenic, TD 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 5-15 and graphical representation of WAE arsenic, WAE chromium, WAE copper, WAE lead, WAE nickel and WAE zinc showing increasing trends is presented in Figure 5-52.

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 2019 TV were from the following sources:

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

Table 5-14 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 = 102)			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	0.13	ND	ND	ND		
As-WAE	1.4	1.8	2.5	ND	ND	ND	20	20
As-TD	7.7	11	13	6.5	10	14		

Parameter	UpRivs Ref 24 month (n = 102)			UpRivs Baseline (<63µm) (n = 2)			ANZG (2018) SDGV	UpRiv TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
Cd-WAE	0.05	0.05	0.068	ND	ND	ND	1.5	1.5
Cd-TD	0.05	0.05	0.093	0.06	0.08	0.098		
Cr-WAE	1.6	4.0	9.7	ND	ND	ND	80	80
Cr-TD	18	27	74	28	31	33		
Cu-WAE	3.8	8.2	15	ND	ND	ND	65	65
Cu-TD	14	30	45	133	175	217		
Hg-WAE	0.01	0.01	0.01	ND	ND	ND	0.15	0.15
Hg-TD	0.04	0.056	0.076	ND	ND	ND		
Ni-WAE	4.5	10	22	ND	ND	ND	21	22
Ni-TD	24	39	85	23	29	34		
Pb-WAE	5.5	7.7	9.5	ND	ND	ND	50	50
Pb-TD	10	15	19	13	17	20		
Se-WAE	0.10	0.11	0.15	ND	ND	ND	NA	0.15
Se-TD	0.30	0.39	0.53	0.46	0.50	0.54		
Zn-WAE	12	18	38	ND	ND	ND	200	200
Zn-TD	66	88	100	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

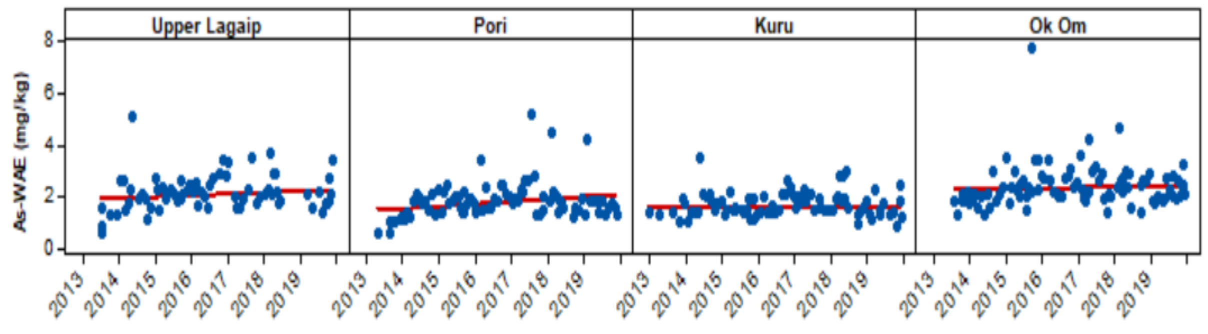
Table 5-15 Trends for sediment quality for upper river reference sites determined by Spearman Rank correlation against time (2010 – 2019)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2010 – 2019)
UpRivs Ref (Trend of all data WAE from 2013–2019 TD from 2010-2019)	Ag-WAE*	-0.848	<0.001	No change over time
	Ag-TD*	-0.799	<0.001	No change over time
	As-WAE	0.147	0.007	Increased over time
	As-TD	0.118	0.014	Increased over time
	Cd-WAE*	-0.739	<0.001	No change over time
	Cd-TD*	-0.806	<0.001	No change over time
	Cr-WAE	0.215	<0.001	Increased over time
	Cr-TD	-0.119	0.013	Reduced over time
	Cu-WAE	0.194	<0.001	Increased over time
	Cu-TD	0.019	0.691	No change over time
	Pb-WAE	0.248	<0.001	Increased over time
	Pb-TD	0.022	0.651	No change over time
	Hg-WAE*	-0.353	<0.001	No change over time
	Hg-TD*	-0.504	<0.001	No change over time
	Ni-WAE	0.236	<0.001	Increased over time
	Ni-TD	-0.039	0.415	No change over time

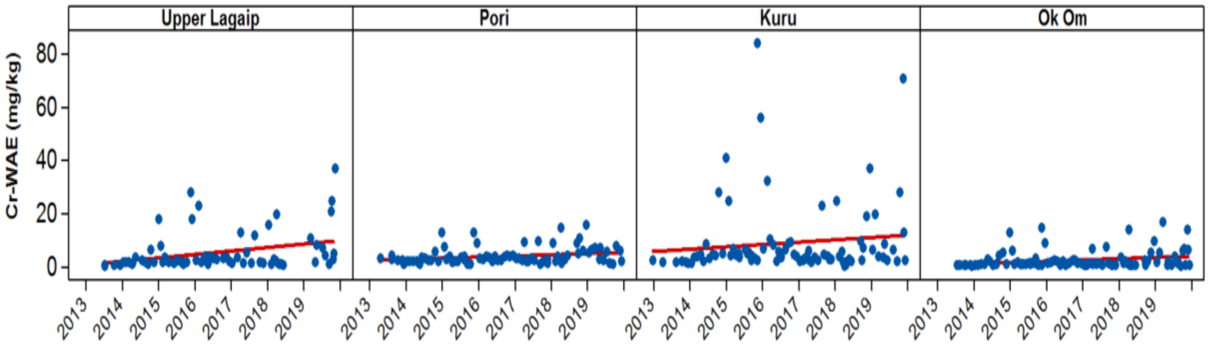
Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2010 – 2019)
	Se-WAE*	-0.705	<0.001	No change over time
	Se-TD*	-0.426	<0.001	No change over time
	Zn-WAE	0.31	<0.001	Increased over time
	Zn-TD	0.090	0.060	No change over time

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

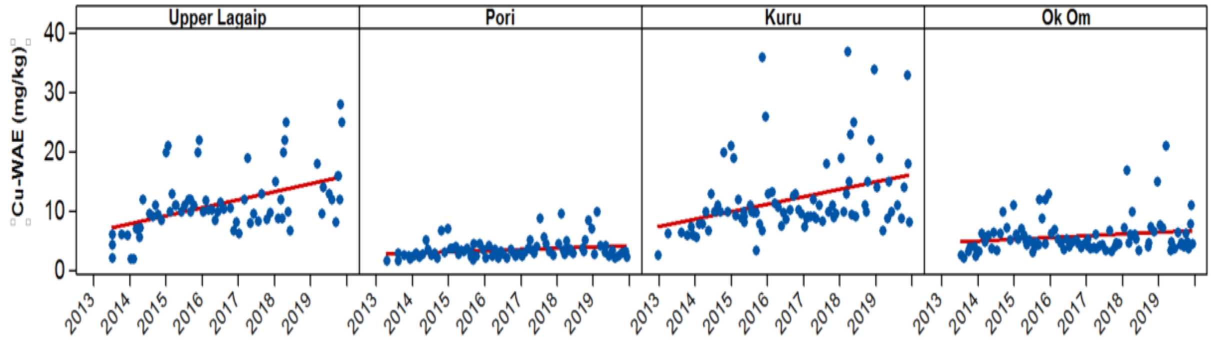
* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore, the finding has been corrected to indicate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



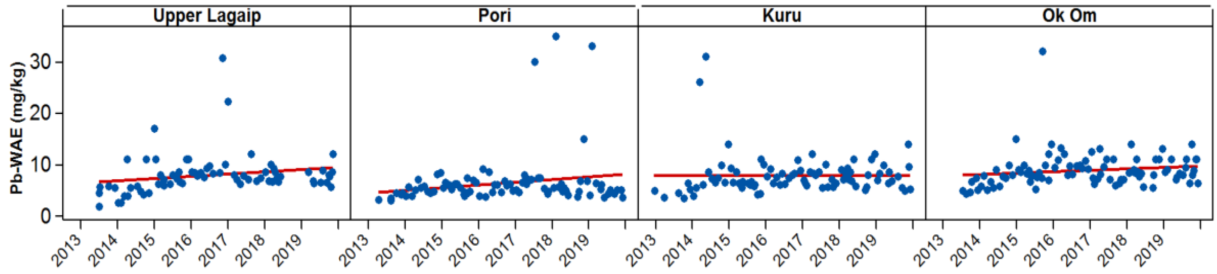
WAE Arsenic concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2019



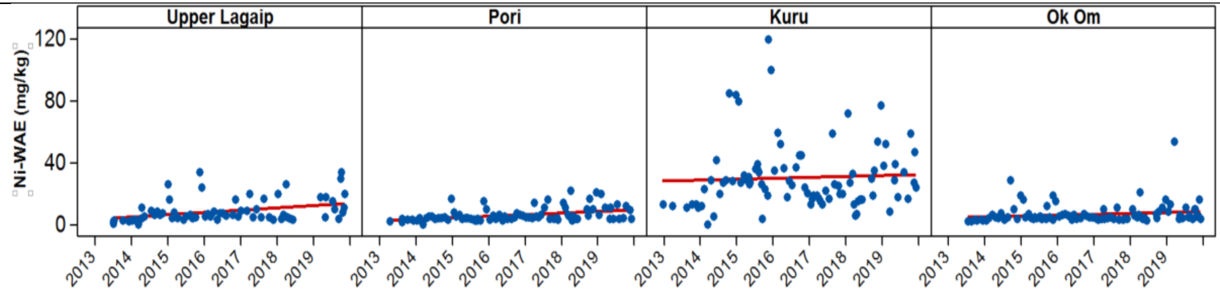
WAE Chromium concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2019



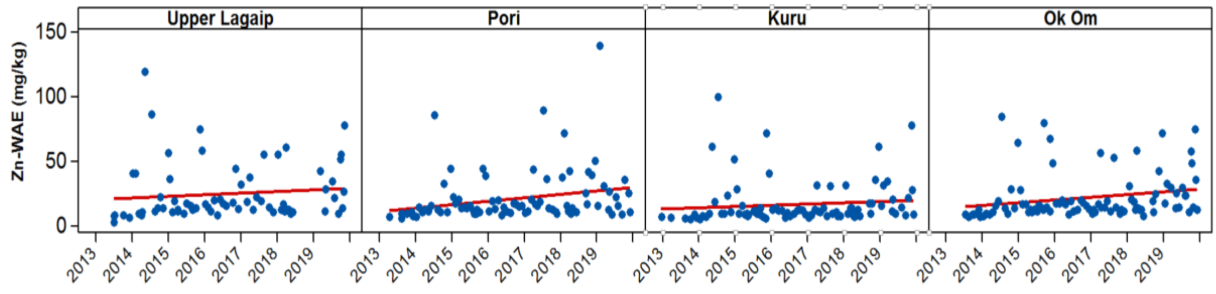
WAE Copper concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2019



WAE Lead concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2019



WAE Nickel concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2019



WAE Zinc concentrations (mg/kg dry whole fraction) – Upper River reference sites 2013 - 2019

Figure 5-52 Trend analysis upper rivers sediment quality showing elements with statistically significant increasing trends (scatter plot of all data from 2013 – 2019 with linear trend line)

5.4.3 Lower River and Off-River Water Bodies

This section presents sediment quality data collected from test sites prior to mining operations commencing (baseline data), from reference sites during the previous 24 months 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 2019 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 5-16.

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 2010 and 2019 show all metals either reduced or did not change over the time period. Trend analysis results are shown in Table 5-17. 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 2019 TV were from the following sources:

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

Table 5-16 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=28)			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	0.30	0.69	1.0	ND	ND	ND	20	20
As-TD	1.4	2.6	4.0	2.8	10	14		
Cd-WAE	0.05	0.075	0.11	ND	ND	ND	1.5	1.5
Cd-TD	0.05	0.09	0.13	2.4	2.4	2.4		
Cr-WAE	2.2	5.5	6.8	ND	ND	ND	80	80
Cr-TD	29	48	53	12	12	12		
Cu-WAE	2.9	3.8	6.1	ND	ND	ND	65	65
Cu-TD	11	15	19	24	24	24		
Hg-WAE	0.01	0.01	0.01	ND	ND	ND	0.15	0.15
Hg-TD	0.01	0.013	0.02	0.34	0.57	0.94		
Ni-WAE	3.7	7.1	13	ND	ND	ND	21	21
Ni-TD	30	47	63	38	38	38		
Pb-WAE	2.3	2.6	3.4	ND	ND	ND	50	50
Pb-TD	3.7	5.3	5.7	22	22	22		
Se-WAE	0.10	0.10	0.10	ND	ND	ND	NA	0.10
Se-TD	0.11	0.17	0.19	0.2	0.2	0.2		
Zn-WAE	11	17	22	ND	ND	ND	200	200
Zn-TD	54	79	116	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 5-17 Trends for sediment quality for lower river reference sites determined by Spearman Rank correlation against time (2010 – 2019)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2010 – 2019)
LwRivs Ref (Trend of all data WAE from 2013–2019 TD from 2010-2019)	Ag-WAE*	-0.840	<0.001	Reduced over time
	Ag-TD*	-0.798	<0.001	Reduced over time
	As-WAE	-0.299	0.013	Reduced over time
	As-TD	0.101	0.239	No change over time
	Cd-WAE*	-0.710	<0.001	Reduced over time
	Cd-TD*	-0.719	<0.001	Reduced over time
	Cr-WAE	-0.104	0.393	No change over time
	Cr-TD	-0.097	0.259	No change over time
	Cu-WAE	-0.070	0.565	No change over time

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2010 – 2019)
	Cu-TD	0.100	0.245	No change over time
	Hg-WAE*	-0.303	0.011	Reduced over time
	Hg-TD*	-0.816	<0.001	Reduced over time
	Ni-WAE	-0.055	0.653	No change over time
	Ni-TD	-0.155	0.07	No change over time
	Pb-WAE	-0.440	<0.001	Reduced over time
	Pb-TD	-0.255	0.003	Reduced over time
	Se-WAE	-0.858	<0.001	Reduced over time
	Se-TD	-0.763	<0.001	Reduced over time
	Zn-WAE	-0.105	0.388	No change over time
	Zn-TD	-0.118	0.169	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.

5.4.4 Lake Murray

This section presents sediment quality data collected from test sites prior to mining operations commencing (baseline data), from reference sites during the previous 24-months 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 2019 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 5-18.

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 2010 and 2019 shows the increasing concentrations of WAE arsenic, TD arsenic and TD zinc. Concentrations of all other metals either reduced or did not change over the time period. Trend analysis results are shown in Table 5-19 and Figure 5-53 for WAE arsenic.

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 2019 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 5-18 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	0.05	ND	ND	ND		
As-WAE	0.77	1.0	1.2	ND	ND	ND	20	20
As-TD	4.4	4.8	5.5	2.8	10	14		
Cd-WAE	0.06	0.08	0.10	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	5.1	6.0	ND	ND	ND	80	80
Cr-TD	34	39	45	12	12	12		
Cu-WAE	7.6	10	11	ND	ND	ND	65	65
Cu-TD	19	22	25	24	24	24		
Hg-WAE	0.03	0.03	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	6.9	9.2	11	ND	ND	ND	21	21
Ni-TD	29	33	38	38	38	38		
Pb-WAE	5.0	6.2	8.1	ND	ND	ND	50	50
Pb-TD	12	13	15	22	22	22		
Se-WAE	0.11	0.14	0.27	ND	ND	ND	NA	0.27
Se-TD	0.60	0.75	0.86	0.2	0.2	0.2		
Zn-WAE	30	42	47	ND	ND	ND	200	200
Zn-TD	92	100	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

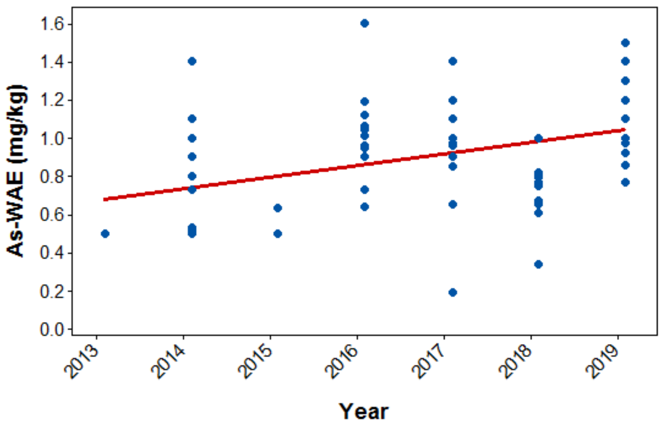
Table 5-19 Trends for sediment quality Lake Murray and ORWBs reference sites determined by Spearman Rank correlation against time (2013 - 2019)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2019)
Lake Murray Ref (Trend of all data WAE from 2013 – 2019 TD from 2009 - 2019)	Ag-WAE*	-0.825	<0.001	No change over time
	Ag-TD*	-0.851	<0.001	No change over time
	As-WAE	0.395	0.001	Increased over time
	As-TD	0.376	0.001	Increased over time
	Cd-WAE*	-0.641	<0.001	No change over time
	Cd-TD*	-0.750	<0.001	No change over time
	Cr-WAE	-0.259	0.036	Reduced over time
	Cr-TD	-0.096	0.424	No change over time
	Cu-WAE	-0.132	0.292	No change over time

Sediment Quality	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2019)
Site				
	Cu-TD	0.097	0.419	No change over time
	Hg-WAE	0.215	0.083	No change over time
	Hg-TD*	0.066	0.58	No change over time
	Ni-WAE	0.228	0.065	No change over time
	Ni-TD	0.207	0.081	No change over time
	Pb-WAE	-0.211	0.09	No change over time
	Pb-TD	-0.023	0.85	No change over time
	Se-WAE*	-0.323	0.008	No change over time
	Se-TD	0.035	0.771	No change over time
	Zn-WAE	0.174	0.161	No change over time
	Zn-TD	0.264	0.025	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 & ORWBS As-WAE concentrations (mg/kg dry whole fraction) (Ref site)

Figure 5-53 Trend analysis LMY reference sites sediment quality (scatter plot of As-WAE, for all data from 2013 – 2019 with linear trend line)

5.5 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 2019 TV for use in the tissue metal risk assessment presented in Section 7. The sites are grouped into regions; Local Sites, Upper River, Lower River and Lake Murray. Tissue metal sampling is not performed in the ORWBs.

5.5.1 Upper River

A summary of tissue metal TVs for the upper river reference sites are presented in Table 5-20 and Table 5-21.

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 individuals 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 2010 and 2019 indicates that concentrations for metals at the reference site either remained constant or decreased, with the exception of chromium in fish flesh, which showed an increasing trend. Trend analysis results are shown in Table 5-22 and Table 5-23, while a graph showing increasing chromium concentrations is shown in Figure 5-54.

Baseline data for fish flesh tissue metal 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 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 2019 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 2019 reference site 80%ile, the 2019 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 and nickel
    - Prawn abdomen: arsenic, cadmium, chromium, copper, mercury, nickel, lead, selenium and zinc.
- Baseline data:
    - Fish flesh: arsenic, cadmium, copper, mercury, lead, zinc.
    - Prawn abdomen: NA
- US EPA Guidelines:
    - Fish flesh: selenium
    - Prawn abdomen: NA

Table 5-20 Tissue metal data for upper river reference site Ok Om for previous 24 months (As, Cd, Cr, Cu) (µg/g wet wt.)

Site	Sample	n	As		Cd		Cr		Cu	
			Median	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile
Ok Om	Fish Flesh	24	0.01	0.014	0.003	0.004	0.010	0.021	0.17	0.21
	Prawn Ab	24	0.03	0.039	0.003	0.003	0.018	0.026	4.6	6.3
Wankipe baseline	Fish Flesh	28	0.20	0.200	0.010	0.020	ND	ND	0.21	0.48
Trigger Value	Fish Flesh	-	-	0.200	-	0.020	-	0.021	-	0.48
	Prawn Ab	-	-	0.039	-	0.003	-	0.026	-	6.3

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 5-21 Tissue metal data for upper river reference site Ok Om for previous 24 months and applicable US EPA guideline value (Hg, Ni, Pb, Se, Zn) (µg/g wet wt.)

Site	Sample	n	Hg		Ni		Pb		Se		Zn	
			Median	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile
Ok Om	Fish Flesh	24	0.04	0.05	0.01	0.01	0.01	0.01	0.24	0.31	4.9	5.9
	Prawn Ab	24	0.01	0.01	0.01	0.01	0.01	0.01	0.48	0.57	13.0	14
Wankipe baseline	Fish Flesh	28	0.07	0.08	0.10	0.10	0.07	0.17	0.20	0.20	8.9	10.4
USEPA (2016)	Fish Flesh	NA	NA	NA	NA	NA	NA	NA	2.26 (11.3 dry wt.)		NA	NA
Trigger Value	Fish Flesh	-	-	0.08	-	0.01	-	0.17	-	2.26	-	10.4
	Prawn Ab	-	-	0.01	-	0.01	-	0.01	-	0.57	-	14

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

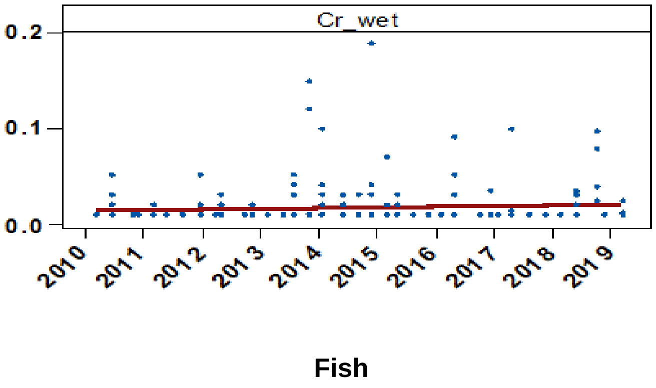
Table 5-22 Trends of metals in fish flesh for upper river reference sites 2010 - 2019 determined by Spearman Rank correlation against time

Fish Flesh **Site**	**Parameter**	**Spearman's rho**	**p-Value (p=0.05)**	**Trend (2010–2019)**
UpRivs Ref (Trend of Ok Om data 2010-2019)	As	-0.041	0.496	No change over time
	Cd	-0.713	<0.001	Reduced over time
	Cr	0.169	0.005	Increased over time
	Cu	-0.154	0.011	Reduced over time
	Hg	-0.199	0.001	Reduced over time
	Ni	-0.095	0.118	No change over time
	Pb	-0.008	0.891	No change over time
	Se	-0.341	<0.001	Reduced over time
	Zn	-0.148	0.015	Reduced over time

Table 5-23 Trends of metals in prawn abdomen for upper river reference sites 2010 - 2019 determined by Spearman Rank correlation against time

Prawn Abdomen **Site**	**Parameter**	**Spearman's rho**	**p-Value (p=0.05)**	**Trend (2010–2019)**
UpRivs Ref (Trend of Ok Om data 2010-2019)	As	-0.417	<0.001	Reduced over time
	Cd	-0.801	<0.001	Reduced over time
	Cr	0.058	0.359	No change over time
	Cu	-0.195	0.002	Reduced over time
	Hg*	-	-	No change over time
	Ni	-0.055	0.381	No change over time
	Pb	-0.054	0.396	No change over time
	Se	-0.136	0.03	Reduced over time
	Zn	-0.167	0.008	Reduced 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.



Chromium concentration (µg/g wet wt.) in fish – Upper River reference (Ok Om 2010 – 2019)

Figure 5-54 Trend analysis of chromium concentration in fish (µg/g wet wt.) – Upper River reference sites Ok Om 2010 – 2019. Graph shows weak increasing linear trend.

5.5.2 Lower River

A summary of tissue metal TVs for the lower river reference sites are presented in Table 5-24 and Table 5-25.

Reference site data were generated by combining the 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 2010 and 2019 indicated increasing trends of chromium in fish flesh, and arsenic, copper, selenium and zinc in prawn abdomen. All other metals either reduced or did not change over the same period. Trend analysis results are shown in Table 5-26 and Table 5-27, graphical representation of chromium in fish flesh and prawn abdomen data showing increasing trends is presented in Figure 5-55.

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 2019 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 5-24 Tissue metal data for lower river reference sites for previous 24 months (As, Cd, Cr, Cu) (µg/g wet wt.)

Site	Sample	n	As		Cd		Cr		Cu	
			Median	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile
Baia	Fish	18	0.01	0.012	0.003	0.003	0.012	0.034	0.081	0.10
	Prawn	19	0.077	0.086	0.003	0.004	0.03	0.05	6.8	8.22
Tomu	Fish	21	0.01	0.01	0.003	0.003	0.01	0.021	0.083	0.15
	Prawn	22	0.061	0.084	0.003	0.0066	0.0355	0.0494	8.9	12.8
Lower River Ref	Fish Flesh	39	0.010	0.010	0.003	0.003	0.010	0.030	0.08	0.13
	Prawn Ab	41	0.065	0.085	0.003	0.005	0.030	0.050	7.7	10
SG4 baseline	Fish Flesh	19	0.036	0.071	0.003	0.003	0.024	0.026	0.133	0.17
Trigger Value	Fish Flesh	-	-	0.071	-	0.003	-	0.030	-	0.17
	Prawn Ab	-	-	0.085	-	0.005	-	0.050	-	10

n – number of samples, Ab - Abdomen

Table 5-25 Tissue metal data for lower river reference sites for previous 24 months and applicable US EPA guideline value (Hg, Pb, Se, Zn) (µg/g wet wt.)

Site	Sample	n	Hg		Ni		Pb		Se		Zn	
			Median	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile
Baia	Fish	18	0.015	0.024	0.010	0.010	0.010	0.010	0.06	0.076	2.8	3.92
	Prawn	19	0.010	0.010	0.010	0.01	0.010	0.010	0.30	0.324	12	13
Bebs	Fish	21	0.045	0.075	0.010	0.011	0.010	0.010	0.13	0.20	2.7	3.6
	Prawn	22	0.010	0.01	0.01	0.01	0.01	0.01	0.255	0.286	12	14
Lower River Ref	Fish Flesh	39	0.036	0.047	0.010	0.010	0.010	0.010	0.08	0.16	2.8	3.9
	Prawn Ab	41	0.010	0.010	0.010	0.010	0.010	0.010	0.27	0.32	12	14
SG4 baseline	Fish Flesh	19	0.060	0.12	0.076	0.165	0.026	0.03	0.128	0.17	3.3	7.5
USEPA (2014)	Fish Flesh	NA	NA	NA	NA	NA	NA	NA	2.26 (11.3 dry wt.)		NA	NA
Trigger Value	Fish Flesh	-	-	0.12	-	0.165	-	0.03	-	2.26	-	7.5
	Prawn Ab	-	-	0.01	-	0.01	-	0.01	-	0.32	-	14

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

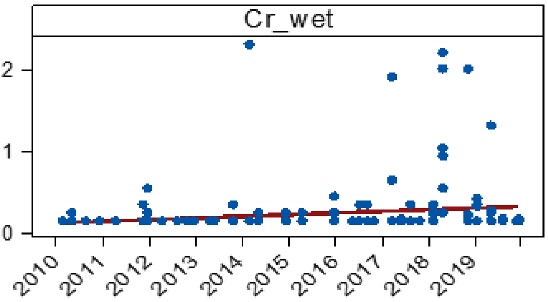
Table 5-26 Trends of metals in fish flesh at lower river reference site 2010 - 2019 determined by Spearman Rank correlation against time

Fish flesh Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (2010–2019)
LwRivs Ref (Trend of all data 2010-2019)	As	0.061	0.382	No change over time
	Cd	-0.844	<0.001	Reduced over time
	Cr	0.239	0.001	Increased over time
	Cu	-0.217	0.002	Reduced over time
	Hg	-0.412	<0.001	Reduced over time
	Ni	-0.025	0.725	No change over time
	Pb	-0.087	0.214	No change over time
	Se	-0.416	<0.001	Reduced over time
	Zn	-0.030	0.666	No change over time

Table 5-27 Trends of metals in prawn abdomen at lower river reference sites 2010 - 2019 determined by Spearman Rank correlation against time

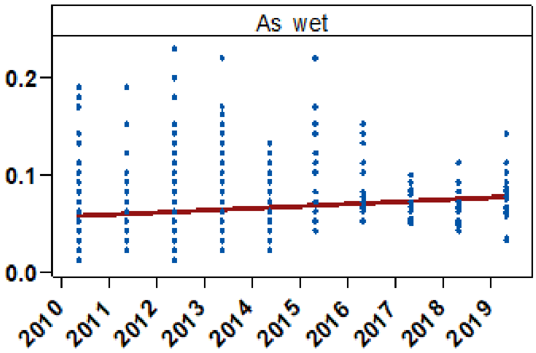
Prawn Abdomen Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (2010–2019)
LwRivs Ref (Trend of all data 2010-2019)	As	0.240	<0.001	Increased over time
	Cd	-0.599	<0.001	Reduced over time
	Cr	0.038	0.359	No change over time
	Cu	0.319	<0.001	Increased over time
	Hg*	-	-	No change over time
	Ni	-0.113	0.006	Reduced over time
	Pb	-0.098	0.018	Reduced over time
	Se	0.152	<0.001	Increased over time
	Zn	0.203	<0.001	Increased 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.



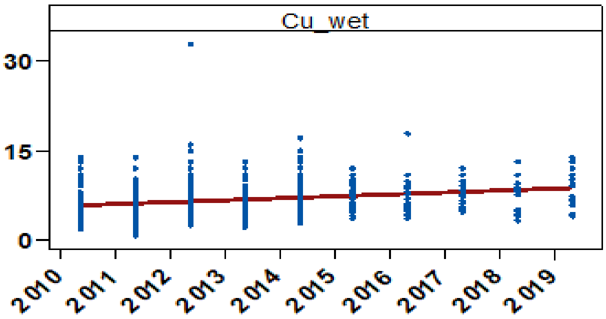
Fish

Chromium concentrations (μg/g wet wt.) – Lower River reference sites combined 2010 - 2019



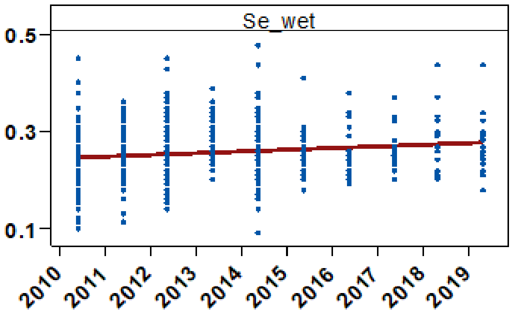
Prawn

Arsenic concentrations (μg/g wet wt.) – Lower River reference sites combined 2010 - 2019



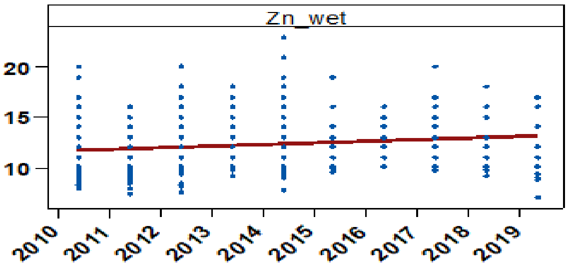
Prawn

Copper concentrations (μg/g wet wt.) – Lower River reference sites combined 2010 - 2019



Prawn

Selenium concentrations (μg/g wet wt.) – Lower River reference sites combined 2010 - 2019



Prawn

Zinc concentrations (μg/g wet wt.) – Lower River reference sites combined 2010 - 2019

Figure 5-55 Trend analysis of chromium concentration (μg/g wet wt.) in fish and arsenic, copper, selenium and zinc concentration in prawns – Lower River reference sites combined 2010 – 2019. Graphs show weak increasing linear trend.

5.5.3 Lake Murray

Data summaries and presentation of tissue metal TVs for the Lake Murray reference sites are presented in Table 5-28 and Table 5-29.

Reference data were generated by combining the data 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 2009 and 2019 indicated that the concentration of selenium in fish flesh increased while concentrations of all other metals either reduced or did not change over the time period. Trend analysis results are shown in Table 5-30.

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 2019 TV were from the following sources:

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

Table 5-28 Summarised tissue metal data for Lake Murray reference sites for previous 24 months (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	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile
Maka	Fish Flesh	9	0.010	0.017	0.003	0.003	0.010	0.010	0.085	0.088
Miwa baseline	Fish Flesh	7	0.04	0.05	0.002	0.002	0.02	0.028	0.16	0.203
Trigger Value	Fish Flesh	-	-	0.05	-	0.003	-	0.028	-	0.203

n – number of samples

Table 5-29 Summarised tissue metal data for Lake Murray reference sites for previous 24 months 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.)

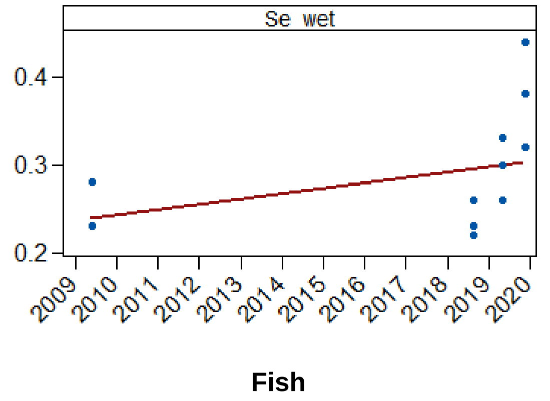
Site	Sample	n	Hg		Ni		Pb		Se		Zn	
			Median	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile
Maka	Fish Flesh	9	0.22	0.328	0.010	0.010	0.010	0.010	0.30	0.35	2.5	2.64
Miwa baseline	Fish Flesh	7	0.11	0.17	0.10	0.19	0.05	0.071	0.13	0.17	2.87	3.12
USEPA (2016)	Fish Flesh	NA	NA	NA	NA	NA	NA	NA	2.26 (11.3 dry wt.)		NA	NA
Trigger Value	Fish Flesh	-	-	0.328	-	0.19	-	0.071	-	2.26	-	3.12

n – number of samples, NA – not applicable

Table 5-30 Trends of metals in fish flesh at Lake Murray and ORWB reference sites 2010-2019 determined by Spearman Rank correlation against time

Fish Flesh	Element	Spearman's rho	p-Value (p=0.05)	Trend (2009-2018)
Site				
LMY Ref Site (Maka) (Trend of all data 2009-2019)	As	0.289	0.362	No change over time
	Cd	-0.707	0.010	Reduce over time
	Cr	0.423	0.171	No change over time
	Cu	-0.391	0.208	No change over time
	Hg	-0.862	<0.001	Reduce over time
	Ni	0.286	0.367	No change over time
	Pb	*	*	No change over time
	Se	0.691	0.013	Increased over time
	Zn	-0.316	0.316	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.



Se concentrations (µg/g wet wt.) – Lake Murray reference site 2009 - 2019

Figure 5-56 Trend analysis of selenium concentration (µg/g wet wt.) in fish – Lake Murray reference site (Maka) 2009 – 2019. Graphs show weak increasing linear trend.

5.6 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 2.6 of this report.

A summary of biological indicator parameters and TVs for the upper river, lower river and Lake Murray are presented in Table 5-31, Table 5-32 and Table 5-33 respectively.

Table 5-31 Trigger Values for Upper River Impact Assessment

Test Site	Indicator Parameter		TV Source	TV
Wasiba & Wankipe	Fish	Total Fish Abundance	Ok Om Reference	3.6
		Total Fish Biomass (g)		174.7
		N. equinus Abundance		2.4
		N. equinus Biomass (g)		129.4
	Prawn	Total Prawn Abundance	Ok Om Reference	6.0
		Total Prawn Biomass		24.6
		M. handschini Abundance		3.2
		M. handschini Biomass		14.1
		M. lorentzi Abundance		2.8
		M. lorentzi Biomass		10.5

Table 5-32 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'	4.0
		Total Fish Abundance		10.5
		Total Fish Biomass		6.2
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
		Total Fish Richness	Option B3 Mean of Tomu Reference	5.0
		Total Fish Abundance		17.1
		Total Fish Biomass		12.8

Table 5-33 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	4.8
		Total Fish Abundance		9.9
		Total Fish Biomass		17.5
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	4.8
		Total Fish Abundance		9.9
		Total Fish Biomass		17.5

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

There were four short duration events at three of the five sewage treatment plants during the year where TSS concentrations in the discharge deviated from the target concentration. The duration of each event was less than 24 hr and TSS in the discharge remained below that of the receiving environment, as a result the environmental impact associated with these events is considered negligible.

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. Table 6-2 is a summary of water quality results measured at SG3 during 2019 and shows that water quality at SG3 complied with the permit criteria during 2019. 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 2019. Monitoring was not conducted at SG1 due to security concerns.

Table 6-1 Compliance summary 2019

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.
TOTAL	**100%**	Target is 100% compliance.

Table 6-2 Median water quality at Upper River Test Sites against SG3 permit criteria 2019 (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	14	7.7	0.01	1.1	0.12	0.43	1.4	0.97	0.18	8.9
Wasiba	15	7.5	0.01	1.0	0.09	0.26	1.2	0.76	0.18	7.2
Wankipe	17	7.7	0.01	1.1	0.05	0.43	1.3	0.71	0.26	5.4
SG3	196	7.6	0.01	1.0	0.05	0.28	1.2	0.63	0.13	4.0
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 Hydrology and Environmental Flows

7.1.1 Waile Creek

Figure 7-1 shows the flow duration curve for Waile Creek Dam in 2019, which has been generated from dam water level measurements and used for estimation of spillway flows to the creek downstream of the extraction point. Overflow was relatively constant for the reporting period but occasional higher peak flows occurred. The frequency and duration of zero-flow periods are important in terms of environmental flows and maintaining downstream ecological values, although it should be noted that some flow continues to occur downstream of the dam wall even when the dam is not overflowing due to leakage from the dam. During 2019, there were 15 occurrences when the dam did not overflow (for one or more days) with the longest period being 9 days.

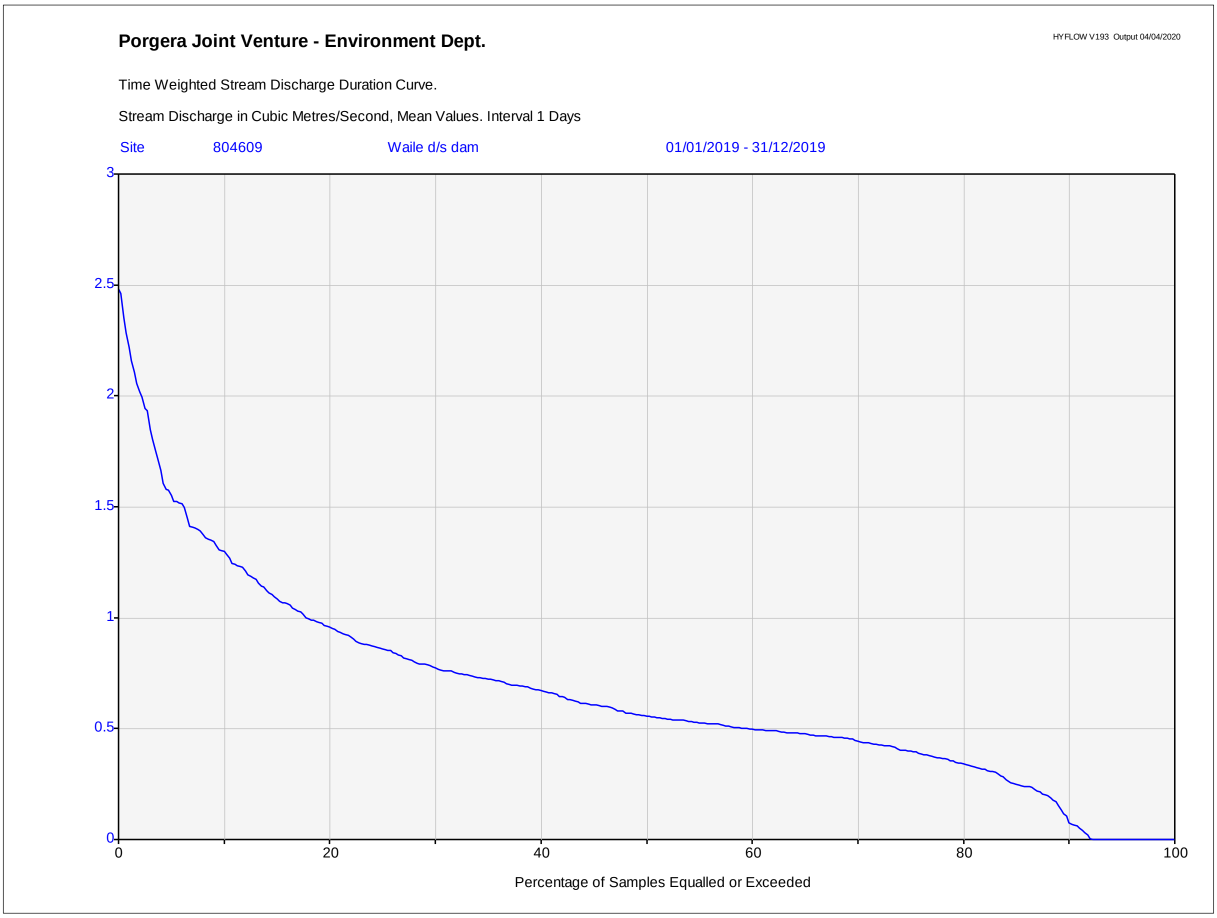


Figure 7-1 Daily flow duration curve (estimated) for Waile Creek Dam overtopping

7.1.2 Kogai Creek

Figure 7-2 shows daily flow duration curves for Kogai Creek upstream (Kogai at SAG Mill) and downstream of the Mill extraction point (Kogai Culvert). Less water is extracted at a constant daily rate and the graph shows that water extraction resulted in minimal change to the flow duration curve downstream. Approximately 500m downstream of the extraction point, and 50 m upstream of Kogai Culvert, Kulapi Creek joins with Kogai Creek. The water extraction resulted in a reduction of the Kogai flow but did not result in any zero flow events within Kogai Creek.

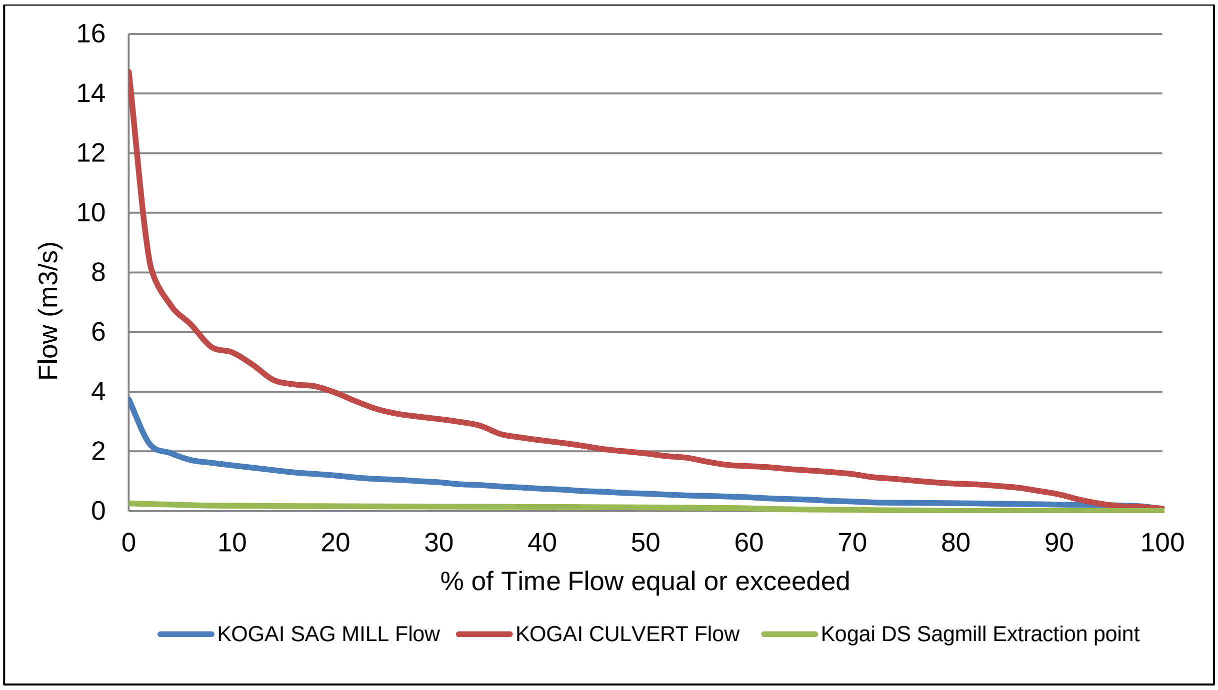


Figure 7-2 Daily flow duration curves for Kogai Creek

7.2 Sediment Transport and Fate of Sediment

Sediments contained in the tailings discharge and exported from the toe of the erodible dumps, are transported downstream by the river flow. Erodible waste rock is deposited at the head of the Anawe and Anjolek erodible waste rock dumps and discharged in slurry from the Yarik portal, from where it is gradually eroded into the river system. Tailings are discharged at the head of the Anawe erodible dump, and it is estimated that 95% of the sediment contained in the tailings makes its way into the river system, with approximately 5% of the tailings solids being retained by deposition along the Anawe erodible dump surface. These are estimates based on professional experience as no tailings mass balance for the dumps has been undertaken.

Estimating the volumes of sediment that actually reach the river system each year, and the relative contributions of natural sediment, waste rock and tailings, were made using a combination of: the measured volumes of waste deposited to the erodible dumps; the volume and density of tailings discharged; the measured change in volume of the erodible dumps from year to year using survey data; the TSS of water from non-mine related catchments downstream of the mine; and river flow rates. This calculation is applied at SG3 as a much higher sampling intensity is performed at this location for compliance purposes, which therefore provides a much larger TSS data set which can be combined with a continuous stream-flow record. Only single monthly TSS samples are taken at the other river monitoring stations, meaning that suspended sediment load estimates at these locations are not as reliable as at SG3.

It should be noted that the river stage at the time of sampling has a significant effect on the TSS concentration, with higher TSS generally measured during high flows, although the relationship between TSS and flow is complex and varies with distance downstream from the mine because mine inputs are relatively constant while natural inputs are more variable. Sampling at SG3 is carried out over 4 successive days each month, so the conditions at the time of sampling may not be representative of flows during the whole of the month. Despite this limitation, the data are considered to provide a reasonable estimate of monthly suspended sediment loads for SG3.

Monthly mean TSS concentrations at SG3 during 2019 are shown in Figure 7-3, 2019 monthly TSS loads are shown in Figure 7-4 and historical (1990-2019) monthly TSS loads are shown in Figure 7-5.

The annual suspended sediment load at SG3 was estimated from the TSS and flow records using a statistical analysis to correct the results for discrepancies arising from irregularly sampled record and continuous record of flow. The statistical analysis is contained in a computer program called *Gumleaf* (Generator for Uncertainty Measures and Load Estimates using Alternative Formulae). The program computes sediment load using 22 different formulae. The program authors are Dr. K. Tan, Professor David Fox (Environmetrics Australia P/L) and Dr. Teri Etchells. Permission for use of Gumleaf was kindly provided by Professor Fox.

The median annual suspended sediment load at SG3 for 2019 was estimated by Gumleaf to be 56.7 Mt, this compares to the long-term median since 1990 of approximately 45 Mt/a, and an annual load in 2018 of 21.5 Mt (which was acknowledged to be an underestimate as a result of a period of poor quality flow record for 2018).

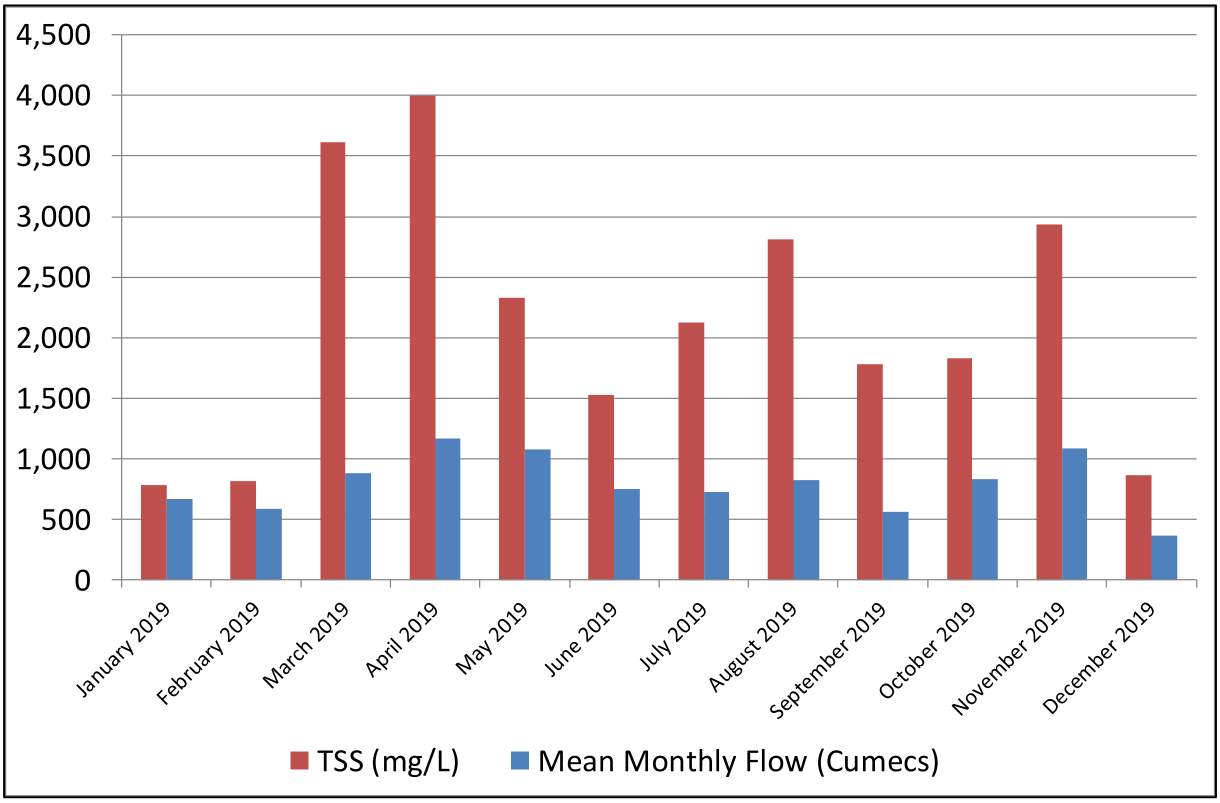


Figure 7-3 Mean monthly TSS and flow at SG3 for 2019

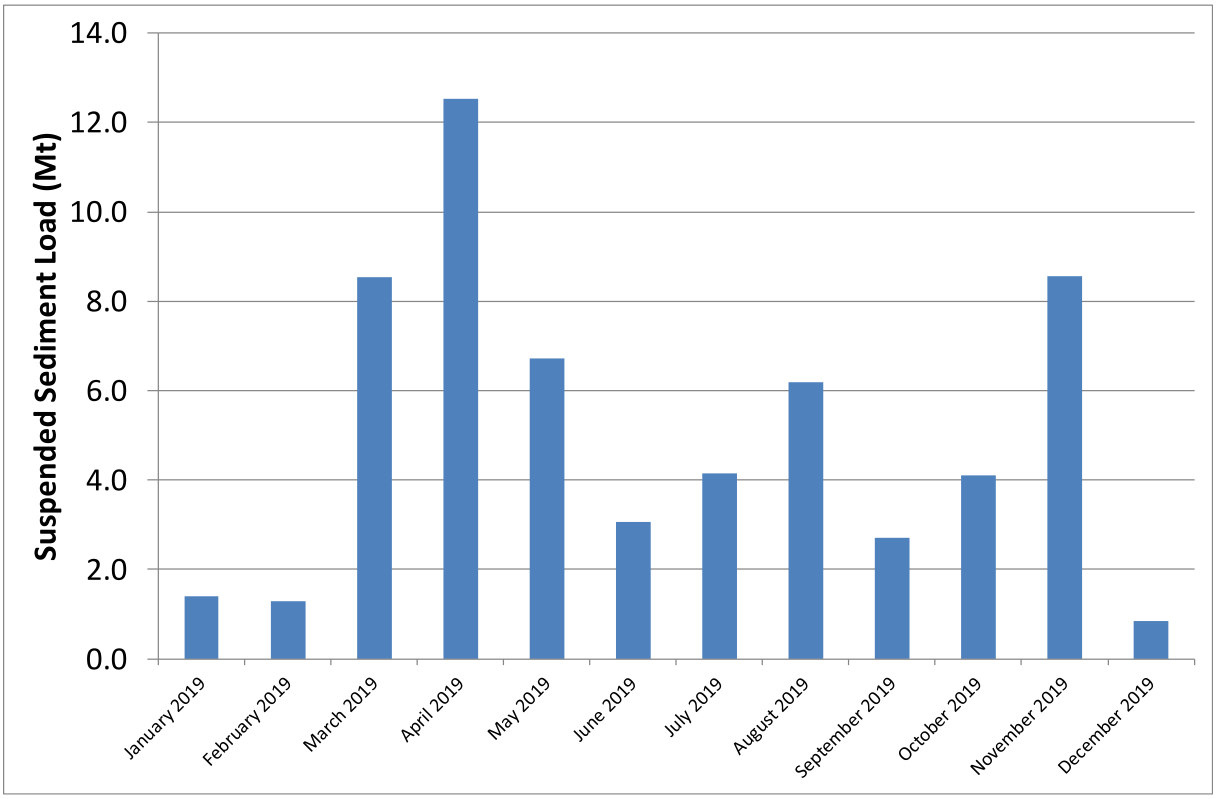


Figure 7-4 Estimated mean monthly suspended sediment loads for SG3 (Mt).

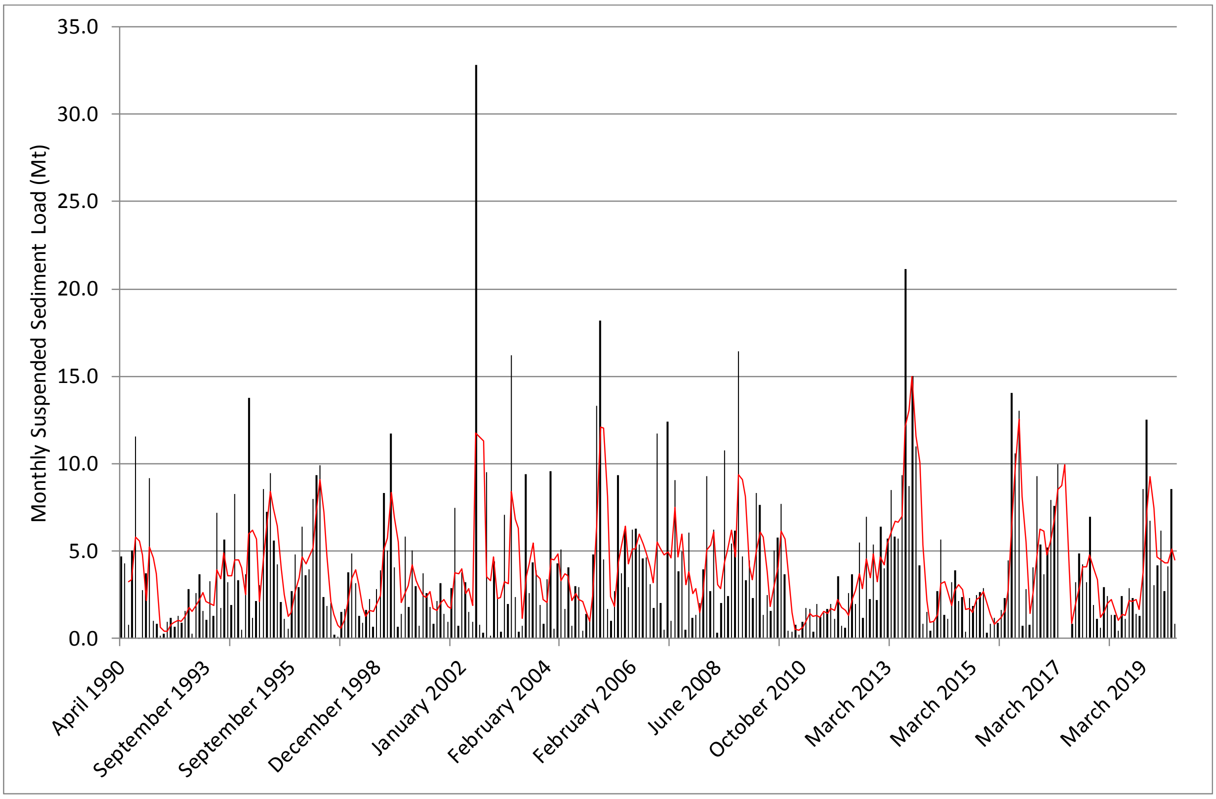
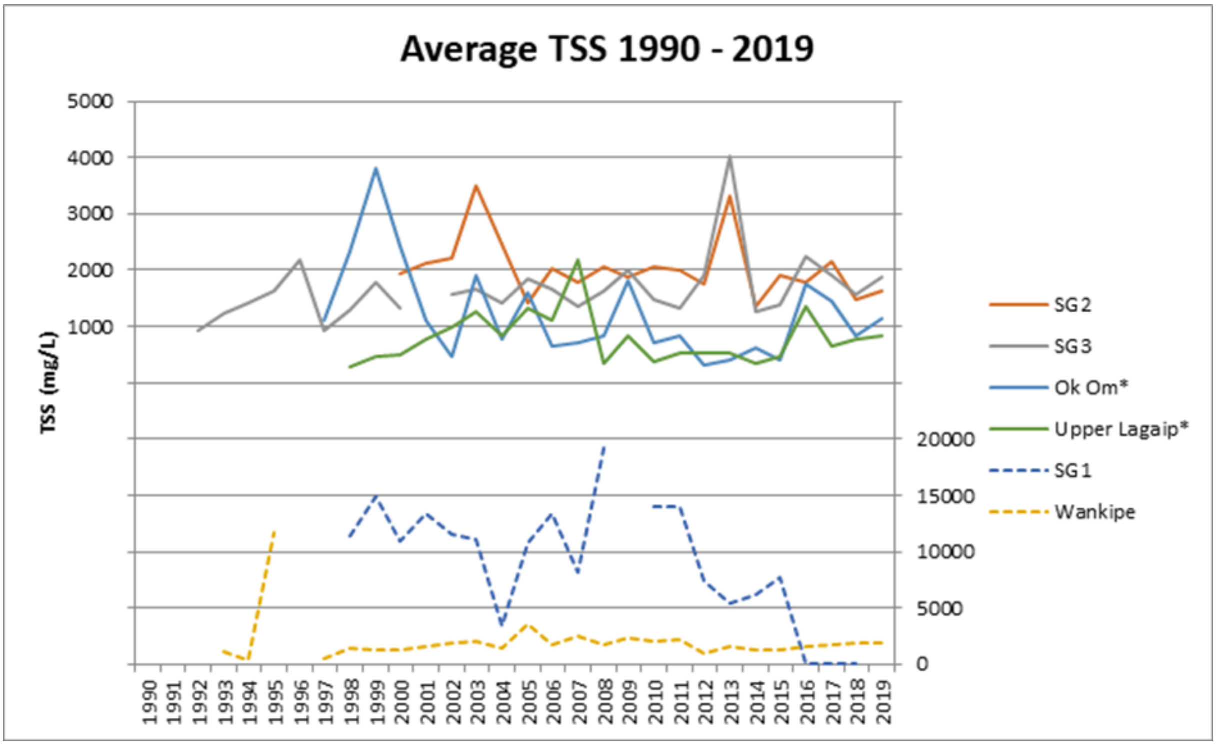


Figure 7-5 Estimated monthly suspended sediment load (black bars) with 3-month moving average at SG3 for full record (red solid line)

To determine the relative contributions of mine-derived and natural sediment to the total sediment load at SG3, the results of the Gumleaf analysis were compared with estimates of mine-derived inputs based on the erodible dump survey analysis and tailings data.

Figure 7-6 shows historical annual average TSS concentrations at river monitoring stations upstream of SG3. In 2019, all reference and test sites showed similar TSS concentrations compared to recent historical values.



* Reference site

Figure 7-6 Historical annual average TSS 1990-2019

Figure 7-7 shows the estimated relative contribution of tailings, waste rock and natural suspended sediment to the total suspended sediment load at SG3 since 1991. Figure 7-8 shows the same dataset presented in terms of the percentage contribution of tailings, waste rock and natural suspended sediment to the overall suspended sediment load.

The analysis shows that the estimated loads contributed by tailings and waste rock in 2019 were consistent with historical rates. However, the background TSS load (computed from SG3 flow and TSS data) was relatively high, and therefore the proportion of that load made up of mine-derived sediment was relatively low by historic standards.

The percentage of total suspended sediment that was mine-derived during 2019 was calculated to be 19%, which compares to a long term median of approximately 22%. By way of comparison, geochemical analyses on sediments conducted as part of the NSF (US National Science Foundation) sponsored Margins Source to Sink Research Program found that, by using silver and lead as tracers, the percentage of mine-derived sediment was 29% for SG3 and 12-13% for SG4 (Swanson et al. 2008).

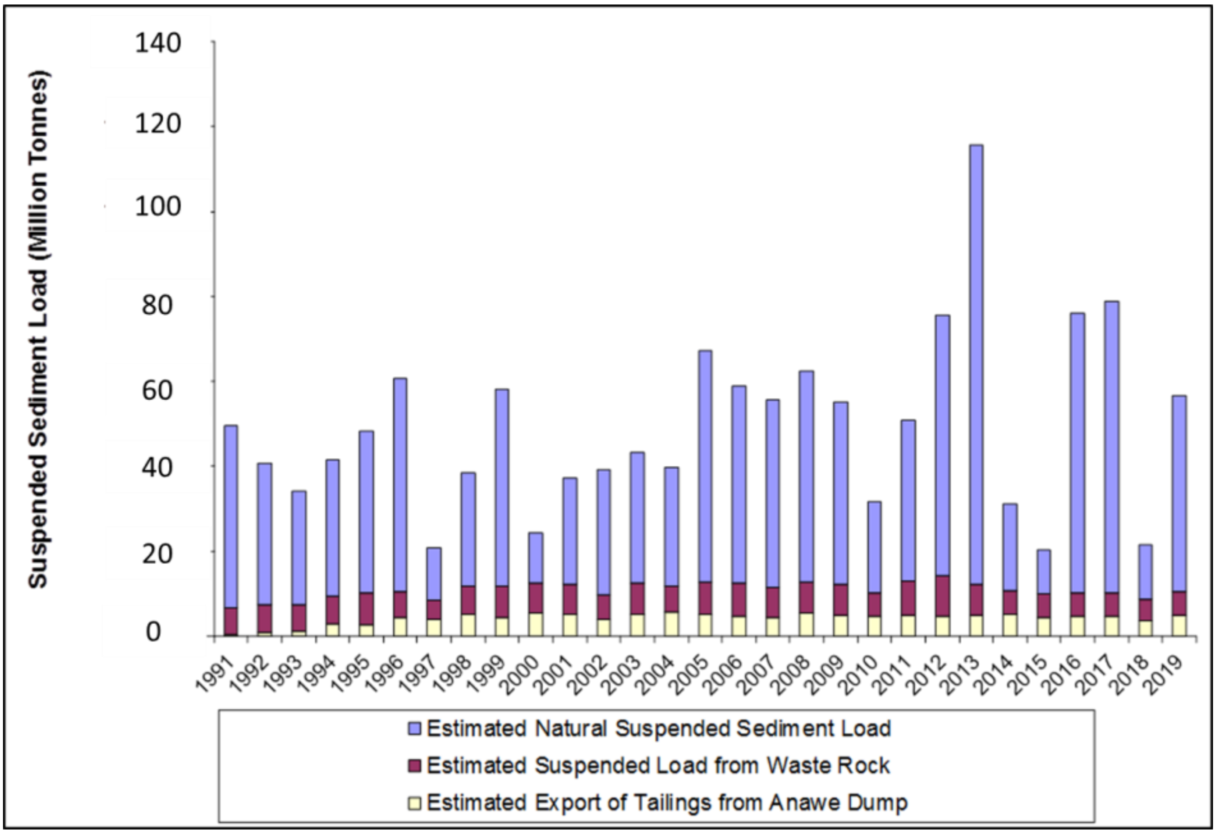


Figure 7-7 Suspended sediment budget at SG3 1991-2019

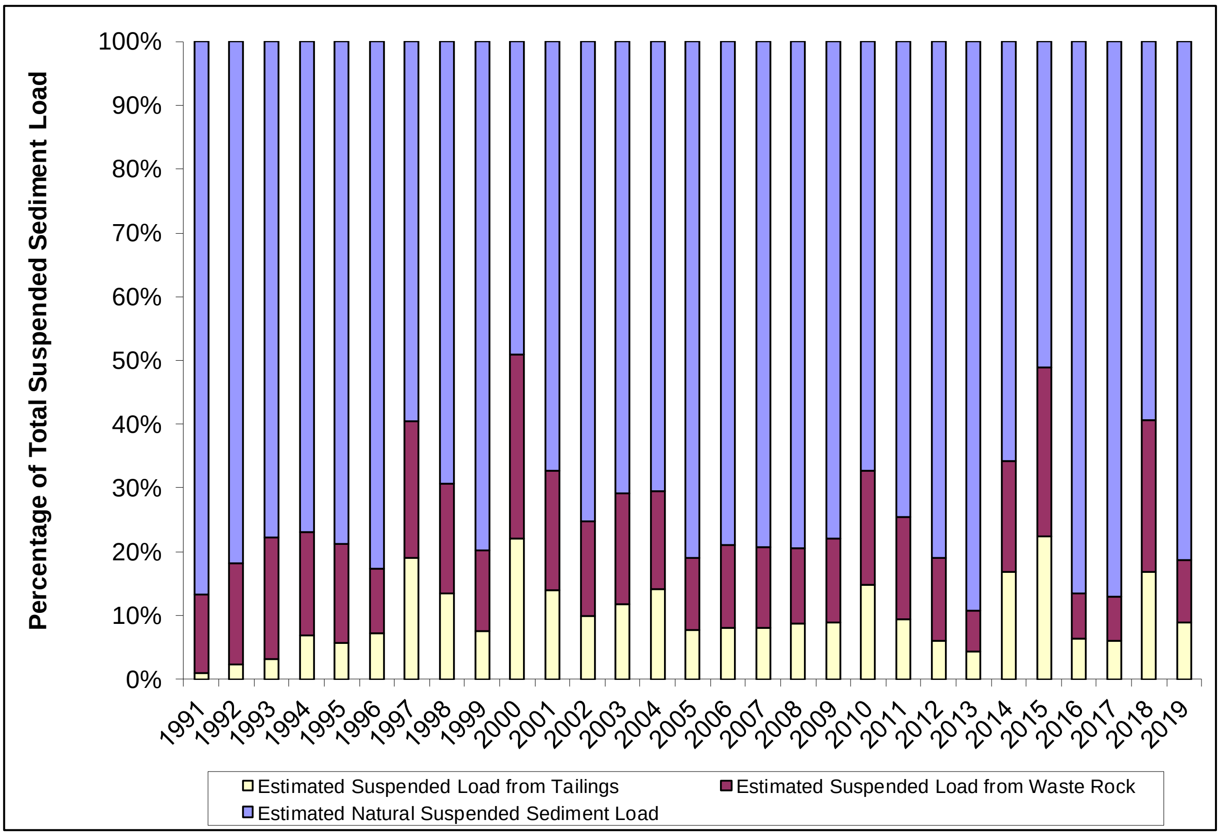


Figure 7-8 Relative contribution of natural and mine-derived suspended sediment at SG3 (%) 1991-2019

7.3 Sediment Aggradation and Erosion

Surveying of river profiles (river-bed cross sections) is performed downstream of the mine at designated locations to evaluate changes in bed levels (aggradation or degradation). Unfortunately over the last five years, it has not been possible to undertake surveys at historical sites along the Porgera River at SG1 (8 km downstream of the mine) due to security concerns, or at SG2, 42 km downstream of the mine, due to security concerns and repeated vandalism of the monitoring infrastructure. The Kaiya River cross section was also not surveyed in 2019 due to security concerns but a helicopter flight over the sites confirmed no significant changes in sediment aggradation and erosion of river walls had occurred.

Helicopter inspections of the Kaiya River valley in 2019 show no evidence of substantial change to the river morphology in 2019 and relative to the last survey in 2016, although areas of valley wall failure were noted (refer to earlier discussion) as well as gradual widening in places. Kaiya profiling will resume in the 2020 AER if security concerns abate.

Figure 7-9 Photo of profile site at Kaiya River downstream of Kogai Creek Confluence

Figure 7-10 Photo of profile site at Kaiya River upstream of Yuyan Bridge

Figure 7-11 Photo of profile site at the Kaiya River downstream of Yuyan Bridge

As discussed in previous Annual Reports, the bed of the Porgera River at SG1 aggraded (built-up) during mine construction due to the initial disposal of erodible waste rock at Anawe erodible dump between about 1989 and 1991 (see Figure 4-12). Since the initial aggradation, the bed elevation has remained more or less consistent, with only minor variation. Although there have been no flow measurements or cross-section surveys along the Porgera River for some time, due to law and order issues preventing access, there is no evidence from qualitative observations alone that significant aggradation or erosion of valley walls is occurring along the Porgera River.

River profiles at SG2, 42 km downstream of the mine, are shown in Figure 7-12 and indicate alternate periods of sediment aggradation and degradation over the years. Long term data show no trend towards either consistent aggradation or degradation. It was not possible to undertake a survey at SG2 during 2018 or 2019 due to security concerns and continuous vandalism of the traversing wire for traveller stream gauging at the site. The physical observations confirm there was no change in river flow and aggradation during the year.

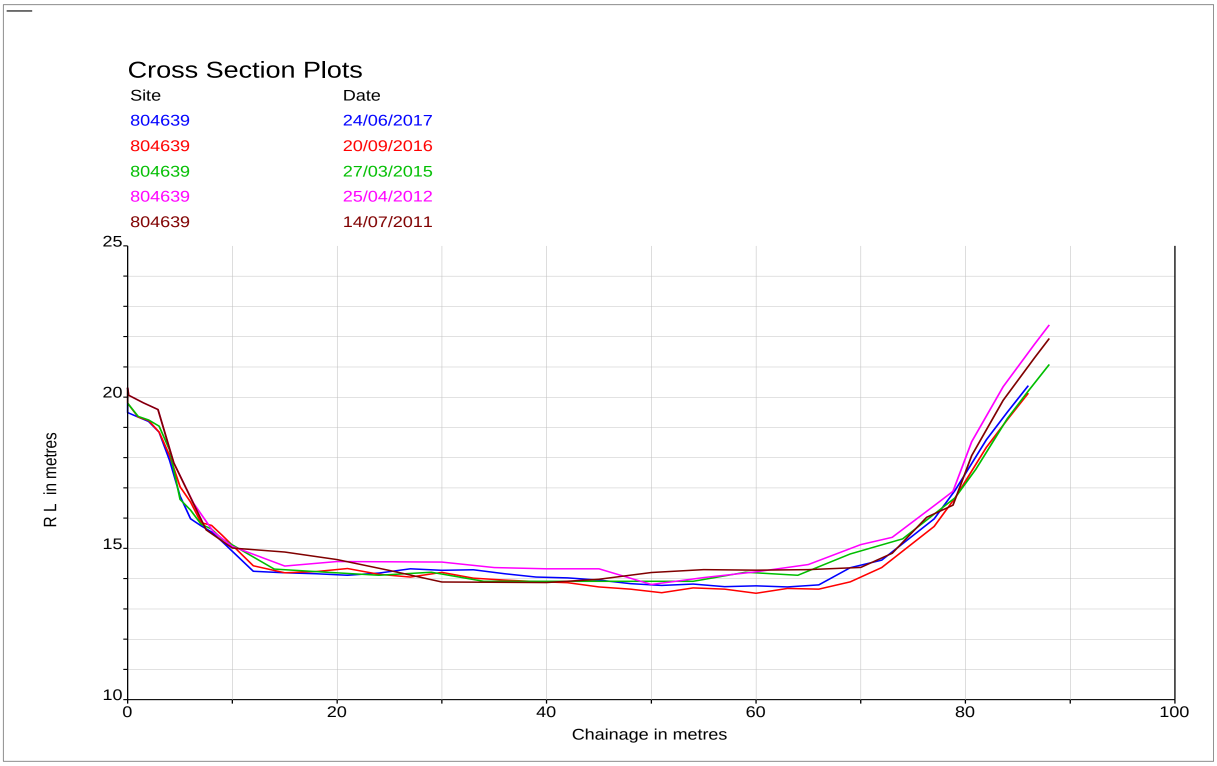


Figure 7-12 Profile comparison (2011-2017) of the Lagaip River at SG2 – 42 km downstream

As the river descends from the upland areas to the lowlands (the Fly Platform), the velocity slows and temporary sediment deposition starts to occur in the form of transient gravel and sand bars. Further downstream, floodplain connections become better established and the bed material changes to predominantly sands and silts.

Profiles recorded at SG4, 360km downstream and PF10, 400 km downstream of the mine, are presented in Figure 7-13 and Figure 7-14. Prior to 2018, at SG4 the right bank of the channel had been progressively eroded, gradually widening the channel by approximately 50 m, and at PF10 there was generally no discernible change or evidence of sediment aggradation. Variation observed at both sites was considered typical of meandering lowland rivers.

On the 26th February 2018 a magnitude 7.5 earthquake struck the PNG Highlands, the epicentre of the quake was located in the headwaters of the Nomad and Rintoul Rivers which flow into the Lower Strickland River upstream of SG4. The earthquake caused landslides that released vast quantities of sediment into the river system, the sediment was flushed down into the Strickland River upstream of SG4.

The build-up of sediment observed at SG4 and PF10 in the 2018 survey is attributed to natural sediment inflows from the earthquake. The 2019 survey at both sites shows a gradual erosion of that freshly deposited sediment, the expectation is that this trend will continue back towards to pre-2017 conditions in future years.

SG5 cross-sections are shown in Figure 7-15. Bed profile at this site varies from year to year, consistent with natural variation expected in lowland rivers, a slight build-up was observed in 2018, also attributable to the earthquake, but by 2019 the level of the river bed had returned to the level observed in 2017 prior to the earthquake.

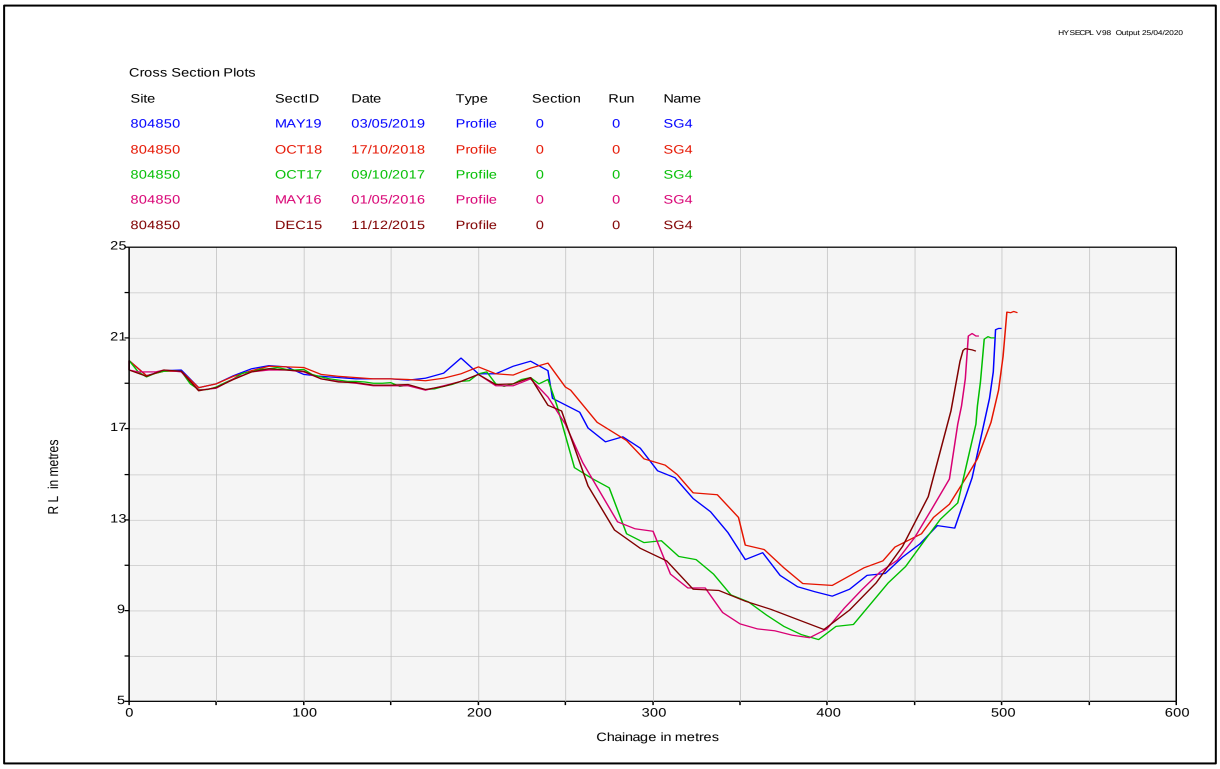


Figure 7-13 Profile comparison (2015-2019) at SG4 – 360 km downstream

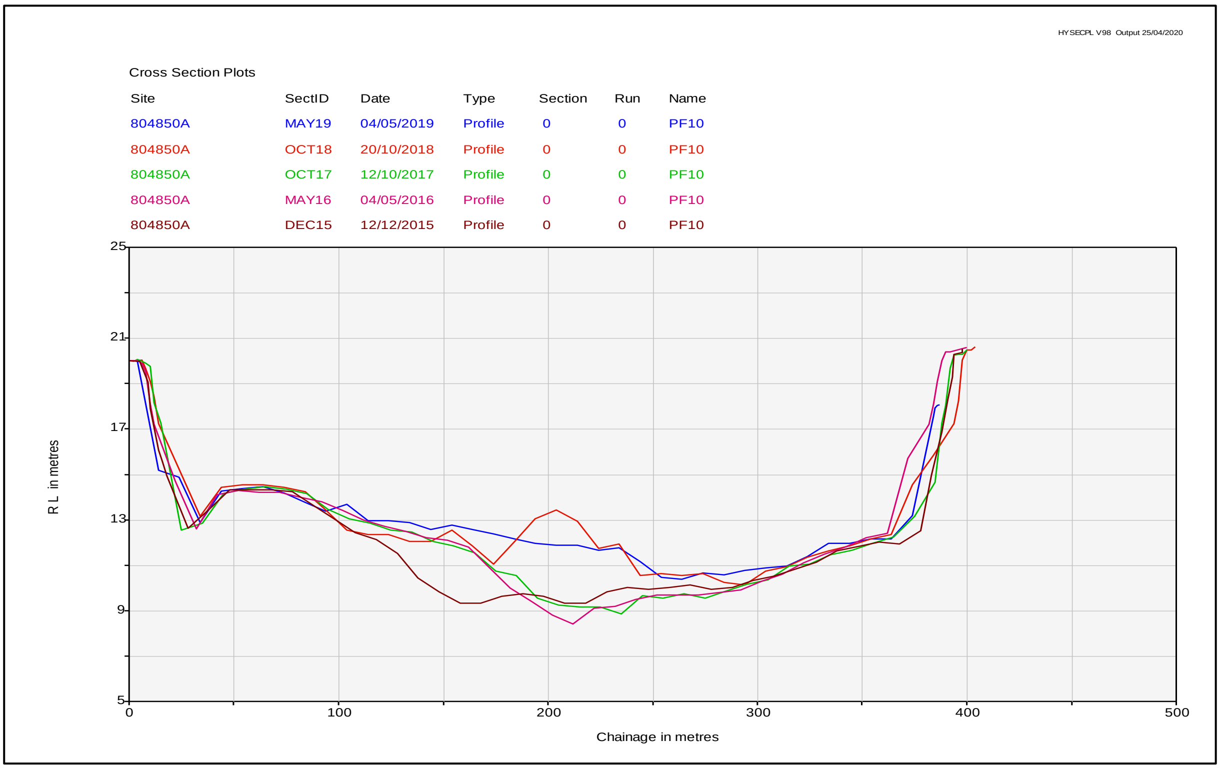


Figure 7-14 Profile comparison (2015-2019) at Profile 10 – 400 km downstream

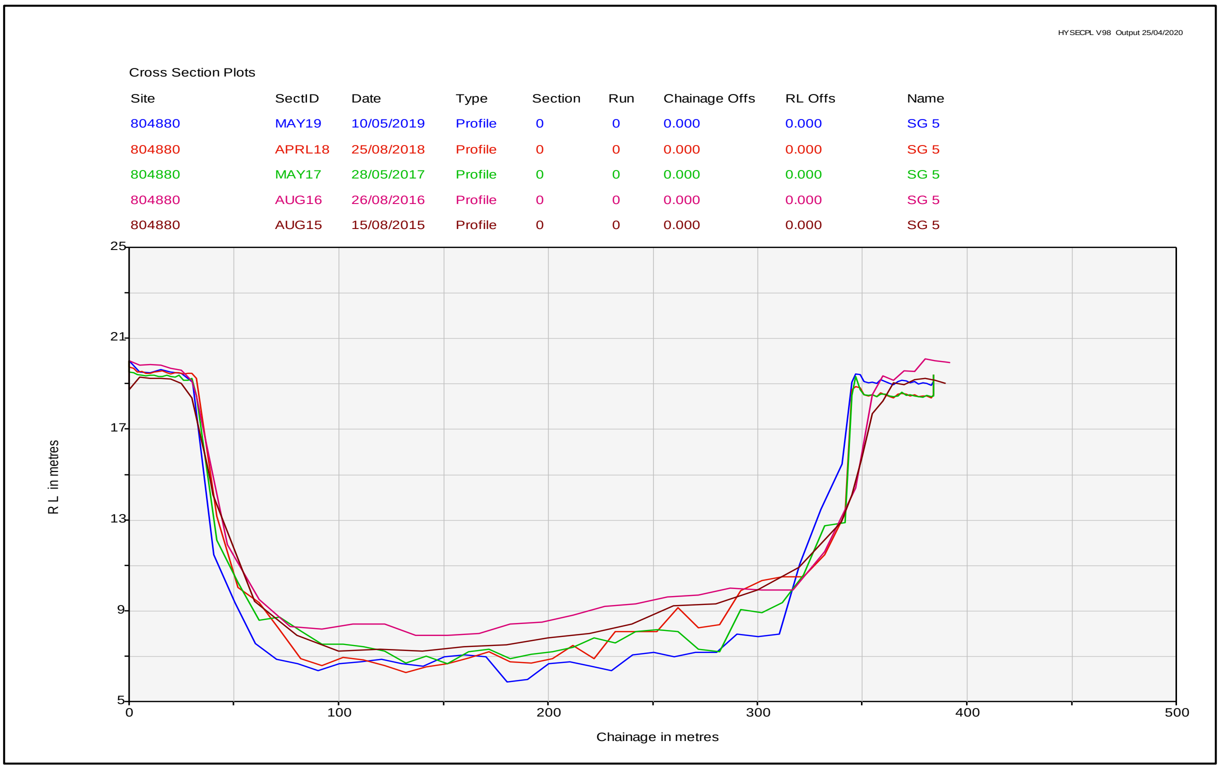


Figure 7-15 Profile comparison (2012-2019) at SG5 – 560 km downstream

7.4 Water Quality, Sediment Quality and Tissue Metals Risk Assessment

This section assesses the risks posed to aquatic ecosystems by physical and chemical stressors and toxicants in water, benthic sediment and fish and prawn tissue. The risk assessment is performed in accordance with the methodology outlined in Section 2.1. The results of each risk assessment are first presented separately for each section of the river system. However, given that a complex relationship exists between physical and chemical toxicants, matrices and other environmental factors such as natural inputs, hydrology and topography, it is also necessary to investigate the potential risks posed by the behaviour of each physical and chemical toxicant throughout the receiving environment. This summary of risks is provided in Section 7.4.

7.4.1 Water quality

7.4.1.1 Upper River, Lower River and ORWBs

The risk assessment for water quality at the upper river, lower river and ORWBs involved comparing the 2019 median value at each test site, the test site median (TSM), against the relevant TV in accordance with the risk assessment procedure described in Section 2. The test site median is derived from the most recent 12-month data set.

The comparison of the TSM against the TV is supported by a statistical analysis using Wilcoxon's Rank Test 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 and lower river are summarised in Table 7-1, Table 7-2 and Table 7-3 respectively. Detailed results of the statistical analysis are shown in Appendix D, Tables D-3 to D-13 and figures showing comparisons of the historical data against the TVs are shown in Appendix D, Figures D-1 to D-46.

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 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 2019 median pH at all upper river, lower river and ORWB test sites were within the upper and lower pH TVs, with the exception of ORWB Avu, which was not significantly different from the lower TV.

The 2019 median 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 TSM for TSS was not significantly different from the TV.

The 2019 median EC at SG2, Wasiba, Wankipe, SG3 and Bebelubi were significantly higher than the respective TV, and at SG4 and ORWB Levame, the 2019 median EC was not significantly different from the TV. At all other test sites within the lower rive and ORWBs, the 2019 median EC was less than the TV, indicating low risk.

The risk assessment results for metals indicated that the 2019 TSM for dissolved copper concentrations at SG2, Wasiba and Wankipe, dissolved iron at Wankipe in the upper river and dissolved copper, dissolved silver and dissolved zinc at Bebelubi, dissolved silver and zinc at SG4, dissolved copper at SG5 and dissolved iron at Avu were all not significantly different from the respective TVs. All other dissolved metals concentrations at all sites within the upper river, lower river and ORWBs were below their respective TVs.

Table 7-1 Risk assessment – median water quality at upper river test sites in 2019 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
SG1	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SG2	14	7.7	1,550	286	0.01	1.1	0.12	0.43	1.4[1]	9.3	0.05	0.97	0.18	0.2	8.9
Wasiba	15	7.5	1,500	265	0.01	0.99	0.09	0.26	1.2[1]	15	0.05	0.76	0.18	0.2	7.2
Wankipe	17	7.7	1,400	239	0.01	1.1	0.05	0.43	1.3[1]	12[1]	0.05	0.71	0.26	0.2	5.4
SG3	196	7.6	1,500	233	0.01	0.99	0.05	0.28	1.2	12	0.05	0.63	0.13	0.2	4.0
UpRivs WQ TV		**6.0-8.1**	**2,837**	**228**	**0.05**	**24****	**0.34**	**1.0**	**1.4**	**75**	**0.60**	**21**	**7.3**	**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] 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 is not statistically significantly different from the TV.

Table 7-2 Risk assessment – Median water quality results at lower river test sites in 2019 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	7	7.4	550	217	0.01[1]	0.81	0.05	0.45	1.3[1]	7.9	0.05	0.67	0.23	0.2	3.4[1]
SG4	8	7.4	455[1]	182[1]	0.01[1]	0.83	0.05	0.46	0.98	8.2	0.05	0.65	0.19	0.2	2.2[1]
SG5	13	7.4	280	159	0.01	0.88	0.05	0.33	1.0[1]	25	0.05	0.50	0.10	0.2	2.4
LwRivs WQ TV		**6.0-8.1**	**983**	**186**	**0.05**	**24****	**0.20**	**1.0**	**1.4**	**75**	**0.60**	**15**	**3.4**	**11**	**8.0**
🟩	Low risk = significantly < TV														
🟨	Potential risk = significantly > TV OR not significantly different from TV														

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

[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 is not statistically significantly different from the TV.

Table 7-3 Risk Assessment – Median water quality results at ORWB test sites in 2019 compared against LMY and 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
Kuku-fionga	10	7.1	64	157	0.01	1.0	0.05	0.29	0.98	16	0.06	0.50	0.10	0.2	2.3
Zonga-mange	12	6.9	2.5	110	0.01	0.53	0.05	0.16	0.49	39	0.06	0.50	0.14	0.2	1.6
Avu	12	6.3[1]	5.0	55	0.01	0.61	0.05	0.43	0.29	375	0.05	0.70	0.14	0.2	2.1
Levame	9	7.3	18	165[1]	0.01	1.0	0.05	0.19	1.0	29	0.05	0.50	0.11	0.2	1.1
ORWB WQ TV		**6.0-8.1**	**983**	**186**	**0.05**	**24****	**0.20**	**1.0**	**1.4**	**75**	**0.60**	**15**	**3.4**	**11**	**8.0**
🟩	Low risk = significantly < TV														
🟨	Potential risk = significantly > TV or not significantly different from TV														

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

[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 is found to be not statistically significantly different from the TV

Trends of water quality in the upper river, lower river and ORWB test sites over the period 2010-2019 are summarised in Table 7-4 to Table 7-6. Detailed results are shown in Appendix D, Tables D-14 to D-16.

The results showed that in the upper river pH, dissolved iron and dissolved mercury at Wasiba and dissolved iron and dissolved zinc at Wankipe and at SG3 exhibited a statistically significant increasing trend over the period. In the lower river, dissolved zinc at Bebelubi exhibited a statistically significant increasing trend over the period. In the ORWBs, TSS and dissolved iron at Kukufionga and dissolved lead at Levame exhibited a statistically significant increasing trend over the period. Graphical representation of trends at these sites are shown in Figure 7-16.

The trend analysis also showed statistically significant increasing trends for dissolved zinc at reference sites Upper Lagaip, Pori, Kuru and Ok Om and upper river test sites Wasiba, Wankipe, SG3 and SG4. A statistically significant increasing trend in dissolved and total zinc in the tailings discharge is noted, however, this would not influence the trends observed at the reference sites. Therefore, the increasing trends in dissolved zinc concentrations at the test sites are indicative of a combination of mine-derived zinc, predominantly from the tailings discharge, and non-mine related change observed at the reference sites. Graphical representation of trends for dissolved zinc at these sites are shown in Figure 7-17.

Table 7-4 Water quality trends at the upper river test sites 2010-2019

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
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 2010- 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
Bebelubi	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨
SG4	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG5	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
🟩	Reduced or no change over time													
🟨	Increased over time													

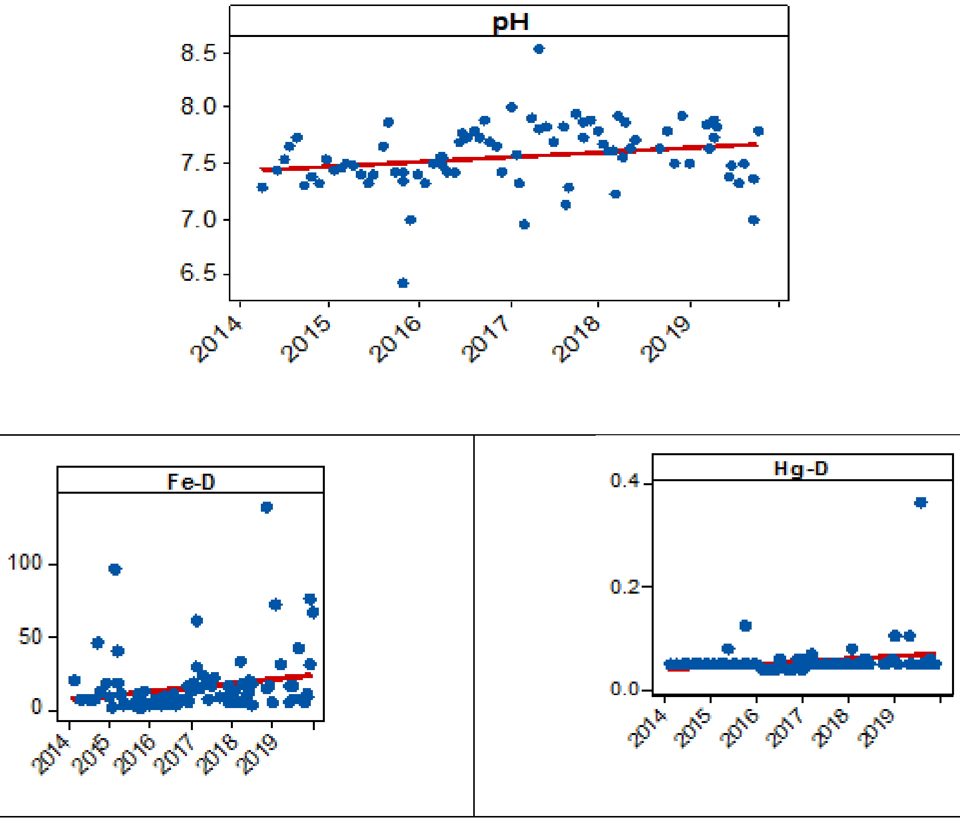
D - Dissolved fraction

Table 7-6 Water quality trends at ORWB reference and test sites 2010-2019

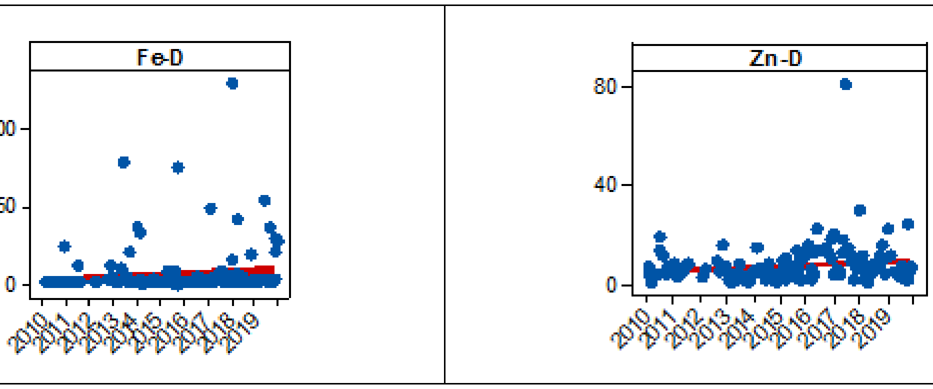
Site	pH	TSS	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Kukufionga	🟩	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟩
Zongamange	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Avu	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Levame	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩	🟩

🟩	Reduced or no change over time
🟧	Increased over time

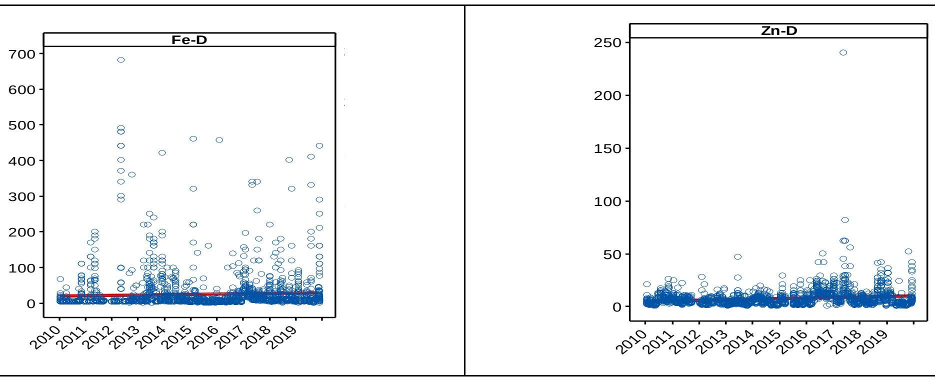
D - Dissolved fraction



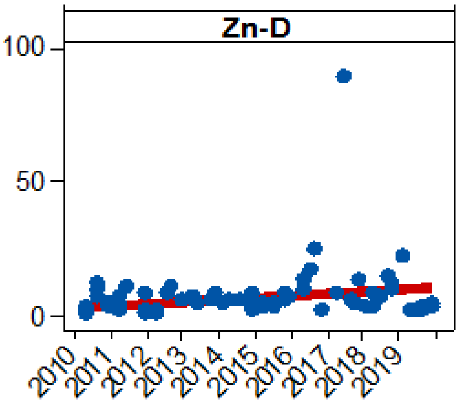
Wasiba pH (standard units), dissolved iron and dissolved mercury concentrations (µg/L) (Test site)



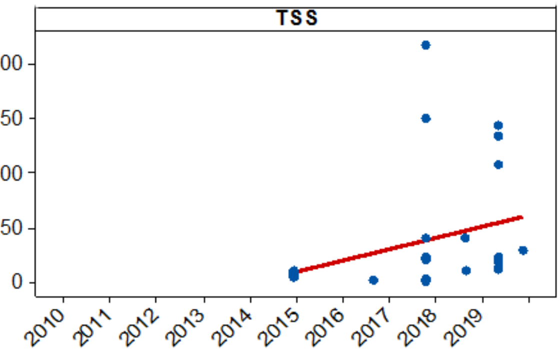
Wankipe dissolved iron and dissolved zinc concentrations (µg/L) (Test site)



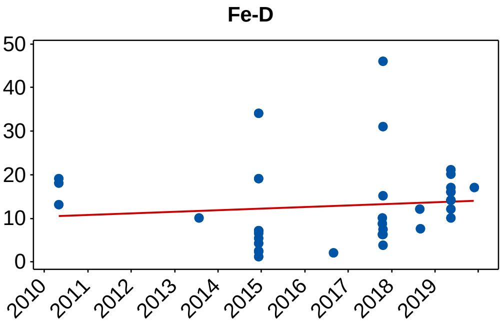
SG3 dissolved iron and dissolved zinc concentrations (µg/L) (Test site)



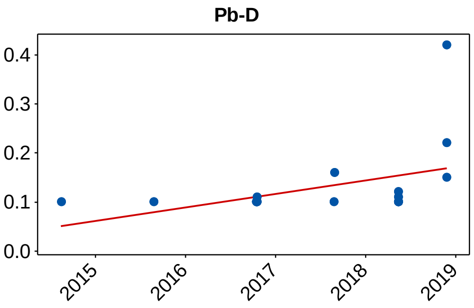
Bebelubi dissolved zinc concentrations (µg/L) (Test site)



Kukufionga TSS concentrations (mg/L) (Test site)

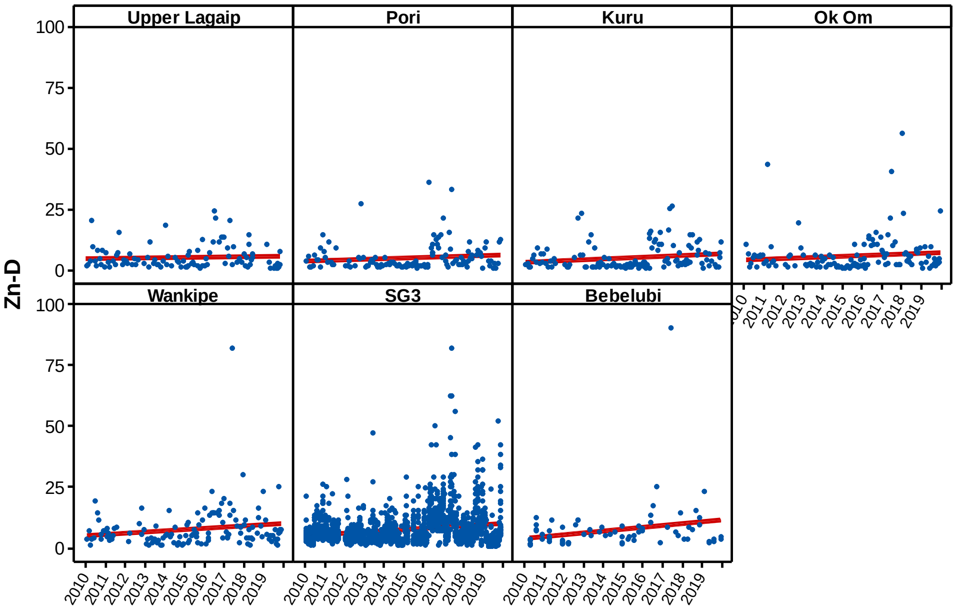


Kukufionga dissolved iron concentrations (µg/L) (Test site)



Levame dissolved lead concentrations (µg/L) (Test site)

Figure 7-16 Trend analysis upper rivers, lower rivers and ORWB water quality showing elements with statistically significant increasing trends (scatter plot of all data from 2010 – 2019 with linear trend line)



Dissolved zinc at Upper Lagaip, Pori, Kuru and Ok Om (Ref Sites) and Wankipe, SG3 and Bebelubi (Test Sites)

Figure 7-17 Trend analysis upper rivers and lower rivers water quality showing statistically significant increasing trends in dissolved zinc at reference and test sites (scatter plot of all data from 2010 – 2019 with linear trend line)

7.4.1.2 Lake Murray

A summary of the water quality risk assessment results for Lake Murray is shown in Table 7-7 and shows that the 2019 TSM for pH was between the upper and lower pH TVs at Central Lake, Southern Lake and SG6. The 2019 TSM for TSS was below the TV at Central Lake and Southern Lake, but higher than the TV at SG6. The TSDM for EC was below the TV at Central Lake and above the TV at Southern Lake and SG6. The 2019 TSM concentration for all dissolved metals at all sites were below the respective TVs.

Trend analysis results presented in Table 7-8 and show a statistically significant increasing trend in dissolved chromium and dissolved zinc in the Central Lake, dissolved zinc at Southern Lake and TSS and pH, TSS and EC at SG6. Graphical representation of these trends is shown in Figure 7-18.

Details of the statistical analysis are shown in Appendix D, Tables D-17 to D-19, Figures showing comparisons of 2019 data against the TVs are shown in Appendix D, Figures D-47 to D-62 and detailed results of the trend analysis are presented in Table D-20.

Table 7-7 Risk Assessment – Median water quality results at Lake Murray test sites in 2019 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	15	5.4	2.0	16	0.01	0.15	0.05	0.50	0.37	81	0.06	0.57	0.10	0.2	3.9
Southern Lake	22	6.3	2.0	23	0.01	0.23	0.05	0.33	0.41	78	0.07	0.50	0.15	0.2	2.9
SG6	14	6.7	19	84	0.01	0.45	0.05	0.18	0.66	71	0.05	0.50	0.18	0.2	1.7
LMY WQ TV		**5.0-8.0**	**13**	**21**	**0.05**	**24****	**0.72**	**1.0**	**1.4**	**340**	**0.60**	**11**	**3.4**	**11**	**8.1**

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

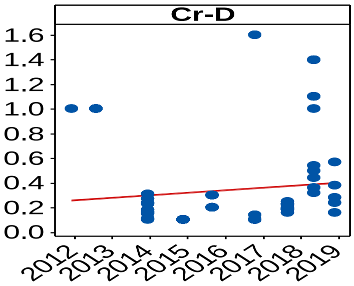
^ std units, * mg/L, D - Dissolved fraction, **Arsenic (III)

Table 7-8 Water quality trends at Lake Murray reference and test sites 2010-2019

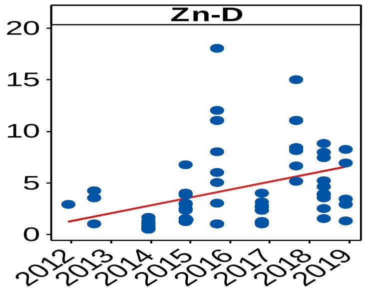
Site	pH	TSS	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Central Lake	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟧
Southern Lake	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
SG6	🟧	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

🟩	Reduced or no change over time
🟧	Increased over time

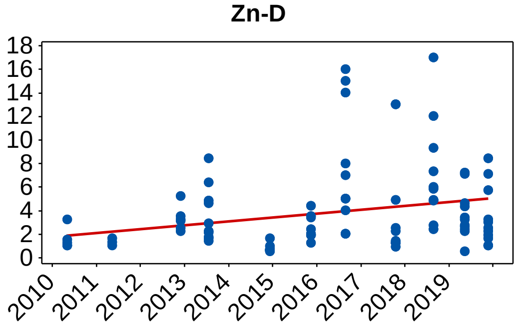
D - Dissolved fraction



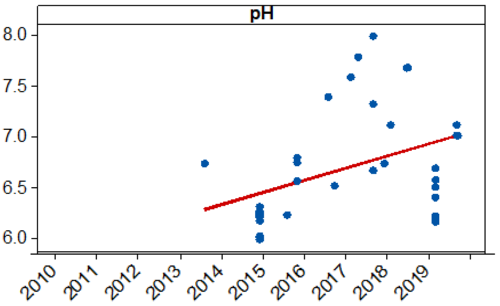
Central Lake dissolved chromium concentrations (µg/L) (Test site)



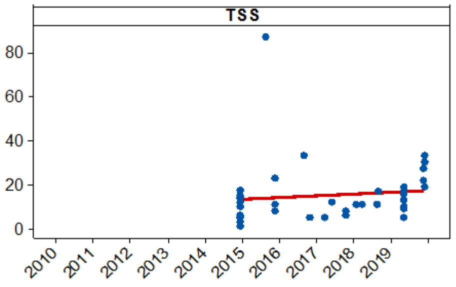
Central Lake dissolved zinc concentrations (µg/L) (Test site)



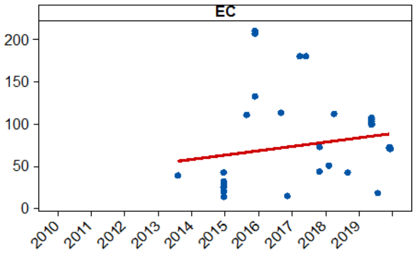
Southern Lake dissolved zinc concentrations (µg/L) (Test site)



SG6 pH (Test site)



SG6 TSS concentrations (mg/L) (Test site)



SG6 EC (µS/cm) (Test site)

Figure 7-18 Trend analysis Lake Murray water quality showing elements with statistically significant increasing trends (scatter plot of all data from 2010 – 2019 with linear trend line)

7.4.2 Sediment quality

7.4.2.1 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 at SG2, the 2019 TSM for WAE lead was higher than the TV and the 2019 TSMs for WAE selenium and WAE zinc were not significantly different from the respective TVs. WAE lead at Wasiba and WAE selenium at SG3 were not significantly different from the TVs. Results for the lower river are presented in Table 7-10 and show that the 2019 TSM for WAE selenium at Bebelubi was not significantly different from the TV while the 2019 TSMs for WAE selenium at SG4 and SG5 were higher than the TV. Results for the ORWBs are presented in Table 7-11 and show that the 2019 TSMs for WAE selenium at Kukufionga, Zongemange, Avu and Levame were higher than the TV.

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, WAE nickel WAE lead and WAE zinc at SG2, WAE nickel at Wankipe and WAE arsenic, WAE chromium, WAE copper, WAE nickel, WAE lead and WAE zinc at SG3 between 2013 and 2019. The results of trend analysis of sediment quality in the lower river are shown in Table 7-13 and show a statistically significant increasing trend for WAE copper at SG4 and SG5 between 2013 and 2019. 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 and for WAE arsenic and copper at Levame between 2013 and 2019. Graphical representation of the statistically significant increasing trends are shown in Figure 7-19.

Detailed results of the statistical analysis are shown in Appendix E, Tables E-2 to E-12 and figures showing comparisons of the historical data against the TVs are shown in Appendix E, Figures E-1 to E-32, and detailed results of the trend analysis are presented in Appendix E, Table E-13 to E-15.

Table 7-9 Risk Assessment – Median sediment quality results at upper river test sites in 2019 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	12	0.16	4.7	0.97	6.8	12	0.01	11	115	0.15[1]	140[1]
Wasiba	15	0.05	3.8	0.69	4.2	10	0.01	11	33[1]	0.13	110
Wankipe	17	0.05	3.6	0.44	3.5	9.5	0.01	13	31	0.13	68
SG3	14	0.05	3.6	0.47	6.3	9.5	0.01	18	29	0.13[1]	88
UpRivs Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**22**	**50**	**0.15**	**200**
🟩	Low risk = significantly < TV										
🟧	Potential risk = significantly > TV OR not significantly different from TV										

WAE – Weak-Acid-Extractable; NS – Not sampled due to security concerns.

[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 is found to be not statistically significantly different from the TV.

Table 7-10 Risk Assessment – Median sediment quality results at lower river test sites in 2019 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	7	0.05	2.8	0.28	2.5	6.3	0.01	10	15	0.10[1]	47
SG4	8	0.05	2.5	0.22	3.4	7.1	0.01	10	13	0.12	38
SG5	14	0.05	3.4	0.29	2.2	12	0.01	6.4	15	0.12	41
LwRivs Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.10**	**200**

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

WAE – Weak-Acid-Extractable; NS – Not sampled due to security concerns.

[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 is found to be not statistically significantly different from the TV.

Table 7-11 Risk assessment – median sediment quality results at ORWB test sites in 2019 compared against LMY and 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	10	0.05	3.7	0.34	2.3	12	0.01	6.6	16	0.12	47
Zongamange	12	0.17	9.1	0.33	2.8	22	0.01	9.6	33	0.21	64
Avu	12	0.06	4.0	0.25	1.6	18	0.01	8.3	18	0.20	53
Levame	12	0.11	6.2	0.27	2.7	18	0.01	7.0	28	0.19	55
ORWBs Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.10**	**200**

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

WAE – Weak-Acid-Extractable; NS – Not sampled due to security concerns.

Table 7-12 Sediment quality trends at upper river reference and test sites 2013-2019 (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 Comparison of trends of sediment quality at lower river reference and test sites 2013-2019 (mg/kg dry, whole sediment)

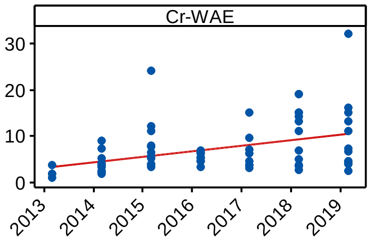
Site	Ag - WAE	As - WAE	Cd - WAE	Cr - WAE	Cu - WAE	Hg - WAE	Ni - WAE	Pb - WAE	Se - WAE	Zn - WAE
Bebelubi	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SG4	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟩
SG5	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟩
🟩	No change or reduced over time									
🟧	Increased over time									

WAE – Weak-Acid-Extractable

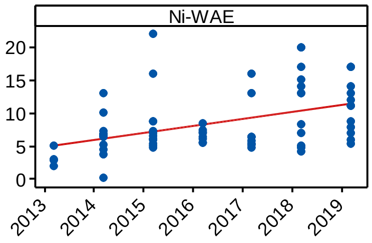
Table 7-14 Sediment quality trends at Lake Murray and ORWB reference and test sites 2013-2019 (mg/kg dry, whole sediment)

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

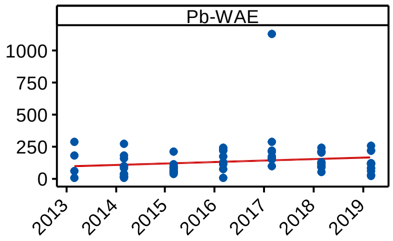
WAE - Weak-Acid-Extractable



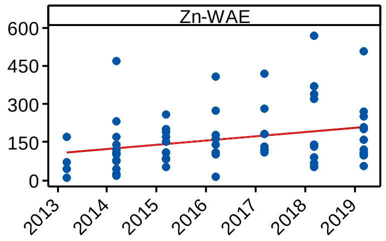
SG2 - WAE chromium concentrations (mg/kg dry, whole sediment) (Test site)



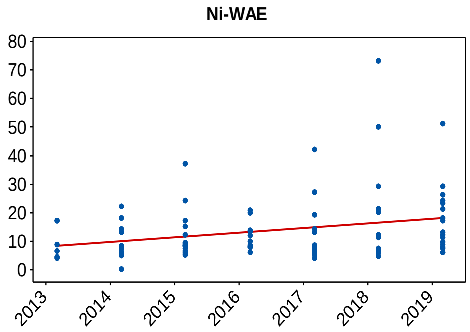
SG2 - WAE nickel concentrations (mg/kg dry, whole sediment) (Test site)



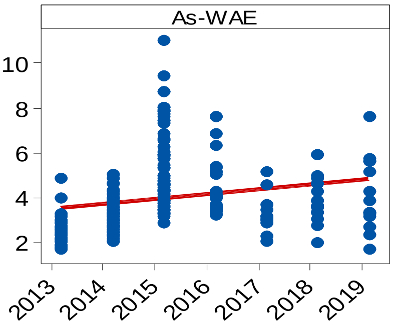
SG2 - WAE lead concentrations (mg/kg dry, whole sediment) (Test site)



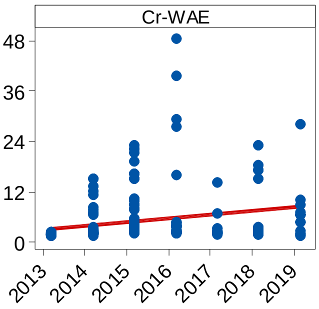
SG2 - WAE zinc concentrations (mg/kg dry, whole sediment) (Test site)



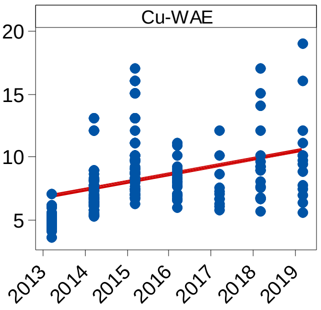
Wankipe - WAE nickel concentrations (mg/kg dry, whole sediment) (Test site)



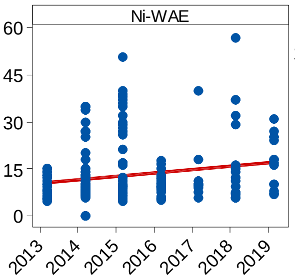
SG3 - WAE arsenic (mg/kg dry, whole sediment) (Test site)



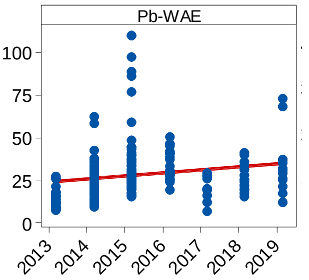
SG3 - WAE chromium (mg/kg dry, whole sediment) (Test site)



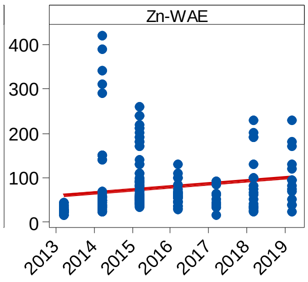
SG3 - WAE copper (mg/kg dry, whole sediment) (Test site)



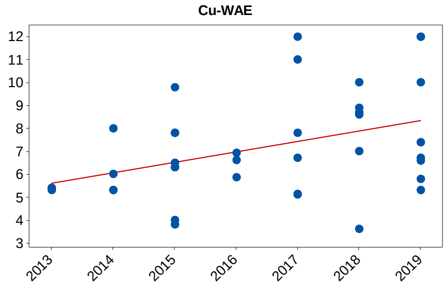
SG3 - WAE nickel (mg/kg dry, whole sediment) (Test site)



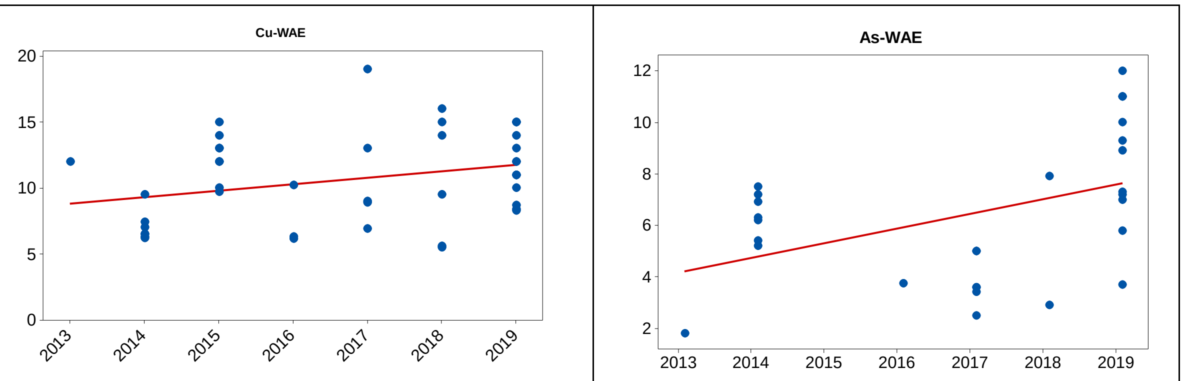
SG3 - WAE lead (mg/kg dry, whole sediment) (Test site)



SG3 - WAE zinc (mg/kg dry, whole sediment) (Test site)

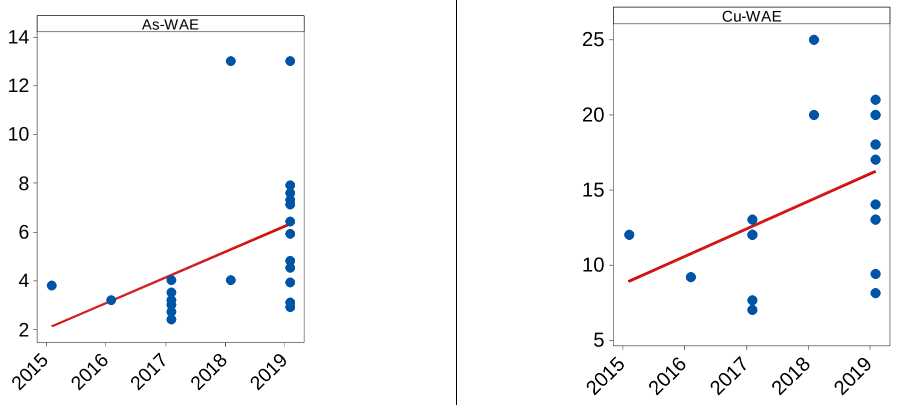


SG4 - WAE copper concentrations (mg/kg dry, whole sediment) (Test site)



SG5 - WAE copper concentrations (mg/kg dry, whole sediment) (Test site)

Zongamange - WAE arsenic concentrations (mg/kg dry, whole sediment) (Test site)



Levame - WAE arsenic concentrations (mg/kg dry, whole sediment) (Test site)

Levame - WAE copper concentrations (mg/kg dry, whole sediment) (Test site)

Figure 7-19 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 – 2019 with linear trend line)

7.4.2.2 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 2019 TSM for all other metals at all sites were below their respective TVs.

Analysis of trends of benthic sediment quality at Lake Murray test sites is presented in Table 7-16 and showed that no metals displayed statistically significant increasing trends between 2013 and 2019.

Detailed results of the statistical analysis are shown in Appendix E, Tables E-16 to E-18 and figures showing comparisons of the historical data against the TVs are shown in Appendix E, Figures E-33 to E-42. Details of the statistical analysis are shown in Appendix E, Table E-19.

Table 7-15 Risk assessment – median sediment quality results at Lake Murray test sites in 2019 compared against LMY and 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
Central Lake	10	0.06	1.7	0.10	5.3	12	0.03	11	9.8	0.14	46
Southern Lake	10	0.15	3.7	0.21	4.4	15	0.01	11	27	0.22	64
SG6	16	0.15	5.5	0.32	3.6	18	0.01	9.7	29	0.20	59
Lake Murray Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.27**	**200**

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

WAE – Weak-Acid-Extractable

[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 is found to be not statistically significantly different from the TV.

Table 7-16 Sediment quality trends at Lake Murray and ORWB reference and test sites 2013-2019 (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

7.4.3 Tissue metals

7.4.3.1 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 2019 TSMs for cadmium, lead and selenium in prawn abdomen were greater than the TVs and the 2019 TSMs for arsenic, chromium, copper and zinc were not significantly different from the TVs. At Wankipe, the 2019 TSMs for cadmium, copper and lead in prawn abdomen were greater than the respective TVs while the 2019 TSMs for arsenic, chromium, and zinc were not significantly different from the TVs.

In the lower river, the risk assessment showed that at Bebelubi, the 2019 TSMs for arsenic, cadmium, nickel, selenium and zinc in prawn abdomen were not significantly different from the TVs. At SG4 the 2019 TSMs for cadmium and selenium in prawns were greater than the TV, while the 2019 TSMs for arsenic, nickel and lead in prawn abdomen were not significantly different from the TVs. The 2019 TSMs for all metals in fish tissue were less than the respective TVs.

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, lead and selenium in prawn abdomen at Wasiba showed a statistically significant increasing trend between 2010 and 2019. In the lower river, concentrations of copper in prawn abdomen at Bebelubi and copper and selenium in prawn abdomen at SG4 showed a statistically significant increasing trend between 2010 and 2019. Scatter plots with linear trend lines for metals with statistically significant increasing trends are shown in Figure 7-20.

Detailed results of the statistical analysis are shown in Appendix F, Tables F-2 to F-5, comparisons of the historical data against the TVs are shown in Appendix F, Figures F-1 to F-36, and detailed results of the statistical analysis are shown in Appendix F, Tables F-7 to F-10.

Table 7-17 Risk assessment – median tissue metal results at upper river test sites in 2019 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	12	0.023	0.004	0.01	0.14	0.05	0.01	0.01	0.46	3.5
	Prawn Ab	12	0.030[1]	0.010	0.014[1]	4.9[1]	0.01	0.01	0.016	0.65	13[1]
Wankipe	Fish Flesh	12	0.016	0.004	0.01	0.19	0.05	0.01	0.01	0.37	3.7
	Prawn Ab	12	0.033[1]	0.010	0.024[1]	8.3	0.01	0.01	0.011	0.49	14[1]
UpRivs TV	Fish Flesh		0.200	0.020	0.021	0.48	0.08	0.01	0.17	2.26	10.4
	Prawn Ab		0.039	0.003	0.026	6.3	0.01	0.01	0.01	0.57	14
🟩	Low risk = significantly < TV										
🟧	Potential risk = significantly > TV OR not significantly different from TV										

[1] Although TSM is equal to or less than the TV, the 2018 dataset contains some values that do exceed the TV, this increases the standard deviation of the dataset and as a result, the TSM was found to be not statistically significantly different from the TV.

Ab – Abdomen

Table 7-18 Risk assessment – median tissue metal results at lower river test sites in 2019 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	12	0.015	0.003	0.01	0.065	0.03	0.01	0.01	0.074	2.4
	Prawn Ab	12	0.077[1]	0.004[1]	0.019	7.6	0.01	0.01[1]	0.01	0.30[1]	12.5[1]
SG4	Fish Flesh	12	0.01	0.003	0.01	0.069	0.04	0.01	0.01	0.13	2.3
	Prawn Ab	12	0.065[1]	0.01	0.022	6.9	0.01	0.01[1]	0.01[1]	0.37	12
LwRivs TV	Fish Flesh		0.071	0.003	0.03	0.17	0.12	0.165	0.03	2.26	7.5
	Prawn Abdo		0.085	0.005	0.05	10	0.01	0.01	0.01	0.32	14
🟩	Low risk = significantly < TV										
🟧	Potential risk = significantly > TV OR not significantly different from TV										

[1] Although TSM is equal to or less than 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 found to be not statistically significantly different from the TV.

Ab – Abdomen

Table 7-19 Tissue metal trends at upper river ref and test sites 2010 - 2019

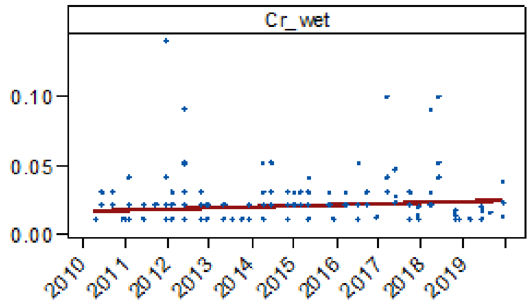
Site	Sample	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Wasiba	Fish Flesh	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Prawn Ab	🟩	🟩	🟧	🟩	🟩	🟩	🟧	🟧	🟩
Wankipe	Fish Flesh	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Prawn Ab	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
🟩	No change or reduced over time									
🟧	Increased over time									

Ab – Abdomen

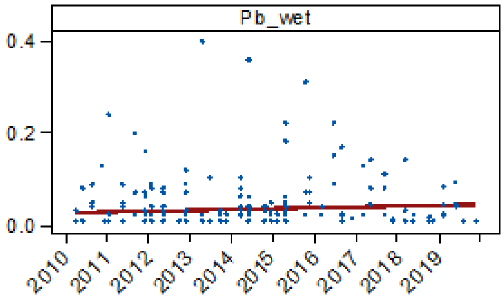
Table 7-20 Tissue metal trends at lower river ref and test sites 2010–2019

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									

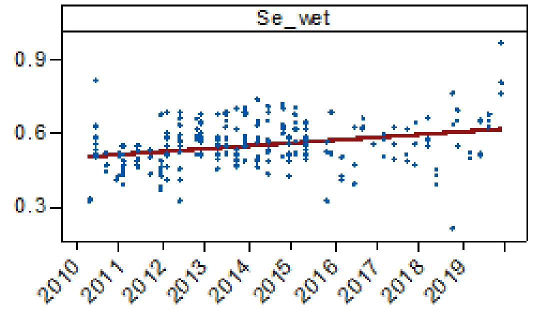
Ab – Abdomen



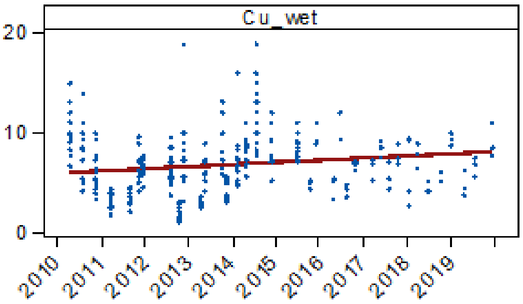
Chromium concentration (µg/g wet wt.) in Prawn – Wasiba 2010 – 2019



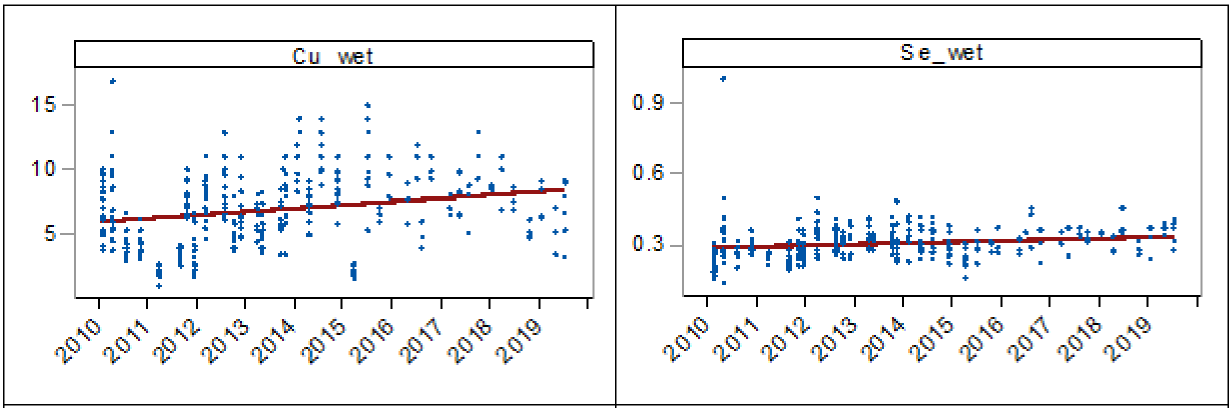
Lead concentration (µg/g wet wt.) in Prawn – Wasiba 2010 – 2019



Selenium concentration (µg/g wet wt.) in Prawn – Wasiba 2010 – 2019



Copper concentration (µg/g wet wt.) in Prawn – Bebelubi 2010 – 2019



Copper concentration (µg/g wet wt.) in Prawn – SG4 2010 – 2019

Selenium concentration (µg/g wet wt.) in Prawn – SG4 2010 – 2019

Figure 7-20 Trend analysis of statistically significant increasing trends in tissue metal at upper river and lower river test sites 2010 – 2019.

7.4.3.2 Lake Murray

The results of the tissue metal risk assessment for Lake Murray are shown in Table 7-21. The assessment showed that the 2019 TSM for zinc in fish flesh at Pangoa was not significantly different from the TV and the 2019 TSM for chromium in fish flesh at Miwa was not significantly different from the TV. The 2019 TSM for all other metals in fish flesh were below the TVs.

A summary of results from trend analysis performed for Lake Murray sites is presented in Table 7-22. The results showed that the concentration of chromium in fish flesh at Pangoa displayed a statistically significant increasing trend between 2002 and 2019 and the concentration of selenium in fish flesh at Miwa displayed a statistically significant increasing trend between 2010 and 2019. Scatter plots with linear trend lines for metals with statistically significant increasing trends are shown in Figure 7-21.

Detailed results of the direct comparison are shown in Appendix F, Table F-6 and graphical comparisons of the data against the TVs are shown in Appendix F, Figures F-37 to F-45. and detailed results of the statistical analysis are shown in Appendix F, Table F-11.

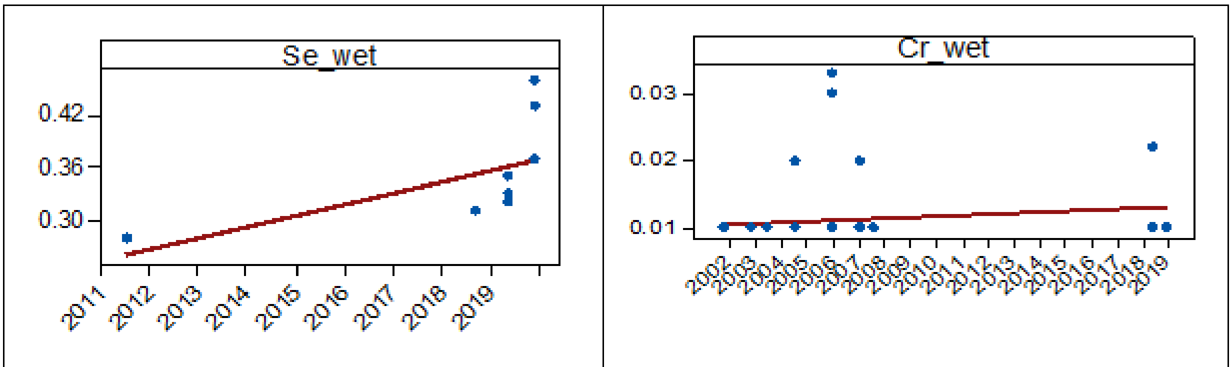
Table 7-21 Risk assessment – median tissue metal results at Lake Murray test site in 2019 compared against Lake Murray TVs showing which indicators pose low and potential risk (µg/g wet wt.)

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
C. Lake - Pangoa	Fish Flesh	6	0.015	0.003	0.01	0.08	0.19	0.01	0.01	0.32	2.35[1]
S. Lake - Miwa	Fish Flesh	6	0.016	0.003	0.01[1]	0.08	0.20	0.01	0.01	0.36	2.40
Lake Murray TV	Fish Flesh		0.053	0.003	0.028	0.203	0.328	0.19	0.071	2.26	3.12
🟩	Low risk = significantly < TV										
🟧	Potential risk = significantly > TV OR not significantly different from TV										

[1] Although TSM is equal to or less than 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 found to be not statistically significantly different from the TV.

Table 7-22 Tissue metal trends at Lake Murray test sites 2010–2019

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									



Selenium concentration (µg/g wet wt.) in Fish – Miwa 2010 – 2019

Chromium concentration (µg/g wet wt.) in Fish – Pangoa 2002 – 2019

Figure 7-21 Trend analysis of statistically significant increasing trends in tissue metal at upper river and lower river test sites 2010 – 2019 (Miwa) and 2002 – 20202 (Pangoa)

7.4.4 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 7-33 to Table 7-35 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 7.7.

7.4.4.1 pH

Rainfall runoff discharged from the lime plant exhibited elevated pH as a result of contact with limestone and lime within the lime plant area. 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.

Within the receiving environment downstream of the Porgera River, at all sites with the exception of ORWB Avu, the pH was within upper and lower bounds of the respective TVs, indicating low risk to the condition of the receiving environment.

At Avu, the 2019 median pH was 6.3, which was not significantly different from the lower TV of pH 6.3, the initial risk assessment therefore indicates potential risk. Further analysis of the data shows that although the test site median falls within the TV range of 6.0 – 8.1, the range of values recorded in 2019 were between pH 5.5 and pH 6.9, resulting in a large standard deviation within the data set and contributing to Wilcoxon's test finding the median was not statistically significantly different from the TV. Figure 7-22 is a scatter plot of all pH data recorded at Avu between 2013 and 2019 and shows that data in 2019 were collected on two separate occasions in May and November 2019. pH recorded in May was lower than in November, the latter being more consistent with historical pH. It should also be noted that the analysis of trends of pH at Avu shows no change between 2013 and 2019. pH measured in the main Strickland River channel on the 1st May 2019 was pH 7.38, suggesting that the cause of low pH at Avu in May was not from inflow from the Strickland River, but from natural localised conditions within the oxbow lake, such as rainfall runoff high in natural fluvic and humic acids generated by vegetation decomposition in the surrounding catchment.

Therefore, the result of the initial risk assessment for pH at Avu 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 7-33.

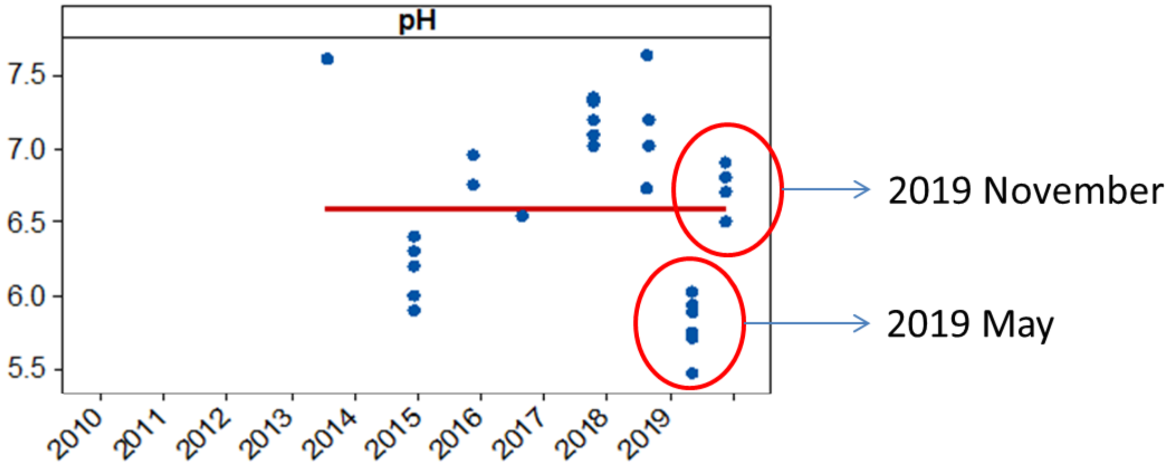


Figure 7-22 Scatter plot showing pH at Avu between 2013 and 2019

7.4.4.2 Total Suspended Solids

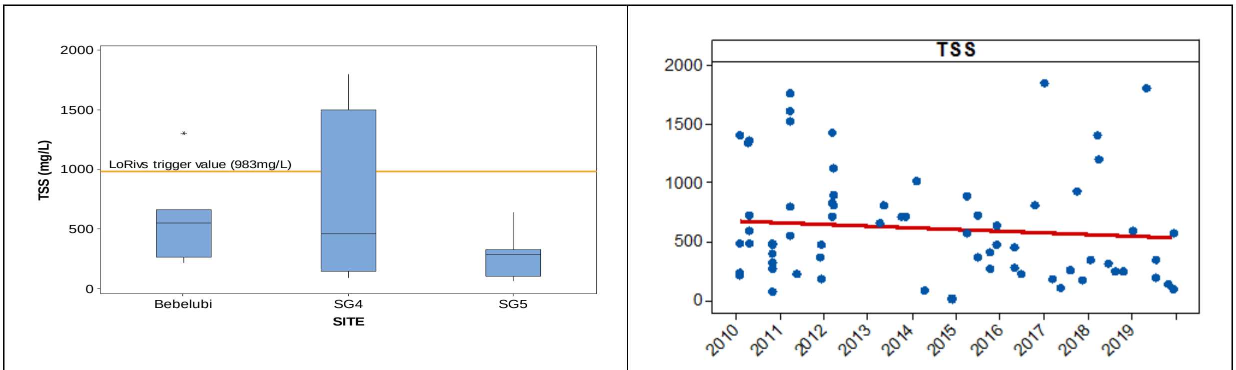
Tailings ex-pipe and water discharged from Yunarilama/Yarik at Portal exhibited median TSS concentrations in 2019 which exceeded the upper river TV, and therefore posed a potential risk to the receiving environment.

Within the receiving environment, the concentrations of TSS at all sites within the upper river downstream of the Porgera River were below the upper river TV indicating low risk.

In the lower river, the 2019 median TSS concentration at SG4 was not significantly different from the TV, and at SG6, the 2019 median was also not significantly different than the TV. Further analysis of TSS data at SG4 shows that the result of the 2019 risk assessment is driven by a large standard deviation of the 2019 data at SG4, caused by a wide range of results when compared with the reference sites. Table 7-24 shows the descriptive statistics for TSS at reference sites Baia and Tomu and at test site SG4 between 2018 and 2019, while TSS at SG4 is consistently higher than Tomu, the range of results are comparable to Baia. The high maximum concentration recorded at Baia in 2018 (11,000 mg/L) was caused by natural sediment inputs as a result of the 2018 PNG Highlands earthquake which occurred in the headwaters of the Baia catchment. Additionally, trend analysis of TSS at SG4 shows that TSS concentrations have not changed between 2010 and 2019. Therefore, the result of the initial risk assessment for TSS at SG4 is considered to be within the natural range of TSS recorded at each site and is therefore not considered to be related to the operation of the Porgera Mine. As a result, the initial risk assessment for TSS at SG4 has been adjusted from potential risk to low risk. The change is reflected in Table 7-33.

Table 7-24 Descriptive statistics for TSS at Baia, Tomu and SG4 between 2017 and 2019

Parameter	Year	Site	N	Mean	StDev	Min	Q1	Median	Q3	Max
TSS (mg/L)	2018	Baia (R)	7	2,245	3,885	34	530	1,000	1,300	11,000
		Tomu (R)	6	13	11	2.0	5.0	11	23	30
		SG4	6	622	531	240	240	325	1,250	1,400
	2019	Baia (R)	7	547	335	270	280	420	910	1,100
		Tomu (R)	7	48	38	2	8	44	87	98
		SG4	8	688	711	86	145	455	1,498	1,800



SG4 TSS concentrations 2019 (mg/L)

SG4 TSS concentrations 2019 (mg/L) 2010 – 2019

Figure 7-23 TSS results for lower river test sites in 2019 and trend for TSS at SG4 between 2010 and 2019

At SG6, the results from the initial risk assessment show that the 2019 median for TSS exceeded the Lake Murray TV, indicating potential risk. The SG6 site is located on the Herbert River which connects the lower Strickland River to Lake Murray, and as a result, water quality at this site is influenced by water flowing from Lake Murray into the Strickland River, as well as by water flowing from the Strickland River into Lake Murray during reverse flow events. Reverse flow events are known to occur when the water level in the Strickland River is higher than in Lake Murray, causing water to flow from the river into the lake via the Herbert River and the Mamboi breakthrough.

TSS and EC results at SG6 in 2019 are indicative of water quality at SG6 being influenced by inflow from the Strickland River. SG6, being located on the Herbert River is also not considered completely analogous with the Lake Murray reference sites, located in the northern section of the lake. The hydrological characteristics of the Herbert River, where it is subjected to higher flow velocities than a lake environment, make is subject to higher turbulence and higher TSS concentrations than a large lake. When comparing TSS data at the Northern Lake and with Baia and Tomu lower river reference sites, it can be seen that TSS at SG6 in 2019 was comparable to TSS at Tomu and lower than TSS at Baia. Table 7-25 shows the descriptive statistics for TSS at lower river reference sites Baia and Tomu, Lake Murray reference site Nth Lake and test site SG6 for 2019.

As a result, it is concluded that TSS at SG6 in 2019 was influenced by inflow from the Strickland River during a flow reversal event, that the Northern Lake is not an entirely appropriate reference for SG6 located on the Herbert River, and that TSS at SG6 in 2019 was comparable to TSS at the lower river reference sites Baia and Tomu. Therefore, the initial risk assessment for TSS at SG6 has been adjusted from potential risk to low risk. The change is reflected in Table 7-33.

Table 7-25 TSS Descriptive Statistics 2010 – 2019 at Baia, Tomu, Nth Lake and SG6

Parameter	Site	N	Mean	StDev	Min	Q1	Median	Q3	Max
TSS	Baia	7	547	335	270	280	420	910	1,100
	Tomu	7	48	38	2	8	44	87	98
	Nth Lake	20	2.2	0.5	2.0	2.0	2.0	2.0	4.0
	SG6	14	19	8.3	5.0	12	19	25	33

7.4.4.3 Electrical Conductivity (EC)

Electrical conductivity (EC) is a measure of waters capability to pass electrical flow, 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. In the tailings, EC is driven by 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.

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.

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 test sites within the upper river, the 2019 median EC was greater than the TV, indicating potential risk. In the lower river the 2019 median EC was greater than the TV at Bebelubi and not significantly different from the TV at SG4, indicating potential risk as each of these sites. Further review of the data indicates that the results of the initial risk assessment at these sites are supported.

At SG5 in the lower river and ORWBs Kukufionga, Zongamange and Avu, the 2019 median EC was below the TV, indicating low risk. At the ORWB Levame, the 2019 median EC was not significantly different from the TV, with the initial risk assessment therefore indicating potential risk. Upon further review of the results it can be seen that the range of EC results measured at Levame during 2019 is comparable to the range measured at the reference site Baia. Table 7-26 shows the descriptive statistics for the lower river reference sites Baia and Tomu and ORWB Levame. Given that the 2019 median EC at Levame is less than, but not significantly different from the TV derived from the combined data from reference sites Baia and Tomu, and the range in 2019 is comparable to that observed at reference site Baia in 2019, the result of the initial risk assessment for EC at Levame has been adjusted from potential risk to low risk. The change is reflected in Table 7-33.

Table 7-26 EC Descriptive Statistics 2019 at Lower River Reference Sites and Test Site Levame

Parameter	Year	N	Mean	StDev	Min	Q1	Median	Q3	Max
EC (µS/cm)	Baia	7	185	11	170	171	186	196	200
	Tomu	7	78	48	34	38	74	77	179
	Levame	9	178	20	163	165	165	200	210

In Lake Murray, the 2019 median EC in the Central Lake was less than the TV. At Southern Lake and SG6, the 2019 median EC were higher than the TV, indicating potential risk. Upon further review, the potential risk indicated at southern lake is deemed to be a valid result and therefore the result of the initial risk assessment is left unchanged. At SG6 however, similar to TSS at SG6, as discussed above in 7.4.4.2, it is concluded that EC at SG6 in 2019 was influenced by inflow from the Strickland River during a flow reversal event, that the Northern Lake is not an entirely appropriate reference for SG6 located on the Herbert River, and that EC at SG6 in 2019 was comparable to EC at the lower river reference sites Baia and Tomu. Table 7-26 shows the descriptive statistics for EC at lower river reference sites Baia and Tomu, Lake Murray reference site Nth Lake and test sites Sth Lake and SG6 for 2019. Therefore, the result of the initial risk assessment for EC at SG6 has been adjusted from potential risk to low risk. The change is reflected in Table 7-33.

Table 7-27 EC Descriptive Statistics 2019 TSS at Baia, Tomu, Nth Lake and SG6

Parameter	Site	N	Mean	StDev	Min	Q1	Median	Q3	Max
EC	Baia	7	185	11	170	171	186	196	200
	Tomu	7	78	48	34	38	74	77	179
	Nth Lake	20	17	3.6	13	13	17	21	23
	SG6	14	82	24	17	70	84	100	106

7.4.4.4 Silver (Ag)

The 2019 median concentration of dissolved silver in water discharged from the Yunarilama at Portal was not significantly different from the upper river TV. The 2019 median concentrations of dissolved silver in water discharged from all other discharge points during 2019 were below the upper river TV, indicating low risk.

Throughout the receiving environment the 2019 median silver concentrations at all test sites indicated low risk, with the exception of Bebelubi and SG4 in the lower river, where the median silver concentrations in 2019 were not significantly different from the TV. At both sites the trends for dissolved silver in water have not changed between 2015 and 2019.

Median concentrations of WAE silver in sediment discharged at 28 Level, Kogai Culvert and Yakatabari Creek D/S 28 level exceeded the upper river TV, indicating potential risk. Within the receiving environment downstream of the Porgera River, 2019 median WAE silver concentrations in benthic sediment were below the TVs, indicating low risk.

Overall, given the low concentrations in discharge from the mine and the low concentrations of silver in water and sediment throughout the receiving environment downstream of the Porgera River, the risk posed by silver to the condition of the receiving environment downstream of the Porgera River in 2019 was low. Therefore, the initial risk assessments for silver at Bebelubi and SG4 have been adjusted from potential risk to low risk, the change is reflected in Table 7-33.

7.4.4.5 Arsenic (As)

The 2019 median concentrations of dissolved arsenic in tailings and all contact waters discharged from the mine were below the upper river TV and therefore posed a low risk to the receiving environment. Throughout the receiving environment, the 2019 median concentrations of dissolved arsenic in water were below the TVs and therefore posed a low risk.

In sediment discharged from the operation, the 2019 median concentration of WAE arsenic in tailings and from 28 level exceeded the upper river TV, indicating potential risk. Throughout the receiving environment, the 2019 median WAE arsenic concentrations in sediment were below the TVs and therefore posed a low risk.

The 2019 median concentrations of arsenic in prawn abdomen at Wasiba and Wankipe in the upper river and at Bebelubi and SG4 in the lower river, were not significantly different from the TVs, indicating potential risk. The trends of arsenic in prawn abdomen at each site did not change between 2010 and 2019.

Overall, there is a low risk posed by arsenic in water and sediment throughout the receiving environment, combined with a finding that the 2019 median concentrations of arsenic at Wasiba, Wankipe, Bebelubi and SG4 were less than, but not significantly different from the TVs and the trends of arsenic in prawn abdomen at each site did not change between 2010 and 2019. As a result, the overall risk posed by arsenic in 2019 to the condition of the receiving environment downstream of the Porgera River in 2019 was considered low. Therefore, the results of the initial risk assessment for arsenic in prawn abdomen at Wasiba, Wankipe, Bebelubi and SG4 have been adjusted from potential risk to low risk, the change is reflected in Table 7-35.

7.4.4.6 Cadmium (Cd)

The 2019 median concentrations of dissolved cadmium in water discharged in tailings and at Wendoko Creek D/S Anawe Nth exceeded the upper river TV, and at Kogai Culvert and Kogai Stable Dump Toe, the 2019 median concentrations of dissolved cadmium were not significantly different from the upper river TV, indicating potential risk. The 2019 median concentrations of dissolved cadmium in waters discharged from all other discharge points were below the upper river TV, indicating low risk. In the receiving environment downstream of the Porgera River, dissolved cadmium in water was below the TVs at all test sites, indicating low risk.

The 2019 median concentrations of WAE cadmium in sediment discharged from the operation in tailings and from 28 Level, Kogai Culvert and Kogai Stable Dump Toe and Yakatabari Creek D/S 28 Level exceeded the upper river TV, indicating potential risk. The 2019 median concentrations of WAE cadmium at all other sites were below the upper river TV, indicating low risk. In the receiving environment downstream of the Porgera River, WAE cadmium in sediment was below the TVs at all test sites, indicating low risk.

The 2019 median concentrations of cadmium in prawn abdomen at Wasiba and Wankipe in the upper river were higher than the TV, indicating potential risk. The 2019 median concentration of cadmium in prawn abdomen at Bebelubi was not significantly different from the TV and at SG4, the 2019 median concentration of cadmium in prawn abdomen was greater than the TV. The 2019 median concentration of cadmium in fish flesh at all upper river, lower river and Lake Murray test sites was below the respective TVs, indicating low risk.

Trends for cadmium in water, sediment, fish flesh and prawn abdomen at all test sites and reference sites within the upper river, lower river, ORWBs and Lake Murray either did not change or decreased between 2010 and 2019.

Further investigation of the elevated concentrations of cadmium in prawn abdomen at Wasiba, Wankipe, Bebelubi and SG4 shows that the results of the initial risk assessment for Wasiba and Wankipe in the upper river are reflective of potential risk at these sites.

However, in the lower river, the range of values observed at the test site Bebelubi in 2019 was generally comparable to the range of values at the reference sites Baia and Tomu. Descriptive statistics for cadmium in prawn abdomen at Bebelubi, SG4 and the combined data for lower river test sites Baia and Tomu are shown in Table 7-28. For this reason, and due to the either no change in trend or decreasing trends observed for cadmium in all indicators throughout the upper river and lower river, the risk posed by cadmium to the environment in the lower river at Bebelubi is considered low, and consequently, the result of initial risk assessment for cadmium in prawn abdomen at Bebelubi has been adjusted from potential risk to low risk, the change is reflected in Table 7-35.

Table 7-28 Descriptive statistics for cadmium in prawn abdomen at upper river test and reference sites in 2019

Variable	Site	N	Mean	StDev	Min	Q1	Median	Q3	Max
Cd **Prawn Abdomen**	Bebelubi	12	0.005	0.003	0.003	0.003	0.004	0.007	0.012
	SG4	12	0.009	0.004	0.003	0.006	0.010	0.014	0.017
	LwRiv Ref	20	0.004	0.002	0.003	0.003	0.003	0.005	0.012

7.4.4.7 Chromium (Cr)

The 2019 median concentration of dissolved chromium in water discharged from the Lime Plant exceeded the upper river TV, and at 28 Level, Kaiya Riv D/S Anj Dump, Kogai Stable Dump Toe and Yakatabari Crk D/S 28 Level, the median concentrations of dissolved chromium in water were not significantly different from the upper river TV, indicating potential risk. The 2019 median concentrations of dissolved chromium in water from all other discharge points were below the upper river TV, indicating low risk. In the receiving environment, the 2019 median concentrations of dissolved chromium in water at all test sites were below the respective TVs, indicating low risk.

The 2019 median concentrations of WAE chromium in sediment discharged from the site were below the upper river TV, indicating low risk. In the receiving environment, the 2019 median concentrations of WAE chromium in sediment at all test sites were below the respective TVs, indicating low risk.

The 2019 median concentrations of chromium in prawn abdomen at upper river test sites Wasiba and Wankipe and in fish flesh at southern Lake Murray test site Miwa were all less than the respective TVs, but not significantly different from the TVs. The 2019 median concentrations of chromium in fish flesh and prawn abdomen at all other test sites were below the respective TVs.

Overall, given the low concentrations of chromium in discharge from the site, the 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 and Wankipe, and in fish flesh at Miwa, were less than, but not significantly different from the respective

TVs, the risk of chromium to the condition of the receiving environment downstream of the Porgera River in 2019 was considered to be low. 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 7-35.

7.4.4.8 Copper (Cu)

The 2019 median concentration of dissolved copper in water discharged in tailings was higher than the upper river TV, while at Kogai Culvert and Lime Plant, the 2019 median concentration of dissolved copper in water was not significantly different from the upper river TV, indicating potential risk.

In the receiving environment, the 2019 median concentrations of dissolved copper in water at upper river test sites SG2, Wasiba, Wankipe, and in the lower river at Bebelubi and SG5 were not significantly different from the TVs, indicating potential risk. It should be noted that Angel et al (2019, 2017) showed that a significant portion of dissolved copper is not Chelex labile indicating low bioavailability/toxicity. Therefore, while the result of the initial risk assessment is maintained, it should be considered conservative and is likely to overestimate the actual risk posed by copper in water.

The 2019 median concentration of WAE copper in sediment discharged in tailings exceeded the upper river TV, indicating potential risk. Within the receiving environment, the 2019 median concentrations of WAE copper in sediment at all test sites within the upper river, lower river, ORWBs and Lake Murray were below the respective TVs, indicating low risk.

The risk assessment for tissue metal indicated that the 2019 median concentration of copper in prawn abdomen in the upper river at Wasiba was not significantly different from the TV, and higher than the TV at Wankipe, both indicating potential risk. The 2019 median concentrations of copper in fish flesh and prawn abdomen at all other test sites within the upper river, lower river and Lake Murray were below the TVs, indicating low risk.

Overall, given the elevated concentrations of copper in water and prawn abdomen in the upper river, copper is considered to pose a potential risk to the environmental condition within the upper river between the mine and Wankipe. In the upper river downstream of Wankipe and the lower river, ORWBs and Lake Murray, given that the only indicator of potential risk from copper is in water at Bebelubi and SG5, where the 2019 median concentrations were less than, but not significantly different from the TV, and there is low risk posed by copper in sediment, fish flesh and prawn abdomen, the overall risk posed by copper is considered to be low. As a result, the initial risk assessments for dissolved copper in water at Bebelubi and SG5 have been revised from potential risk to low risk, the change is reflected in Table 7-33.

7.4.4.9 Mercury (Hg)

The 2019 median concentrations of mercury in water discharged from all sites were below the upper river TV, indicating low risk. Similarly, at all test sites within the upper river, lower river, ORWBs and Lake Murray, the 2019 median concentrations of dissolved mercury in water were below the respective TVs, indicating low risk.

In sediment discharged in the tailings, the 2019 median concentration of WAE mercury was higher than the upper river TV, indicating potential risk. The 2019 median concentrations of WAE mercury in sediment discharged from all other sites were below the upper river TV, indicating low risk. Within the receiving environment, the 2019 median concentrations of WAE mercury in sediment at all test sites within the upper river, lower river, ORWBs and Lake Murray were below the respective TVs, indicating low risk.

In fish tissue and prawn abdomen, the 2019 median concentrations of mercury at test sites within the upper river, lower river, ORWBs and Lake Murray were below the respective TVs, indicating low risk.

Overall, given the low risk posed by mercury in water, sediment, fish flesh and prawn abdomen at all test sites, the risk posed by mercury is considered to be low.

7.4.4.10 Nickel (Ni)

The 2019 median concentration of dissolved nickel in water discharged in tailings was higher than the upper river TV, indicating potential risk. In the receiving environment, the 2019 median concentrations of dissolved nickel in water at all test sites within the upper river, lower river, ORWBs and Lake Murray, were below the respective TVs, indicating low risk.

The 2019 median concentration of WAE nickel in sediment discharged in tailings exceeded the upper river TV, indicating potential risk. Within the receiving environment, WAE nickel concentrations in sediment at all test sites within the upper river, ORWBs and Lake Murray were below the respective TVs, indicating low risk.

The risk assessment for tissue metal indicated that the 2019 median concentrations of nickel in prawn abdomen at the lower river test sites Bebelubi and SG4 were equal to, but not significantly different from the TV, indicating potential risk. The 2019 median concentrations of nickel in fish flesh and prawn abdomen at all other test sites within the upper river and Lake Murray were below the TVs, indicating low risk.

Overall, given the only indicator of potential risk from nickel is in prawn abdomen at Bebelubi and SG4, where the 2019 median concentrations were equal to, but not significantly different from the TVs, the overall risk posed by nickel in the receiving environment is considered to be low. 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 7-35.

7.4.4.11 Lead (Pb)

The 2019 median concentrations of dissolved lead in water from all discharge sites were below the upper river TV, indicating low risk. Similarly in the receiving environment, at all test sites within the upper river, lower river, ORWBs and Lake Murray, the 2019 median concentrations of dissolved lead in water were below the respective TVs, indicating low risk.

Sediment from all discharge points except the lime plant, exhibited median concentrations of WAE lead in 2019 that exceeded the upper river TV, indicating potential risk. Within the receiving environment in the upper rivers the 2019 median concentration of WAE lead in sediment at SG2 was higher than the upper river TV, and at Wasiba, the 2019 median concentration of WAE lead in sediment was not significantly different from the TV, indicating potential risk. The 2019 median concentrations of WAE lead in sediment at all other test sites within the upper river, lower river, ORWBs and Lake Murray were below the respective TVs, indicating low risk.

The results of the risk assessment performed on prawn abdomen showed that the 2019 median concentrations of lead in prawn abdomen at Wasiba and Wankipe in the upper river were higher than the TV, indicating potential risk. In the lower river at SG4, the 2019 median concentration of lead in prawn abdomen was not significantly different from the TV, indicating potential risk. All other results showed the 2019 median concentrations of lead in prawn abdomen and fish flesh in the upper river, lower river and Lake Murray were below the TVs, indicating low risk.

Overall, given the elevated concentrations of lead in sediment at SG2 and Wasiba and in prawn abdomen at Wasiba and Wankipe, lead is considered to pose a potential risk to the environmental condition within the upper river between the mine and Wankipe. Downstream of Wankipe in the upper river and in the lower river, ORWBs and Lake Murray, given the only indicator of potential risk from lead is in prawn abdomen at SG4, where the 2019 median concentration was equal to, but was not significantly different from the TV, and low risk posed by lead in water, sediment and fish flesh, the overall risk posed by lead is considered to be low. Therefore, the result of the initial risk assessment for lead in prawn abdomen at SG4 has been revised from potential risk to low risk, the change is reflected in Table 7-35.

7.4.4.12 Selenium (Se)

The 2019 median concentrations of dissolved selenium in water from all discharge sites were below the upper river TV, indicating low risk. Similarly in the receiving environment, at all test sites within the upper river, lower river, ORWBs and Lake Murray, the 2019 median concentrations of dissolved selenium in water were below the respective TVs, indicating low risk.

Sediment from all discharge points except the lime plant, Wendoko Creek D/S Anawe Nth and Yakatabari Creek D/S 28 Level exhibited median concentrations of WAE selenium that exceeded the upper rivers TV, indicating potential risk. Within the receiving environment in the upper river the 2019 median concentrations of WAE selenium in sediment at SG2 and SG3 were not significantly different from the TV, indicating potential risk. At Wasiba and Wankipe in the upper river, the 2019 median concentrations of selenium in sediment were below the TV, indicating low risk.

In the lower river and ORWBs, the 2019 median concentration of WAE selenium in sediment at Bebelubi was not significantly different from the TV, and at SG4, SG5, Kukufionga, Zongamange, Avu and Levame, the 2019 median concentrations of WAE selenium in sediment were higher than the TV, all indicating potential risk. At the Lake Murray test sites, Pangoa, Miwa and SG6, the 2019 median concentrations of WAE selenium in sediment were less than the TV, indicating low risk.

The 2019 median concentration of selenium in prawn abdomen at upper river test site Wasiba was higher than the TV, indicating potential risk. In prawn abdomen at Wankipe and in fish flesh as Wasiba and Wankipe, the 2019 median concentrations of selenium were below the TVs, indicating low risk. In the lower river, the 2019 median concentration of selenium in prawn abdomen at Bebelubi was not significantly different from the TV, and at SG4 the 2019 median concentration of selenium in prawn abdomen was higher than the TV, indicating potential risk. In fish flesh at Bebelubi and SG4, the 2019 median concentrations of selenium were less than the TV, indicating low risk. In Lake Murray at Pangoa and Miwa, the 2019 median concentrations of selenium in fish flesh were below the TV, indicating low risk.

The trend of selenium concentrations in water and sediment have either not changed or decreased at all test sites within the upper river, lower river, ORWBs and Lake Murray between 2010 and 2019. The concentrations of selenium in prawn abdomen at Wasiba and SG4 and in fish tissue at Miwa have increased between 2010 and 2019. At all other test sites in the upper river, lower river, and Lake Murray, the concentrations of selenium in fish tissue and prawn abdomen either had not changed or decreased between 2010 and 2019.

Further review of WAE selenium in sediment shows that the range of WAE selenium concentrations in sediment at the upper river test sites are comparable to those at the reference sites. The maximum concentration at the reference sites in 2019 was 2.9 mg/kg, compared to a maximum at SG2 of 0.20 mg/kg, Wasiba 0.17 mg/kg, Wankipe 3.1 mg/kg and SG3 0.23mg/kg. Descriptive statistics for WAE selenium in sediment at the upper river reference and test sites are shown in Table 7-29. These results indicate while discharge from the mine does contribute low concentrations of WAE selenium in sediment to the system, there are also natural contributions of low concentrations of WAE selenium in sediment from the reference sites.

In the lower river, the ranges of concentrations of WAE selenium in sediment at the test sites are higher than the ranges observed at the lower river reference sites, however they are lower than the range observed at the upper river reference sites. It is likely that selenium from the upper river reference sites is contributing to the selenium signature at the lower river test sites, along with low concentrations in discharge from the mine. Descriptive statistics for WAE selenium in sediment at the lower river reference and test sites are shown in Table 7-30.

Similarly for selenium in prawn abdomen, the concentrations observed at the upper and lower river test and reference sites are comparable, indicating bioaccumulation from low natural selenium signature throughout the system. Descriptive statistics for selenium in prawn abdomen at the upper and lower river reference and test sites are shown in Table 7-31 and Table 7-32 respectively.

Overall, given the generally low concentrations of selenium in discharge from the mine, the presence of low natural selenium contributions from the reference sites, the risk posed by selenium to the environmental condition within the upper river, lower river, ORWBs and Lake Murray is considered to be 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 7-33, Table 7-34 and Table 7-35.

Table 7-29 Descriptive Statistics WAE Selenium in Sediment Upper River Reference and Test Sites 2019 (whole sediment mg/kg)

Parameter	Site	N	Mean	StDev	Min	Q1	Median	Q3	Max
Se-WAE Sediment	UpRiv Ref	51	0.22	0.5	0.1	0.1	0.12	0.14	2.9
	SG2	12	0.15	0.024	0.1	0.13	0.15	0.16	0.20
	Wasiba	15	0.13	0.02	0.1	0.12	0.13	0.14	0.17
	Wankipe	17	0.31	0.72	0.1	0.11	0.13	0.16	3.1
	SG3	14	0.14	0.041	0.1	0.1	0.13	0.17	0.23

Table 7-30 Descriptive Statistics WAE Selenium in Sediment Lower River and ORWB Reference and Test Sites 2019 (whole sediment mg/kg)

Parameter	Site	N	Mean	StDev	Min	Q1	Median	Q3	Max
Se-WAE Sediment	LwRiv Ref	14	0.10	0	0.10	0.10	0.10	0.10	0.10
	Bebelubi	7	0.12	0.029	0.10	0.10	0.10	0.15	0.17
	SG4	8	0.13	0.034	0.10	0.10	0.12	0.16	0.19
	SG5	14	0.13	0.038	0.10	0.11	0.12	0.17	0.21
	Kukufionga	10	0.13	0.026	0.10	0.11	0.12	0.15	0.17
	Zongamange	12	0.22	0.08	0.12	0.16	0.21	0.28	0.39
	Avu	12	0.22	0.090	0.10	0.16	0.20	0.27	0.42
	Levame	12	0.18	0.05	0.10	0.14	0.19	0.23	0.24

Table 7-31 Descriptive Statistics Selenium in Prawn Abdomen Upper River Reference and Test Sites 2019 (wet mg/kg)

Parameter	Site	N	Mean	StDev	Min	Q1	Median	Q3	Max
Se Prawn Abdomen	UpRiv Ref	12	0.51	0.071	0.39	0.44	0.50	0.57	0.59
	Wasiba	12	0.65	0.14	0.49	0.52	0.65	0.74	0.97
	Wankipe	12	0.51	0.10	0.31	0.45	0.49	0.57	0.70

Table 7-32 Descriptive Statistics Selenium in Prawn Abdomen Lower River Reference and Test Sites 2019 (wet mg/kg)

Parameter	Site	N	Mean	StDev	Min	Q1	Median	Q3	Max
Se Prawn Abdomen	LwRiv Ref	20	0.28	0.06	0.18	0.24	0.27	0.32	0.44
	Bebelubi	12	0.32	0.07	0.24	0.27	0.30	0.40	0.43
	SG4	12	0.35	0.05	0.24	0.32	0.37	0.39	0.41

7.4.4.13 Zinc (Zn)

The 2019 median concentrations of dissolved zinc in water discharged in tailings and from 28 level, Kogai Stable Dump Toe and Wendoko Crk D/S 28 Level were greater than the upper river TV, and in water from Kogai Culvert, the 2019 median concentration of dissolved zinc in water was not significantly different from the upper river TV, indicating potential risk. In the receiving environment, at all test sites within the upper river, ORWBs and Lake Murray, the 2019 median concentration of dissolved zinc in water was below the respective TVs, indicating low risk. In the lower river at Bebelubi and SG4, the 2019 median concentrations of dissolved zinc in water were less than, but not significantly different from the TV, indicating potential risk. At SG5 in the lower river, the 2019 median concentration of dissolved zinc was below the TV, indicating low risk.

In sediment discharged in tailings and from 28 Level, Kogai Culvert, Kogai Stable Dump Toe and Yakatabari Crk D/S 28 Level, the 2019 median concentrations of WAE zinc were greater than the upper river TV, and at Wendoko Crk D/S Anawe Nth, the 2019 median concentration of WAE zinc in sediment was equal to, but not significantly different from the TV, indicating potential risk. At the upper river test site SG2, the 2019 median concentration of WAE zinc in sediment was not significantly different from the TV, indicating potential risk. At all other test sites in the upper river, lower river, ORWBs and Lake Murray, the 2019 median concentrations of WAE zinc were below the respective TVs, indicating low risk.

Zinc concentrations in prawn abdomen at upper river test site Wankipe and Wasiba and lower river test site Bebelubi, and in fish tissue at Lake Murray test site Pangoa were not significantly different from the respective TVs, indicating potential risk.

Further investigation of these results shows that the finding of potential risk at SG2, where the 2019 median zinc concentration was less than, but not significantly different from the TV, was driven by a large standard deviation within the 2019 data, driven in turn by a number of results that exceeded the TV. Additionally, the concentration of WAE zinc in sediment at SG2 showed an increasing trend between 2015 and 2019. As a result, zinc was considered to pose a potential risk to environmental condition at SG2 during 2019.

The 2019 median concentrations of zinc in prawn abdomen were not significantly different from the TV at Wasiba and Wankipe. Additionally, the concentrations of zinc in fish and prawns did not change between 2010 and 2019 and in the absence of potential risk for water, sediment or fish tissue at these sites, the overall risk posed by zinc in 2019 is considered low. Therefore, the results of the initial risk assessment for zinc in prawn abdomen at Wasiba and Wankipe have been revised from potential risk to low risk, the change is reflected in Table 7-35.

At the lower river test sites Bebelubi and SG4, potential risk is indicated by dissolved zinc in water, where the 2019 median concentrations were not significantly different from the TV, and by zinc in prawn abdomen at Bebelubi, where the 2019 median concentration of zinc was not significantly different from the TV. The results for water were driven by a single high value at each site (23µg/L at Bebelubi and 16µg/L at SG4) recorded during 2019, these results increased the standard deviation within the data sets and contributed to the findings that the 2019 medians were not significantly different from the TV. The trend of dissolved zinc in water at Bebelubi increased between 2010 and 2019 and at SG4 the trend showed no change between 2010 and 2019.

Investigation of the risk assessment for prawn abdomen found that the 2019 median concentration of zinc in prawn abdomen at Bebelubi was less than, but not significantly different from the TV. This result was influenced by a number of values recorded at Bebelubi during 2019 which exceeded the TV. However, an analysis of the range of results recorded at the lower river test sites during 2019 show that the range of results recorded in prawn abdomen at the reference sites were comparable to those recorded at the test sites Bebelubi and SG4. Descriptive statistics for zinc in prawn abdomen at the lower river reference and test sites are shown in Table 7-26. Therefore, the overall risk posed by zinc to the condition of the receiving environment in the lower river is considered to be low and the result of the initial risk assessment for zinc in water at Bebelubi and SG4 and in prawn abdomen at

Bebelubi have been revised from potential risk to low risk, the change is reflected in Table 7-33 and Table 7-35 respectively.

Figure 7-24 Descriptive Statistics Zinc in Prawn Abdomen Lower River Reference and Test Sites 2019 (wet mg/kg)

Variable	Year	N	Mean	StDev	Min	Q1	Median	Q3	Max
Zn Prawn Abdomen	LwRiv Ref	20	12	2.5	7.0	9.5	12	14	17
	Bebelubi	12	13	3.3	8.8	9.2	13	16	18
	SG4	12	12	1.6	10	11	12	13	16

In Lake Murray at test site Pangoa, the 2019 median concentration of zinc in fish flesh was less than, but not significantly different from the TV, indicating potential risk. All indicators, water, sediment and fish flesh at Miwa indicated low risk for zinc. Given that the median concentration of zinc in fish flesh at Pangoa was not significantly different from the TV and there were no other indications of risk associated with zinc in Lake Murray, the overall risk posed by zinc to the environmental condition of Lake Murray is considered to be low. Therefore, the result of the initial risk assessment for zinc in fish tissue at Pangoa has been revised from potential risk to low risk, the change is reflected in Table 7-35 respectively.

7.4.5 Metals speciation and toxicity

Elevated concentrations of copper, lead and zinc in tailings and in drainage from the waste rock dumps resulted in concentrations of these metals that exceeded the TVs and presented potential risk to the aquatic ecosystem in the Porgera River and in the upper reaches of the Lagaip River. 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 PJV 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 PJV. 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 PJV 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 ANZGV (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)

Table 7-33 Summary of mine discharge water quality compared against respective TVs and receiving environment water quality risk assessment results, showing indicators in discharge and test sites that pose potential risk to the receiving environment in 2019 (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	Tailings	7.1	98,300	3,900	0.01	1.0	32	0.29	17	0.12	975	0.10	1.5	6,580
	28 Level	7.6	67	717	0.01	3.1	0.07	0.48[1]	0.54	0.05	3.1	0.46	0.20	27
	SDA Toe	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kaiya Riv D/S Anj Dump	7.9	2,500	274	0.02	1.1	0.1	0.47[1]	1.0	0.10	0.9	0.38	0.45	6.2
	Kogai Culvert	7.8	620	815	0.01	1.6	0.15[1]	0.28	1.1[1]	0.06	1.3	1.1	0.20	16[1]
	Kogai Stable Dump Toe	7.7	99	1,747	0.01	0.89	0.91	0.32[1]	0.62	0.05	2.2	1.3	0.21	170
	Lime Plant	11.7	97	1,157	0.01	0.13	0.05	3.6	0.80[1]	0.05	0.5	0.14	0.20	1.8
	Wendoko Creek D/S Anawe Nth	7.8	10	2,127	0.01	0.87	1.1	0.31	0.45	0.05	1.6	0.13	0.39	370
	Yakatabari Creek D/S 28 Level	7.5	1,700	635	0.01	9.0	0.05	0.82[1]	1.1	0.06	1.3	0.78	0.20	4.1
	Yunarilama/Yarik @ Portal	7.6	11,500	1,904	0.01[1]	2.2	0.06	0.67	0.40	0.06	2.1	0.35	1.1	5.5
Upper River	SG1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SG2	7.7	1,550	286	0.01	1.1	0.12	0.43	1.4[1]	0.05	0.97	0.18	0.20	8.9
	Wasiba	7.5	1,500	265	0.01	0.99	0.09	0.26	1.2[1]	0.05	0.76	0.18	0.20	7.2
	Wankipe	7.7	1,400	239	0.01	1.1	0.05	0.43	1.3[1]	0.05	0.71	0.26	0.20	5.4
	SG3	7.6	1,500	233	0.01	0.99	0.05	0.28	1.2	0.05	0.63	0.13	0.20	4.0
Lower River	Bebelubi	7.4	550	217	0.01[1]	0.81	0.05	0.45	1.3[1]	0.05	0.67	0.23	0.20	3.4[1]
	SG4	7.4	455[1]	182[1]	0.01[1]	0.83	0.05	0.46	0.98	0.05	0.65	0.19	0.20	2.2[1]
	SG5	7.4	280	159	0.01	0.88	0.05	0.33	1.0[1]	0.05	0.50	0.10	0.20	2.4
ORWBs	Kukufionga	7.1	64	157	0.01	1.0	0.05	0.29	0.98	0.06	0.50	0.10	0.20	2.3
	Zongamange	6.9	2.5	110	0.01	0.53	0.05	0.16	0.49	0.06	0.50	0.14	0.20	1.6
	Avu	6.3[1]	5.0	55	0.01	0.61	0.05	0.43	0.29	0.05	0.70	0.14	0.20	2.1
	Levame	7.3	18	165[1]	0.01	1.0	0.05	0.19	1.0	0.05	0.50	0.11	0.20	1.1
Lake Murray	Central Lake - Pangoa	5.4	2.0	16	0.01	0.15	0.05	0.50	0.37	0.06	0.57	0.10	0.20	3.9
	Southern Lake - Miwa	6.3	2.0	23	0.01	0.23	0.05	0.33	0.41	0.07	0.50	0.15	0.20	2.9
	SG6	6.7	19	84	0.01	0.45	0.05	0.18	0.66	0.05	0.50	0.18	0.20	1.7

🟩 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.

Table 7-34 Summary of mine discharge sediment quality compared against respective TVs and receiving environment sediment quality risk assessment results, showing indicators in discharge and test sites that pose low and potential risk to the receiving environment in 2019 (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	0.73	50	5.2	27	89	0.20	35	105	0.25	915
	28 Level	1.0	50	2.2	9	14	0.01	21	430	0.14	550
	SDA Toe	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kaiya Riv D/S Anj Dump	0.15	4.8	0.8	7.1	6.5	0.01	11	110	0.17	170
	Kogai Culvert	1.1	12	2.2	6.5	12	0.01	8.9	270	0.17	440
	Kogai Stable Dump Toe	0.62	9.9	2.2	6.1	8.3	0.01	8.6	420	0.15	340
	Lime Plant	0.05	0.43	0.24	8.3	1.6	0.01	1.9	1.8	0.10	11
	Wendoko Creek D/S Anawe Nth	0.35	6.1	1.1	5.2	8.3	0.01	7.2	54	0.14	200
	Yakatabari Creek D/S 28 Level	1.9	14	1.9	11	23	0.01	14	285	0.13	395
	Yunarilama/Yarik @ Portal	0.13	5.2	0.6	6.3	5.1	0.01	8.5	95	0.20	129
Upper River	SG1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SG2	0.16	4.7	0.97	6.8	12	0.01	11	115	0.15[1]	140[1]
	Wasiba	0.05	3.8	0.69	4.2	10	0.01	11	33[1]	0.13	110
	Wankipe	0.05	3.6	0.44	3.5	9.5	0.01	13	31	0.13	68
	SG3	0.05	3.6	0.47	6.3	9.5	0.01	18	29	0.13[1]	88
Lower River	Bebelubi	0.05	2.8	0.28	2.5	6.3	0.01	10	15	0.10[1]	47
	SG4	0.05	2.5	0.22	3.4	7.1	0.01	10	13	0.12	38
	SG5	0.05	3.4	0.29	2.2	12	0.01	6.4	15	0.12	41
ORWBs	Kukufionga	0.05	3.7	0.34	2.3	12	0.01	6.6	16	0.12	47
	Zongamange	0.17	9.1	0.33	2.8	22	0.01	9.6	33	0.21	64
	Avu	0.06	4.0	0.25	1.6	18	0.01	8.3	18	0.20	53
	Levame	0.11	6.2	0.27	2.7	18	0.01	7.0	28	0.19	55
Lake Murray	Central Lake	0.06	1.7	0.10	5.3	12	0.03	11	9.8	0.14	46
	Southern Lake	0.15	3.7	0.21	4.4	15	0.01	11	27	0.22	64
	SG6	0.15	5.5	0.32	3.6	18	0.01	9.7	29	0.20	59

🟩	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 7-35 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	7.5	1,500	265[1]	0.01	0.99	0.09	0.26	1.2[1]	0.05	0.76	0.18	0.20	7.2
		Sed-WAE	mg/kg	-	-	-	0.05	3.8	0.69	4.2	10	0.01	11	33[1]	0.13	110
		Fish Flesh	µg/g	-	-	-	-	0.023	0.004	0.01	0.14	0.05	0.01	0.01	0.46	3.5
		Prawn Abdo	µg/g	-	-	-	-	0.030[1]	0.01	0.014[1]	4.9[1]	0.01	0.01	0.016	0.65	13[1]
	Wankipe	Water-D	µg/L	7.7	1,400	239[1]	0.01	1.1	0.05	0.43	1.3[1]	0.05	0.71	0.26	0.20	5.4
		Sed-WAE	mg/kg	-	-	-	0.05	3.6	0.44	3.5	9.5	0.01	13	31	0.13	68
		Fish Flesh	µg/g	-	-	-	-	0.016	0.004	0.01	0.19	0.05	0.01	0.01	0.37	3.7
		Prawn Abdo	µg/g	-	-	-	-	0.033[1]	0.01	0.024[1]	8.3	0.01	0.01	0.011	0.49	14[1]
Lower River	Bebelubi	Water-D	µg/L	7.4	550	217[1]	0.01[1]	0.81	0.05	0.45	1.3[1]	0.05	0.67	0.23	0.20	3.4[1]
		Sed-WAE	mg/kg	-	-	-	0.05	2.8	0.28	2.5	6.3	0.01	10	15	0.10[1]	47
		Fish Flesh	µg/g	-	-	-	-	0.015	0.003	0.01	0.065	0.03	0.01	0.01	0.074	2.4
		Prawn Abdo	µg/g	-	-	-	-	0.077[1]	0.004[1]	0.019	7.6	0.01	0.01[1]	0.01	0.30[1]	12.5[1]
	SG4	Water-D	µg/L	7.4	455[1]	182[1]	0.01[1]	0.83	0.05	0.46	0.98	0.05	0.65	0.19	0.20	2.2[1]
		Sed-WAE	mg/kg	-	-	-	0.05	2.5	0.22	3.4	7.1	0.01	10	13	0.12	38
		Fish Flesh	µg/g	-	-	-	-	0.01	0.003	0.01	0.069	0.04	0.01	0.01	0.13	2.3
		Prawn Abdo	µg/g	-	-	-	-	0.065[1]	0.01	0.022	6.9	0.01	0.01[1]	0.01[1]	0.37	12
Lake Murray	C. Lake - Pangoa	Water-D	µg/L	5.4	2.0	16	0.01	0.15	0.05	0.50	0.37	0.06	0.57	0.10	0.20	3.9
		Sed-WAE	mg/kg	-	-	-	0.06	1.7	0.10	5.3	12	0.03	11	9.8	0.14	46
		Fish Flesh	µg/g	-	-	-	-	0.015	0.003	0.01	0.08	0.19	0.01	0.01	0.32	2.35[1]
	S. Lake - Miwa	Water-D	µg/L	6.3	2.0	23	0.01	0.23	0.05	0.33	0.41	0.07	0.50	0.15	0.2	2.9
		Sed-WAE	mg/kg	-	-	-	0.15	3.7	0.21	4.4	15	0.01	11	27	0.22	64
		Fish Flesh	µg/g	-	-		-	0.016	0.003	0.01[1]	0.08	0.20	0.01	0.01	0.36	2.40

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

[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.

7.5 Local Water Supplies

Participatory sampling of local village water supplies was carried out in January 2020 at Special Mining Lease (SML) and Lease for Mining Purposes (LMP) villages (Yarik, Timorope, Panadaka, Alipis, Pakien Camp, Mungalep and Kulapi). Ongoing security issues within the Porgera Valley during 2019 prevented the PJV team from safely access villages for sampling. The purpose of the program is to assess the suitability of water from known drinking water sources for domestic use. Apalaka village was not sampled in January 2020 due to community issues that prevented the PJV team from sampling. Sampling at Yarik was performed on three new water tanks installed by PJV.

The sampling was arranged in consultation with the Porgera Land Owners Association (PLOA), who assisted to identify the sampling sites and participated in the sample collection. Sampling sites and details are listed in Table 7-36 and locations are shown in Figure 7-25.

Table 7-36 Sampling sites for local village water supplies

Village	Site	Name on map	Easting	Northing
Yarik	Porep Pulawa (Tank)	YR_PP	732651	9397387
	Akope Mare (Tank)	YR-AM	732936	9397395
	Jenny Bolo (Tank)	YR_JB	732922	9397591
	Kapio Kendo (Spring)	YR_KS	732678	9397507
Panadaka	Panadaka 1 Bilip Aile Tank	PA_V1H6	733671	9395507
	Panadaka 2 Timothy Kerene Tank	PA_V2H4	733845	9395780
Alipis	Alipis Village Tank 3	AL_T3	733346	9395775
Kulapi	Kulapi V4 H1 tank	KL_V4H1	732772	9394700
Timorope	Iso Kulina Tank	TI_H2	733221	9397580
	Wari Ekali	TI_H1	733234	9397568
Pakien	Pakien United Church	PA_UC	734407	9397184
Mungalep	Catholic Mission	MG_CC	734407	9397184
	Tawano Pos	MG_TP	735429	9397430

The water quality results are presented in Table 7-37 and Table 7-38 and are compared against the PNG Raw Drinking Water Standard (PNG 1984) and the World Health Organisation (WHO) Guidelines for Drinking Water Quality (WHO 2017).

The pH was below the WHO and PNG drinking water quality guideline lower value at nine sites. It is suspected that the low pH was due to the presence of organic matter in the tanks, such as leaves and sticks, which enter the tanks from the rooftop catchments that feed the tanks. Organic matter breaks down and generates natural tannins (humic and fulvic acid) that will reduce pH in water. Three sites exceeded colour guideline value while turbidity was exceeded at one site only.

Concentrations of dissolved and total metals were below, and therefore compliant with, both the PNG and WHO guidelines.

PJV has implemented a supplementary water project involving the installation of rainwater tanks in villages within the special mining lease (SML) to improve the availability and reliability of safe drinking water for local communities.

Since 2011, 114 water tanks have been installed in more than 85 separate locations, throughout the seven main communities on the SML.

The water is captured from existing catchment structures and piped to a central location which is accessible to the broader community. The water is considered a communal resource and is managed by the Village Water Committee.

The total capacity of all water tanks installed under this program to date is 550,000 litres. PJV will continue to work with relevant communities on an ongoing basis to determine where the installation of further supplemental water supplies may be required.

Figure 7-25 Sampling sites for local village water supplies

Table 7-37 Physiochemical and biological water quality 2018* at drinking water sites against Drinking Water Quality Standards

Site / Parameter	pH	EC	Total Solids	Colour	Turbidity	Total Hardness	Faecal Coliforms	Total Coliforms
Unit	SU	µS/cm	mg/L	HU	NTU	mg/L	cfu/100 mL	cfu/100 mL
Porep Pulawa (Tank)	6.1	6.9	135	9.0	2.1	2.9	None	None
Akope Mare (Tank)	6.7	5.8	5.0	5.0	1.3	1.8	None	None
Jenny Bolo (Tank)	6.1	7.2	50	5.0	0.9	4.3	None	None
Kapio Kendo (Spring)	6.8	244	260	23	9.4	72	None	None
Wari Ekali	6.9	13	85	34	1.2	3.2	None	None
Iso Kulina (Tank)	6.8	8.3	65	23	1.6	3.6	None	None
Alipis Village (Tank 3)	6.0	61	80	14	1.6	1.4	None	None
Bilip Aile (Tank)	6.3	56	135	14	1.4	1.1	None	None
Timothy Kerene (Tank)	5.3	56	30	14	1.5	2.8	None	None
Kulapi V4 H1 (Tank)	6.4	7.7	155	7.0	1.4	1.7	None	None
Pakien United Church	6.4	11	95	5.0	1.2	8.3	None	None
Mungalep Catholic Mission	6.0	5.6	65	7.0	0.7	4.7	None	None
Tawano Pos	5.4	2.7	100	6.0	0.6	3.7	None	None
PNG (1984)	**6.5 - 9.2**	**NA**	**500**	**15**	**<5**	**200**	**None**	**<10**
WHO (2017)	**6.5 – 8.5**	**NA**	**NA**	**15**	**<4**	**200**	**None**	**None**

🟩	Compliant
🟧	Non-compliant

PNG (1984), PNG Public Health (Drinking Water) Regulation 1984. Schedule 1 Standard for Raw Water.

WHO (2017), WHO Guidelines for drinking-water quality: fourth edition incorporating the first addendum

NA - Not Applicable; Cfu – Colony forming units; SU - Standard Units

Table 7-38 Metal concentrations of drinking water sites against Drinking Water Quality Standards (µg/L)

Site / Parameter	As		Cd		Cu		Pb		Hg		Ni		Se		Zn	
	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T
Porep Pulawa (Tank)	0.4	0.4	0.05	0.05	18	45	1.5	1.6	0.05	0.05	0.5	0.5	0.2	0.2	190	190
Akope Mare (Tank)	0.6	0.4	0.05	0.05	1.6	1.6	0.6	0.6	0.05	0.05	0.5	0.5	0.2	0.2	150	140
Jenny Bolo (Tank)	0.2	0.1	0.05	0.05	3.1	3.1	0.5	0.4	0.05	0.05	0.5	0.5	0.2	0.2	190	180
Kapio Kendo (Spring)	0.3	0.4	0.05	0.05	0.2	0.2	0.2	0.8	0.20	0.05	0.6	0.6	0.7	0.5	4.7	2.5
Wari Ekali	0.2	0.2	0.05	0.05	0.9	0.8	0.4	0.2	0.05	0.05	0.5	0.5	0.2	0.2	200	180
Iso Kulina (Tank)	0.2	0.2	0.05	0.05	1.9	1.9	0.5	0.6	0.05	0.05	0.5	0.5	0.2	0.2	170	170
Alipis Village (Tank 3)	0.4	0.4	0.05	0.05	1.3	1.6	1.8	0.9	0.05	0.05	0.5	0.5	0.2	0.2	290	290
Bilip Aile (Tank)	0.2	0.2	0.10	0.10	2.1	2.1	0.8	0.7	0.05	0.05	0.5	0.5	0.2	0.2	190	170
Timothy Kerene (Tank)	0.4	0.4	0.05	0.05	3.8	3.9	0.5	0.5	0.05	0.05	0.5	0.5	0.2	0.2	130	120
Kulapi V4 H1 (Tank)	0.3	0.1	0.09	0.08	0.7	0.5	0.4	0.5	0.05	0.05	0.5	0.5	0.2	0.2	260	250
Pakien United Church	0.1	0.1	0.05	0.05	0.2	0.2	1.7	0.2	0.05	0.05	0.5	0.5	0.2	0.2	51	52
Mungalep Catholic Mission	0.1	0.1	0.05	0.05	0.2	0.2	0.3	0.2	0.05	0.05	0.5	0.5	0.2	0.2	940	880
Tawano Pos	0.1	0.1	0.05	0.05	1.8	2.0	0.3	0.3	0.05	0.05	0.5	0.5	0.2	0.2	93	92
PNG (1984)	**7**		**2**		**1,000**		**10**		**1**		**20**		**10**		**3,000**	
WHO (2017)	**10**		**3**		**2,000**		**10**		**6**		**70**		**40**		**NA**	

🟩	Compliant
🟧	Non-compliant

PNG (1984), PNG Public Health (Drinking Water) Regulation 1984. Schedule 1 Standard for Raw Water.

WHO (2017), WHO Guidelines for drinking-water quality: fourth edition incorporating the first addendum.

D – Dissolved, T – Total, NA – Not Applicable

7.6 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 7-39 and showed that concentrations of dissolved cadmium, nickel and zinc in undiluted tailings exceeded the guideline values, which therefore indicated potential risk to persons exposed to undiluted tailings. The only mechanism for exposure to undiluted tailings is for individuals to illegally enter the mining lease and enter the undiluted tailings stream at the discharge point to pan for gold.

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.

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 7-39 Comparison of 2019 median receiving water quality concentrations with recreational exposure guideline values (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
Tailings	48	7.1	0.01	1.0	32	0.29	17	31	0.12	975	0.10	1.5	6,580
SG1	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SG2	14	7.7	0.01	1.1	0.12	0.43	1.4	9.3	0.05	0.97	0.18	0.20	8.9
Wasiba	15	7.5	0.01	0.99	0.09	0.26	1.2	15	0.05	0.76	0.18	0.20	7.2
Wankipe	17	7.7	0.01	1.1	0.05	0.43	1.3	12	0.05	0.71	0.26	0.20	5.4
SG3	196	7.6	0.01	0.99	0.05	0.28	1.2	12	0.05	0.63	0.13	0.20	4.0
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

7.7 Fish and Prawn Consumption

Median tissue metal concentrations in fish flesh and prawn abdomen are compared against relevant food standards in Table 7-40. 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 7-40 Risk assessment – median tissue metal results at upper and lower river and Lake Murray test sites in 2019 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	12	0.023	0.004	0.01	0.14	0.05	0.01	0.01	0.46	3.5
	Prawn Ab	12	0.030	0.01	0.014	4.9	0.01	0.01	0.016	0.65	13
Wankipe	Fish Flesh	12	0.016	0.004	0.01	0.19	0.05	0.01	0.01	0.37	3.7
	Prawn Ab	12	0.033	0.01	0.024	8.3	0.01	0.01	0.011	0.49	14
Bebelubi	Fish Flesh	12	0.015	0.003	0.01	0.065	0.03	0.01	0.01	0.074	2.4
	Prawn Ab	12	0.077	0.004	0.019	7.6	0.01	0.01	0.01	0.30	12.5
SG4	Fish Flesh	12	0.01	0.003	0.01	0.069	0.04	0.01	0.01	0.13	2.3
	Prawn Ab	12	0.065	0.01	0.022	6.9	0.01	0.01	0.01	0.37	12
Pangoa	Fish Flesh	2	0.015	0.003	0.01	0.08	0.19	0.01	0.01	0.32	2.35
Miwa	Fish flesh	2	0.016	0.003	0.011	0.08	0.20	0.01	0.01	0.36	2.40
Food Std	**Fish**		**2**	**0.050**	**1**	**2**	**0.5**	**NA**	**0.30**	**2**	**15**
	Prawn		**2**	**0.500**	**1**	**20**	**0.5**	**NA**	**0.50**	**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)

NS – Not sampled, Ab - Abdomen

7.8 Air Quality

Monitoring of point source emissions to air is conducted by PJV every two years, the most recent having been performed in 2019. Papua New Guinea has not enacted legislation for controlling emissions to air, therefore PJV has voluntarily set a target of reporting against the relevant Australian Standards, which are the NSW Protection of the Environment Operations (Clean Air) Regulation 2010 and the Victoria State Environment Protection Policy (Air Quality Management) 2001. A comparison of results from 2019 against the standards is presented in Table 7-41. The results show that particulate matter in emissions from the Lime Kiln No. 2, oxides of nitrogen (NO_x) in emissions from the Anawe Diesel and Aggreko Diesel Generators and Hg from the Carbon Regen Kiln exceeded the targets. PJV is continuing to assess options for improving emissions controls to achieve the targets at each discharge point.

Table 7-41 Point source emission metal concentrations (mg/Nm^3)

Source	PM	NO_X	As	Cd	Pb	Ni	Hg	SO_3
Anawe Diesel Generator	21	3,430	0.012	0.143	0.025	0.002	0.011	2.6
Aggreko Diesel Generator	48	2,510	0.010	0.001	0.022	0.005	0.001	0.001
Assay Laboratory	4.3	NA	0.004	0.001	1.6	0.001	0.001	NA
Anawe Autoclaves	38	2.1	0.132	0.070	1.4	0.16	0.161	0.34
Carbon Regeneration Kiln	77	181	0.012	0.088	0.024	0.021	23.8	NA
Gold Room Retort	3.4	2.1	0.007	0.001	0.009	0.003	0.067	0.03
Lime Kiln No 2	750	47	0.008	0.017	0.061	0.10	0.002	NA
Primary Crusher	19	NA	0.004	0.001	0.011	0.065	0.001	NA
Hides Gas Turbine	7.4	256	0.009	0.001	0.012	0.008	0.002	0.30
789 Haul Truck 93	22	NA	0.015	0.004	0.063	0.008	0.001	2.2
777 Haul Truck 22	66	NA	0.014	0.001	0.030	0.048	0.001	2.9
Criterion	**500**	**1,000**	**10**	**3**	**10**	**20**	**3**	**200**

🟩	Compliant
🟧	Non-Compliant

As, Cd, Pb, Ni SO_3, PM, NO_x – Victoria State Environment Protection Policy (Air Quality Management) 2001 Schedule D

Hg – New South Wales Protection of the Environment Operations (Clean Air) Regulation 2010

PM = Particulate Matter

8 IMPACT ASSESSMENT

The impact assessment was performed by firstly comparing the 2019 mean value for biological indicators at each test site against their respective TVs using a one sample t-test to test statistical significance. Where the test site mean is significantly greater than or not significantly different from the TV, this indicates no impact has occurred. Where the test site mean is significantly less than the TV, this indicates impact has occurred.

Secondly, the trend over time (2015 - 2019) 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 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.

8.1.1.1 Comparison against fish impact assessment TVs

Results from the comparison of 2019 test site means for fish impact indicators in the upper river against their respective TVs are provided in Table 8-1 and include the t-statistic and significance value (p) for each test.

Results for upper river test site Wasiba showed that the 2019 test site means for *N. equinus* (mountain tandan) abundance and biomass were significantly less than their respective TVs, indicating adverse impact to this species in the upper river at this site. Total fish species abundance and total fish species biomass showed no impact at Wasiba during 2019.

At Wankipe, total abundance and biomass of all fish species and of the indicator species *N. equinus* (mountain tandan) showed no impact.

Table 8-1 Fish - Results from one-sample t-tests testing for significant (p < 0.05) differences between average values for Wasiba and Wankipe for 2019, and TVs derived from the previous 24 months for reference Ok Om. NS = not significantly different.

Test Site	Indicator Parameter	2019 Test Mean	TV SOURCE	TV	t-Test			Level of Impact
					df	t-stat	p	
Wasiba	Total Fish Abundance	4.5	Ok Om Reference	3.6	3	0.88	0.220	NS.
	Total Fish Biomass (g)	255.1		174.7	3	1.52	0.113	NS.
	N. equinus Abundance	0.6		2.4	3	-18.67	<0.001	Signif. < TV
	N. equinus Biomass (g)	62.1		129.4	3	-5.34	0.006	Signif. < TV

Test Site	Indicator Parameter	2019 Test Mean	TV SOURCE	TV	t-Test			Level of Impact
					df	t-stat	p	
Wankipe	Total Fish Abundance	4.6	Ok Om Reference	3.6	3	1.95	0.073	NS.
	Total Fish Biomass (g)	374		174.7	3	4.43	0.011	Signif. > TV.
	N. equinus Abundance	3.1		2.4	3	3.10	0.015	Signif. > TV.
	N. equinus Biomass (g)	253		129.4	3	2.57	0.04	Signif. > TV.

8.1.1.2 *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 8-2, and time series plots for each site for all fish species combined, and for the indicator 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 potential to 'fish-down' a site by sampling on consecutive dates (WRM 2018).

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 2019. These decreasing trends and the significantly low means described in Section 8.1.1.1, indicate adverse impact to *N. equinus* at Wasiba. At Wankipe, where no impact was detected for *N. equinus* in 2019, the declining trend indicates the potential for impact to occur in the future, should the declining trend continue. 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.

Table 8-2 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 - 2019. NS = not significant.

Site		Parameter	n	Spearman Corr.		Linear Regress.		Trend
				Rho	p	R	p	
Test	Wasiba 2015-2019	Total Fish Abundance	19	0.274	0.128	0.285	0.118	NS
		Total Fish Biomass (g)	19	0.118	0.316	0.116	0.319	NS
		N. equinus Abundance	19	-0.343	0.075	-0.453	0.026	Sig. -ve
		N. equinus Biomass (g)	19	-0.251	0.150	-0.391	0.049	Sig. -ve
	Wankipe 2015-2019	Total Fish Abundance	21	0.092	0.345	0.077	0.370	NS
		Total Fish Biomass (g)	21	-0.203	0.189	-0.167	0.235	NS
		N. equinus Abundance	21	-0.237	0.151	-0.211	0.179	NS
		N. equinus Biomass (g)	21	-0.377	0.046	-0.343	0.064	Sig. -ve
Ref	Ok Om 2015-2019	Total Fish Abundance	20	0.008	0.486	-0.040	0.433	NS
		Total Fish Biomass (g)	20	-0.131	0.291	-0.236	0.158	NS
		N. equinus Abundance	20	0.032	0.446	0.005	0.491	NS
		N. equinus Biomass	20	-0.156	0.255	-0.248	0.146	NS

All Fish Species

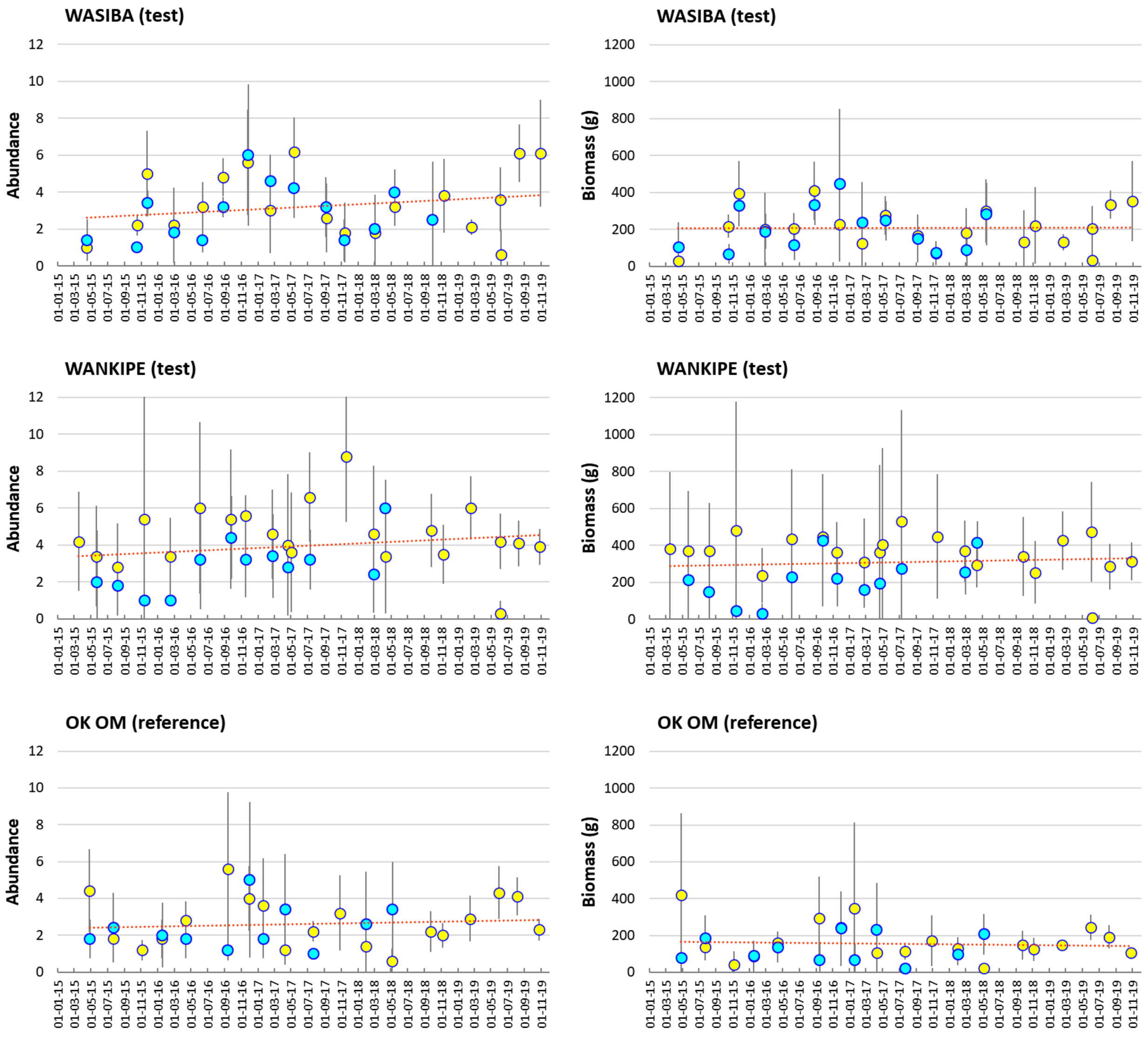


Figure 8-1 Time series plots of average (± 95% CIs) abundance and biomass (g) for combined fish species replicate hook and line catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2019. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) were used for impact assessment.

N. equinus

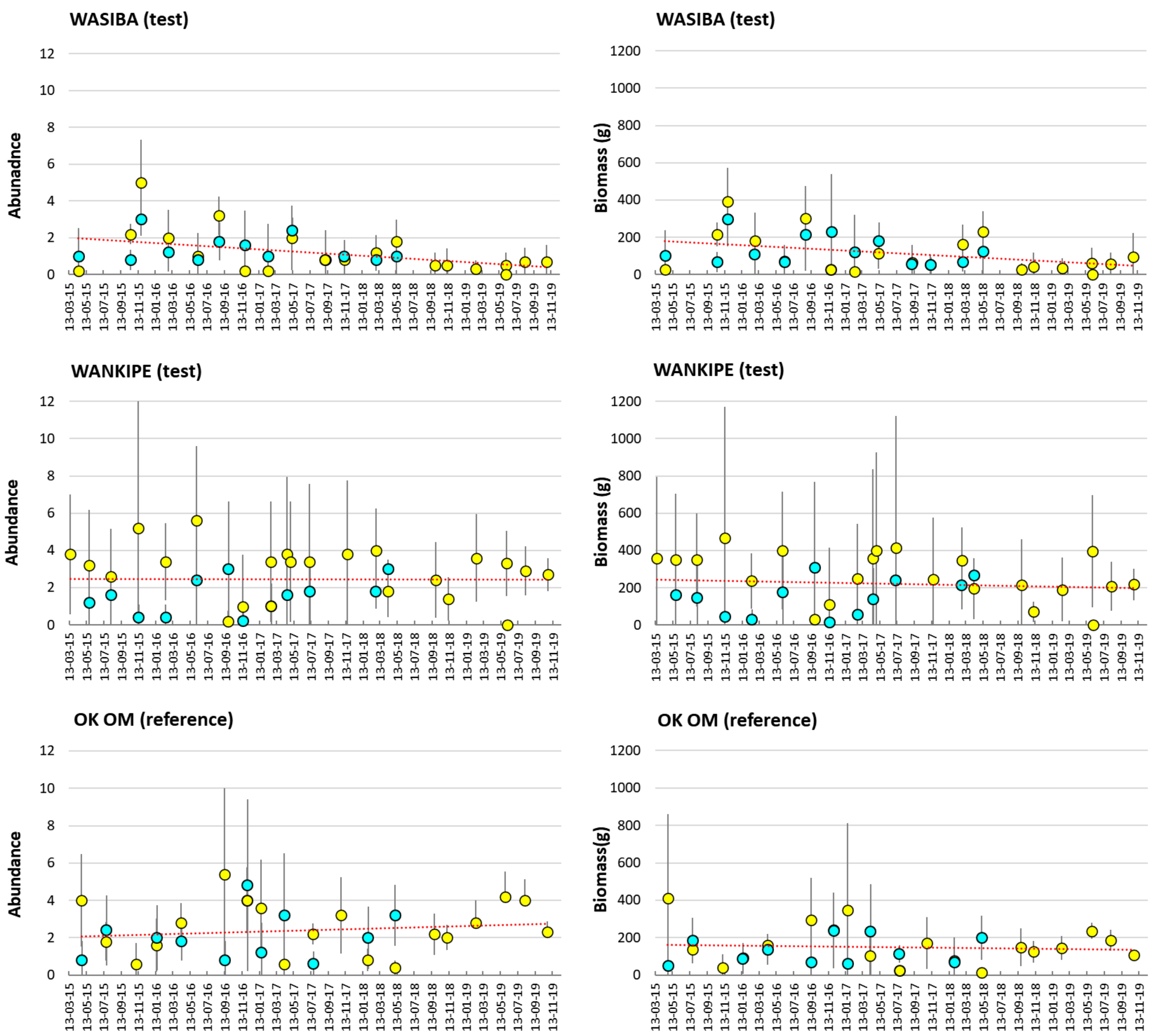


Figure 8-2 Time series plots of average (±95% CIs) abundance and biomass (g) of *Neosilurus equinus* in replicate hook and line catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2019. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) were used for impact assessment.

8.1.2 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.

8.1.2.1 Comparisons against prawn impact TVs

Results from the comparison of 2019 test site means for prawn impact indicators in the upper river against their respective TVs are provided in Table 8-3, and include the t-statistic and significance value (p) for each test.

Results for upper river test sites Wasiba and Wankipe showed that the 2019 test site means for all indicator parameters were not significantly different from their respective TVs, indicating no impact on prawns in the upper rivers during 2019.

Table 8-3 Results from one-sample t-tests testing for significant ($p < 0.05$) differences between average values for Wasiba and Wankipe for 2019, and TVs derived from the previous 24 months for reference Ok Om. NS = not significantly different.

Test Site	Indicator Parameter	2019 Test Mean	TV SOURCE	TV	t-Test			Level of Impact
					df	t-stat	p	
Wasiba	Total Prawn Abundance	10.6	Ok Om Ref	6.0	3	1.81	0.083	NS.
	Total Prawn Biomass	56.8		24.6	3	2.18	0.059	NS.
	M. handschini Abundance	6.4		3.2	3	1.68	0.095	NS.
	M. handschini Biomass	37.8		14.1	3	2.39	0.048	Signif. > TV.
	M. lorentzi Abundance	4.2		2.8	3	1.82	0.083	NS.
	M. lorentzi Biomass	19.0		10.5	3	1.59	0.104	NS.
Wankipe	Total Prawn Abundance	13.8	Ok Om Ref	5.6	3	3.88	0.015	Signif. > TV.
	Total Prawn Biomass	49.4		24.6	3	3.19	0.025	Signif. > TV.
	M. handschini Abundance	7.1		3.2	3	2.63	0.039	Signif. > TV.
	M. handschini Biomass	31.1		14.1	3	2.82	0.033	Signif. > TV.
	M. lorentzi Abundance	6.7		2.8	3	5.29	0.007	Signif. > TV.
	M. lorentzi Biomass	18.3		10.5	3	3.40	0.021	Signif. > TV.

8.1.2.2 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 8-4, 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 total abundance of prawns, and in abundance and biomass of *M. lorentzi* at test site Wasiba between 2015 and 2019. 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 8.1.2.1 showed no impact to *M. lorentzi* abundance and biomass in 2019, therefore the decreasing trend serves as an indicator that if the significant decreasing trend continues then impact may be detected in future years.

Table 8-4 Spearman rank correlation coefficients (rho) and associated significance values (p) for trends over time in total prawn abundance and biomass (g) and in abundance and biomass of the dominant prawn species. Analyses were performed using average of replicate gill net sets averaged within each occasion in each year, 2015 - 2019 (NS = not significant).

Site		**Parameter**	**n**	**Spearman Corr.**		**Linear Regress.**		**Trend**
				Rho	**p**	**R**	**p**	
Test	Wasiba 2015-2019	Total Prawn Abundance	22	-0.348	0.056	-0.369	0.045	Sig. -ve
		Total Prawn Biomass	22	-0.023	0.459	0.043	0.424	NS
		M. handschini Abundance	22	0.283	0.101	0.195	0.193	NS
		M. handschini Biomass	22	0.563	0.003	0.483	0.011	Sig. +ve
		M. lorentzi Abundance	22	-0.527	0.006	-0.531	0.006	Sig. -ve
		M. lorentzi Biomass	22	-0.383	0.039	-0.329	0.068	Sig. -ve
Test	Wankipe 2015-2019	Total Prawn Abundance	22	0.422	0.025	0.438	0.021	Sig. +ve
		Total Prawn Biomass	22	0.357	0.051	0.413	0.028	Sig. +ve
		M. handschini Abundance	22	0.513	0.007	0.547	0.004	Sig. +ve
		M. handschini Biomass	22	0.616	0.001	0.623	0.001	Sig. +ve
		M. lorentzi Abundance	22	0.248	0.133	0.139	0.269	NS
		M. lorentzi Biomass	22	-0.047	0.418	-0.052	0.409	NS
Ref	Ok Om 2015-2019	Total Prawn Abundance	20	0.062	0.398	0.021	0.464	NS
		Total Prawn Biomass	20	0.029	0.452	0.005	0.491	NS
		M. handschini Abundance	20	0.285	0.111	0.209	0.188	NS
		M. handschini Biomass	20	0.143	0.274	0.192	0.208	NS
		M. lorentzi Abundance	20	0.109	0.323	-0.075	0.376	NS
		M. lorentzi Biomass	20	0.062	0.398	-0.072	0.381	NS

All Prawn Species

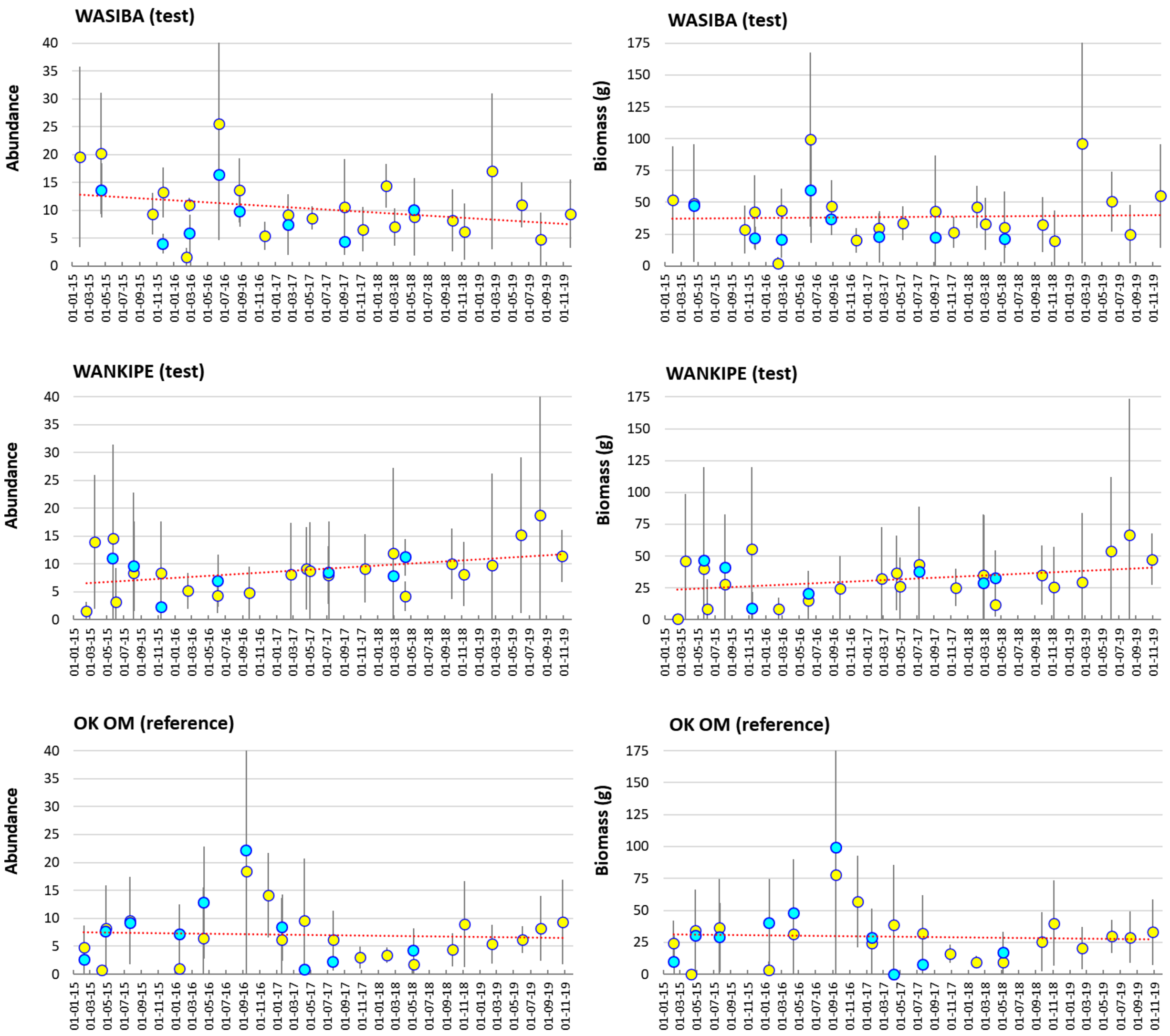


Figure 8-3 Time series plots of average (± 95% CIs) abundance and biomass (g) for combined prawn species from replicate electro-seining catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2019. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) were used for impact assessment.

M. handschini

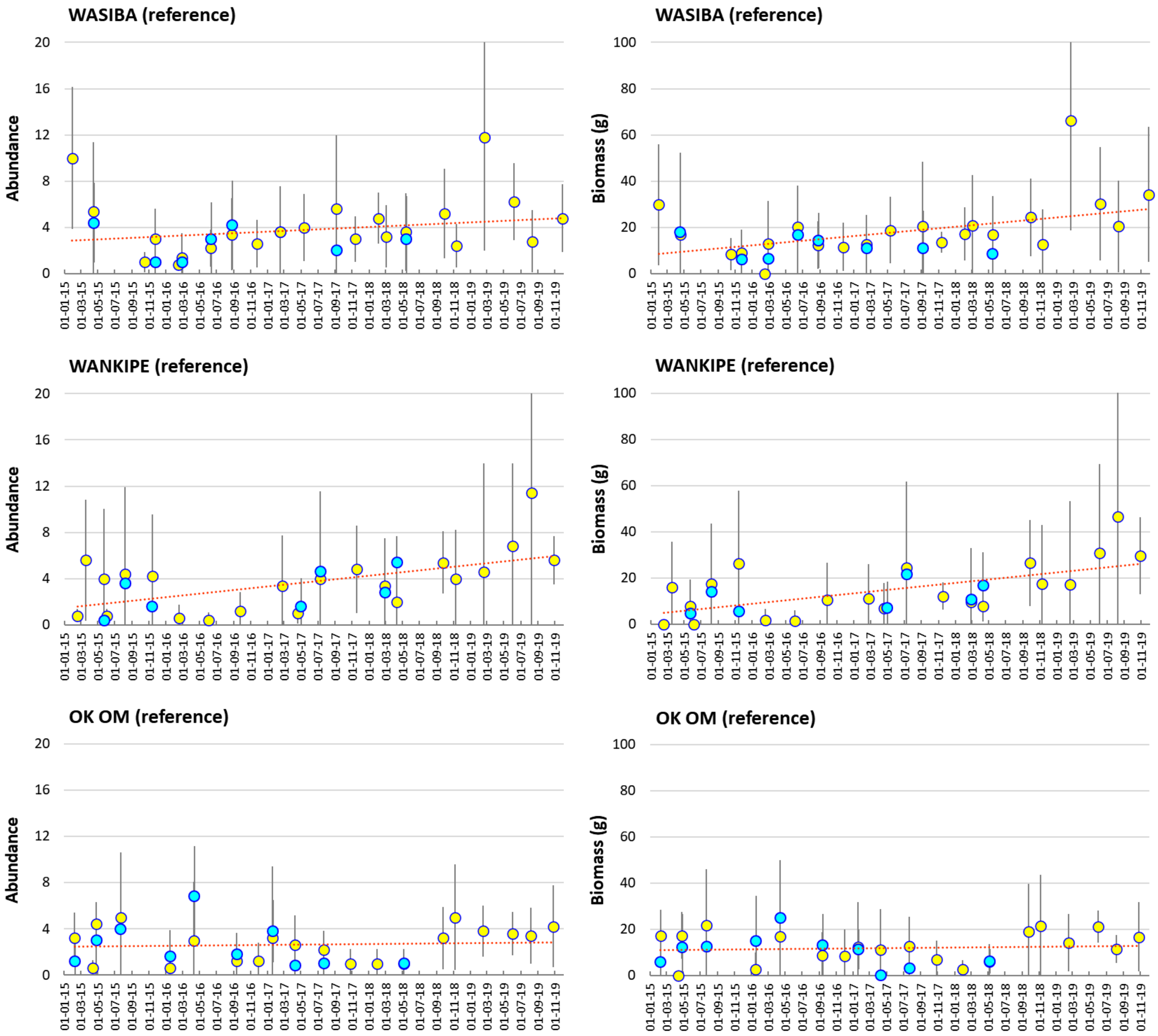


Figure 8-4 Time series plots of average (± 95% CIs) abundance and biomass (g) for *Macrobrachium handschini* in replicate electro-seining catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2019. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) were used for impact assessment.

M. lorentzi

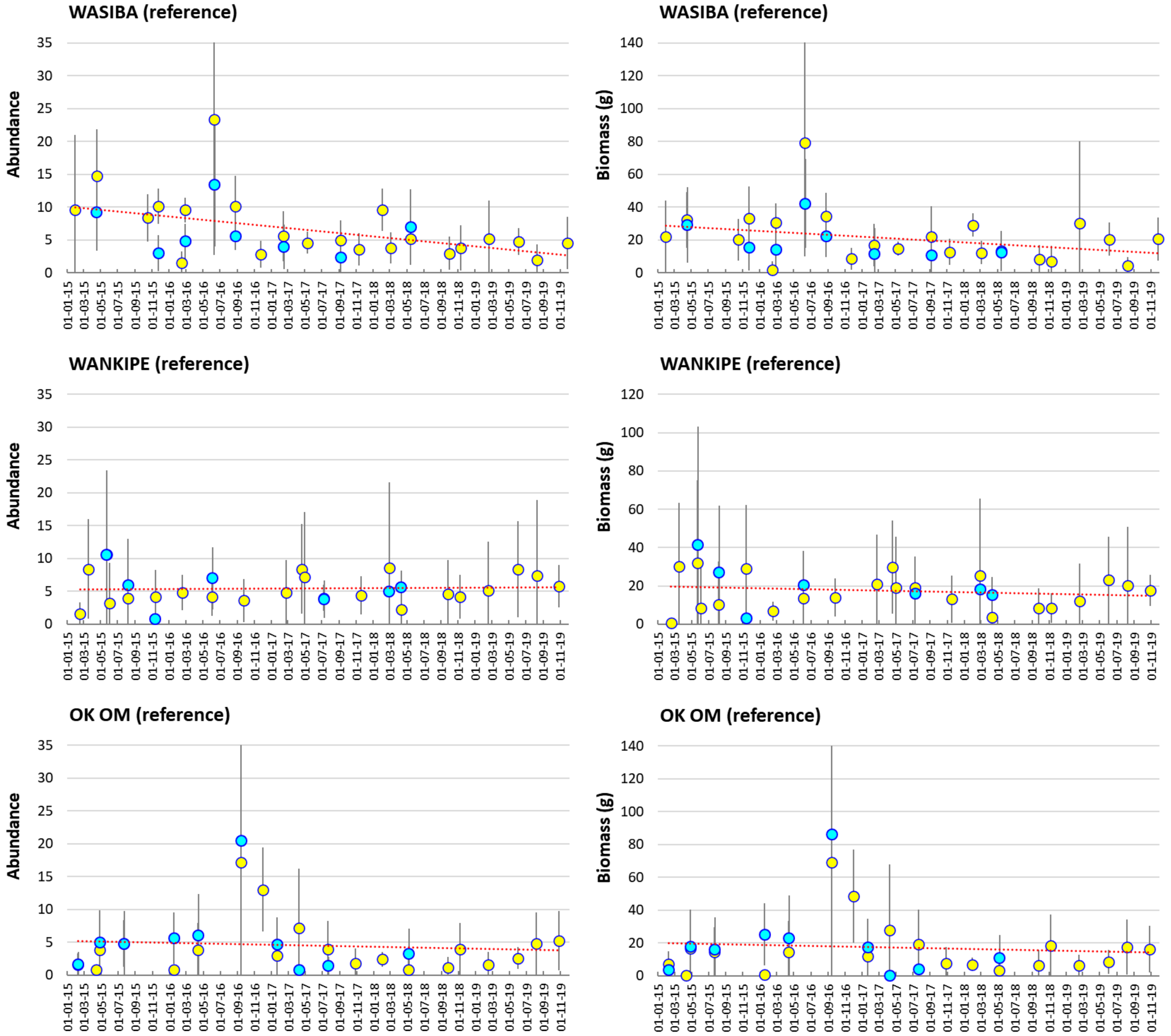


Figure 8-5 Time series plots of average (± 95% CIs) abundance and biomass (g) for *Macrobrachium lorentzi* in replicate electro-seining catch at test sites Wasiba and Wankipe, and reference site Ok Om, for 2015 - 2019. Linear trend lines are shown in red. Data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) were 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 2019 test site means for fish impact indicators in the lower river against their respective TVs are provided in Table 8-5 and include the t-statistic and significance value (p) for each test.

Results for lower river test site Bebelubi showed that the 2019 test site means for all indicators were not significantly different to, or significantly less than the respective TVs, indicating no impact to fish at Bebelubi during 2019.

Results for lower river test site SG4 showed the 2019 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 SG4 during 2019. Abundance was significantly less than the TV based on the average of Tomu baseline data (i.e. 1999-2004), but was not significantly different to, or significantly less than the other TVs for SG4. On a weight of evidence approach, it was concluded there was no impact to fish abundance at SG4.

The mean biomass at SG4 was significantly less than all three TVs. However, further analysis of the trends for each indicator showed statistically significant weak negative (i.e. decreasing) trends in species richness, abundance and biomass at test site SG4, but also in biomass at test site Bebelubi, and reference sites Baia and 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 both reference sites, as well as test sites, and in the absence of risk caused by water quality, sediment quality and tissue metal, indicates that the low biomass recorded at SG4 in 2019 is not 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 8-5 Results from one-sample t-tests testing for significant ($p < 0.05$) differences between average values for Bebelubi and SG4 for 2019, 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	2019 Test Site Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
Bebelubi	Total Fish Richness	6.0	Baia Reference Mean of previous 24 months	4.0	3	2.82	0.033	Signif > TV.
	Total Fish Abundance	14.5		10.5	3	1.57	0.106	NS.
	Total Fish Biomass (kg)	7.2		6.2	3	0.66	0.278	NS.
	Total Fish Richness	6.0	Baia Baseline 80th%ile	3.0	3	4.24	0.011	Signif > TV.
	Total Fish Abundance	14.5		15.0	3	-0.20	0.428	NS.
	Total Fish Biomass (kg)	7.2		8.4	3	-0.78	0.247	NS.

Test Site	Indicator Parameter	2019 Test Site Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
SG4	Total Fish Richness	5.0	Tomu Reference Mean of previous 24 months	5.0	3	0	0.50	NS.
	Total Fish Abundance	15.8		17.1	3	-0.45	0.342	NS.
	Total Fish Biomass (kg)	7.2		12.8	3	-3.69	0.017	Signif. < TV.
	Total Fish Richness	5.0	Tomu Baseline Mean	5.2	3	-0.24	0.411	NS.
	Total Fish Abundance	15.8		24.8	3	-3.01	0.029	Signif. < TV.
	Total Fish Biomass (kg)	7.2	Tomu Baseline 20%ile	13.5	3	-4.13	0.013	Signif. < TV.
	Total Fish Richness	5.0	SG4 Baseline Mean	5.0	3	0	0.50	NS.
	Total Fish Abundance	15.8		21.8	3	-2.01	0.069	NS.
	Total Fish Biomass (kg)	7.2		15.4	3	-5.38	0.006	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 Table 8-6, 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 species richness, abundance and biomass at test site SG4, and in biomass at test site Bebelubi, and reference sites Baia and Tomu.

The fact that declines in biomass were recorded at both reference sites, 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 consumptions (WRM 2018) shows 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). 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 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	46	0.142	0.173	0.067	0.331	NS
		Total Fish Abundance	46	-0.217	0.073	-0.319	0.206	NS
		Total Fish Biomass (kg)	46	-0.225	0.066	-0.353	0.020	Signif. -ve
	SG4 1989-2019	Total Fish Richness	94	-0.233	0.012	-0.211	0.021	Signif. -ve
		Total Fish Abundance	94	-0.195	0.030	-0.255	0.015	Signif. -ve
		Total Fish Biomass (kg)	94	-0.381	<0.001	-0.334	0.001	Signif. -ve
Ref	Baia 2006-2019	Total Fish Richness	43	-0.020	0.450	0.039	0.996	NS
		Total Fish Abundance	43	-0.122	0.219	-0.195	0.169	NS
		Total Fish Biomass (kg)	43	-0.249	0.053	-0.222	0.001	Signif. -ve
	Tomu 1996-2019	Total Fish Richness	86	-0.113	0.149	-0.097	0.187	NS
		Total Fish Abundance	46	-0.075	0.246	-0.178	0.051	NS
		Total Fish Biomass (kg)	46	-0.201	0.031	-0.314	0.002	Signif. -ve

All Fish Species

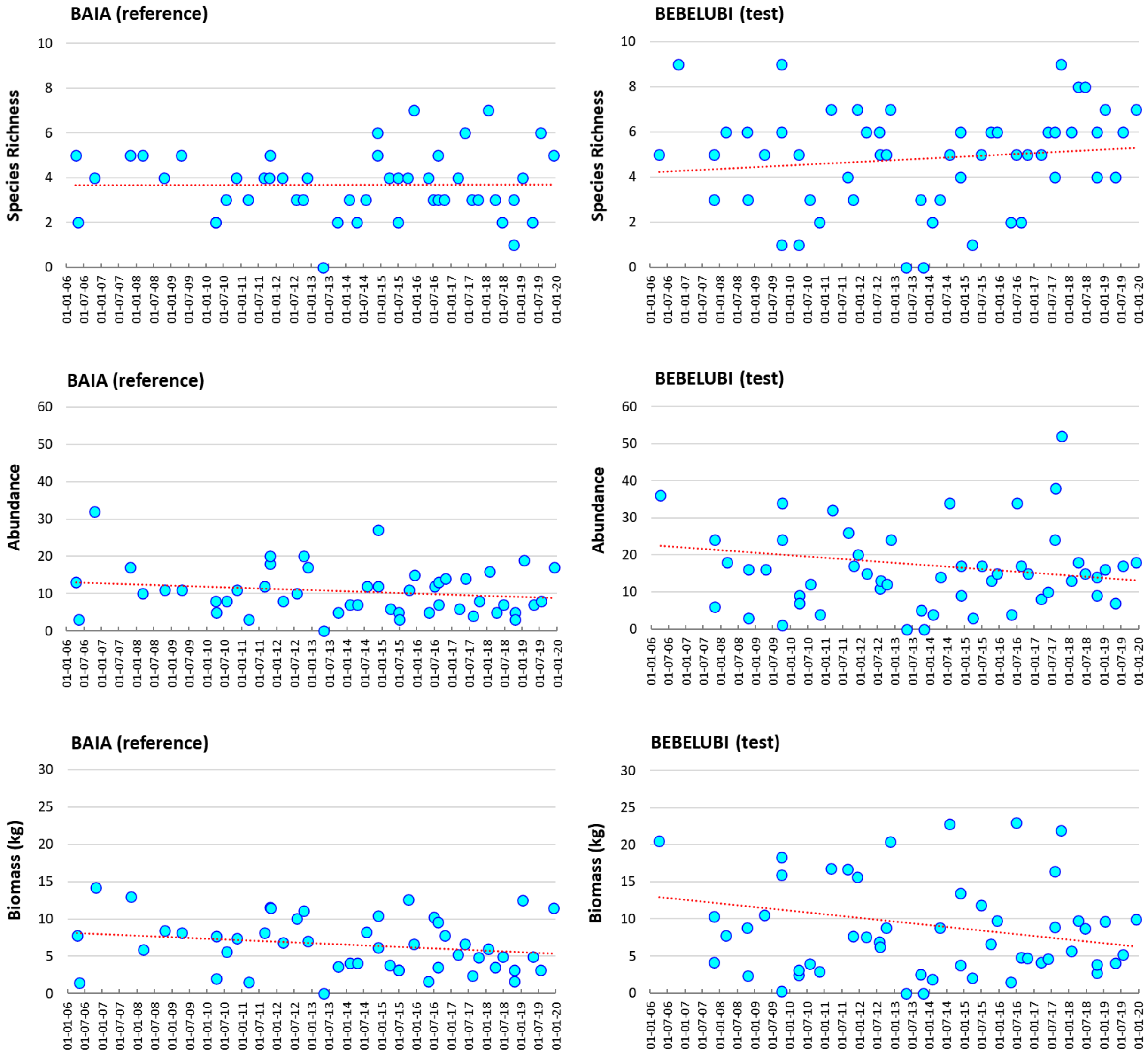


Figure 8-6 Time series plots of species richness, abundance and biomass (kg) from replicate net set #1 gill net catch at paired monitoring sites Bebelubi and Baia, 2006 - 2019. Linear trend lines are shown in red. Data from consecutive days sampling are included in the plots, but only data from the first day sampling were used for impact assessment.

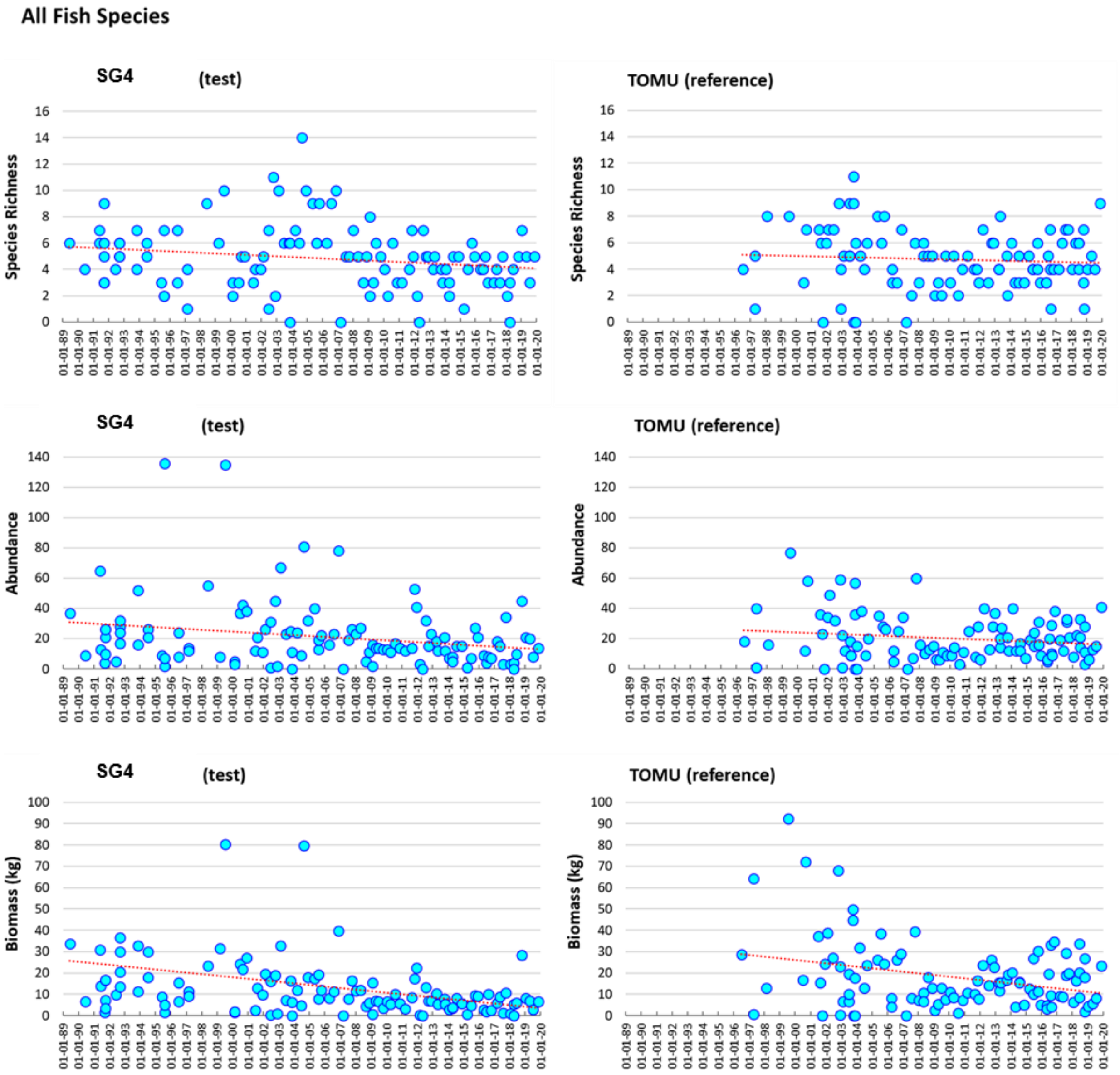


Figure 8-7 Time series plots of species richness, abundance and biomass (kg) from replicate net set #1 gill net catch at paired monitoring sites SG4 and Tomu, 1989 - 2019. Linear trend lines for average values shown in red. Data from consecutive days sampling are included in the plots, but only data 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 2019 test site means for fish impact indicators in Lake Murray against their respective TVs are provided in Table 8-5 and include the t-statistic and significance value (p) for each test.

Results for mid-lake test site Pangoa showed that the 2019 test site means for all indicators were not significantly different to, or significantly less than the respective TVs, indicating no impact to fish at Pangoa during 2019.

Results for lower lake test site Miwa showed the 2019 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 2019. Abundance and biomass were 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.

Table 8-7 Results from one-sample t-tests testing for significant ($p < 0.05$) differences between average values for Miwa and Pangoa for 2019 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	2019 Test Site Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
Miwa	Total Fish Richness	5.8	Maka Reference Mean of previous 24 months	4.8	5	0.95	0.192	NS.
	Total Fish Abundance	12.2		9.9	5	0.71	0.255	NS.
	Total Fish Biomass (kg)	18.0		17.5	5	0.09	0.464	NS.
	Total Fish Richness	5.8	Maka Baseline 20%ile	1.9	5	3.55	0.008	Signif > TV.
	Total Fish Abundance	12.2		4.8	5	2.29	0.035	Signif > TV.
	Total Fish Biomass (kg)	18.0		19.7	5	-0.33	0.379	NS.
	Total Fish Richness	5.8	Miwa Baseline Mean	3.8	5	1.84	0.063	NS.
	Total Fish Abundance	12.2		19.4	5	-2.25	0.037	Signif. < TV.
	Total Fish Biomass (kg)	18.0		66.7	5	-9.36	<0.001	Signif. < TV.

Test Site	Indicator Parameter	2019 Test Site Mean	TV Source	TV	t-Test			Level of Impact
					df	t-stat	p	
Pangoa	Total Fish Richness	3.5	Maka Reference Mean of previous 24 months	4.8	5	-1.18	0.147	NS.
	Total Fish Abundance	5.7		9.9	5	-1.74	0.072	NS.
	Total Fish Biomass (kg)	13.5		17.5	5	-5.12	0.315	NS.
	Total Fish Richness	3.5	Maka Baseline 20th%ile	1.9	5	1.47	0.100	NS.
	Total Fish Abundance	5.7		4.8	5	0.36	0.368	NS.
	Total Fish Biomass (kg)	13.5		19.7	5	-0.78	0.234	NS.

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 8-8, 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 abundance and 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 and tissue metals, the results suggests that the cause is not mine-related.

Table 8-8 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 1989-2019	Total Fish Richness	46	0.092	0.272	0.078	0.302	NS
		Total Fish Abundance	46	-0.007	0.481	-0.124	0.205	NS
		Total Fish Biomass (kg)	46	-0.105	0.243	-0.152	0.156	NS
	Pangoa 1992-2019	Total Fish Richness	38	-0.044	0.398	-0.115	0.246	NS
		Total Fish Abundance	38	-0.148	0.187	-0.058	0.364	NS
		Total Fish Biomass (kg)	38	-0.302	0.033	-0.164	0.162	Signif. -ve
Ref	Maka 1993-2019	Total Fish Richness	31	-0.217	0.120	-0.180	0.166	NS
		Total Fish Abundance	31	-0.294	0.054	-0.312	0.044	Signif. -ve
		Total Fish Biomass (kg)	31	-0.401	0.013	-0.378	0.018	Signif. -ve

All Fish Species

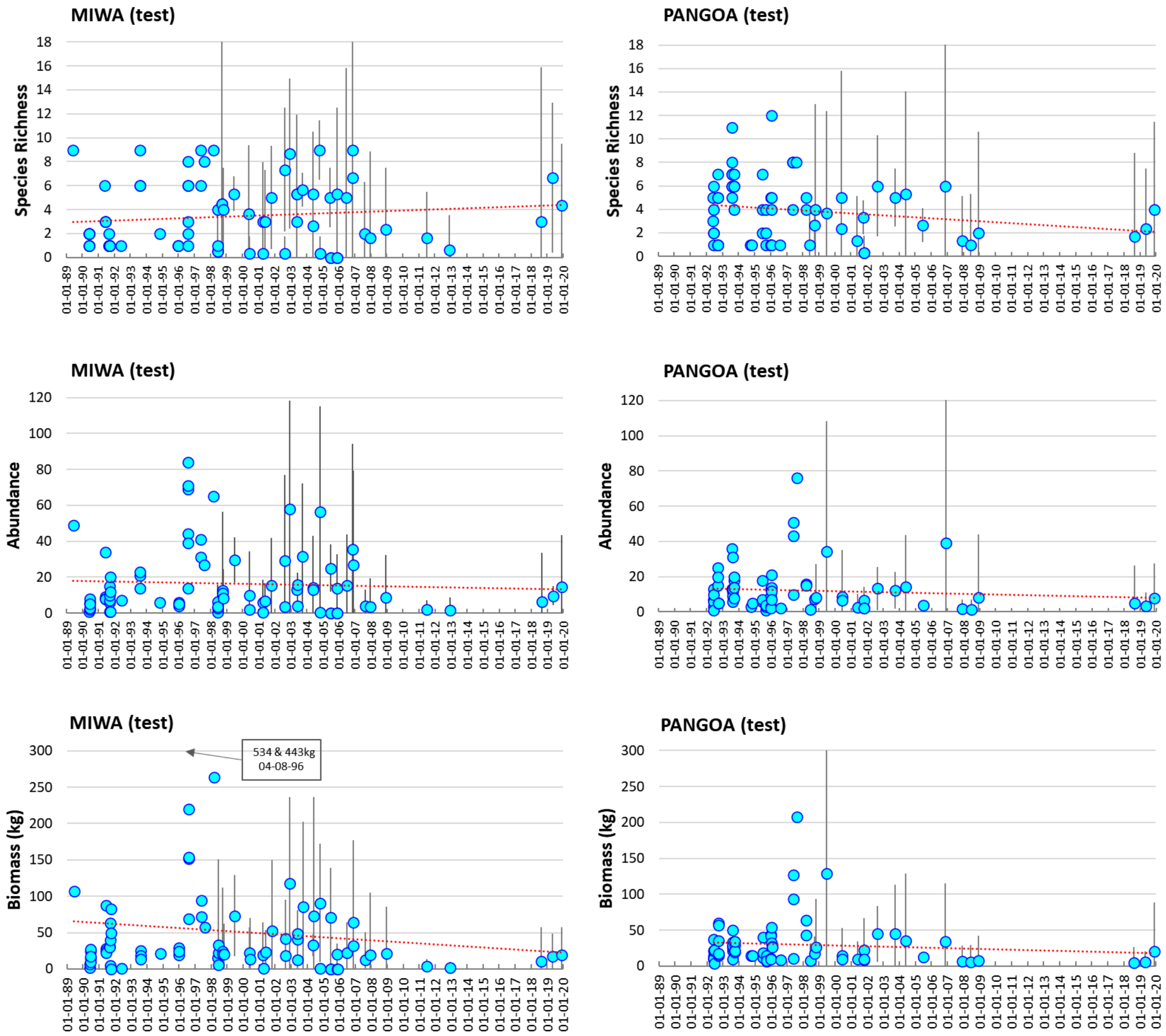


Figure 8-8 Time series plots of average (±95%CIs) species richness, abundance and biomass (kg) from replicate gill net catch at Lake Murray test sites Miwa and Pangoa, 1989 - 2019. Linear trend lines are shown in red. Data from consecutive days sampling are included in the plots, but only data from the first day sampling were used for impact assessment.

All Fish Species

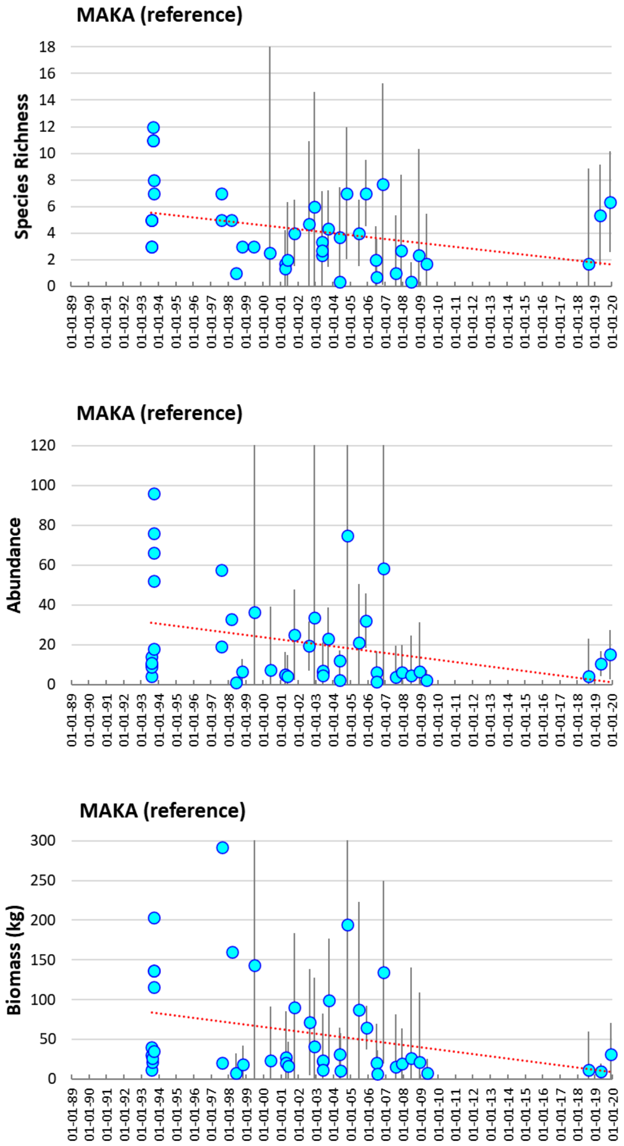


Figure 8-9 Time series plots of average (±95%CIs) species richness, abundance and biomass (kg) from replicate gill net catch at Lake Murray reference site Maka, 1989 - 2019. Linear trend lines are shown in red. Data from consecutive days sampling are included in the plots, but only data from the first day sampling were used for impact assessment.

9 CONCLUSIONS AND OVERALL ASSESSMENT

PJV is a large-scale open cut and underground gold mine that has been operating since 1990. The environmental aspects of the operation are managed through the implementation of the PJV 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 PJV environmental monitoring program provides data and information upon which to measure the ability of the EMS to achieve its objectives.

The monitoring program has continually evolved, benefiting from improvements to scientific knowledge, sampling and data analysis techniques and environmental management practices. The 2019 Annual Environment Report continues this tradition by incorporating historical and newly acquired data, information and knowledge within the AER framework.

Since 1995 the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's preeminent scientific organisation, have provided independent oversight of the PJV environmental monitoring program. CSIRO's role includes undertaking review of PJV's AER, routine quality assurance audits of the PJV 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 PJV's results. The last audit was completed in 2019 and found that CSIRO and PJV results are consistent, confirming the high technical standard and accuracy of PJV's environmental monitoring program.

Consistent with the EMS, the purpose of the AER is to assess compliance, risk, impact and performance of the operation. 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 and the quality and quantity of inputs from the site to the receiving environment in 2019 were consistent with recent years. Natural environmental conditions in 2019 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 are relatively consistent from year to year, particularly in recent history, 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 the PJV commencing operations. 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 PJV 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 the PJV commencing operations, 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 2019 PJV AER assessment was performed by assessing compliance against the conditions of the operation's 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 2019 assessment applies to sites downstream of SG1 on the Porgera River, monitoring was not conducted at SG1 during 2019 due to security concerns, therefore the assessment could not be performed at this location.

Moderate rainfall resulted in consistent water supply from Waile Creek Dam, Aipulungu Creek, FTO7 and Kogai Creek to support mine production throughout the year. Water extraction for the mine supply is considered to present low environmental risk because environmental flows were maintained in Waile Creek, Aipulungu Creek, FT07 and Kogai Creeks downstream of the extraction points.

For the purposes of this AER, 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.

In 2019, the site achieved full (100%) compliance with the conditions of the environmental permits issued by the PNG Government.

There was low risk posed to human health by the operation's activities. However, it should be noted people who illegally accessed the tailings stream within the Porgera Special Mining Lease boundary were exposed to concentrations of dissolved cadmium, nickel and zinc which exceed the ANZG (2018) guideline for recreational water quality.

The environmental impact assessment showed that in 2019 there was moderate mine-related environmental impact within the Porgera and Lagaip Rivers between the mine and Wasiba, located on the Lagaip River 96 km downstream of the mine. Environmental impact was detected in the form of elevated EC and dissolved copper concentrations in water, elevated WAE concentrations of lead and zinc in benthic sediment, elevated cadmium, copper and lead concentrations in prawn abdomen at Wasiba, and a decline in the abundance and biomass of the mountain tandan fish (*N.equinus*) at Wasiba, compared to the reference site Ok Om. There was no mine-related environmental impact downstream of Wasiba, within the upper river from Wasiba to SG3 and throughout the lower river, ORWBs and Lake Murray regions. A summary of compliance, human health risk and environmental impact at each test site in 2019 is presented in Table 9-1

It should be noted that the concentrations of metals in fish flesh and prawn abdomen were below international food standards, indicating that they are safe for human consumption.

Furthermore, the downstream extent of impact, at Wasiba located 96 km downstream from the mine, lies well within the permitted mixing zone, which extends to SG3 on the Strickland River, 164 km downstream of the mine. Additionally, 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.

Table 9-1 Summary of Compliance, Human Health Risk and Environmental Impact at test sites in 2019

Region	Site	Distance From the Mine (km)	Overall Condition			Comments
			Compliance	Human Health Risk	Environmental Impact	
Upper River	SG2	42	Compliant	Low Risk	Moderate Env Impact	Within the permitted mixing and compensation zone.
	Wasiba	96	Compliant	Low Risk	Moderate Env Impact	
	Wankipe	116	Compliant	Low Risk	No Impact	
	SG3	164	Compliant	Low Risk	No Impact	End of the permitted mixing and compensation zone
Lower River	Bebelubi	310	Compliant	Low Risk	No Impact	
	SG4	360	Compliant	Low Risk	No Impact	
	SG5	550	Compliant	Low Risk	No Impact	
ORWBs	Kukufionga	510	Compliant	Low Risk	No Impact	
	Zongamange	560	Compliant	Low Risk	No Impact	
	Avu	575	Compliant	Low Risk	No Impact	
	Levame	600	Compliant	Low Risk	No Impact	
Lake Murray	SG6	570	Compliant	Low Risk	No Impact	
	Miwa	590	Compliant	Low Risk	No Impact	
	Pangoa	600	Compliant	Low Risk	No Impact	

10 RECOMMENDATIONS

The recommendations presented in this section are intended to improve the assessment methodology, communication of the findings to the many stakeholders and to improve the environmental performance of the operation and reduce environmental risk and impact.

Note that a number of the recommendations from the 2018 AER are still in progress and appear in the list below in addition to new recommendations raised from this year's AER.

Assessment Methodology and Communication of Findings

1. Continue to investigate options for increasing 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 AER.
3. Develop a PJV 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. Undertake a study 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 PJV. It may be appropriate to adopt the CSIRO procedure for routine analysis.

Reduce Environmental Risk and Impact and Improve Performance

7. Continue to investigate options for reducing the concentrations of bioavailable metals and mass loads of metals in mine discharges.
8. 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 25 staff 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 in 2019 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 blank per sample batch	±44% of primary sample
NMI lab control sample	Test influence of sample preparation and analysis on recovery.	1 blank per sample batch	75% – 120% recovery
NMI matrix spike	Test influence of sample preparation and analysis on recovery.	1 blank per sample batch	75% – 120% recovery

The results of QA & QC samples from water quality sampling at SG3 in 2019 as shown in Table A-2 indicated good performance for all of QA & QC samples across all parameters.

Table A-2 2019 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	67	100	100	100	83	92	100	100	NA	92	100
CRM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	100	NA
Field Duplicate	100	88	100	92	79	100	88	88	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 in 2019 shown in Table A-3 indicated good performance of all samples for all parameters.

Table A-3 2019 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	96	97	96	92	97	96	93	96	100	93
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 2019 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 and establish corrective and preventative actions. Actions are ongoing to address these results.

Table A-4 Proficiency testing results 2019

Date	Analyte	Units	Lab result	MU	Median	NORM IQR	CV (%)	n	z-score
Mar-19	Alkalinity	mg/L	94	NA	94	5.6	6	40	0
	Chloride	mg/L	55	NA	52.5	2.8	5.4	47	0.89
	Conductivity	µS/cm	459	NA	444	8.9	2.0	47	1.69
	Sulfate	mg/L	33	NA	32.1	1.8	5.5	42	0.51
	Total Solids	mg/L	330	NA	373.5	26.1	7	32	-1.66
Mar-19	WAD Cyanide	mg/L	0.08	NA	0.211	0.0	8.8	20	-7.07
	WAD Cyanide	mg/L	0.963	NA	1.55	0.2	9.8	20	-3.88
May-19	Sulfate	mg/L	7.5	NA	10.25	1.4	13.7	38	-3.44
	Sulfate	mg/L	18	NA	NA	NA	NA	39	NA
	Conductivity	µS/cm	146	NA	NA	NA	NA	49	NA
	Conductivity	µS/cm	173	NA	NA	NA	NA	49	NA
	pH - potable	pH units	7.19	NA	7.44	0.2	2.2	54	-1.53
	pH - potable	pH units	7.08	NA	7.415	0.2	2.2	54	-2.05
	pH - standard	pH units	7.75	NA	7.71	0.03	0.4	55	1.35
	Turbidity standard	NTU	2.13	NA	6.48	0.5	8.2	33	-8.15
	Colour standard	Pt/Co	15	NA	12.2	1.0	8.4	24	2.74
Jun-19	Oil and Grease	mg/L	48.6	NA	63.3	29.8	47.1	34	-1.25
	Oil and Grease	mg/L	30	NA	41.55	14.3	34.4	38	-1.49
Jul-19	Total Solids	mg/L	455	NA	433	20.8	4.8	21	1.06
	Total Solids	mg/L	605	NA	592	20.8	3.5	21	0.63
	Total Suspended Solids	mg/L	8.0	NA	31.95	7.2	22.5	30	-3.33

Date	Analyte	Units	Lab result	MU	Median	NORM IQR	CV (%)	n	z-score
	Total Suspended Solids	mg/L	13	NA	66	12.6	19.1	29	-4.21
Sep-19	Alkalinity	mg/L	100	NA	108	7.0	6.5	25	-1.14
	Chloride	mg/L	56.6	NA	55.3	1.9	3.4	26	0.69
	Conductivity	mg/L	383	NA	413	9.6	2.3	30	-3.11
	Sulphate	mg/L	14	NA	13.9	0.8	5.9	25	0.12
	Totals Solids	mg/L	320	NA	357	14.5	4.0	15	-2.56
Nov-19	Sulphate - Potable	mg/L	17	NA	13.35	1.4	10.1	22	2.7
	Sulphate - Potable	mg/L	119	NA	147	5.7	1.49	23	-4.91
	Conductivity - Potable	µS/cm	206	NA	207	4.1	2.0	31	-0.25
	Conductivity - Potable	µS/cm	1591	NA	1591	20.8	1.3	31	0
	pH - Potable	pH units	7.83	NA	7.74	0.3	3.8	37	0.3
	pH - Potable	pH units	6.97	NA	7.08	0.0	0.5	37	-2.97
	pH - Standard	pH units	7.78	NA	7.74	0.04	0.6	37	0.9
	Colour - Standard	Pt/Co	13	NA	12.6	2.0	16.2	12	0.2
Dec-19	Oil and Grease	mg/L	40.3	NA	57.1	10.6	31.8	21	-1.58
	Oil and Grease	mg/L	22.9	NA	42.4	7.9	36.7	21	-2.47
🟩	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.	1 blank per sample batch	≤LOR for each analyte

QA&QC Sample	Purpose	Sample rate	Acceptance Criteria
	Test for accuracy of laboratory analytical method.		
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 2019 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 selenium in the field duplicate samples and zinc in the field reference sample. 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 2019 Tissue metal QA & QC sample results

	% Within Acceptable Criteria									
	n	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**
Field Duplicate	14	93	100	90	100	90	93	100	86	100
Field Reference Sample	14	100	100	93	100	100	100	100	100	86
NMI Duplicate	10	100	100	100	100	100	100	100	100	100
NMI Lab Control Sample	10	100	100	100	100	100	100	100	100	100
NMI Matrix Spike	10	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 good 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 2020.

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.

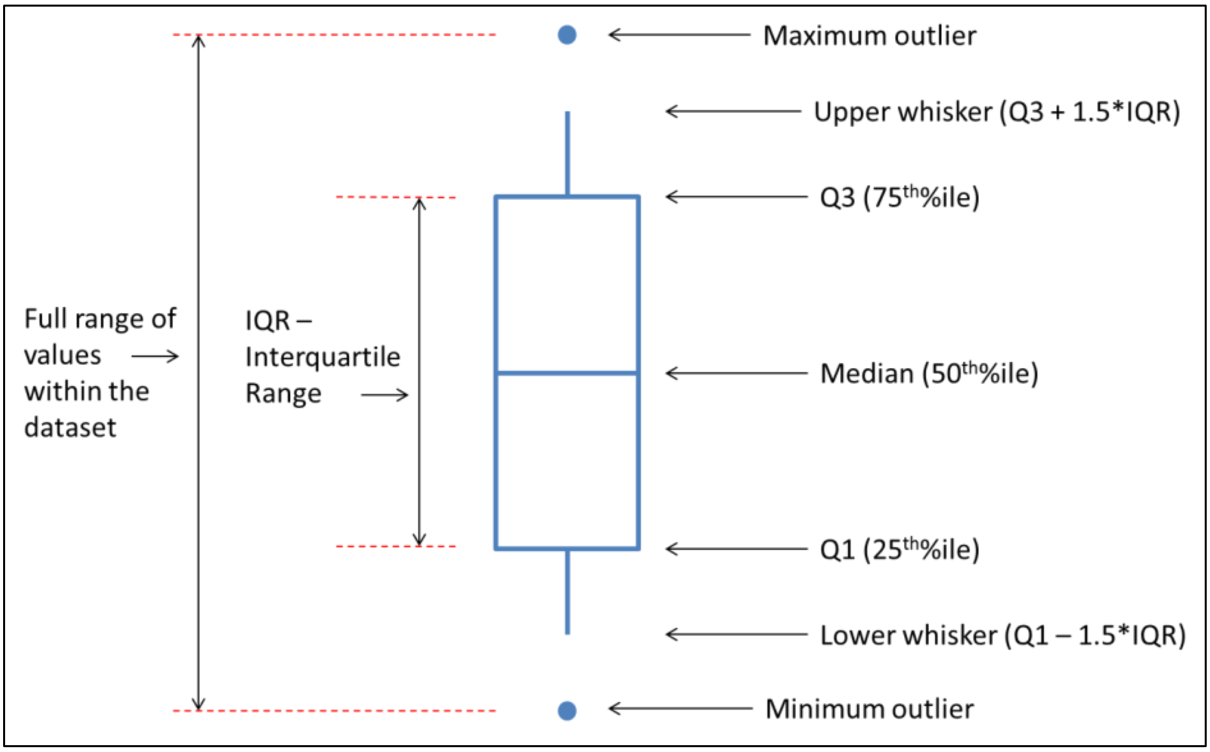

Figure B-1 Box Plot Explained

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.

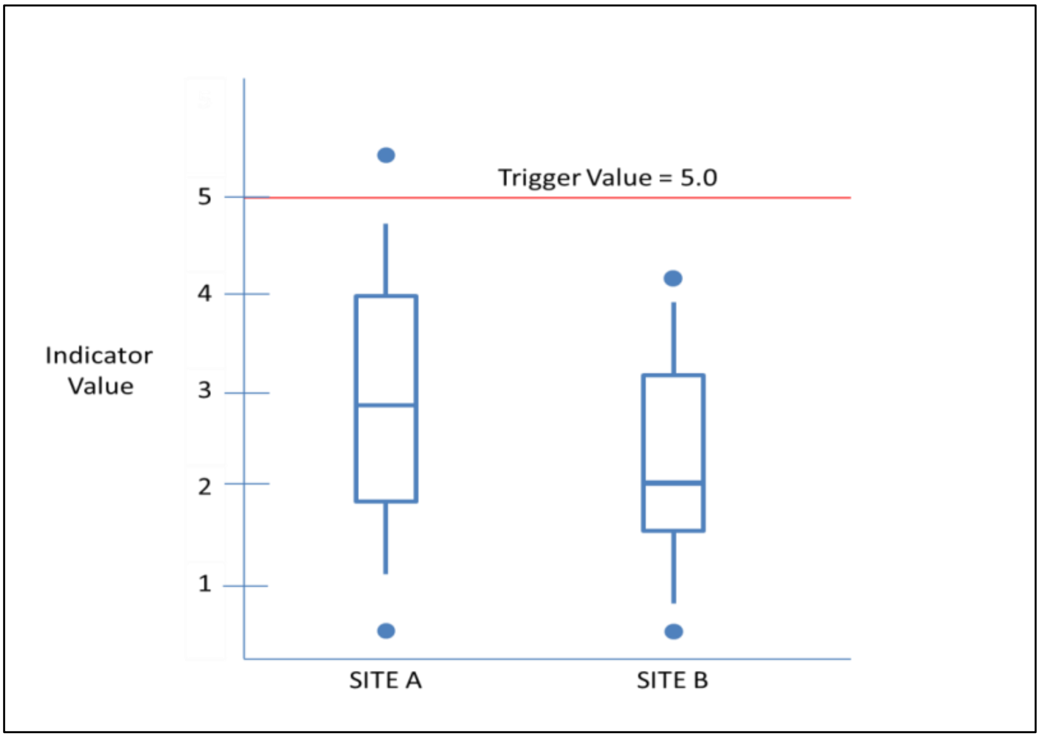

Figure B-1 Comparing box plots between sites and against trigger values

APPENDIX C. BOX PLOTS AND TRENDS OF MINE AREA RUNOFF WATER AND SEDIMENT QUALITY 2010–2019

Table C-1 28 Level 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
28 Level	N	N(Test)	Median	Result	Go to			
pH	12	12	7.6	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	0.001 / 0.001	LOW
EC	12	12	717	TSM ≥ TV	Step 2	228	0.999	POTENTIAL
TSS	12	12	67	TSM < TV	Step 1	2,837	0.019	LOW
Ag-D	12	12	0.01	TSM < TV	Step 1	0.05	0.001	LOW
As-D	12	12	3.1	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.074	TSM < TV	Step 1	0.34	0.001	LOW
Cr-D	12	12	0.48	TSM < TV	Step 1	1.0	0.063	POTENTIAL
Cu-D	12	12	0.54	TSM < TV	Step 1	1.4	0.003	LOW
Fe-D	12	12	33	TSM < TV	Step 1	75	0.019	LOW
Hg-D	12	12	0.05	TSM < TV	Step 1	0.60	0.001	LOW
Ni-D	12	12	3.1	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.46	TSM < TV	Step 1	7.3	0.001	LOW
Se-D	12	12	0.20	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	27	TSM ≥ TV	Step 1	20	0.019	POTENTIAL

Table C-2 Anjolek SDA 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Anjolek	N	N(Test)	Median	Result	Go to			
pH	0	0	NR	NR	NR	NR	NR	NR
EC	0	0	NR	NR	NR	NR	NR	NR
TSS	0	0	NR	NR	NR	NR	NR	NR
Ag-D	0	0	NR	NR	NR	NR	NR	NR
As-D	0	0	NR	NR	NR	NR	NR	NR
Cd-D	0	0	NR	NR	NR	NR	NR	NR
Cr-D	0	0	NR	NR	NR	NR	NR	NR
Cu-D	0	0	NR	NR	NR	NR	NR	NR
Fe-D	0	0	NR	NR	NR	NR	NR	NR
Hg-D	0	0	NR	NR	NR	NR	NR	NR
Ni-D	0	0	NR	NR	NR	NR	NR	NR
Pb-D	0	0	NR	NR	NR	NR	NR	NR
Se-D	0	0	NR	NR	NR	NR	NR	NR
Zn-D	0	0	NR	NR	NR	NR	NR	NR

NR – Not recorded – sampling not performed at this site during 2019 due to security issues preventing safe access.

Table C-3 Kaiya at Yuyan Bridge 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Kaiya	N	N(Test)	Median	Result	Go to			
pH	0	0	NR	NR	NR	NR	NR	NR
EC	0	0	NR	NR	NR	NR	NR	NR
TSS	0	0	NR	NR	NR	NR	NR	NR
Ag-D	0	0	NR	NR	NR	NR	NR	NR
As-D	0	0	NR	NR	NR	NR	NR	NR
Cd-D	0	0	NR	NR	NR	NR	NR	NR
Cr-D	0	0	NR	NR	NR	NR	NR	NR
Cu-D	0	0	NR	NR	NR	NR	NR	NR
Fe-D	0	0	NR	NR	NR	NR	NR	NR
Hg-D	0	0	NR	NR	NR	NR	NR	NR
Ni-D	0	0	NR	NR	NR	NR	NR	NR
Pb-D	0	0	NR	NR	NR	NR	NR	NR
Se-D	0	0	NR	NR	NR	NR	NR	NR
Zn-D	0	0	NR	NR	NR	NR	NR	NR

NR – Not recorded – sampling not performed at this site during 2018 due to security issues preventing safe access.

Table C-4 Kaiya River downstream Anjolek erodible dump 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Kaiya	N	N(Test)	Median	Result	Go to			
pH	9	9	7.8	Lower TV<TSM<Upper	Step 1 / 2	6.0-8.2	0.005 / 0.005	LOW
EC	9	9	494	TSM ≥TV	Step 2	228	0.997	POTENTIAL
TSS	9	9	2800	TSM < TV	Step 1	2,837	0.682	POTENTIAL
Ag-D	9	9	0.01	TSM < TV	Step 1	0.05	0.009	LOW
As-D	9	9	1.3	TSM < TV	Step 1	24	0.005	LOW
Cd-D	9	9	0.05	TSM < TV	Step 1	0.34	0.005	LOW
Cr-D	9	9	0.31	TSM < TV	Step 1	1.0	0.062	POTENTIAL
Cu-D	9	9	0.90	TSM < TV	Step 1	1.4	0.005	LOW
Fe-D	9	9	12	TSM < TV	Step 1	75	0.062	POTENTIAL
Hg-D	9	9	0.05	TSM < TV	Step 1	0.60	0.005	LOW
Ni-D	9	9	0.98	TSM < TV	Step 1	21	0.005	LOW
Pb-D	9	9	0.26	TSM < TV	Step 1	7.3	0.006	LOW
Se-D	9	9	0.37	TSM < TV	Step 1	11	0.005	LOW
Zn-D	9	9	4.8	TSM < TV	Step 1	20	0.005	LOW

Table C-5 Kogai Culvert 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Kogai	N	N(Test)	Median	Result	Go to			
pH	13	13	7.8	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	0.003 / 0.001	LOW
EC	13	13	815	TSM ≥TV	Step 2	228	0.999	POTENTIAL
TSS	13	13	620	TSM < TV	Step 1	2,837	0.001	LOW
Ag-D	13	13	0.01	TSM < TV	Step 1	0.05	0.013	LOW
As-D	13	13	1.6	TSM < TV	Step 1	24	0.001	LOW
Cd-D	13	13	0.15	TSM < TV	Step 1	0.34	0.104	POTENTIAL
Cr-D	13	12	0.28	TSM < TV	Step 1	1.0	0.019	LOW
Cu-D	13	13	1.1	TSM < TV	Step 1	1.4	0.232	POTENTIAL
Fe-D	13	13	12	TSM < TV	Step 1	75	0.001	LOW
Hg-D	13	13	0.06	TSM < TV	Step 1	0.60	0.001	LOW
Ni-D	13	13	1.3	TSM < TV	Step 1	21	0.001	LOW
Pb-D	13	13	1.1	TSM < TV	Step 1	7.3	0.001	LOW
Se-D	13	13	0.20	TSM < TV	Step 1	11	0.001	LOW
Zn-D	13	13	16	TSM < TV	Step 1	20	0.300	POTENTIAL

Table C-6 Kogai Stable dump toe area 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Kogai	N	N(Test)	Median	Result	Go to			
pH	13	13	7.7	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	0.001 / 0.001	LOW
EC	13	13	1747	TSM ≥TV	Step 2	228	0.999	POTENTIAL
TSS	13	13	99	TSM < TV	Step 1	2,837	0.001	LOW
Ag-D	13	13	0.01	TSM < TV	Step 1	0.05	0.001	LOW
As-D	13	13	0.89	TSM < TV	Step 1	24	0.001	LOW
Cd-D	13	13	0.91	TSM ≥TV	Step 2	0.34	0.997	POTENTIAL
Cr-D	13	13	0.32	TSM < TV	Step 1	1.0	0.081	POTENTIAL
Cu-D	13	13	0.62	TSM < TV	Step 1	1.4	0.001	LOW
Fe-D	13	13	10	TSM < TV	Step 1	75	0.001	LOW
Hg-D	13	13	0.05	TSM < TV	Step 1	0.60	0.001	LOW
Ni-D	13	13	2.2	TSM < TV	Step 1	21	0.001	LOW
Pb-D	13	13	1.3	TSM < TV	Step 1	7.3	0.001	LOW
Se-D	13	13	0.21	TSM < TV	Step 1	11	0.001	LOW
Zn-D	13	13	170	TSM ≥TV	Step 2	20	0.999	POTENTIAL

Table C-7 Lime Plant discharge 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
L Plant	N	N(Test)	Median	Result	Go to			
pH	11	11	11.7	TSM ≥TV	Step 3	6.0-8.2	0.997	POTENTIAL
EC	11	11	1157	TSM ≥TV	Step 2	228	0.994	POTENTIAL
TSS	11	11	97	TSM < TV	Step 1	2,837	0.007	LOW
Ag-D	11	11	0.01	TSM < TV	Step 1	0.05	0.002	LOW
As-D	11	11	0.13	TSM < TV	Step 1	24	0.002	LOW
Cd-D	11	11	0.05	TSM < TV	Step 1	0.34	0.002	LOW
Cr-D	11	11	3.6	TSM ≥TV	Step 2	1.0	0.997	POTENTIAL
Cu-D	11	11	0.80	TSM < TV	Step 1	1.4	0.395	POTENTIAL
Fe-D	11	11	5.4	TSM < TV	Step 1	75	0.002	LOW
Hg-D	11	11	0.05	TSM < TV	Step 1	0.60	0.002	LOW
Ni-D	11	11	0.50	TSM < TV	Step 1	21	0.002	LOW
Pb-D	11	11	0.14	TSM < TV	Step 1	7.3	0.002	LOW
Se-D	11	11	0.20	TSM < TV	Step 1	11	0.002	LOW
Zn-D	11	11	1.8	TSM < TV	Step 1	20	0.002	LOW

Table C-8 Wendoko Creek D/S Anawe Nth 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Wend	N	N(Test)	Median	Result	Go to			
pH	10	10	7.8	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	0.003 / 0.003	LOW
EC	10	10	2127	TSM ≥TV	Step 2	228	0.998	POTENTIAL
TSS	10	10	10	TSM < TV	Step 1	2,837	0.003	LOW
Ag-D	10	10	0.01	TSM < TV	Step 1	0.05	0.004	LOW
As-D	10	10	0.87	TSM < TV	Step 1	24	0.003	LOW
Cd-D	10	10	1.1	TSM ≥TV	Step 2	0.34	0.998	POTENTIAL
Cr-D	10	10	0.31	TSM < TV	Step 1	1.0	0.005	LOW
Cu-D	10	10	0.45	TSM < TV	Step 1	1.4	0.003	LOW
Fe-D	10	10	6.9	TSM < TV	Step 1	75	0.003	LOW
Hg-D	10	10	0.05	TSM < TV	Step 1	0.60	0.003	LOW
Ni-D	10	10	1.6	TSM < TV	Step 1	21	0.003	LOW
Pb-D	10	10	0.13	TSM < TV	Step 1	7.3	0.003	LOW
Se-D	10	10	0.39	TSM < TV	Step 1	11	0.003	LOW
Zn-D	10	10	370	TSM ≥TV	Step 2	20	0.998	POTENTIAL

Table C-9Yakatabari Creek D/S 28 level 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Yakatabari	N	N(Test)	Median	Result	Go to			
pH	12	12	7.5	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	0.001 / 0.001	LOW
EC	12	12	635	TSM ≥TV	Step 2	228	0.999	POTENTIAL
TSS	12	12	1700	TSM < TV	Step 1	2,837	0.027	LOW
Ag-D	12	12	0.01	TSM < TV	Step 1	0.05	0.002	LOW
As-D	12	12	9.0	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.05	TSM < TV	Step 1	0.34	0.001	LOW
Cr-D	12	12	0.82	TSM < TV	Step 1	1.0	0.453	POTENTIAL
Cu-D	12	12	1.1	TSM < TV	Step 1	1.4	0.013	LOW
Fe-D	12	12	15	TSM < TV	Step 1	75	0.001	LOW
Hg-D	12	12	0.055	TSM < TV	Step 1	0.60	0.001	LOW
Ni-D	12	12	1.3	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.78	TSM < TV	Step 1	7.3	0.001	LOW
Se-D	12	12	0.20	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	4.1	TSM < TV	Step 1	20	0.001	LOW

Table C-10 Yunarilama at Portal 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Yunarilama	N	N(Test)	Median	Result	Go to			
pH	10	10	7.6	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	0.003 / 0.003	LOW
EC	10	10	1904	TSM ≥TV	Step 2	228	0.998	POTENTIAL
TSS	10	10	11500	TSM ≥TV	Step 2	2,837	0.997	POTENTIAL
Ag-D	10	10	0.013	TSM < TV	Step 1	0.05	0.051	POTENTIAL
As-D	10	10	2.2	TSM < TV	Step 1	24	0.042	LOW
Cd-D	10	10	0.056	TSM < TV	Step 1	0.34	0.003	LOW
Cr-D	10	10	0.67	TSM < TV	Step 1	1.0	0.033	LOW
Cu-D	10	10	0.40	TSM < TV	Step 1	1.4	0.004	LOW
Fe-D	10	10	13	TSM < TV	Step 1	75	0.003	LOW
Hg-D	10	10	0.055	TSM < TV	Step 1	0.60	0.003	LOW
Ni-D	10	10	2.1	TSM < TV	Step 1	21	0.003	LOW
Pb-D	10	10	0.35	TSM < TV	Step 1	7.3	0.003	LOW
Se-D	10	10	1.1	TSM < TV	Step 1	11	0.003	LOW
Zn-D	10	10	5.5	TSM < TV	Step 1	20	0.003	LOW

Table C-11 Tailings slurry 2019 median against upper river TV (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Tails W	N	N(Test)	Median	Result	Go to			
pH	48	48	7.1	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	<0.001 / <0.001	LOW
EC	48	48	3900	TSM ≥TV	Step 2	228	1.0	POTENTIAL
TSS	48	48	98300	TSM ≥TV	Step 2	2,837	1.0	POTENTIAL
Ag-D	48	48	0.01	TSM < TV	Step 1	0.05	<0.001	LOW
As-D	48	48	1.0	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	48	48	32	TSM ≥TV	Step 2	0.34	<0.001	LOW
Cr-D	48	47	0.29	TSM < TV	Step 1	1.0	0.013	LOW
Cu-D	48	48	17	TSM ≥TV	Step 2	1.4	<0.001	LOW
Fe-D	48	48	31	TSM < TV	Step 1	75	0.625	POTENTIAL
Hg-D	48	47	0.12	TSM < TV	Step 1	0.60	<0.001	LOW
Ni-D	48	48	975	TSM ≥TV	Step 2	21	1.0	POTENTIAL
Pb-D	48	48	0.10	TSM < TV	Step 1	7.3	<0.001	LOW
Se-D	48	48	1.5	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	48	48	6580	TSM ≥TV	Step 2	20	1.0	POTENTIAL

Table C-12 Tailings solids 2019 median against upper river sediment TV (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Tails S	N	N(Test)	Median	Result	Go to			
Ag-WAE	48	47	0.73	TSM < TV	Step 1	1.0	0.498	POTENTIAL
As- WAE	48	48	50	TSM > TV	Step 2	20	1.0	POTENTIAL
Cd- WAE	48	48	5.2	TSM > TV	Step 2	1.5	1.0	POTENTIAL
Cr- WAE	48	48	27	TSM < TV	Step 1	80	<0.001	LOW
Cu- WAE	48	47	89	TSM > TV	Step 2	65	1.0	POTENTIAL
Hg- WAE	48	48	0.20	TSM > TV	Step 2	0.15	1.0	POTENTIAL
Ni- WAE	48	47	35	TSM > TV	Step 2	22	1.0	POTENTIAL
Pb- WAE	48	47	105	TSM > TV	Step 2	50	1.0	POTENTIAL
Se- WAE	48	48	0.25	TSM > TV	Step 2	0.15	1.0	POTENTIAL
Zn- WAE	48	48	915	TSM > TV	Step 2	200	1.0	POTENTIAL

Table C-13 28 Level 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
28 Level	**N**	**N(Test)**	**Median**	**Result**	**Go to**			
Ag-WAE	3	2	1.0	TSM = Upper TV	Step 1	1.0	0.814	POTENTIAL*
As- WAE	3	3	20	TSM = Upper TV	Step 1	20	0.909	POTENTIAL*
Cd- WAE	3	3	2.2	TSM > Upper TV	Step 2	1.5	0.969	POTENTIAL*
Cr- WAE	3	3	9.0	TSM < Upper TV	Step 1	80	0.091	LOW*
Cu- WAE	3	3	14	TSM < Upper TV	Step 1	65	0.091	LOW*
Hg- WAE	3	3	0.01	TSM < Upper TV	Step 1	0.15	0.091	LOW*
Ni- WAE	3	3	21	TSM < Upper TV	Step 1	22	0.395	LOW*
Pb- WAE	3	3	430	TSM > Upper TV	Step 2	50	0.969	POTENTIAL*
Se- WAE	3	3	0.14	TSM < Upper TV	Step 1	0.15	0.395	LOW*
Zn- WAE	3	3	550	TSM > Upper TV	Step 2	200	0.969	POTENTIAL*

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

Table C-14 Anjolek SDA 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Anjolek	**N**	**N(Test)**	**Median**	**Result**	**Go to**			
Ag-WAE	NR	NR	NR	NR	NR	1.0	NR	NR
As- WAE	NR	NR	NR	NR	NR	20	NR	NR
Cd- WAE	NR	NR	NR	NR	NR	1.5	NR	NR
Cr- WAE	NR	NR	NR	NR	NR	80	NR	NR
Cu- WAE	NR	NR	NR	NR	NR	65	NR	NR
Hg- WAE	NR	NR	NR	NR	NR	0.15	NR	NR
Ni- WAE	NR	NR	NR	NR	NR	22	NR	NR
Pb- WAE	NR	NR	NR	NR	NR	50	NR	NR
Se- WAE	NR	NR	NR	NR	NR	0.15	NR	NR
Zn- WAE	NR	NR	NR	NR	NR	200	NR	NR

NR – Not recorded – sampling not performed at this site during 2019 due to security issues preventing safe access.

Table C-15 Kaiya at Yuyan Bridge 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Kaiya	N	N(Test)	Median	Result	Go to			
Ag-WAE	3	3	0.19	TSM < Upper TV	Step 1	1.0	0.091	LOW*
As- WAE	3	3	4.4	TSM < Upper TV	Step 1	20	0.091	LOW*
Cd- WAE	3	3	0.58	TSM < Upper TV	Step 1	1.5	0.091	LOW*
Cr- WAE	3	3	6.9	TSM < Upper TV	Step 1	80	0.091	LOW*
Cu- WAE	3	3	7.1	TSM < Upper TV	Step 1	65	0.091	LOW*
Hg- WAE	3	3	0.01	TSM < Upper TV	Step 1	0.15	0.091	LOW*
Ni- WAE	3	3	10	TSM < Upper TV	Step 1	22	0.091	LOW*
Pb- WAE	3	3	170	TSM > Upper TV	Step 2	50	0.969	POTENTIAL*
Se- WAE	3	3	0.18	TSM > Upper TV	Step 2	0.15	0.909	POTENTIAL*
Zn- WAE	3	3	130	TSM < Upper TV	Step 1	200	0.091	LOW*

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

Table C-16 Kaiya River downstream Anjolek erodible dump 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Kaiya	N	N(Test)	Median	Result	Go to			
Ag-WAE	3	3	0.15	TSM < Upper TV	Step 1	1.0	0.091	LOW*
As- WAE	3	3	4.8	TSM < Upper TV	Step 1	20	0.091	LOW*
Cd- WAE	3	3	0.76	TSM < Upper TV	Step 1	1.5	0.091	LOW*
Cr- WAE	3	3	7.1	TSM < Upper TV	Step 1	80	0.091	LOW*
Cu- WAE	3	3	6.5	TSM < Upper TV	Step 1	65	0.091	LOW*
Hg- WAE	3	3	0.01	TSM < Upper TV	Step 1	0.15	0.091	LOW*
Ni- WAE	3	3	11	TSM < Upper TV	Step 1	22	0.091	LOW*
Pb- WAE	3	3	110	TSM > Upper TV	Step 2	50	0.969	POTENTIAL*
Se- WAE	3	2	0.17	TSM > Upper TV	Step 2	0.15	0.963	POTENTIAL*
Zn- WAE	3	3	170	TSM < Upper TV	Step 1	200	0.091	LOW*

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

Table C-17 Kogai Culvert 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Kogai C	N	N(Test)	Median	Result	Go to			
Ag-WAE	5	5	1.1	TSM > Upper TV	Step 1	1.0	0.791	POTENTIAL*
As- WAE	5	5	12	TSM < Upper TV	Step 1	20	0.500	LOW*
Cd- WAE	5	5	2.2	TSM < Upper TV	Step 1	1.5	0.705	POTENTIAL*
Cr- WAE	5	5	6.5	TSM < Upper TV	Step 1	80	0.030	LOW*
Cu- WAE	5	5	12	TSM < Upper TV	Step 1	65	0.030	LOW*
Hg- WAE	5	5	0.01	TSM < Upper TV	Step 1	0.15	0.030	LOW*
Ni- WAE	5	5	8.9	TSM < Upper TV	Step 1	22	0.030	LOW*
Pb- WAE	5	5	270	TSM > Upper TV	Step 2	50	0.985	POTENTIAL*
Se- WAE	5	5	0.17	TSM > Upper TV	Step 2	0.15	0.985	POTENTIAL*
Zn- WAE	5	5	440	TSM > Upper TV	Step 2	200	0.911	POTENTIAL*

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

Table C-18 Kogai Stable dump toe area 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Kogai S	N	N(Test)	Median	Result	Go to			
Ag-WAE	5	5	0.62	TSM < Upper TV	Step 1	1.0	0.705	LOW*
As- WAE	5	4	9.9	TSM < Upper TV	Step 1	20	0.292	LOW*
Cd- WAE	5	5	2.2	TSM ≥ TV	Step 2	1.5	0.911	POTENTIAL*
Cr- WAE	5	5	6.1	TSM < Upper TV	Step 1	80	0.030	LOW*
Cu- WAE	5	5	8.3	TSM < Upper TV	Step 1	65	0.030	LOW*
Hg- WAE	5	5	0.01	TSM < Upper TV	Step 1	0.15	0.030	LOW*
Ni- WAE	5	5	8.6	TSM < Upper TV	Step 1	22	0.030	LOW*
Pb- WAE	5	5	420	TSM ≥ TV	Step 2	50	0.985	POTENTIAL*
Se- WAE	5	4	0.15	TSM ≥ TV	Step 2	0.15	0.642	POTENTIAL*
Zn- WAE	5	5	340	TSM ≥ TV	Step 2	200	0.947	POTENTIAL*

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

Table C-19 Lime Plant discharge 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
L Plant	N	N(Test)	Median	Result	Go to			
Ag-WAE	4	4	0.05	TSM < Upper TV	Step 1	1.0	0.050	LOW*
As- WAE	4	4	0.43	TSM < Upper TV	Step 1	20	0.050	LOW*
Cd- WAE	4	4	0.24	TSM < Upper TV	Step 1	1.5	0.050	LOW*
Cr- WAE	4	4	8.3	TSM < Upper TV	Step 1	80	0.050	LOW*
Cu- WAE	4	4	1.6	TSM < Upper TV	Step 1	65	0.050	LOW*
Hg- WAE	4	4	0.01	TSM < Upper TV	Step 1	0.15	0.050	LOW*
Ni- WAE	4	4	1.9	TSM < Upper TV	Step 1	22	0.050	LOW*
Pb- WAE	4	4	1.8	TSM < Upper TV	Step 1	50	0.050	LOW*
Se- WAE	4	4	0.10	TSM < Upper TV	Step 1	0.15	0.050	LOW*
Zn- WAE	4	4	11	TSM < Upper TV	Step 1	200	0.050	LOW*

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

Table C-20 Wendoko Creek D/S Anawe Nth 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Wend	N	N(Test)	Median	Result	Go to			
Ag-WAE	3	3	0.35	TSM < Upper TV	Step 1	1.0	0.091	LOW*
As- WAE	3	3	6.1	TSM < Upper TV	Step 1	20	0.091	LOW*
Cd- WAE	3	3	1.1	TSM < Upper TV	Step 1	1.5	0.211	LOW*
Cr- WAE	3	3	5.2	TSM < Upper TV	Step 1	80	0.091	LOW*
Cu- WAE	3	3	8.3	TSM < Upper TV	Step 1	65	0.091	LOW*
Hg- WAE	3	3	0.01	TSM < Upper TV	Step 1	0.15	0.091	LOW*
Ni- WAE	3	3	7.2	TSM < Upper TV	Step 1	22	0.091	LOW*
Pb- WAE	3	2	54	TSM ≥ TV	Step 2	50	0.963	POTENTIAL*
Se- WAE	3	3	0.14	TSM < Upper TV	Step 1	0.15	0.091	LOW*
Zn- WAE	3	2	200	TSM ≥ TV	Step 2	200	0.814	POTENTIAL*

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

Table C-21 Yakatabari Creek D/S 28 level 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Yakatabari	N	N(Test)	Median	Result	Go to			
Ag-WAE	4	4	1.9	TSM ≥ TV	Step 2	1.0	0.978	POTENTIAL*
As- WAE	4	4	14	TSM < Upper TV	Step 1	20	0.050	LOW*
Cd- WAE	4	4	1.9	TSM ≥ TV	Step 2	1.5	0.928	POTENTIAL*
Cr- WAE	4	4	11	TSM < Upper TV	Step 1	80	0.050	LOW*
Cu- WAE	4	4	23	TSM < Upper TV	Step 1	65	0.050	LOW*
Hg- WAE	4	4	0.01	TSM < Upper TV	Step 1	0.15	0.050	LOW*
Ni- WAE	4	4	14	TSM < Upper TV	Step 1	22	0.050	LOW*
Pb- WAE	4	4	285	TSM ≥ TV	Step 2	50	0.978	POTENTIAL*
Se- WAE	4	4	0.13	TSM < Upper TV	Step 1	0.15	0.428	LOW*
Zn- WAE	4	4	395	TSM ≥ TV	Step 2	200	0.978	POTENTIAL*

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

Table C-22 Yunarilama at Portal 2019 median against upper river TV- sediment whole sediment WAE (mg/kg)

Discharge Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Yunarilama	N	N(Test)	Median	Result	Go to			
Ag-WAE	4	4	0.13	TSM < Upper TV	Step 1	1.0	0.050	LOW*
As- WAE	4	4	5.2	TSM < Upper TV	Step 1	20	0.050	LOW*
Cd- WAE	4	4	0.60	TSM < Upper TV	Step 1	1.5	0.181	LOW*
Cr- WAE	4	4	6.3	TSM < Upper TV	Step 1	80	0.050	LOW*
Cu- WAE	4	4	5.1	TSM < Upper TV	Step 1	65	0.050	LOW*
Hg- WAE	4	4	0.01	TSM < Upper TV	Step 1	0.15	0.050	LOW*
Ni- WAE	4	4	8.5	TSM < Upper TV	Step 1	22	0.050	LOW*
Pb- WAE	4	4	95	TSM ≥ TV	Step 2	50	0.978	POTENTIAL*
Se- WAE	4	4	0.20	TSM ≥ TV	Step 2	0.15	0.978	POTENTIAL*
Zn- WAE	4	4	129	TSM < Upper TV	Step 1	200	0.428	LOW*

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison

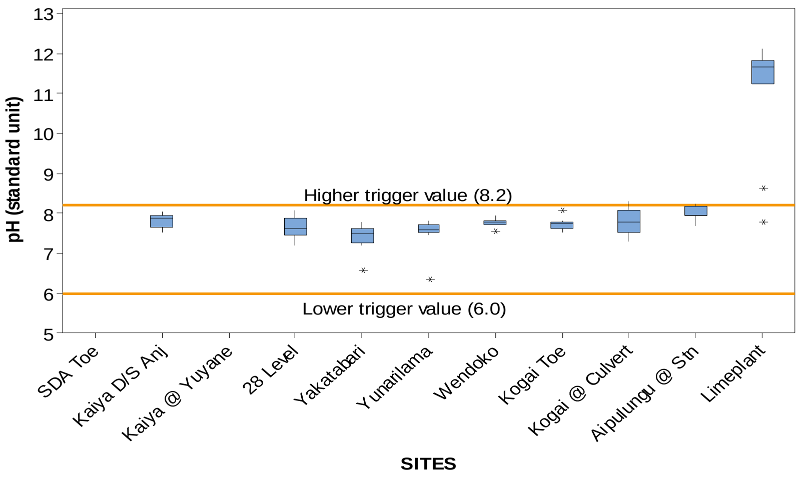

Figure C-1 pH in mine contact runoff 2019

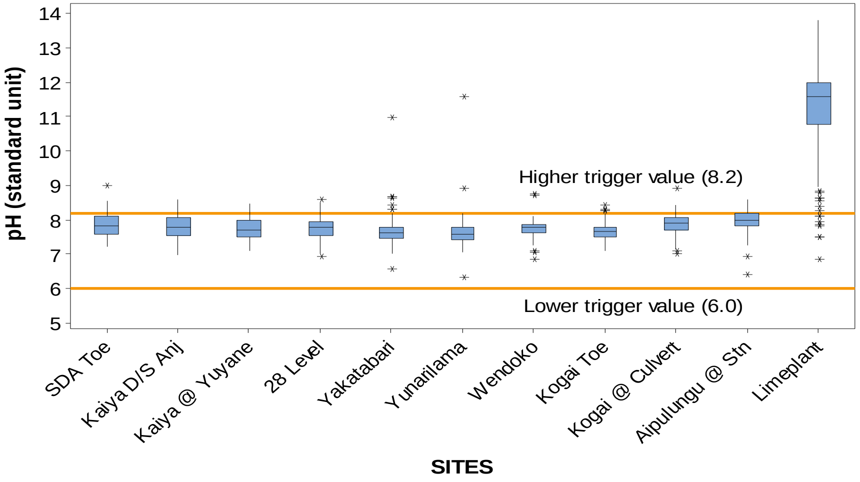

Figure C-2 pH in mine contact runoff 2010-2019

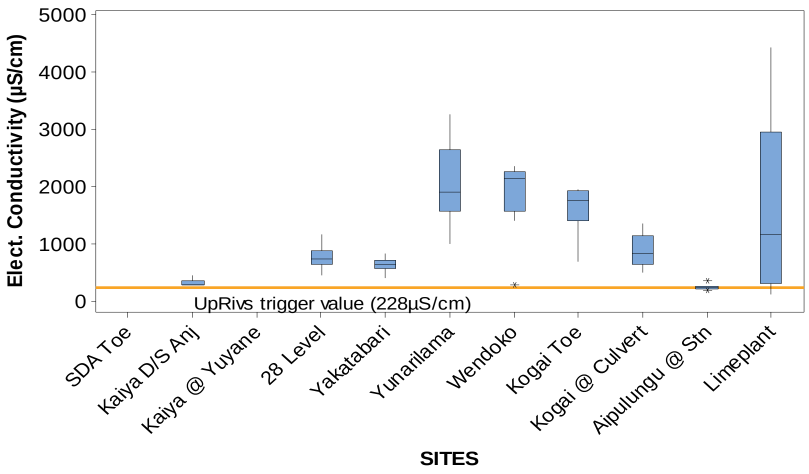

Figure C-3 Electrical conductivity in mine contact runoff 2019

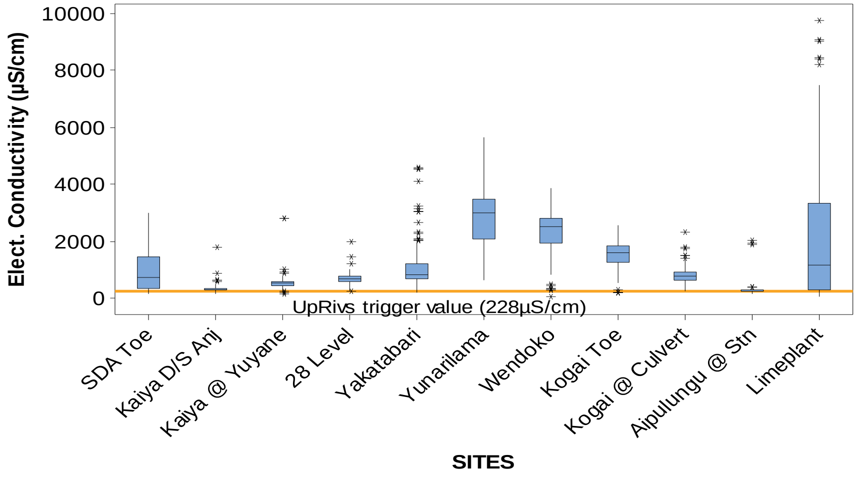

Figure C-4 Electrical conductivity in mine contact runoff 2010-2019

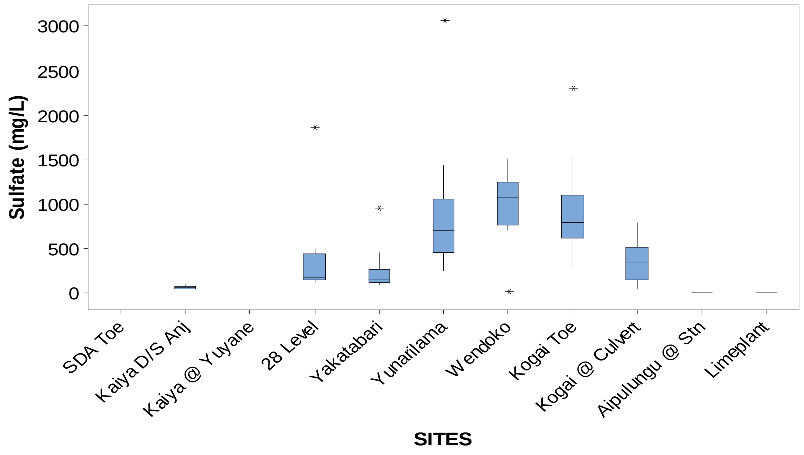

Figure C-5 Sulfate in mine contact runoff 2019

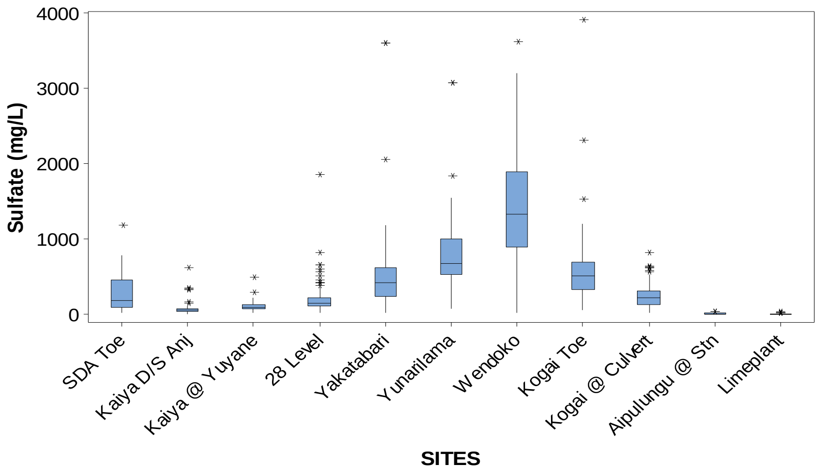

Figure C-6 Sulfate in mine contact runoff 2010-2019

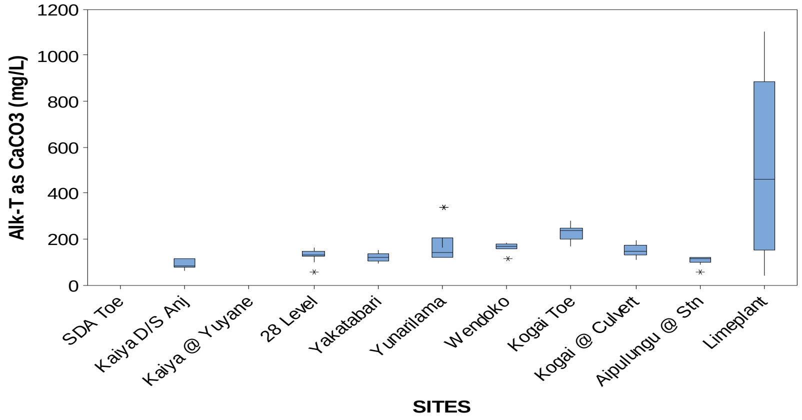

Figure C-7 Alkalinity of contact runoff 2019

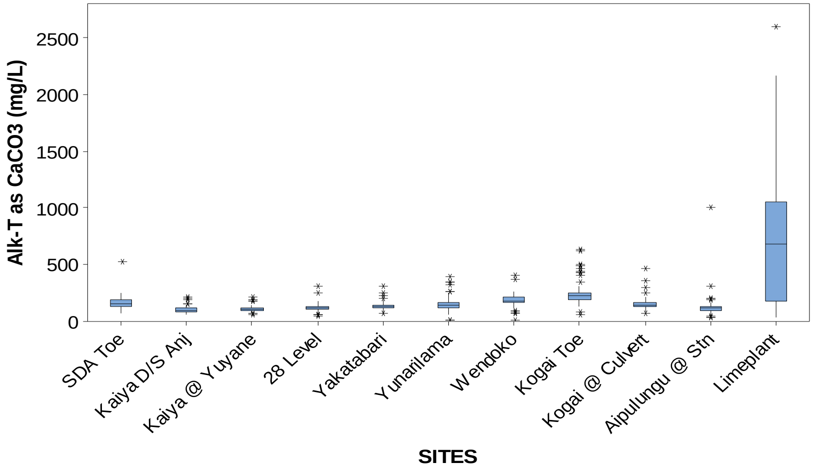

Figure C-8 Alkalinity of contact runoff 2010-2019

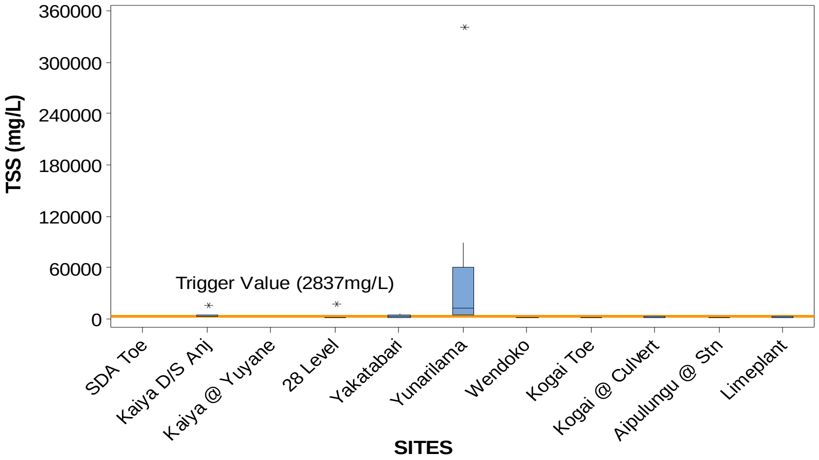

Figure C-9 TSS in contact runoff 2019

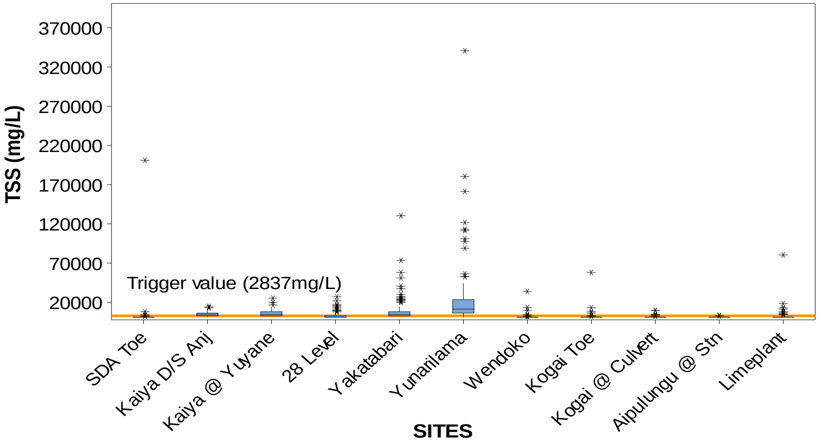

Figure-10 TSS in contact runoff 2010-2019

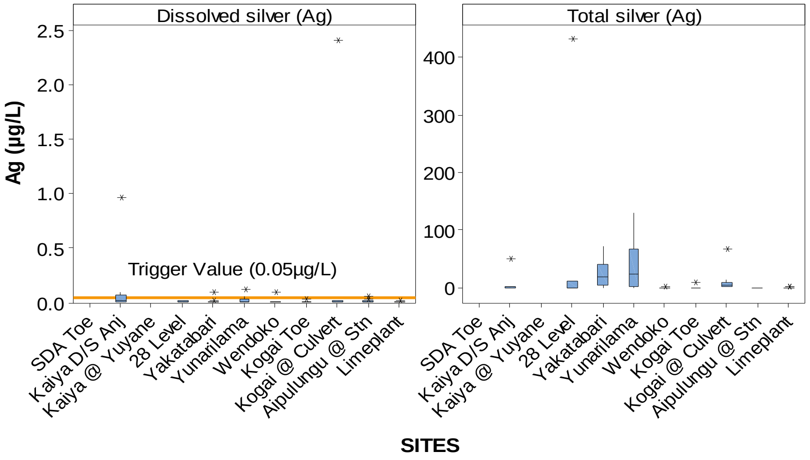

Figure C-11 Dissolved and total silver in contact runoff 2019

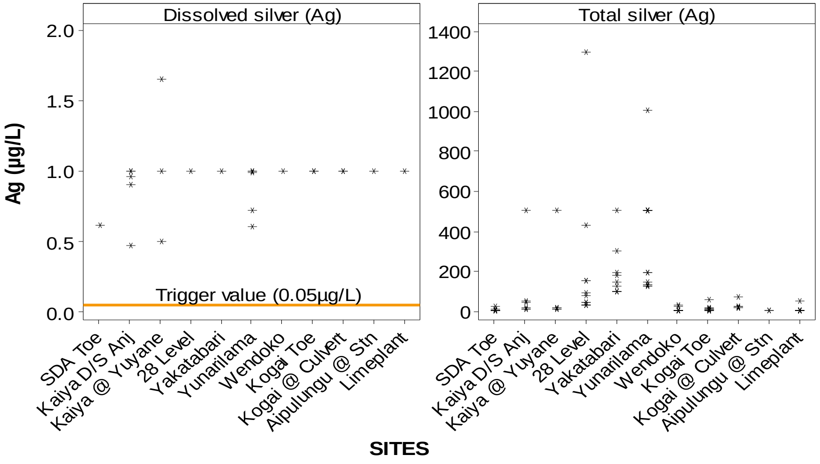

Figure C-12 Dissolved and total silver in contact runoff 2010-2019

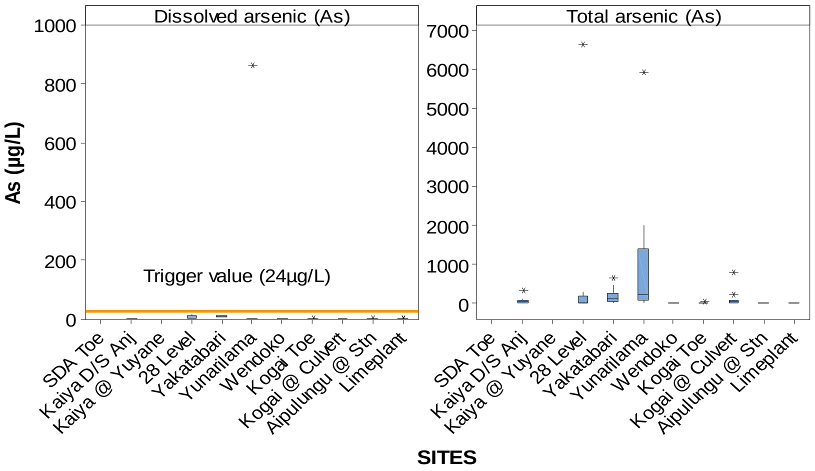

Figure C-13 Dissolved and total arsenic in contact runoff 2019

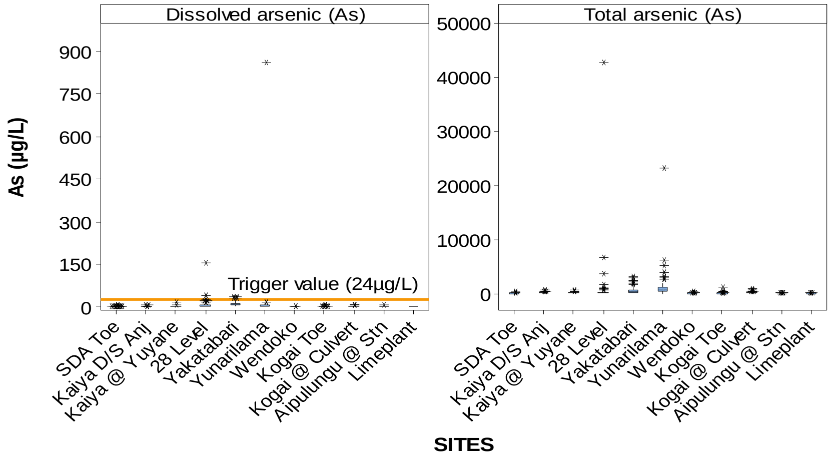

Figure C-14 Dissolved and total arsenic in contact runoff 2010-2019

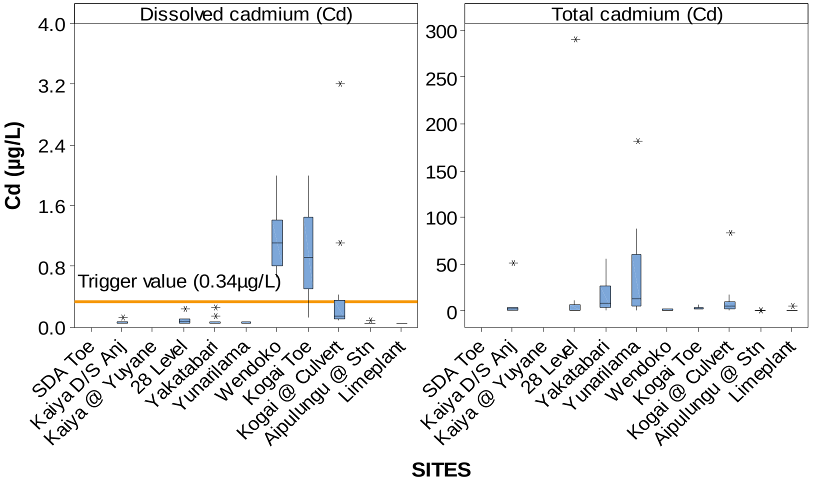

Figure C-15 Dissolved and total cadmium in contact runoff 2019

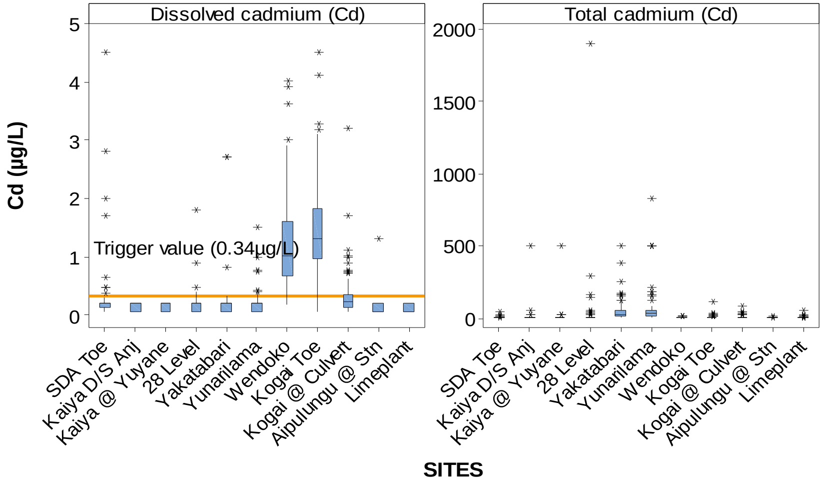

Figure C-16 Dissolved and total cadmium contact runoff 2010-2019

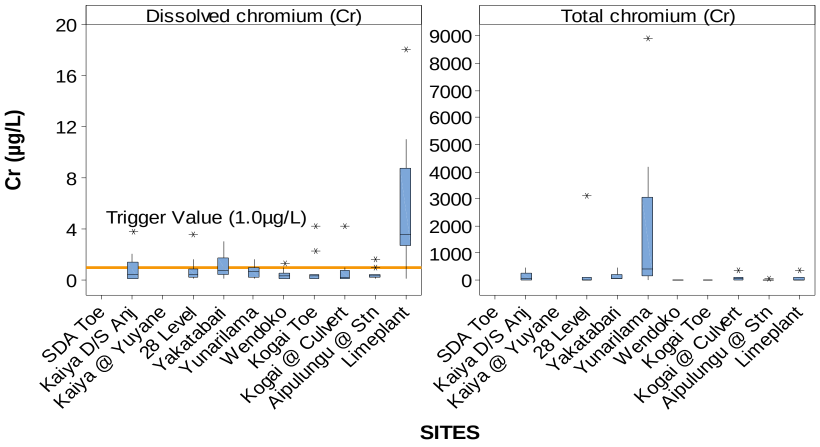

Figure C-17 Dissolved and total chromium in contact runoff 2019

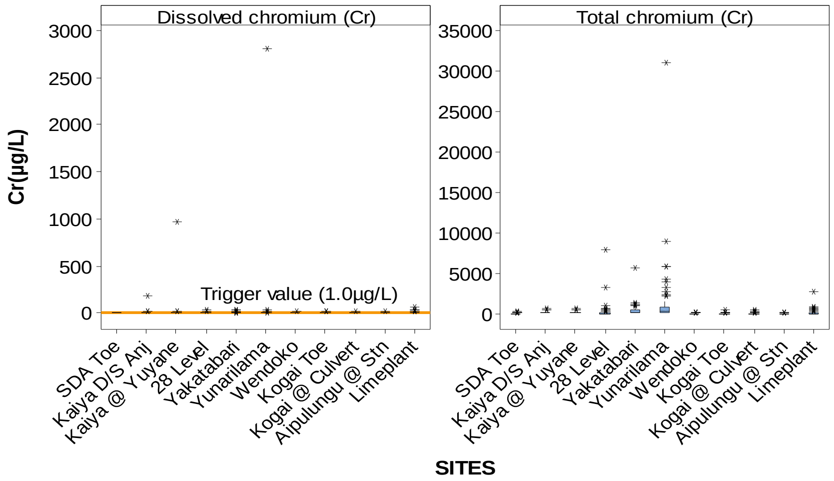

Figure C-18 Dissolved and total chromium in contact runoff 2010-2019

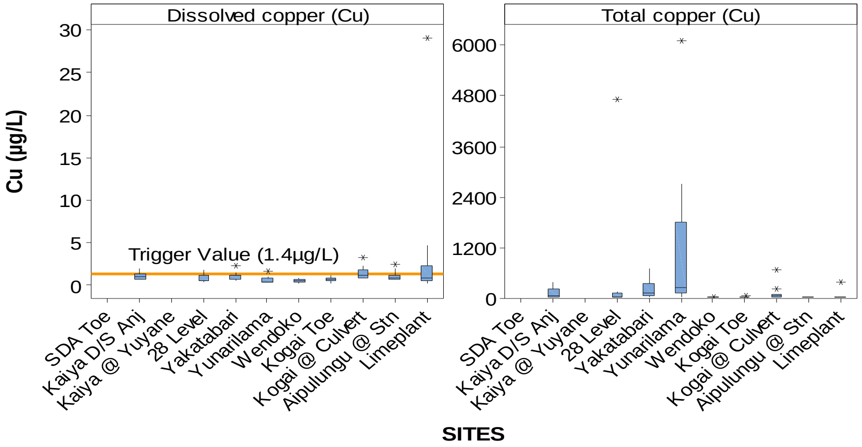

Figure C-19 Dissolved and total copper in contact runoff 2019

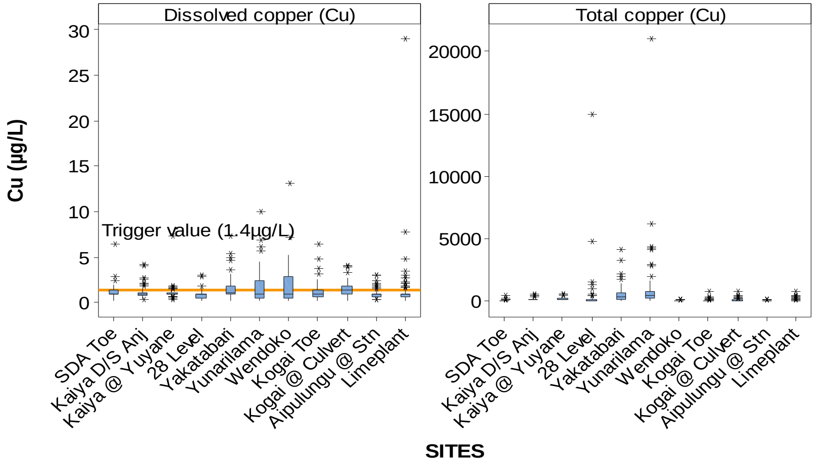

Figure C-20 Dissolved and total copper contact runoff 2010-2019

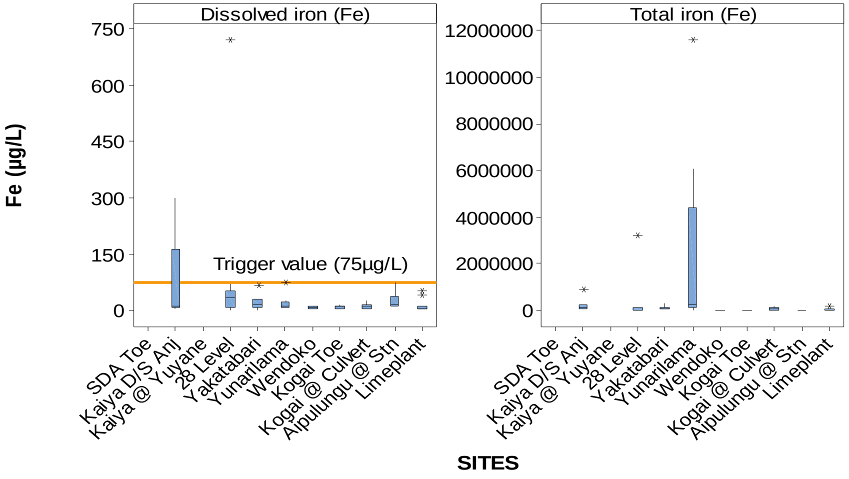

Figure C-21 Dissolved and total iron in contact runoff 2019

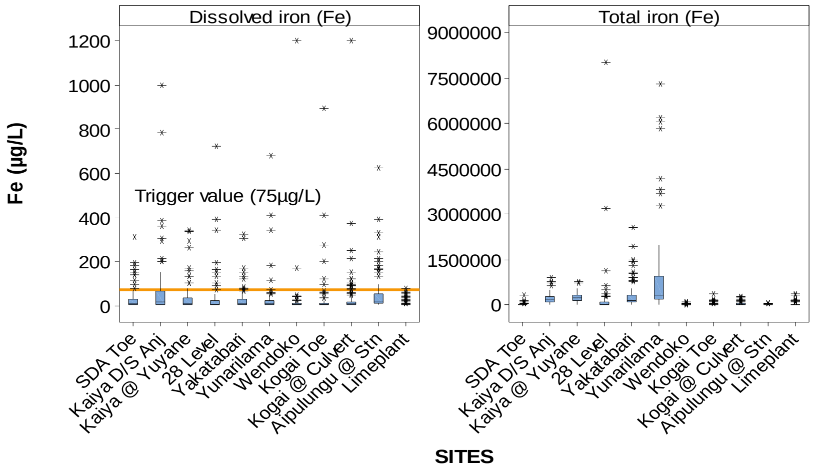

Figure C-22 Dissolved and total iron in contact runoff 2010-2019

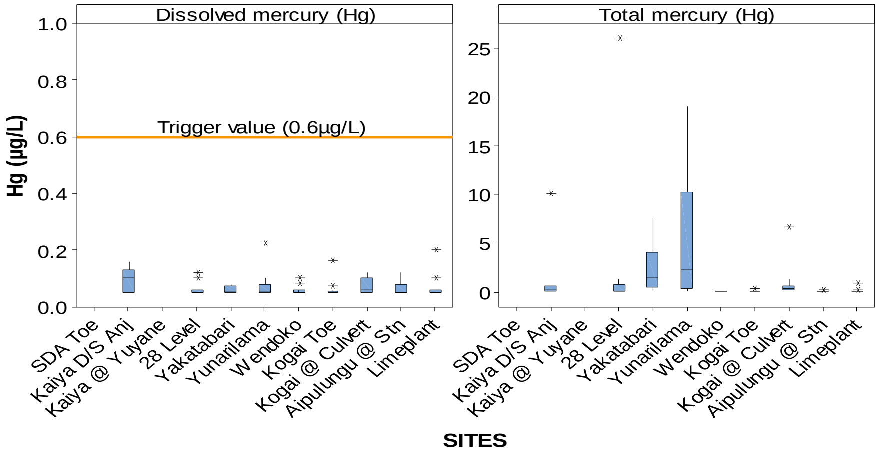

Figure C-23 Dissolved and total mercury in contact runoff 2019

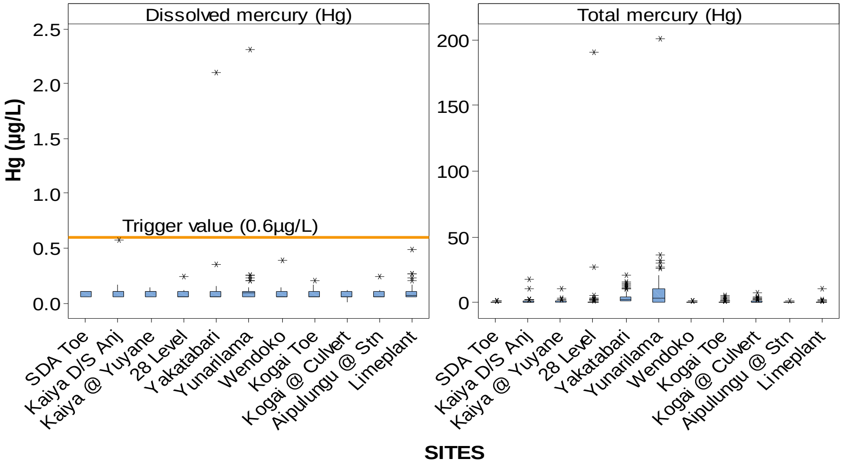

Figure C-24 Dissolved and total mercury in contact runoff 2010-2019

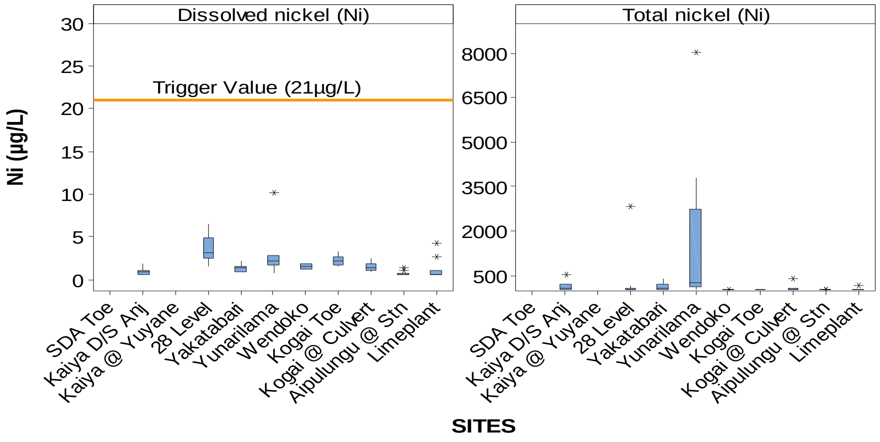

Figure C-25 Dissolved and total nickel in contact runoff 2019

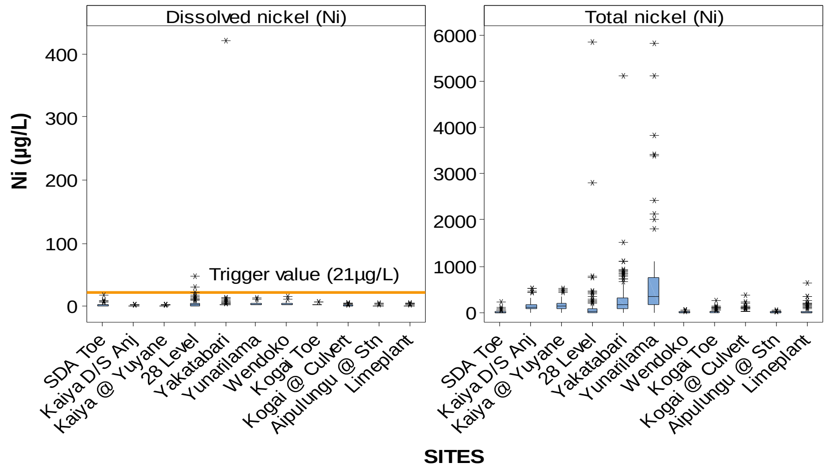

Figure C-26 Dissolved and total nickel in contact runoff 2010-2019

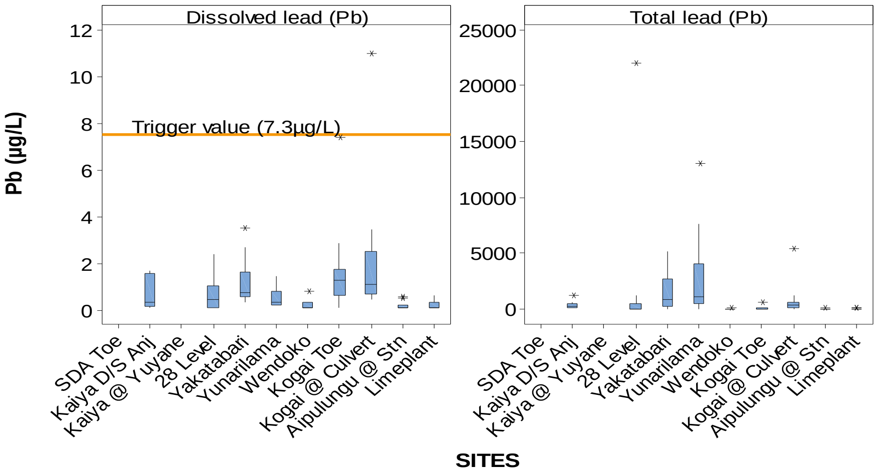

Figure C-27 Dissolved and total lead in contact runoff 2019

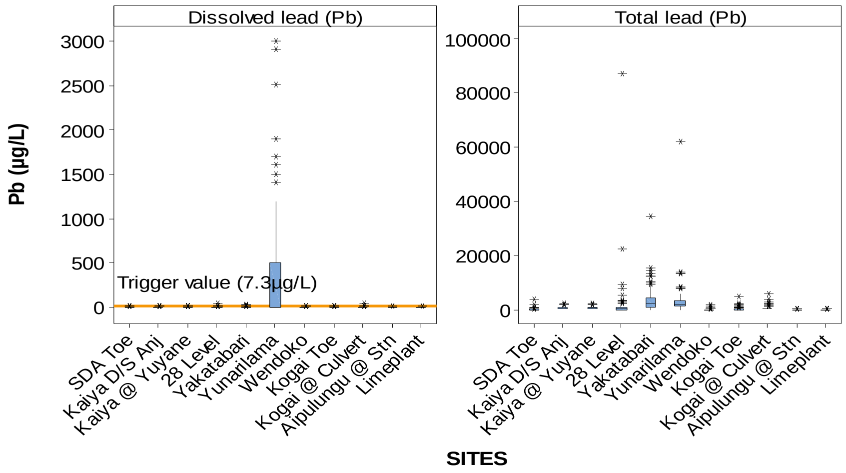

Figure C-28 Dissolved and total lead contact runoff 2010-2019

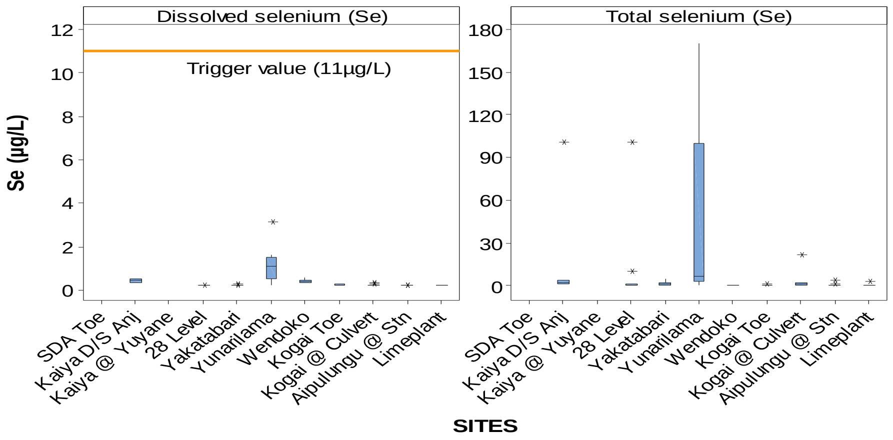

Figure C-29 Dissolved and total selenium in contact runoff 2019

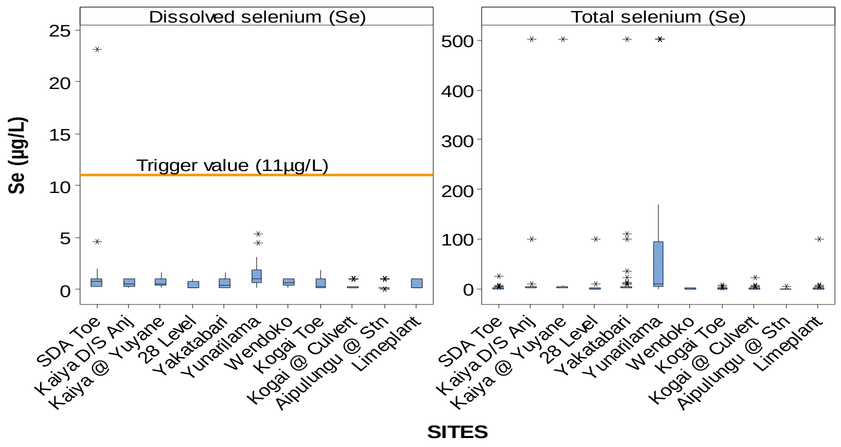

Figure C-30 Dissolved and total selenium in contact runoff 2010-2019

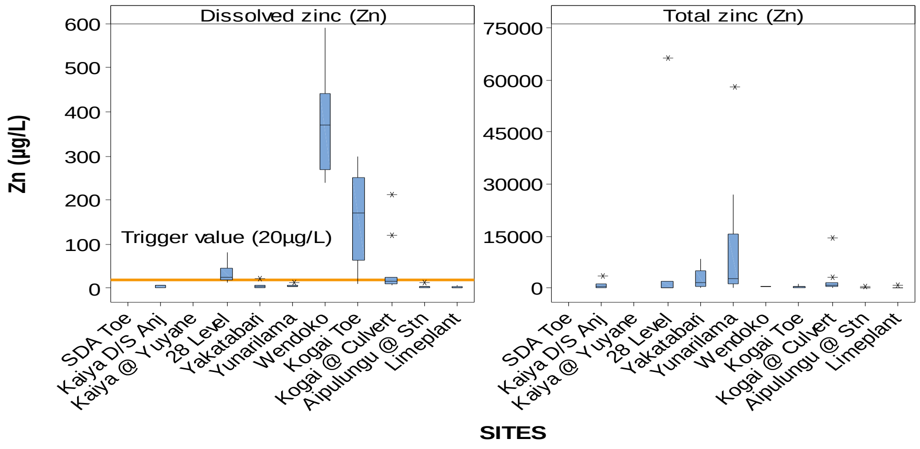

Figure C-31 Dissolved and total zinc in contact runoff 2019

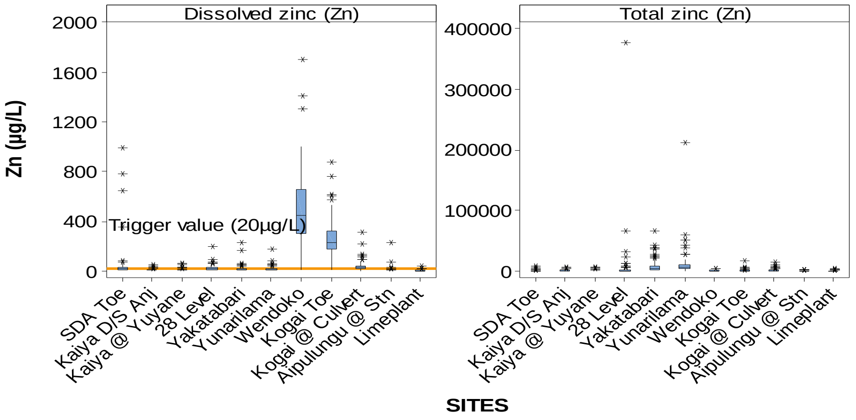

Figure C-32 Dissolved and total zinc in contact runoff 2010-2019

Table C-23 SDA Toe 2010 - 2017 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.429	<0.001	Reduced over time
EC	0.167	0.164	No change over time
Sulfate	-0.090	0.422	No change over time
Alk-T	0.058	0.603	No change over time
TSS	0.404	<0.001	Increased over time
Ag-D	-0.794	<0.001	Reduced over time
Ag-T	0.049	0.668	No change over time
As-D	-0.181	0.101	No change over time
As-T	0.322	0.003	Increased over time
Cd-D	-0.385	<0.001	Reduced over time
Cd-T	0.197	0.074	No change over time
Cr-D	-0.744	<0.001	Reduced over time
Cr-T	0.360	0.001	Increased over time
Cu-D	-0.597	<0.001	Reduced over time
Cu-T	0.255	0.002	Increased over time
Fe-D	0.150	0.175	No change over time
Fe-T	0.312	0.004	Increased over time
Hg-D	-0.828	<0.001	Reduced over time
Hg-T	-0.539	<0.001	Reduced over time
Ni-D	-0.128	0.248	No change over time
Ni-T	0.291	0.008	Increased over time
Pb-D	-0.085	0.444	No change over time
Pb-T	0.272	0.013	Increased over time
Se-D	-0.173	0.239	No change over time
Se-T	-0.046	0.754	No change over time
Zn-D	0.106	0.342	No change over time
Zn-T	0.238	0.029	Increased over time

Table C-24 Kaiya D/S Anjolek Dump 2009 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.472	<0.001	Reduced over time
EC	0.167	0.119	No change over time
Sulfate	0.022	0.841	No change over time
Alk-T	0.031	0.773	No change over time
TSS	-0.067	0.536	No change over time
Ag-D	-0.661	<0.001	Reduced over time
Ag-T	-0.030	0.782	No change over time
As-D	0.025	0.815	No change over time
As-T	-0.085	0.428	No change over time
Cd-D	-0.802	<0.001	Reduced over time
Cd-T	-0.127	0.234	No change over time
Cr-D	-0.663	<0.001	Reduced over time
Cr-T	-0.069	0.516	No change over time
Cu-D	-0.339	0.001	Reduced over time
Cu-T	-0.091	0.394	No change over time
Fe-D	-0.101	0.342	No change over time
Fe-T	-0.174	0.103	No change over time
Hg-D	-0.510	<0.001	Reduced over time
Hg-T	-0.043	0.684	No change over time
Ni-D	-0.590	<0.001	Reduced over time
Ni-T	-0.092	0.390	No change over time
Pb-D	-0.495	<0.001	Reduced over time
Pb-T	-0.188	0.076	No change over time
Se-D	-0.567	<0.001	Reduced over time
Se-T	0.175	0.198	No change over time
Zn-D	0.182	0.088	No change over time
Zn-T	-0.175	0.099	No change over time

Table C-25 Kaiya at Yuyan 2010 - 2017 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.510	<0.001	Reduced over time
EC	-0.218	0.050	Reduced over time
Sulfate	-0.567	<0.001	Reduced over time
Alk-T	-0.100	0.371	No change over time
TSS	-0.093	0.410	No change over time
Ag-D	-0.556	<0.001	Reduced over time
Ag-T	0.039	0.735	No change over time
As-D	-0.243	0.029	Reduced over time
As-T	-0.021	0.852	No change over time
Cd-D	-0.811	<0.001	Reduced over time
Cd-T	-0.169	0.130	No change over time
Cr-D	-0.777	<0.001	Reduced over time
Cr-T	-0.080	0.476	No change over time
Cu-D	-0.336	0.002	Reduced over time
Cu-T	-0.201	0.071	No change over time
Fe-D	0.007	0.947	No change over time
Fe-T	-0.150	0.185	No change over time
Hg-D	-0.660	<0.001	Reduced over time
Hg-T	-0.279	0.012	Reduced over time
Ni-D	-0.431	<0.001	Reduced over time
Ni-T	-0.110	0.327	No change over time
Pb-D	-0.456	<0.001	Reduced over time
Pb-T	-0.241	0.030	Reduced over time
Se-D	-0.581	<0.001	Reduced over time
Se-T	0.224	0.130	No change over time
Zn-D	0.237	0.034	Increased over time
Zn-T	-0.176	0.117	No change over time

Table C-26 28 Level 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.273	0.003	Reduced over time
EC	0.330	0.001	Increased over time
Sulfate	0.202	0.032	Increased over time
Alk-T	0.072	0.446	No change over time
TSS	-0.670	<0.001	Reduced over time
Ag-D	-0.887	<0.001	Reduced over time
Ag-T	-0.516	<0.001	Reduced over time
As-D	-0.074	0.431	No change over time
As-T	-0.312	0.001	Reduced over time
Cd-D	-0.605	<0.001	Reduced over time
Cd-T	-0.501	<0.001	Reduced over time
Cr-D	-0.599	<0.001	Reduced over time
Cr-T	-0.540	<0.001	Reduced over time
Cu-D	-0.606	<0.001	Reduced over time
Cu-T	-0.519	<0.001	Reduced over time
Fe-D	0.110	0.241	No change over time
Fe-T	-0.502	<0.001	Reduced over time
Hg-D	-0.577	<0.001	Reduced over time
Hg-T	-0.461	<0.001	Reduced over time
Ni-D	0.506	<0.001	Increased over time
Ni-T	-0.417	<0.001	Reduced over time
Pb-D	-0.505	<0.001	Reduced over time
Pb-T	-0.553	<0.001	Reduced over time
Se-D	-0.699	<0.001	Reduced over time
Se-T	-0.434	<0.001	Reduced over time
Zn-D	0.659	<0.001	Increased over time
Zn-T	-0.435	<0.001	Reduced over time

Table C-27 Yakatabari Creek D/S 28 Level 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.475	<0.001	Reduced over time
EC	-0.310	0.002	Reduced over time
Sulfate	-0.537	<0.001	Reduced over time
Alk-T	-0.111	0.239	No change over time
TSS	-0.225	0.016	Reduced over time
Ag-D	-0.880	<0.001	Reduced over time
Ag-T	0.108	0.258	No change over time
As-D	0.103	0.275	No change over time
As-T	-0.122	0.193	No change over time
Cd-D	-0.673	<0.001	Reduced over time
Cd-T	-0.038	0.690	No change over time
Cr-D	-0.425	<0.001	Reduced over time
Cr-T	-0.194	0.037	Reduced over time
Cu-D	-0.487	<0.001	Reduced over time
Cu-T	-0.058	0.538	No change over time
Fe-D	0.041	0.662	No change over time
Fe-T	-0.218	0.020	Reduced over time
Hg-D	-0.661	<0.001	Reduced over time
Hg-T	0.182	0.051	No change over time
Ni-D	-0.220	0.018	Reduced over time
Ni-T	-0.168	0.073	No change over time
Pb-D	-0.246	0.008	Reduced over time
Pb-T	-0.034	0.717	No change over time
Se-D	-0.740	<0.001	Reduced over time
Se-T	0.058	0.607	No change over time
Zn-D	-0.121	0.201	No change over time
Zn-T	-0.111	0.237	No change over time

Table C-28 Yunarilama / Yarik @ Portal 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.272	0.010	Reduced over time
EC	-0.480	<0.001	Reduced over time
Sulfate	-0.433	<0.001	Reduced over time
Alk-T	0.503	<0.001	Increased over time
TSS	0.216	0.042	Increased over time
Ag-D	-0.800	<0.001	Reduced over time
Ag-T	0.218	0.044	Increased over time
As-D	-0.468	<0.001	Reduced over time
As-T	0.052	0.631	No change over time
Cd-D	-0.566	<0.001	Reduced over time
Cd-T	0.023	0.830	No change over time
Cr-D	-0.544	<0.001	Reduced over time
Cr-T	0.147	0.171	No change over time
Cu-D	-0.705	<0.001	Reduced over time
Cu-T	0.111	0.300	No change over time
Fe-D	0.325	0.002	Increased over time
Fe-T	0.148	0.170	No change over time
Hg-D	-0.446	<0.001	Reduced over time
Hg-T	0.034	0.749	No change over time
Ni-D	-0.356	0.001	Reduced over time
Ni-T	0.162	0.129	No change over time
Pb-D	-0.717	<0.001	Reduced over time
Pb-T	-0.021	0.842	No change over time
Se-D	-0.032	0.815	No change over time
Se-T	0.002	0.990	No change over time
Zn-D	-0.029	0.786	No change over time
Zn-T	-0.035	0.747	No change over time

Table C-29 Wendoko Creek D/S Anawe Nth 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.134	0.186	No change over time
EC	-0.250	0.019	Reduced over time
Sulfate	-0.444	<0.001	Reduced over time
Alk-T	-0.372	<0.001	Reduced over time
TSS	-0.284	0.004	Reduced over time
Ag-D	-0.872	<0.001	Reduced over time
Ag-T	-0.479	<0.001	Reduced over time
As-D	-0.597	<0.001	Reduced over time
As-T	-0.093	0.358	No change over time
Cd-D	-0.127	0.211	No change over time
Cd-T	-0.366	<0.001	Reduced over time
Cr-D	-0.683	<0.001	Reduced over time
Cr-T	-0.370	<0.001	Reduced over time
Cu-D	-0.777	<0.001	Reduced over time
Cu-T	-0.532	<0.001	Reduced over time
Fe-D	0.249	0.013	Increased over time
Fe-T	-0.072	0.477	No change over time
Hg-D	-0.682	<0.001	Reduced over time
Hg-T	-0.716	<0.001	Reduced over time
Ni-D	-0.771	<0.001	Reduced over time
Ni-T	-0.611	<0.001	Reduced over time
Pb-D	-0.531	<0.001	Reduced over time
Pb-T	-0.136	0.176	No change over time
Se-D	-0.664	<0.001	Reduced over time
Se-T	-0.666	<0.001	Reduced over time
Zn-D	-0.429	<0.001	Reduced over time
Zn-T	-0.461	<0.001	Reduced over time

Table C-30 Kogai Dump Toe 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	0.239	0.012	Increased over time
EC	0.556	<0.001	Increased over time
Sulfate	0.521	<0.001	Increased over time
Alk-T	0.245	0.001	Increased over time
TSS	0.134	0.164	No change over time
Ag-D	-0.895	<0.001	Reduced over time
Ag-T	0.045	0.647	No change over time
As-D	-0.362	<0.001	Reduced over time
As-T	0.183	0.055	No change over time
Cd-D	-0.048	0.621	No change over time
Cd-T	0.235	0.013	Increased over time
Cr-D	-0.534	<0.001	Reduced over time
Cr-T	0.096	0.320	No change over time
Cu-D	-0.718	<0.001	Reduced over time
Cu-T	0.088	0.359	No change over time
Fe-D	0.100	0.300	No change over time
Fe-T	0.113	0.242	No change over time
Hg-D	-0.652	<0.001	Reduced over time
Hg-T	-0.307	0.001	Reduced over time
Ni-D	0.266	0.005	Increased over time
Ni-T	0.178	0.063	No change over time
Pb-D	0.233	0.014	Increased over time
Pb-T	0.186	0.052	No change over time
Se-D	-0.450	<0.001	Reduced over time
Se-T	-0.396	<0.001	Reduced over time
Zn-D	-0.060	0.532	No change over time
Zn-T	0.159	0.096	No change over time

Table C-31 Kogai at Culvert 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.248	0.007	Reduced over time
EC	-0.132	0.154	No change over time
Sulfate	-0.288	0.002	Reduced over time
Alk-T	-0.064	0.489	No change over time
TSS	0.229	0.013	Increased over time
Ag-D	-0.831	<0.001	Reduced over time
Ag-T	0.261	0.005	Increased over time
As-D	-0.414	<0.001	Reduced over time
As-T	-0.025	0.788	No change over time
Cd-D	-0.404	<0.001	Reduced over time
Cd-T	0.002	0.982	No change over time
Cr-D	-0.671	<0.001	Reduced over time
Cr-T	0.166	0.073	No change over time
Cu-D	-0.353	<0.001	Reduced over time
Cu-T	0.096	0.303	No change over time
Fe-D	0.170	0.066	No change over time
Fe-T	0.160	0.085	No change over time
Hg-D	-0.601	<0.001	Reduced over time
Hg-T	0.261	0.004	Increased over time
Ni-D	-0.132	0.155	No change over time
Ni-T	0.174	0.059	No change over time
Pb-D	-0.154	0.098	No change over time
Pb-T	0.034	0.715	No change over time
Se-D	-0.646	<0.001	Reduced over time
Se-T	-0.174	0.188	No change over time
Zn-D	-0.320	<0.001	Reduced over time
Zn-T	-0.015	0.871	No change over time

Table C-32 Aipulungu at Station 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.416	<0.001	Reduced over time
EC	-0.071	0.450	No change over time
Sulfate	-0.403	<0.001	Reduced over time
Alk-T	0.153	0.086	No change over time
TSS	0.148	0.097	No change over time
Ag-D	-0.904	<0.001	Reduced over time
Ag-T	-0.769	<0.001	Reduced over time
As-D	-0.518	<0.001	Reduced over time
As-T	0.033	0.708	No change over time
Cd-D	-0.758	<0.001	Reduced over time
Cd-T	-0.643	<0.001	Reduced over time
Cr-D	-0.674	<0.001	Reduced over time
Cr-T	0.212	0.016	Increased over time
Cu-D	-0.492	<0.001	Reduced over time
Cu-T	0.194	0.028	Increased over time
Fe-D	0.023	0.796	No change over time
Fe-T	0.169	0.058	No change over time
Hg-D	-0.718	<0.001	Reduced over time
Hg-T	-0.725	<0.001	Reduced over time
Ni-D	-0.403	<0.001	Reduced over time
Ni-T	0.218	0.014	Increased over time
Pb-D	-0.607	<0.001	Reduced over time
Pb-T	0.163	0.065	No change over time
Se-D	-0.564	<0.001	Reduced over time
Se-T	-0.301	0.003	Reduced over time
Zn-D	0.277	0.002	Increased over time
Zn-T	0.294	0.001	Increased over time

Table C-33 Lime Plant 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.386	<0.001	Reduced over time
EC	-0.237	0.019	Reduced over time
Sulfate	-0.338	<0.001	Reduced over time
Alk-T	-0.286	0.002	Reduced over time
TSS	0.258	0.007	Increased over time
Ag-D	-0.899	<0.001	Reduced over time
Ag-T	-0.470	<0.001	Reduced over time
As-D	-0.823	<0.001	Reduced over time
As-T	-0.044	0.645	No change over time
Cd-D	-0.861	<0.001	Reduced over time
Cd-T	-0.120	0.208	No change over time
Cr-D	0.062	0.519	No change over time
Cr-T	0.256	0.007	Increased over time
Cu-D	-0.303	0.001	Reduced over time
Cu-T	0.281	0.003	Increased over time
Fe-D	-0.066	0.491	No change over time
Fe-T	0.227	0.017	Increased over time
Hg-D	-0.547	<0.001	Reduced over time
Hg-T	-0.476	<0.001	Reduced over time
Ni-D	-0.641	<0.001	Reduced over time
Ni-T	0.193	0.043	Increased over time
Pb-D	-0.640	<0.001	Reduced over time
Pb-T	0.214	0.024	Increased over time
Se-D	-0.728	<0.001	Reduced over time
Se-T	-0.493	<0.001	Reduced over time
Zn-D	0.098	0.306	No change over time
Zn-T	0.204	0.032	Increased over time

Table C-34 Aipulungu U/S Lime plant 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.363	<0.001	Reduced over time
EC	-0.014	0.882	No change over time
Sulfate	-0.574	<0.001	Reduced over time
Alk-T	0.112	0.238	No change over time
TSS	0.159	0.093	No change over time
Ag-D	-0.831	<0.001	Reduced over time
Ag-T	-0.846	<0.001	Reduced over time
As-D	-0.784	<0.001	Reduced over time
As-T	-0.679	<0.001	Reduced over time
Cd-D	-0.861	<0.001	Reduced over time
Cd-T	-0.804	<0.001	Reduced over time
Cr-D	-0.603	<0.001	Reduced over time
Cr-T	-0.287	0.002	Reduced over time
Cu-D	-0.566	<0.001	Reduced over time
Cu-T	-0.218	0.019	Reduced over time
Fe-D	0.080	0.392	No change over time
Fe-T	-0.162	0.084	No change over time
Hg-D	-0.620	<0.001	Reduced over time
Hg-T	-0.758	<0.001	Reduced over time
Ni-D	-0.693	<0.001	Reduced over time
Ni-T	-0.236	0.011	Reduced over time
Pb-D	-0.693	<0.001	Reduced over time
Pb-T	-0.329	<0.001	Reduced over time
Se-D	-0.692	<0.001	Reduced over time
Se-T	-0.610	<0.001	Reduced over time
Zn-D	0.263	0.005	Increased over time
Zn-T	0.016	0.866	No change over time

Table C-35 Waile Creek 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.315	0.001	Reduced over time
EC	-0.057	0.543	No change over time
Sulfate	-0.570	<0.001	Reduced over time
Alk-T	-0.066	0.480	No change over time
TSS	-0.135	0.147	No change over time
Ag-D	-0.864	<0.001	Reduced over time
Ag-T	-0.785	<0.001	Reduced over time
As-D	-0.815	<0.001	Reduced over time
As-T	-0.819	<0.001	Reduced over time
Cd-D	-0.843	<0.001	Reduced over time
Cd-T	-0.811	<0.001	Reduced over time
Cr-D	-0.691	<0.001	Reduced over time
Cr-T	-0.613	<0.001	Reduced over time
Cu-D	-0.714	<0.001	Reduced over time
Cu-T	-0.539	<0.001	Reduced over time
Fe-D	0.065	0.487	No change over time
Fe-T	-0.266	0.004	Reduced over time
Hg-D	-0.629	<0.001	Reduced over time
Hg-T	-0.749	<0.001	Reduced over time
Ni-D	-0.787	<0.001	Reduced over time
Ni-T	-0.537	<0.001	Reduced over time
Pb-D	-0.672	<0.001	Reduced over time
Pb-T	-0.552	<0.001	Reduced over time
Se-D	-0.747	<0.001	Reduced over time
Se-T	-0.699	<0.001	Reduced over time
Zn-D	0.293	0.001	Increased over time
Zn-T	-0.089	0.345	No change over time

Table C-36 Kaiya U/S Anjolek 2010 - 2017 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.575	<0.001	Reduced over time
EC	-0.001	0.997	No change over time
Sulfate	-0.300	0.007	Reduced over time
Alk-T	-0.006	0.956	No change over time
TSS	-0.050	0.655	No change over time
Ag-D	-0.751	<0.001	Reduced over time
Ag-T	-0.656	<0.001	Reduced over time
As-D	-0.680	<0.001	Reduced over time
As-T	-0.196	0.077	No change over time
Cd-D	-0.809	<0.001	Reduced over time
Cd-T	-0.660	<0.001	Reduced over time
Cr-D	-0.872	<0.001	Reduced over time
Cr-T	-0.034	0.759	No change over time
Cu-D	-0.653	<0.001	Reduced over time
Cu-T	-0.052	0.645	No change over time
Fe-D	-0.013	0.907	No change over time
Fe-T	-0.042	0.708	No change over time
Hg-D	-0.778	<0.001	Reduced over time
Hg-T	-0.676	<0.001	Reduced over time
Ni-D	-0.806	<0.001	Reduced over time
Ni-T	-0.023	0.840	No change over time
Pb-D	-0.635	<0.001	Reduced over time
Pb-T	-0.163	0.143	No change over time
Se-D	-0.729	<0.001	Reduced over time
Se-T	-0.669	<0.001	Reduced over time
Zn-D	0.339	0.002	Increased over time
Zn-T	-0.001	0.998	No change over time

Table C-37 Pongema 2010 - 2019 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.236	0.010	Reduced over time
EC	-0.068	0.466	No change over time
SO4-D	-0.574	<0.001	Reduced over time
Alk-T	0.041	0.662	No change over time
TSS	0.104	0.262	No change over time
Ag-D	-0.840	<0.001	Reduced over time
Ag-T	-0.717	<0.001	Reduced over time
As-D	-0.736	<0.001	Reduced over time
As-T	-0.627	<0.001	Reduced over time
Cd-D	-0.777	<0.001	Reduced over time
Cd-T	-0.797	<0.001	Reduced over time
Cr-D	-0.537	<0.001	Reduced over time
Cr-T	-0.141	0.126	No change over time
Cu-D	-0.595	<0.001	Reduced over time
Cu-T	-0.203	0.026	Reduced over time
Fe-D	-0.005	0.959	No change over time
Fe-T	-0.104	0.263	No change over time
Hg-D	-0.756	<0.001	Reduced over time
Hg-T	-0.740	<0.001	Reduced over time
Ni-D	-0.692	<0.001	Reduced over time
Ni-T	-0.230	0.012	Reduced over time
Pb-D	-0.677	<0.001	Reduced over time
Pb-T	-0.125	0.174	No change over time
Se-D	-0.720	<0.001	Reduced over time
Se-T	-0.675	<0.001	Reduced over time
Zn-D	0.055	0.552	No change over time
Zn-T	-0.030	0.750	No change over time

Table C-38 Trend for sediment quality from mine contact sites 2015 - 2019

Sediment Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend
28 Level (Trend of all data 2015 - 2019)	Ag-WAE	0.116	0.627	No change over time
	As-WAE	0.677	0.001	Increased over time
	Cd-WAE	0.403	0.078	No change over time
	Cr-WAE	-0.325	0.162	No change over time
	Cu-WAE	-0.141	0.553	No change over time
	Fe-WAE	-0.195	0.409	No change over time
	Pb-WAE	0.338	0.145	No change over time
	Hg-WAE	-0.104	0.662	No change over time
	Ni-WAE	-0.213	0.366	No change over time
	Se-WAE	-0.464	0.039	Reduced over time
	Zn-WAE	-0.068	0.774	No change over time
Anjolek SDA (Trend of all data 2015 - 2017)	Ag-WAE	-0.711	0.01	Reduced over time
	As-WAE	-0.091	0.779	No change over time
	Cd-WAE	0.084	0.795	No change over time
	Cr-WAE	-0.259	0.417	No change over time
	Cu-WAE	-0.168	0.602	No change over time
	Fe-WAE	-0.329	0.297	No change over time
	Pb-WAE	0.077	0.812	No change over time
	Hg-WAE	-0.083	0.799	No change over time
	Ni-WAE	0.011	0.974	No change over time
	Se-WAE	-0.719	0.008	Reduced over time
	Zn-WAE	0.27	0.397	No change over time
Kaiya @ Yuyan Bridge (Trend of all data 2015 - 2019)	Ag-WAE	-0.522	0.055	No change over time
	As-WAE	-0.161	0.583	No change over time
	Cd-WAE	0.057	0.846	No change over time
	Cr-WAE	0.253	0.383	No change over time
	Cu-WAE	0.521	0.056	No change over time
	Fe-WAE	0.275	0.342	No change over time
	Pb-WAE	0.495	0.072	No change over time
	Hg-WAE	-0.388	0.17	No change over time
	Ni-WAE	0.354	0.215	No change over time
	Se-WAE	-0.661	0.01	Reduced over time
	Zn-WAE	0.334	0.243	No change over time
Kaiya River downstream Anjolek erodible dump (Trend of all data 2015 - 2019)	Ag-WAE	-0.594	0.025	Reduced over time
	As-WAE	-0.002	0.994	No change over time
	Cd-WAE	-0.046	0.875	No change over time
	Cr-WAE	0.319	0.267	No change over time
	Cu-WAE	0.405	0.151	No change over time
	Fe-WAE	0.257	0.375	No change over time
	Pb-WAE	0.17	0.562	No change over time
	Hg-WAE	-0.291	0.314	No change over time
	Ni-WAE	0.385	0.173	No change over time
	Se-WAE	-0.68	0.007	Reduced over time
	Zn-WAE	0.29	0.314	No change over time
Kogai culvert	Ag-WAE	0.254	0.243	No change over time
	As-WAE	0.13	0.553	No change over time

Sediment Quality	Parameter	Spearman's rho	P-Value (P=0.05)	Trend
Site				
(Trend of all data 2015 - 2019)	Cd-WAE	0.35	0.101	No change over time
	Cr-WAE	0.395	0.062	No change over time
	Cu-WAE	0.591	0.003	Increased over time
	Fe-WAE	0.359	0.093	No change over time
	Pb-WAE	0.363	0.088	No change over time
	Hg-WAE	-0.207	0.344	No change over time
	Ni-WAE	0.617	0.002	Increased over time
	Se-WAE	-0.587	0.003	Reduced over time
	Zn-WAE	0.52	0.011	Increased over time
Kogai stable dump toe (Trend of all data 2015 - 2019)	Ag-WAE	0.188	0.401	No change over time
	As-WAE	0.006	0.978	No change over time
	Cd-WAE	0.412	0.057	No change over time
	Cr-WAE	0.405	0.062	No change over time
	Cu-WAE	0.266	0.231	No change over time
	Fe-WAE	0.34	0.122	No change over time
	Pb-WAE	0.494	0.02	Increased over time
	Hg-WAE	-0.218	0.331	No change over time
	Ni-WAE	0.4	0.065	No change over time
	Se-WAE	-0.38	0.081	No change over time
	Zn-WAE	0.414	0.056	No change over time
Lime Plant discharge (Trend of all data 2015 - 2017)	Ag-WAE	-0.835	<0.001	Reduced over time
	As-WAE	-0.607	0.004	Reduced over time
	Cd-WAE	-0.657	0.001	Reduced over time
	Cr-WAE	-0.082	0.724	No change over time
	Cu-WAE	0.01	0.964	No change over time
	Fe-WAE	0.009	0.969	No change over time
	Pb-WAE	-0.357	0.112	No change over time
	Hg-WAE	-0.485	0.026	Reduced over time
	Ni-WAE	-0.105	0.652	No change over time
	Se-WAE	-0.831	<0.001	Reduced over time
	Zn-WAE	-0.114	0.623	No change over time
Wendoko Creek downstream Anawe North (Trend of all data 2015 - 2019)	Ag-WAE	-0.379	0.163	No change over time
	As-WAE	-0.345	0.208	No change over time
	Cd-WAE	-0.316	0.251	No change over time
	Cr-WAE	0.357	0.191	No change over time
	Cu-WAE	0.068	0.81	No change over time
	Fe-WAE	0.307	0.265	No change over time
	Pb-WAE	-0.468	0.079	No change over time
	Hg-WAE	-0.426	0.113	No change over time
	Ni-WAE	0.495	0.061	No change over time
	Se-WAE	-0.718	0.003	Reduced over time
	Zn-WAE	-0.111	0.694	No change over time
Yakatabari Creek D/S 28 level (Trend of all data 2015 - 2019)	Ag-WAE	0.289	0.205	No change over time
	As-WAE	-0.126	0.586	No change over time
	Cd-WAE	0.214	0.351	No change over time
	Cr-WAE	0.32	0.157	No change over time
	Cu-WAE	0.419	0.059	No change over time

Sediment Quality	Parameter	Spearman's rho	P-Value (P=0.05)	Trend
Site				
	Fe-WAE	0.182	0.43	No change over time
	Pb-WAE	0.191	0.408	No change over time
	Hg-WAE	-0.227	0.322	No change over time
	Ni-WAE	0.534	0.013	Increased over time
	Se-WAE	-0.561	0.008	Reduced over time
	Zn-WAE	0.421	0.057	No change over time
Yunarilama at Portal (Trend of all data 2015 - 2019)	Ag-WAE	-0.332	0.179	No change over time
	As-WAE	-0.252	0.313	No change over time
	Cd-WAE	0.138	0.586	No change over time
	Cr-WAE	0.339	0.169	No change over time
	Cu-WAE	0.031	0.903	No change over time
	Fe-WAE	0.37	0.13	No change over time
	Pb-WAE	0.126	0.618	No change over time
	Hg-WAE	-0.492	0.038	Reduced over time
	Ni-WAE	0.406	0.095	No change over time
	Se-WAE	-0.432	0.073	No change over time
	Zn-WAE	0.33	0.181	No change over time

APPENDIX D. WATER QUALITY – RISK AND PERFORMANCE ASSESSMENT – DETAILS OF STATISTICAL ANALYSIS AND BOX PLOTS

Table D-1 Expanded risk matrix – water quality – metals and TSS

Initial Assessment Result					Go To
TSM < TV					Step 1
TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR					Step 2
TSM = TV and TV, TSM and full TSM data set ≤ LOR					Step 3
Step	**Alt Hypothesis**	**Null Hypothesis**	**Sig Test Result**		**Risk Assessment**
1	TSM < TV	TSM = TV	p < 0.05	Accept Alt	LOW
			p > 0.05	Accept Null	POTENTIAL
			Error	Accept Neither	ND
2	TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR				POTENTIAL
3	TSM = TV and TV, TSM and full TSM data set are ≤ LOR				LOW

TSM = Test Site Median

ND = No determination

Table D-2 Expanded risk matrix – water quality – pH

Initial Assessment Result					Go To
Lower TV < TSM < Upper TV					Step 1
TSM ≤ Lower TV OR TSM ≥ Upper TV					Step 3
Step	**Alt Hypothesis**	**Null Hypothesis**	**Sig Test Result**		**Risk Assessment**
1	TSM < Upper TV	TSM = Upper TV	p < 0.05	Accept Alt	STEP 2
			p > 0.05	Accept Null	POTENTIAL
2	TSM > Lower TV	TSM = Upper TV	p < 0.05	Accept Alt	LOW
			p > 0.05	Accept Null	POTENTIAL
			Error	Accept Neither	ND
3	TSM ≤ Lower TV OR TSM ≥ Upper TV				POTENTIAL

TSM = Test Site Median

ND = No determination

Table D-3 Water quality upper river test sites - SG2 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
SG2	N	N(Test)	Median	Result	Go to			
pH	14	11	7.7	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	0.002 / 0.002	LOW
EC	14	11	286	TSM ≥TV	Step 2	228	0.999	POTENTIAL
TSS	14	14	1550	TSM < TV	Step 1	2837	0.002	LOW
Ag-D	14	14	0.01	TSM < TV	Step 1	0.05	0.001	LOW
As-D	14	14	1.1	TSM < TV	Step 1	24	0.001	LOW
Cd-D	14	14	0.12	TSM < TV	Step 1	0.34	0.030	LOW
Cr-D	14	14	0.43	TSM < TV	Step 1	1.0	0.007	LOW
Cu-D	14	14	1.4	TSM = TV	Step 2	1.4	0.286	POTENTIAL
Fe-D	14	14	9.3	TSM < TV	Step 1	75	0.001	LOW
Hg-D	14	14	0.05	TSM < TV	Step 1	0.60	0.001	LOW
Ni-D	14	14	0.97	TSM < TV	Step 1	21	0.001	LOW
Pb-D	14	14	0.18	TSM < TV	Step 1	7.3	0.001	LOW
Se-D	14	14	0.20	TSM < TV	Step 1	11	0.001	LOW
Zn-D	14	14	8.9	TSM < TV	Step 1	20	0.009	LOW

Table D-4 Water quality upper river test sites - Wasiba 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment			Statistical test Result (p=0.05)	Risk Assessment
Wasiba	N	N(Test)	Median	Result	Go to	TV		
pH	15	15	7.5	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	<0.001 / <0.001	LOW
EC	15	15	265	TSM ≥TV	Step 2	228	0.989	POTENTIAL
TSS	15	15	1500	TSM < TV	Step 1	2837	0.012	LOW
Ag-D	15	15	0.01	TSM < TV	Step 1	0.05	<0.001	LOW
As-D	15	15	0.99	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	15	15	0.09	TSM < TV	Step 1	0.34	0.006	LOW
Cr-D	15	15	0.26	TSM < TV	Step 1	1.0	0.001	LOW
Cu-D	15	14	1.2	TSM < TV	Step 1	1.4	0.275	POTENTIAL
Fe-D	15	14	15	TSM < TV	Step 1	75	0.001	LOW
Hg-D	15	15	0.05	TSM < TV	Step 1	0.60	<0.001	LOW
Ni-D	15	15	0.76	TSM < TV	Step 1	21	<0.001	LOW
Pb-D	15	15	0.18	TSM < TV	Step 1	7.3	<0.001	LOW
Se-D	15	15	0.20	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	15	15	7.2	TSM < TV	Step 1	20	<0.001	LOW

Table D-5 Water quality upper river test sites - Wankipe 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Wankipe	N	N(Test)	Median	Result	Go to			
pH	17	17	7.7	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	<0.001 / <0.001	LOW
EC	17	17	239	TSM ≥TV	Step 2	228	0.935	POTENTIAL
TSS	17	17	1400	TSM < TV	Step 1	2837	0.017	LOW
Ag-D	17	17	0.01	TSM < TV	Step 1	0.05	0.003	LOW
As-D	17	17	1.1	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	17	17	0.05	TSM < TV	Step 1	0.34	0.003	LOW
Cr-D	17	17	0.43	TSM < TV	Step 1	1.0	0.001	LOW
Cu-D	17	17	1.3	TSM < TV	Step 1	1.4	0.251	POTENTIAL
Fe-D	17	17	12	TSM < TV	Step 1	75	0.197	POTENTIAL
Hg-D	17	17	0.05	TSM < TV	Step 1	0.60	<0.001	LOW
Ni-D	17	17	0.71	TSM < TV	Step 1	21	<0.001	LOW
Pb-D	17	17	0.26	TSM < TV	Step 1	7.3	<0.001	LOW
Se-D	17	17	0.20	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	17	17	5.4	TSM < TV	Step 1	20	<0.001	LOW

Table D-6 Water quality upper river test sites - SG3 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
SG3	N	N(Test)	Median	Result	Go to			
pH	196	195	7.6	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.2	<0.001 / <0.001	LOW
EC	196	195	233	TSM ≥TV	Step 2	228	0.968	POTENTIAL
TSS	196	196	1500	TSM < TV	Step 1	2837	<0.001	LOW
Ag-D	196	196	0.01	TSM < TV	Step 1	0.05	<0.001	LOW
As-D	196	196	0.99	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	196	196	0.05	TSM < TV	Step 1	0.34	<0.001	LOW
Cr-D	196	194	0.28	TSM < TV	Step 1	1.0	<0.001	LOW
Cu-D	196	184	1.2	TSM < TV	Step 1	1.4	<0.001	LOW
Fe-D	196	196	12	TSM < TV	Step 1	75	<0.001	LOW
Hg-D	196	196	0.05	TSM < TV	Step 1	0.60	<0.001	LOW
Ni-D	196	196	0.63	TSM < TV	Step 1	21	<0.001	LOW
Pb-D	196	196	0.13	TSM < TV	Step 1	7.3	<0.001	LOW
Se-D	196	196	0.20	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	196	196	4.0	TSM < TV	Step 1	20	<0.001	LOW

Table D-7 Water quality lower river test sites - Bebelubi 2018 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
Bebelubi	N	N (Test)	Median	Result	Go to			
pH	7	7	7.4	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.1	0.011 / 0.011	LOW
EC	7	7	217	TSM ≥TV	Step 2	186	0.974	POTENTIAL
TSS	7	7	550	TSM < TV	Step 1	983	0.017	LOW
Ag-D	7	7	0.01	TSM < TV	Step 1	0.05	0.223	POTENTIAL
As-D	7	7	0.81	TSM < TV	Step 1	24	0.011	LOW
Cd-D	7	7	0.05	TSM < TV	Step 1	0.20	0.026	LOW
Cr-D	7	7	0.45	TSM < TV	Step 1	1.0	0.038	LOW
Cu-D	7	7	1.3	TSM < TV	Step 1	1.4	0.600	POTENTIAL
Fe-D	7	7	7.9	TSM < TV	Step 1	75	0.011	LOW
Hg-D	7	7	0.05	TSM < TV	Step 1	0.60	0.011	LOW
Ni-D	7	7	0.67	TSM < TV	Step 1	15	0.011	LOW
Pb-D	7	7	0.23	TSM < TV	Step 1	3.4	0.011	LOW
Se-D	7	7	0.20	TSM < TV	Step 1	11	0.011	LOW
Zn-D	7	7	3.4	TSM < TV	Step 1	8.0	0.136	POTENTIAL

Table D-8 Water quality lower river test sites - SG4 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical test Result (p=0.05)	Risk Assessment
SG4	N	N (Test)	Median	Result	Go to			
pH	8	7	7.4	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.1	0.011 / 0.011	LOW
EC	8	7	182	TSM < TV	Step 1	186	0.336	POTENTIAL
TSS	8	8	455	TSM < TV	Step 1	983	0.181	POTENTIAL
Ag-D	8	8	0.01	TSM < TV	Step 1	0.05	0.688	POTENTIAL
As-D	8	8	0.83	TSM < TV	Step 1	24	0.007	LOW
Cd-D	8	8	0.05	TSM < TV	Step 1	0.20	0.007	LOW
Cr-D	8	7	0.46	TSM < TV	Step 1	1.0	0.038	LOW
Cu-D	8	8	0.98	TSM < TV	Step 1	1.4	0.007	LOW
Fe-D	8	8	8.2	TSM < TV	Step 1	75	0.007	LOW
Hg-D	8	8	0.05	TSM < TV	Step 1	0.60	0.007	LOW
Ni-D	8	8	0.65	TSM < TV	Step 1	15	0.007	LOW
Pb-D	8	8	0.19	TSM < TV	Step 1	3.4	0.007	LOW
Se-D	8	8	0.20	TSM < TV	Step 1	11	0.007	LOW
Zn-D	8	8	2.2	TSM < TV	Step 1	8.0	0.092	POTENTIAL

Table D-9 Water quality lower river test sites - SG5 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG5	N	N (Test)	Median	Result	Go to			
pH	13	12	7.4	Lower TV<TSM<Upper TV	Step 1 / 2	6.0-8.1	0.001 / 0.001	LOW
EC	13	12	159	TSM < TV	Step 1	186	0.002	LOW
TSS	13	13	280	TSM < TV	Step 1	983	0.001	LOW
Ag-D	13	13	0.01	TSM < TV	Step 1	0.05	0.001	LOW
As-D	13	13	0.88	TSM < TV	Step 1	24	0.001	LOW
Cd-D	13	13	0.05	TSM < TV	Step 1	0.20	0.001	LOW
Cr-D	13	13	0.33	TSM < TV	Step 1	1.0	0.015	LOW
Cu-D	13	13	1.0	TSM < TV	Step 1	1.4	0.071	POTENTIAL
Fe-D	13	13	25	TSM < TV	Step 1	75	0.001	LOW
Hg-D	13	13	0.05	TSM < TV	Step 1	0.60	0.001	LOW
Ni-D	13	12	0.50	TSM < TV	Step 1	15	0.001	LOW
Pb-D	13	13	0.10	TSM < TV	Step 1	3.4	0.001	LOW
Se-D	13	13	0.20	TSM < TV	Step 1	11	0.001	LOW
Zn-D	13	11	2.4	TSM < TV	Step 1	8.0	0.031	LOW

Table D-10 Water quality ORWB test sites - Kukufionga 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Kukufionga	N	N (Test)	Median	Result	Go to			
pH	10	10	7.1	Lower TV < TSM < Upper TV	Step 1/2	6.0-8.1	0.003 / 0.003	LOW
EC	10	10	157	TSM ≥ Upper TV	Step 2	186	0.042	LOW
TSS	10	10	64	TSM ≥ Upper TV	Step 2	983	0.003	LOW
Ag-D	10	10	0.01	TSM < Upper TV	Step 1	0.05	0.003	LOW
As-D	10	10	1.0	TSM < Upper TV	Step 1	24	0.003	LOW
Cd-D	10	10	0.05	TSM < Upper TV	Step 1	0.20	0.003	LOW
Cr-D	10	10	0.29	TSM < Upper TV	Step 1	1.0	0.003	LOW
Cu-D	10	10	0.98	TSM < Upper TV	Step 1	1.4	0.003	LOW
Fe-D	10	10	16	TSM < Upper TV	Step 1	75	0.003	LOW
Hg-D	10	10	0.06	TSM < Upper TV	Step 1	0.60	0.003	LOW
Ni-D	10	10	0.50	TSM < Upper TV	Step 1	15	0.003	LOW
Pb-D	10	10	0.10	TSM < Upper TV	Step 1	3.4	0.003	LOW
Se-D	10	10	0.20	TSM < Upper TV	Step 1	11	0.003	LOW
Zn-D	10	10	2.3	TSM < Upper TV	Step 1	8.0	0.003	LOW

Table D-11 Water quality ORWB test sites - Zongamange 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Zongamange	N	N (Test)	Median	Result	Go to			
pH	12	12	6.9	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	0.001 / 0.001	LOW
EC	12	12	110	TSM < Upper TV	Step 1	186	0.001	LOW
TSS	12	12	2.5	TSM < Upper TV	Step 1	983	0.001	LOW
Ag-D	12	12	0.01	TSM < Upper TV	Step 1	0.05	0.001	LOW
As-D	12	12	0.53	TSM < Upper TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.05	TSM < Upper TV	Step 1	0.20	0.001	LOW
Cr-D	12	12	0.16	TSM < Upper TV	Step 1	1.0	0.001	LOW
Cu-D	12	12	0.49	TSM < Upper TV	Step 1	1.4	0.001	LOW
Fe-D	12	12	39	TSM < Upper TV	Step 1	75	0.039	LOW
Hg-D	12	12	0.06	TSM < Upper TV	Step 1	0.60	0.001	LOW
Ni-D	12	12	0.50	TSM < Upper TV	Step 1	15	0.001	LOW
Pb-D	12	12	0.14	TSM < Upper TV	Step 1	3.4	0.001	LOW
Se-D	12	12	0.20	TSM < Upper TV	Step 1	11	0.001	LOW
Zn-D	12	12	1.6	TSM < Upper TV	Step 1	8.0	0.001	LOW

Table D-12 Water quality ORWB test sites - Avu 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Avu	N	N (Test)	Median	Result	Go to			
pH	12	12	6.3	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	0.001 / 0.098	POTENTIAL
EC	12	12	55	TSM < Upper TV	Step 1	186	0.001	LOW
TSS	12	12	5.0	TSM < Upper TV	Step 1	983	0.001	LOW
Ag-D	12	12	0.01	TSM < Upper TV	Step 1	0.05	0.001	LOW
As-D	12	12	0.61	TSM < Upper TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.05	TSM < Upper TV	Step 1	0.20	0.001	LOW
Cr-D	12	12	0.43	TSM < Upper TV	Step 1	1.0	0.008	LOW
Cu-D	12	12	0.29	TSM < Upper TV	Step 1	1.4	0.004	LOW
Fe-D	12	12	375	TSM ≥ Upper TV	Step 1	75	0.999	POTENTIAL
Hg-D	12	12	0.05	TSM < Upper TV	Step 1	0.60	0.001	LOW
Ni-D	12	12	0.70	TSM < Upper TV	Step 1	15	0.001	LOW
Pb-D	12	12	0.14	TSM < Upper TV	Step 1	3.4	0.001	LOW
Se-D	12	12	0.20	TSM < Upper TV	Step 1	11	0.001	LOW
Zn-D	12	12	2.1	TSM < Upper TV	Step 1	8.0	0.001	LOW

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians; Risk assessment is based on direct comparison.

Table D-13 Water quality ORWB test sites - Levame 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Levame	N	N (Test)	Median	Result	Go to			
pH	9	9	7.3	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	0.005 / 0.005	LOW
EC	9	9	165	TSM < Upper TV	Step 1	186	0.318	POTENTIAL
TSS	9	9	18	TSM < Upper TV	Step 1	983	0.005	LOW
Ag-D	9	9	0.01	TSM < Upper TV	Step 1	0.05	0.005	LOW
As-D	9	9	1.0	TSM < Upper TV	Step 1	24	0.005	LOW
Cd-D	9	9	0.05	TSM < Upper TV	Step 1	0.20	0.005	LOW
Cr-D	9	9	0.19	TSM < Upper TV	Step 1	1.0	0.005	LOW
Cu-D	9	9	1.0	TSM < Upper TV	Step 1	1.4	0.029	LOW
Fe-D	9	9	29	TSM < Upper TV	Step 1	75	0.043	LOW
Hg-D	9	9	0.05	TSM < Upper TV	Step 1	0.60	0.005	LOW
Ni-D	9	9	0.50	TSM < Upper TV	Step 1	15	0.005	LOW
Pb-D	9	9	0.11	TSM < Upper TV	Step 1	3.4	0.005	LOW
Se-D	9	9	0.20	TSM < Upper TV	Step 1	11	0.005	LOW
Zn-D	9	9	1.1	TSM < Upper TV	Step 1	8.0	0.005	LOW

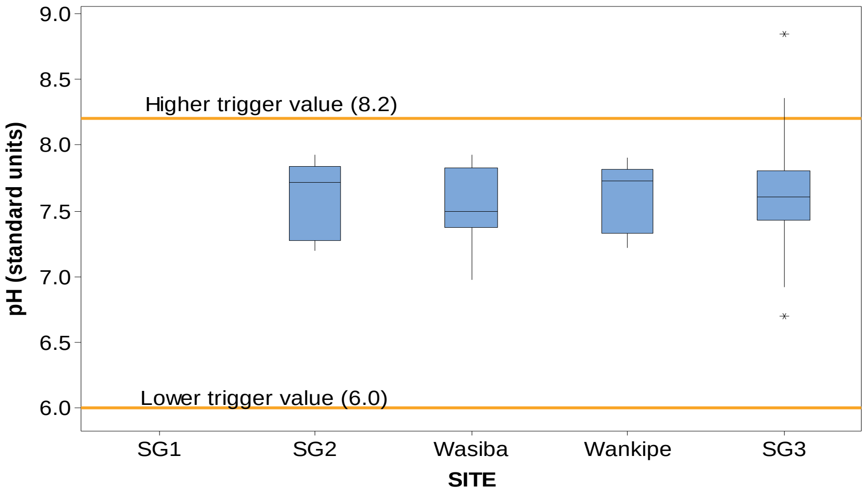

Figure D-1 pH in water upper river test sites 2019

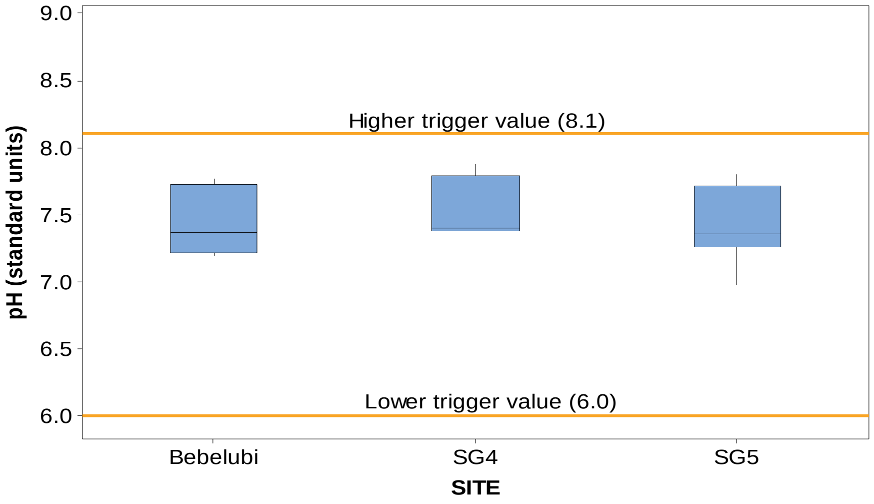

Figure D-2 pH in water at lower river test sites 2019

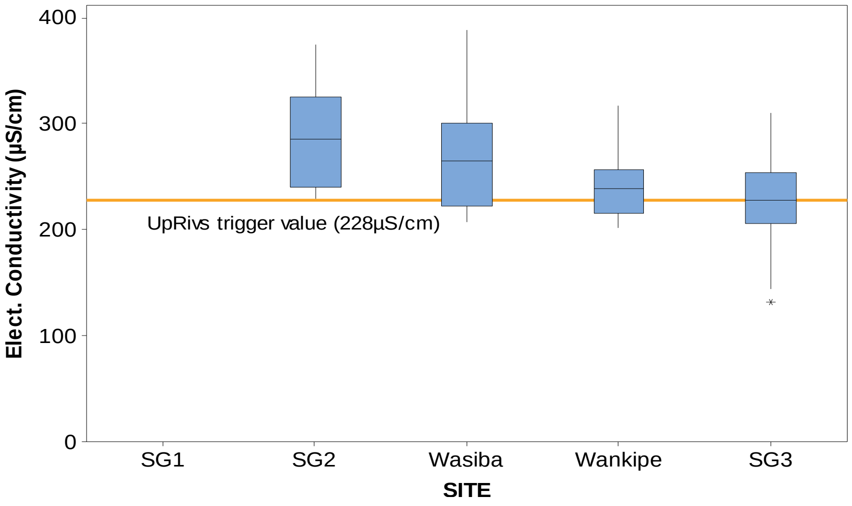

Figure D-3 Electrical conductivity in water upper river test sites 2019

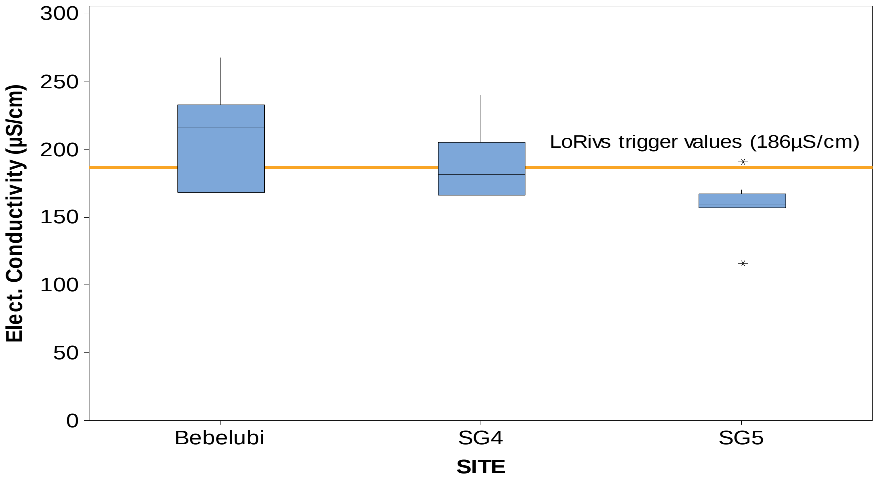

Figure D-4 Electrical conductivity in water at lower river test sites 2019

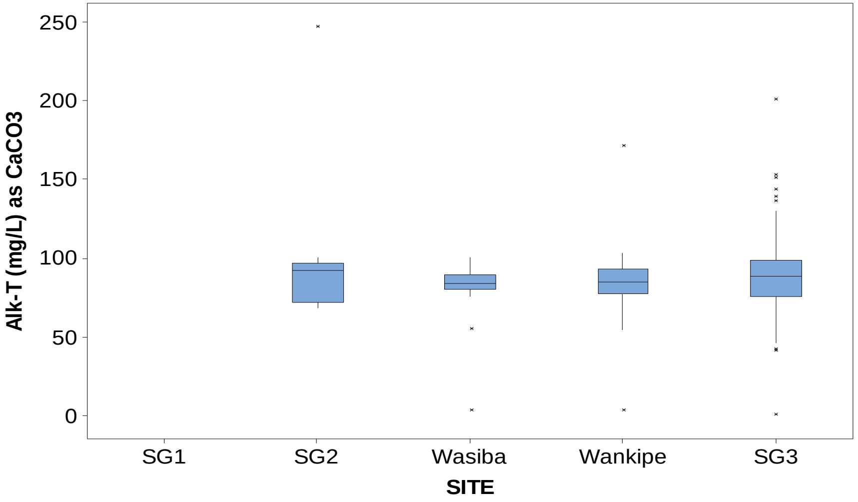

Figure D-5 Alkalinity in water upper river test sites 2019

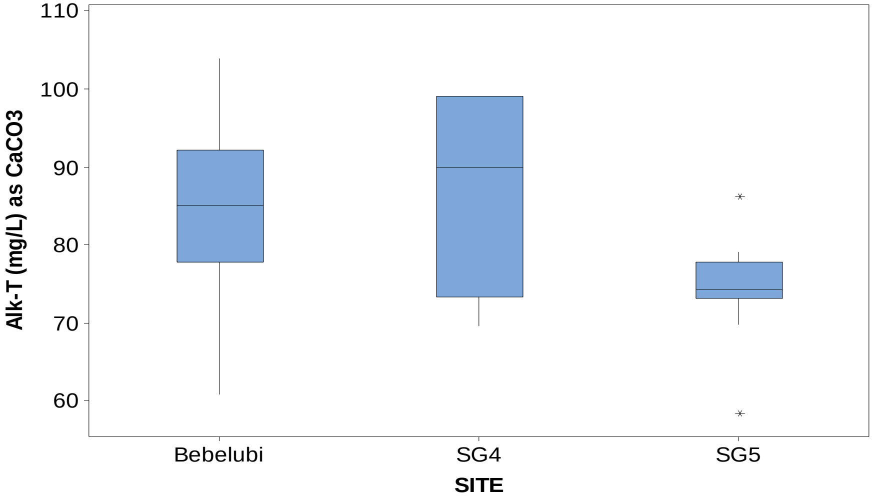

Figure D-6 Alkalinity in water lower river test sites 2019

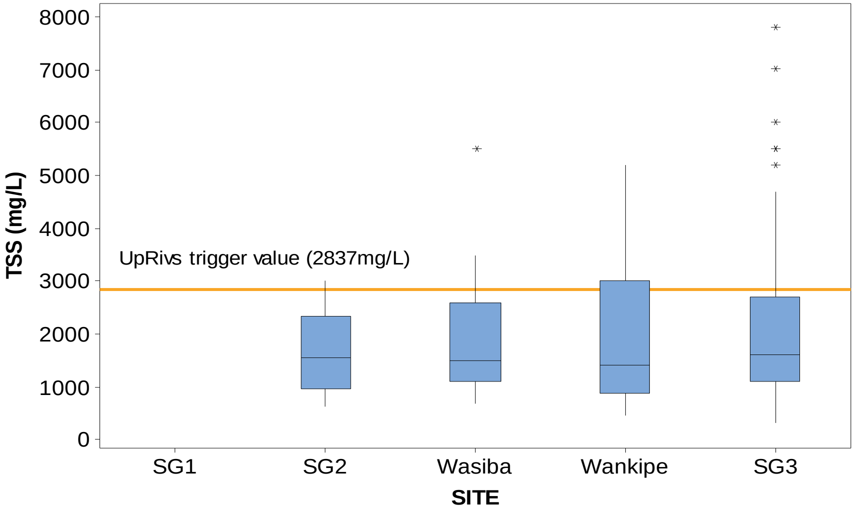

Figure D-7 TSS in water upper river test sites 2019

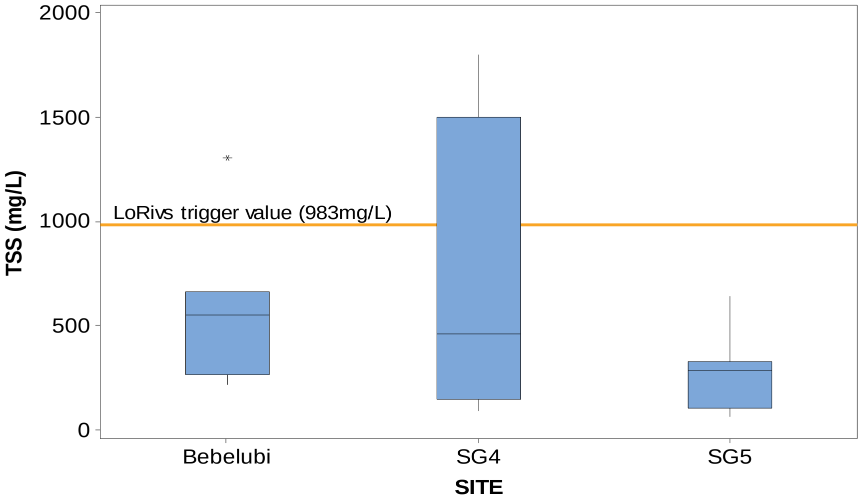

Figure D-8 TSS in water lower river test sites 2019

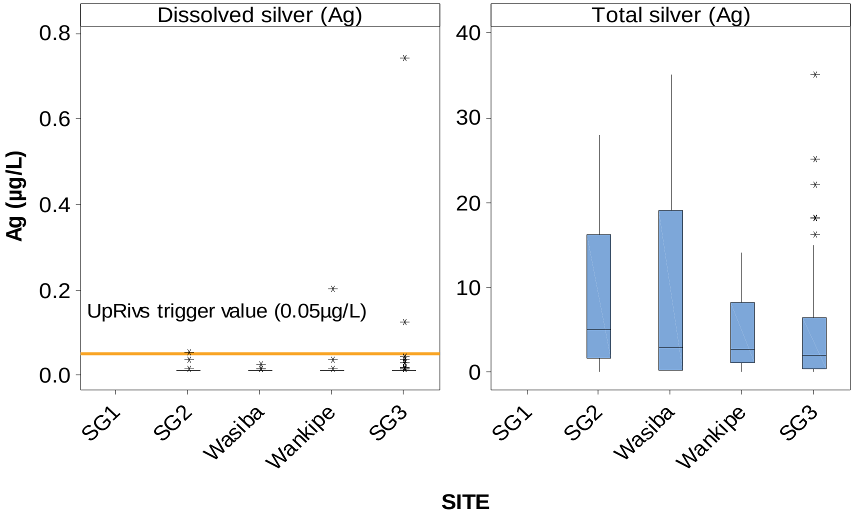

Figure D-9 Silver in water upper river test sites 2019

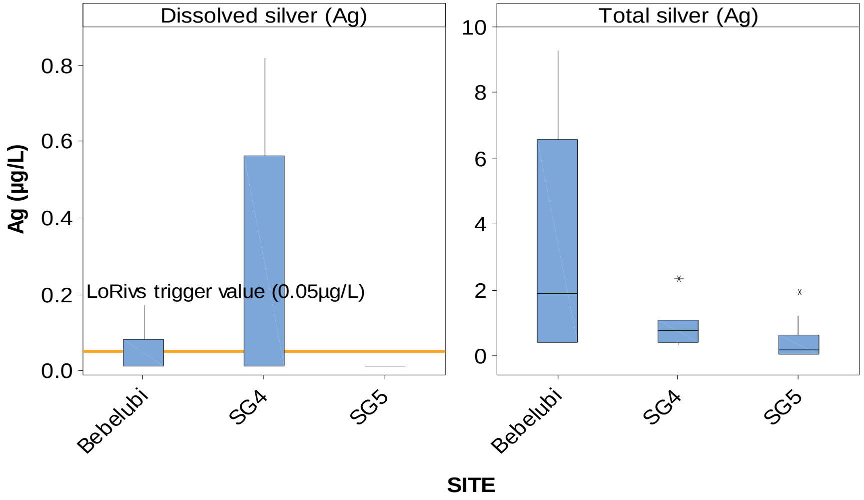

Figure D-10 Silver in water lower river test sites 2019

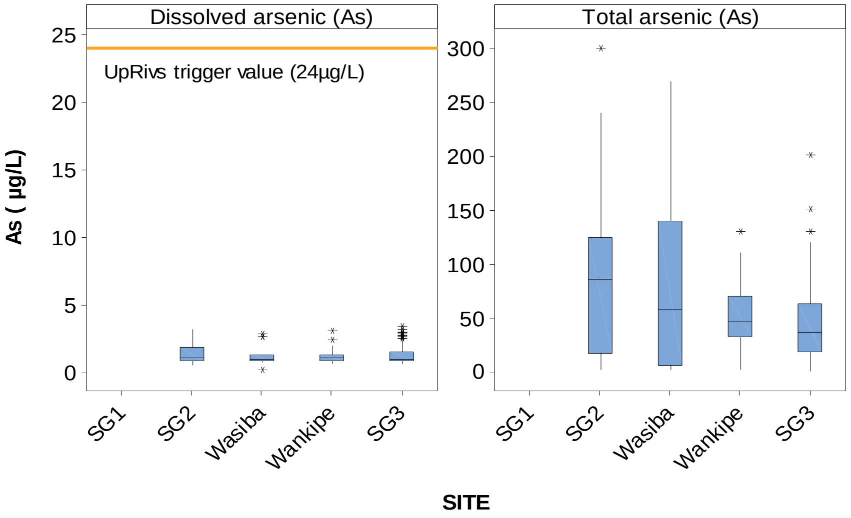

Figure D-11 Arsenic in water upper river test sites 2019

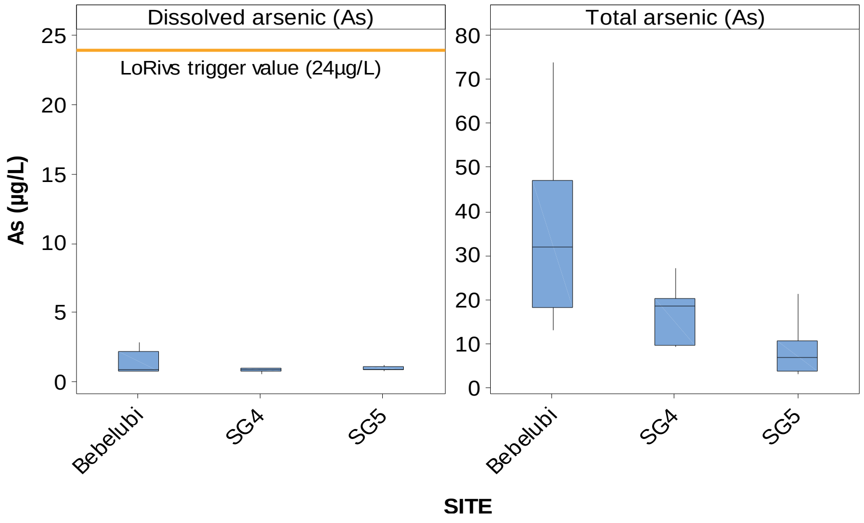

Figure D-12 Arsenic in water lower river test sites 2019

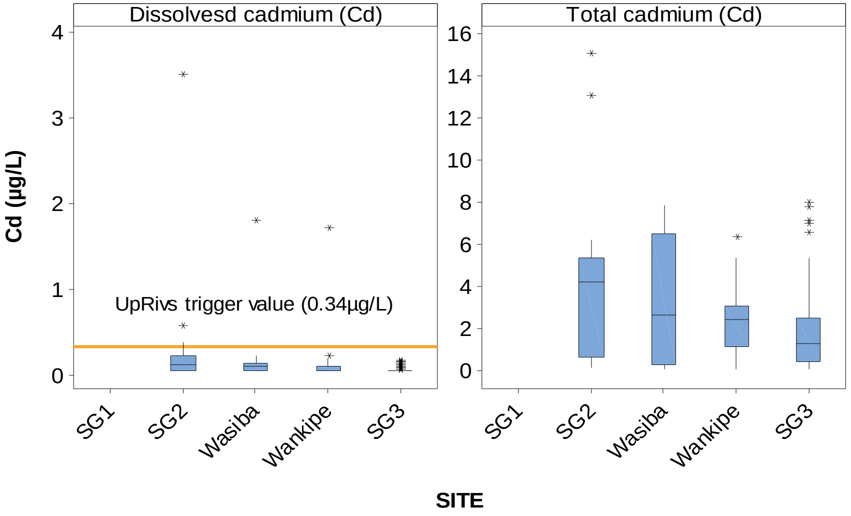

Figure D-13 Cadmium in water upper river test sites 2019

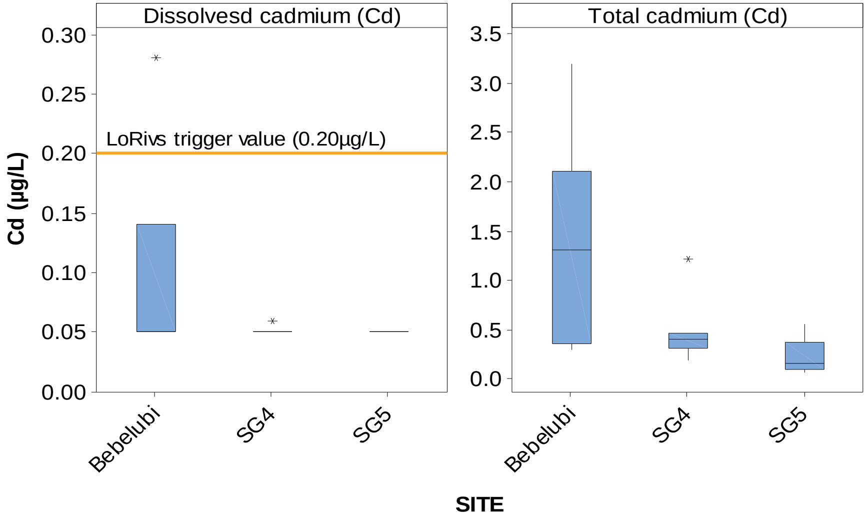

Figure D-14 Cadmium in water lower river test sites 2019

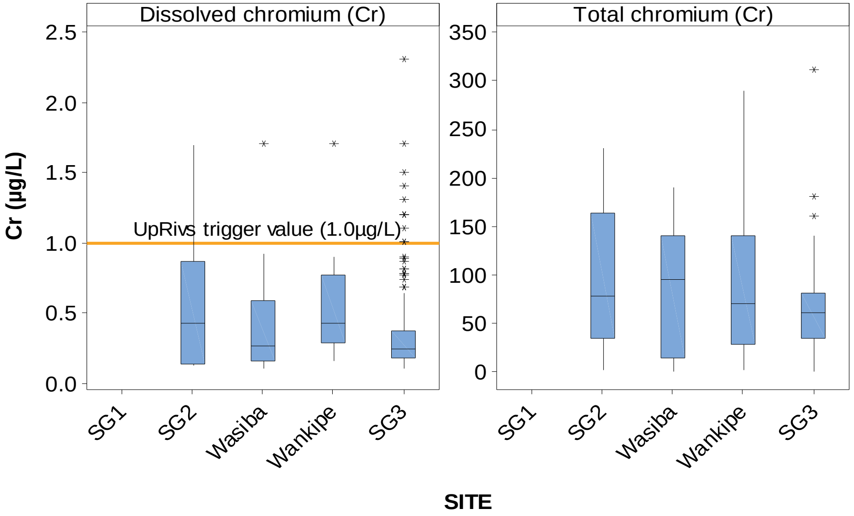

Figure D-15 Chromium in water upper river test sites 2019

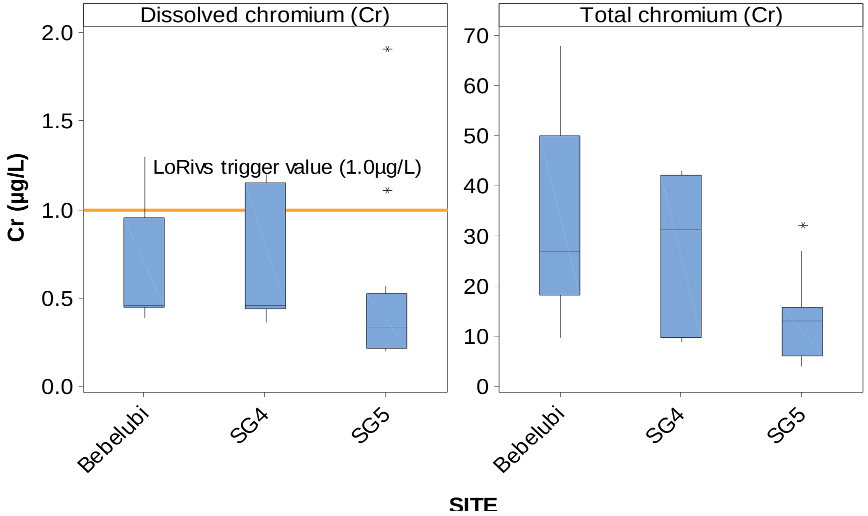

Figure D-16 Chromium in water lower river test sites 2019

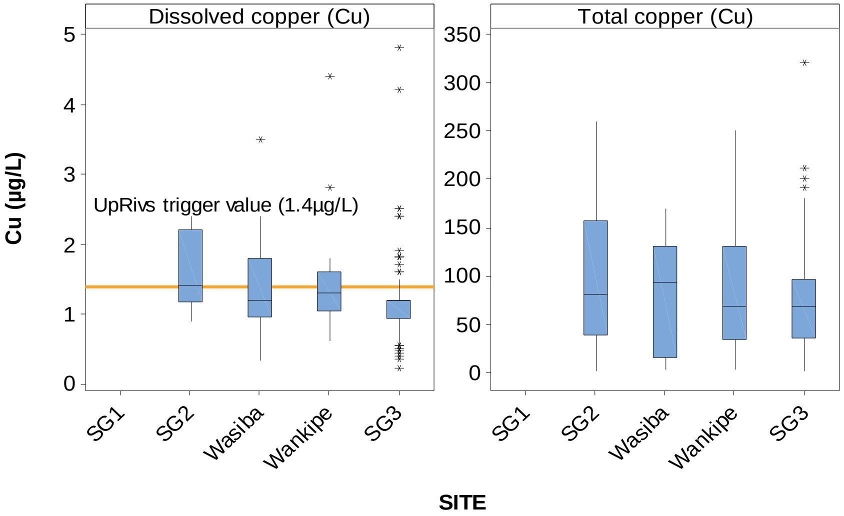

Figure D-17 Copper in water upper river test sites 2019

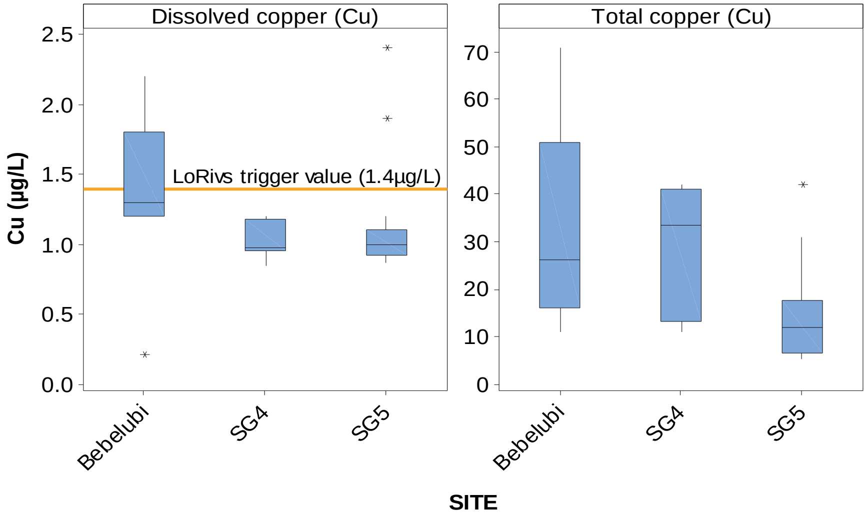

Figure D-18 Copper in water lower river test sites 2019

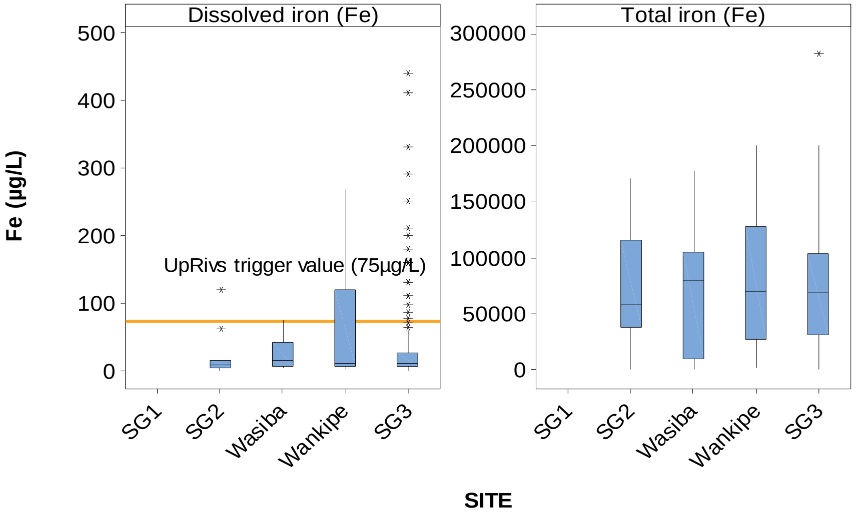

Figure D-19 Iron in water upper river test sites 2019

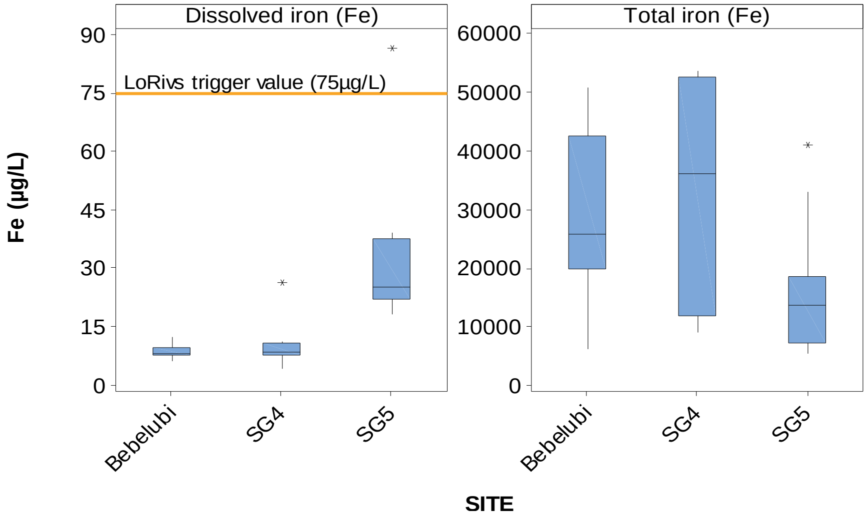

Figure D-20 Iron in water lower river test sites 2019

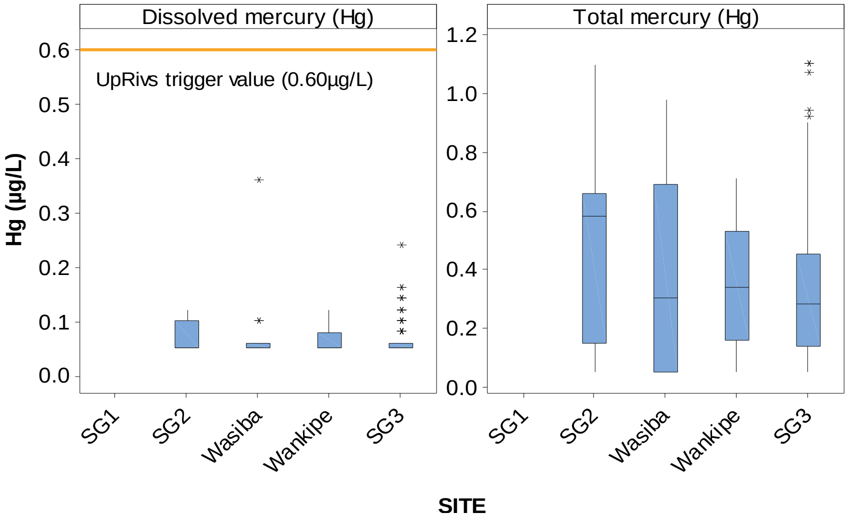

Figure D-21 Mercury in water upper river test sites 2019

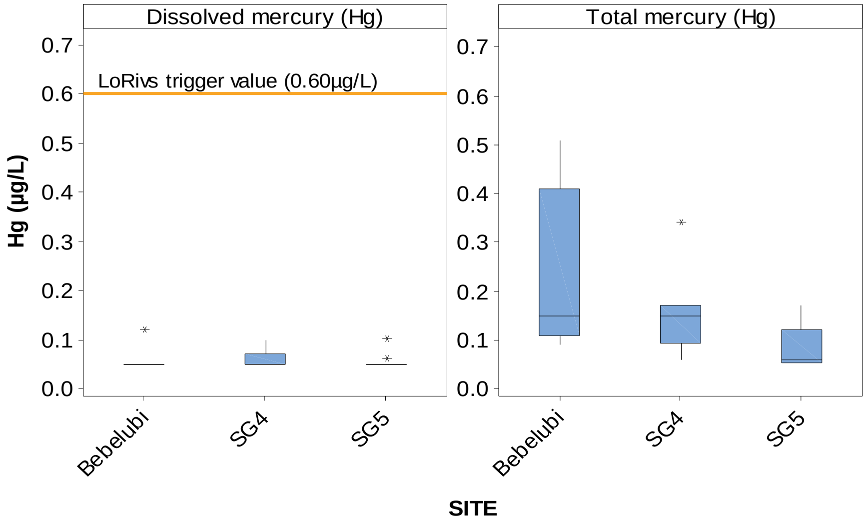

Figure D-22 Mercury in water lower river test sites 2019

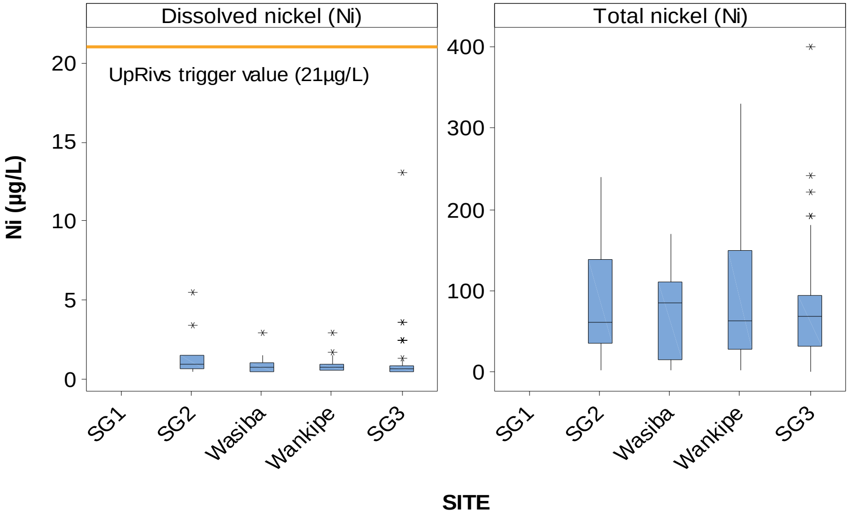

Figure D-23 Nickel in water upper river test sites 2019

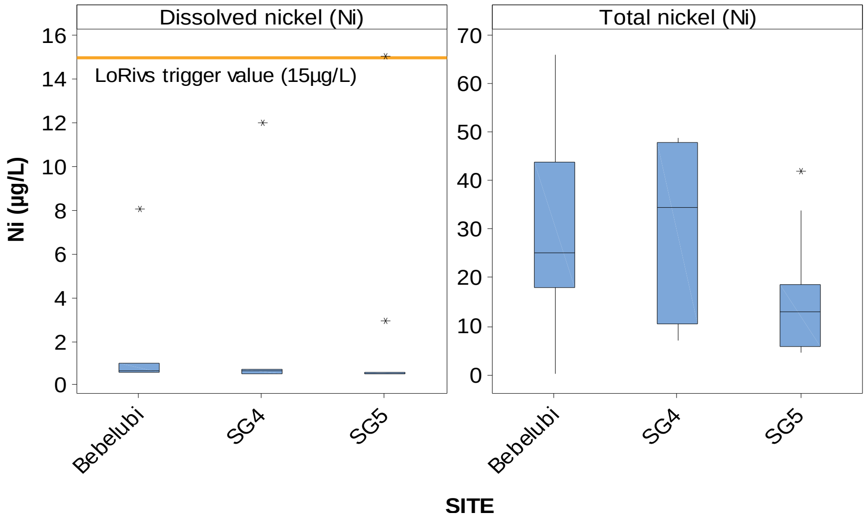

Figure D-24 Nickel in water lower river test sites 2019

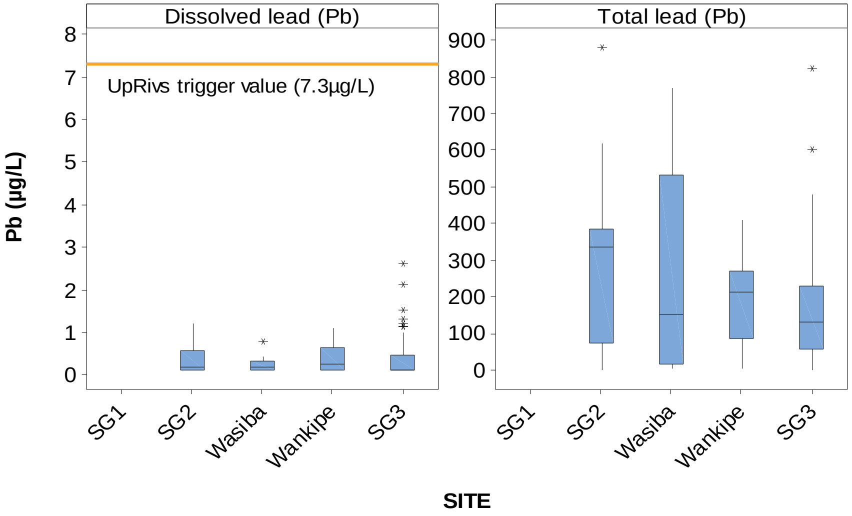

Figure D-25 Lead in water upper river test sites 2019

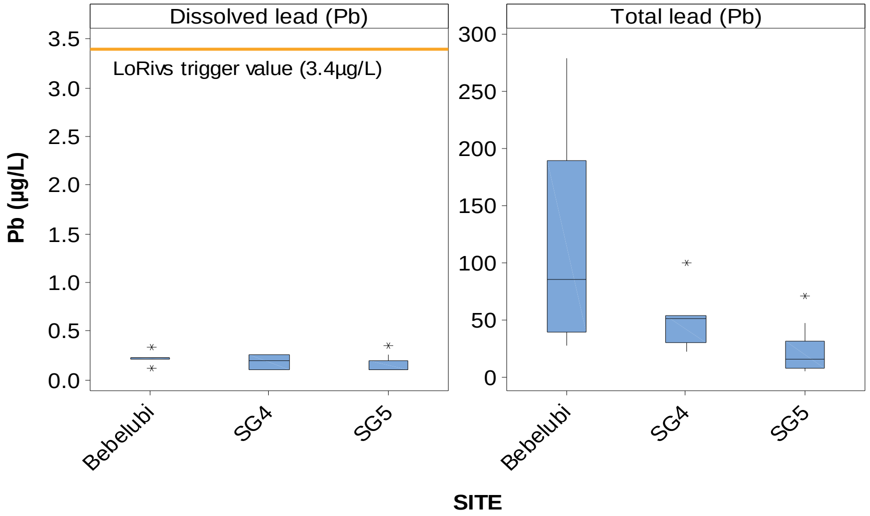

Figure D-26 Lead in water lower river test sites 2019

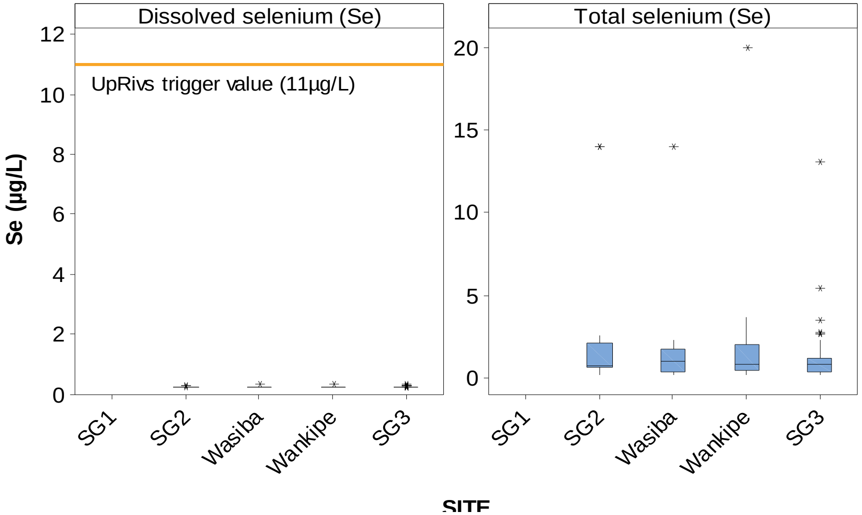

Figure D-27 Selenium in water upper river test sites 2019

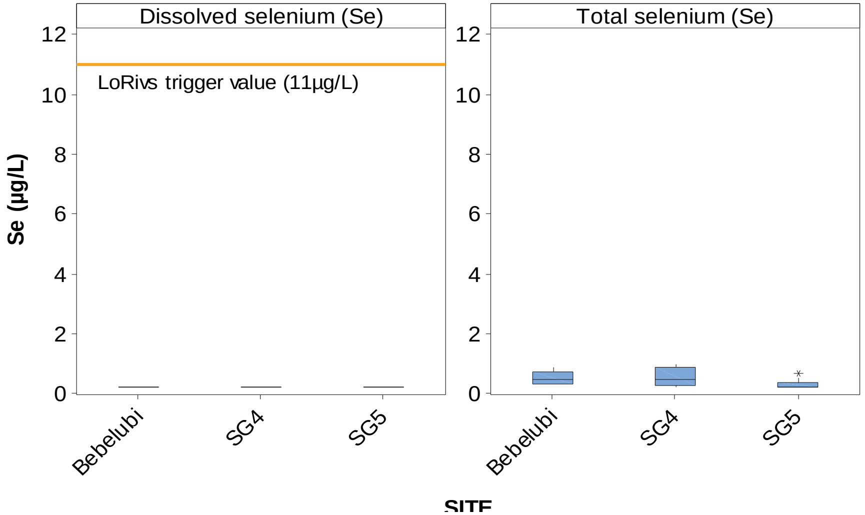

Figure D-28 Selenium in water lower river test sites 2019

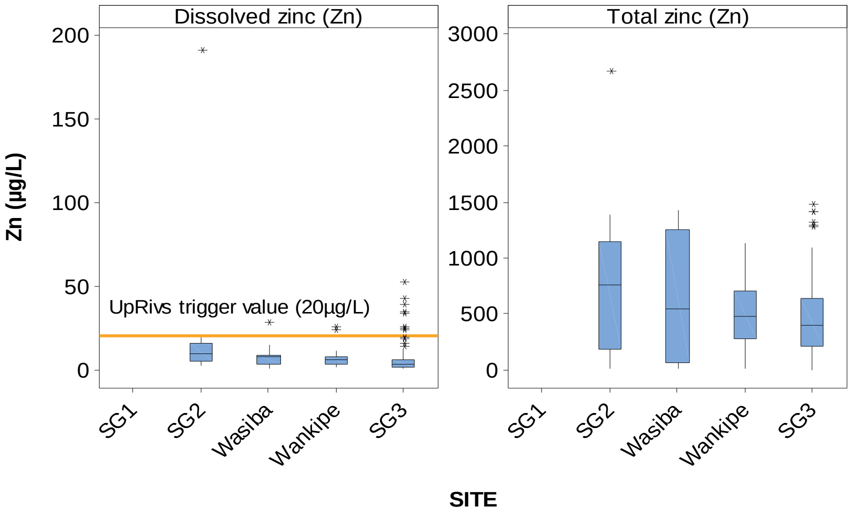

Figure D-29 Zinc in water upper river test sites 2019

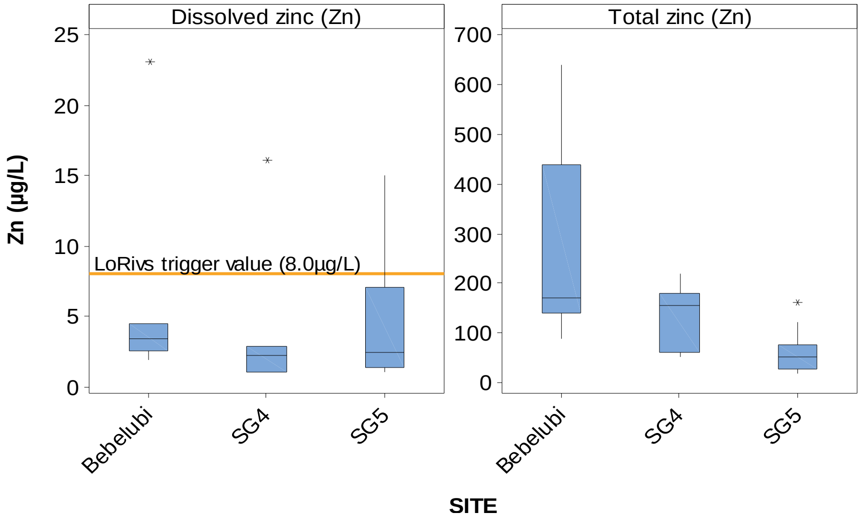

Figure D-30 Zinc in water lower river test sites 2019

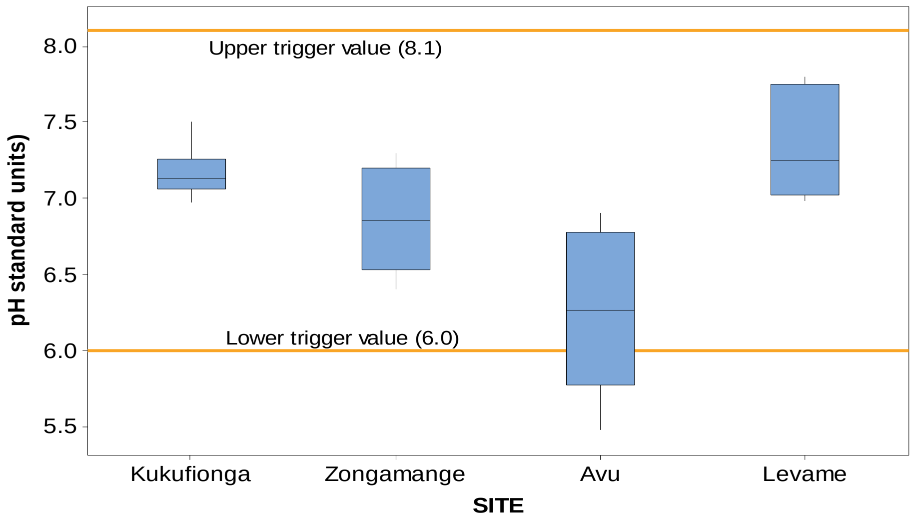

Figure D-31 pH in water ORWB test sites 2019

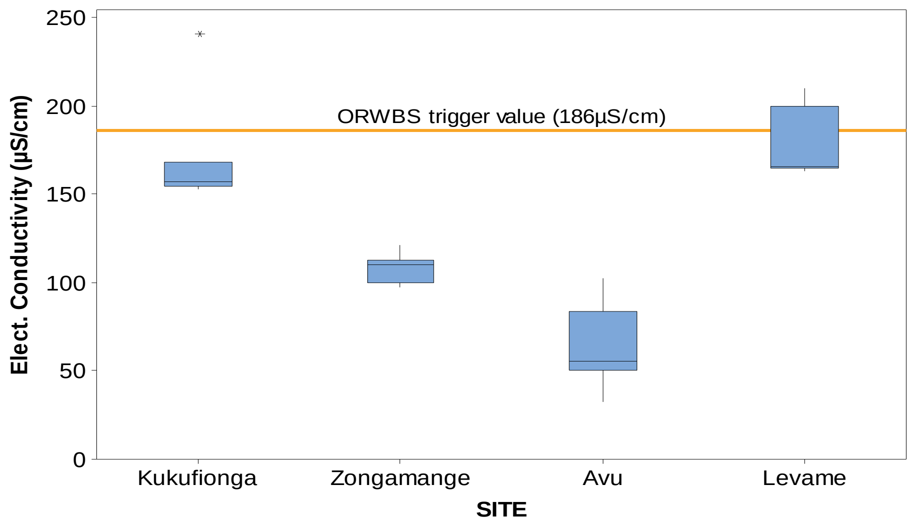

Figure D-32 Electrical conductivity in water ORWB test sites 2019

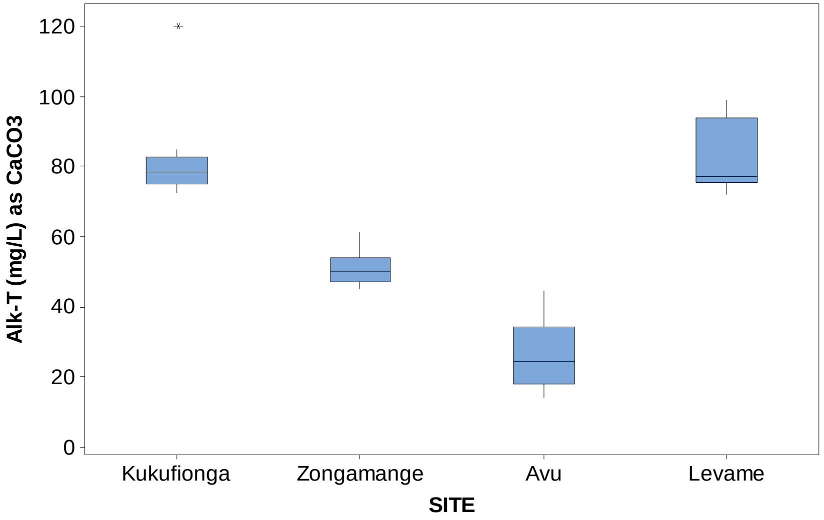

Figure D-33 Alkalinity in water ORWB test sites 2019

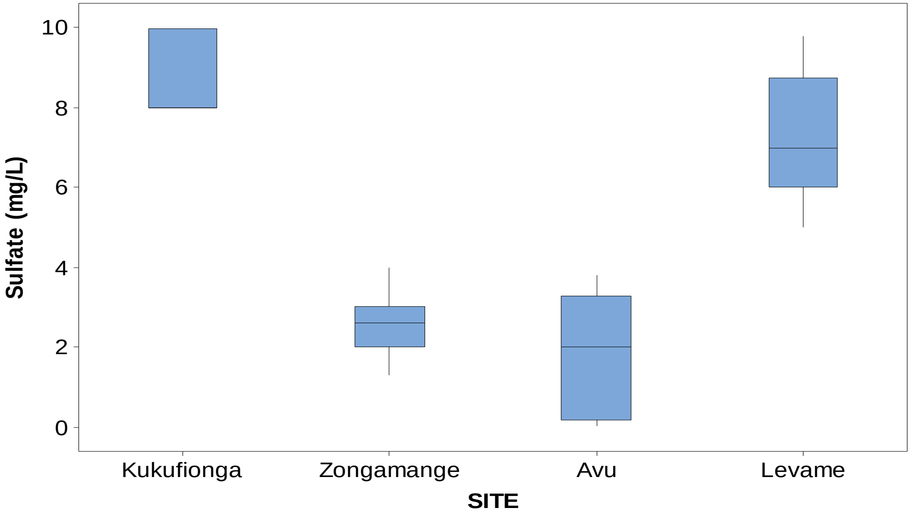

Figure D-34 Sulfate in water ORWB test sites 2019

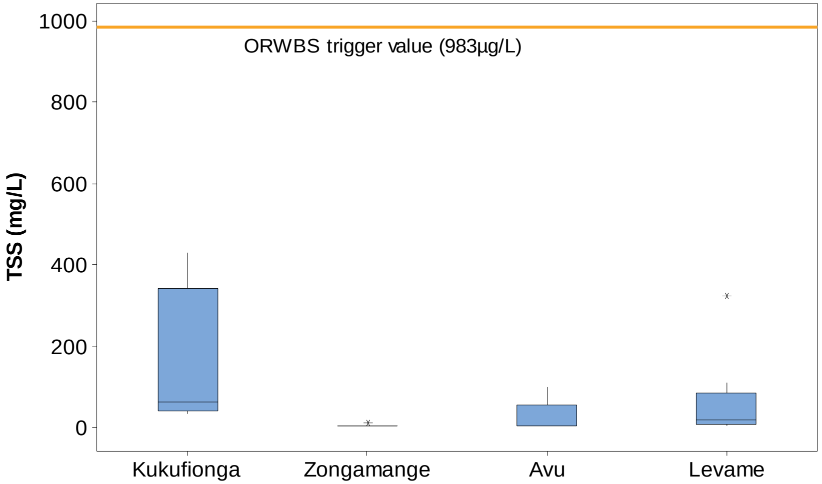

Figure D-35 TSS in water ORWB test sites 2019

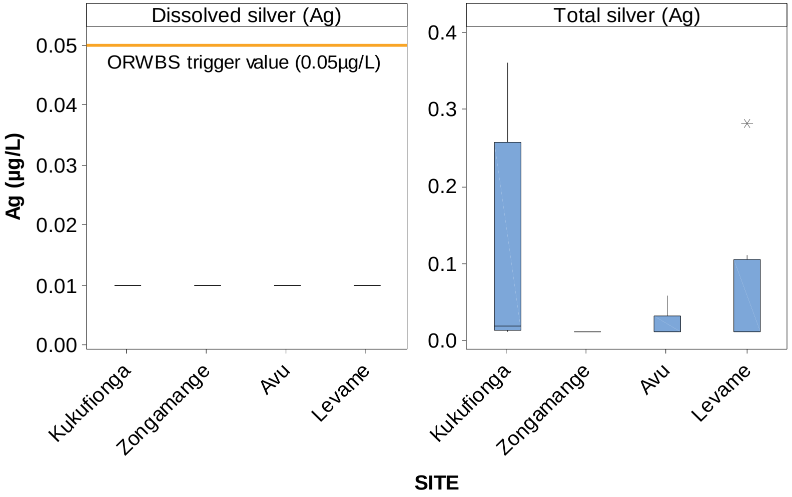

Figure D-36 Silver in water ORWB test sites 2019

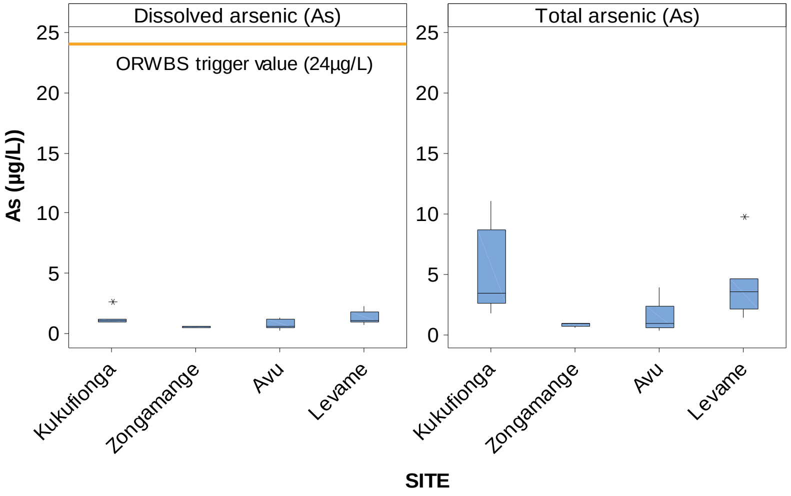

Figure D-37 As in water ORWB test sites 2019

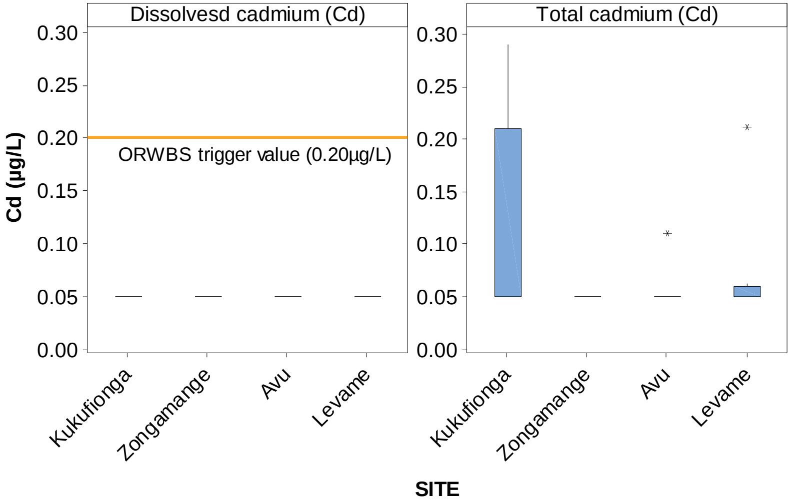

Figure D-38 Cadmium in water ORWB test sites 2019

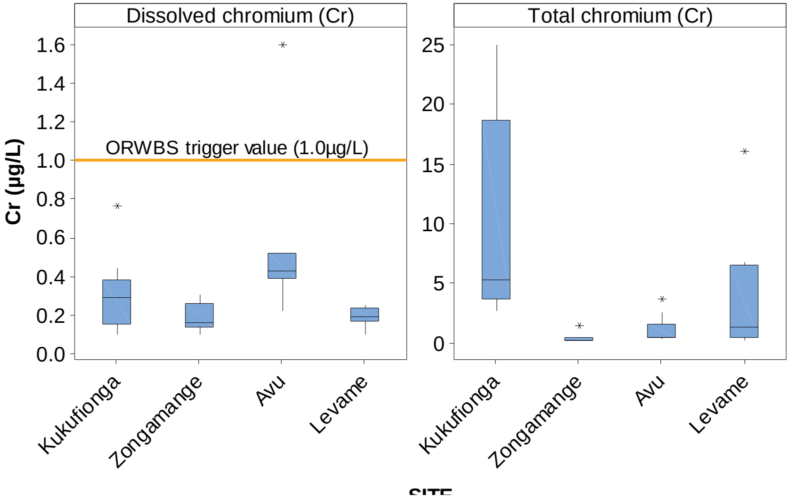

Figure D-39 Cr in water ORWB test sites 2019

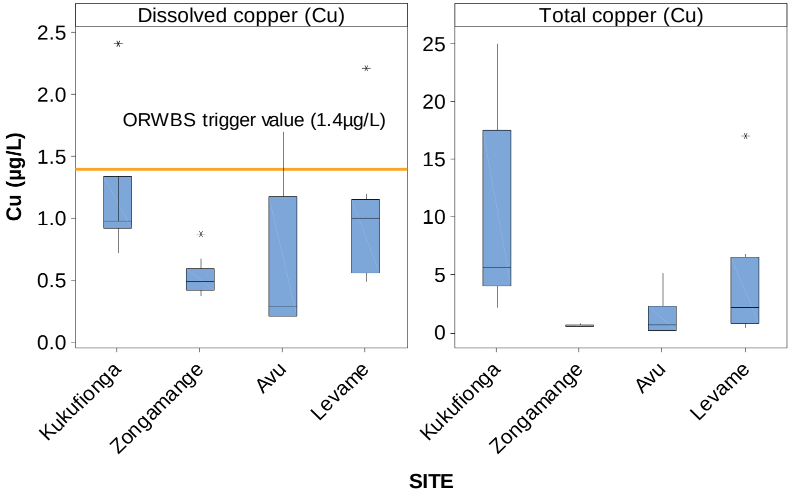

Figure D-40 Copper in water ORWB test sites 2019

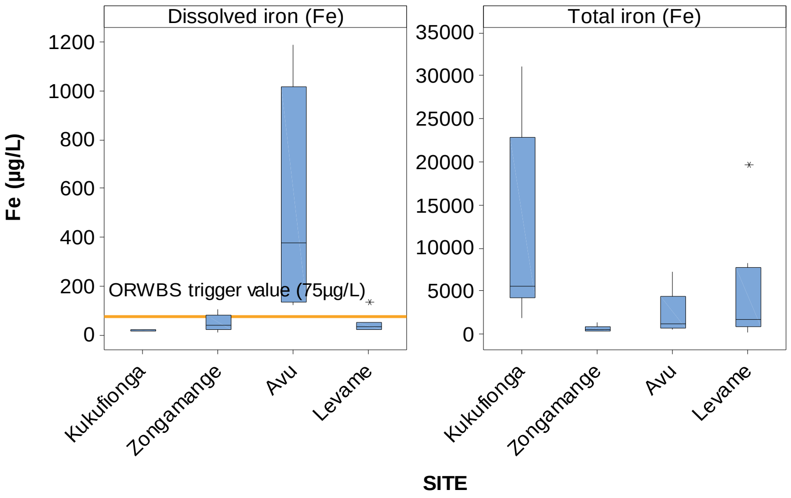

Figure D-41 Iron in water ORWB test sites 2019

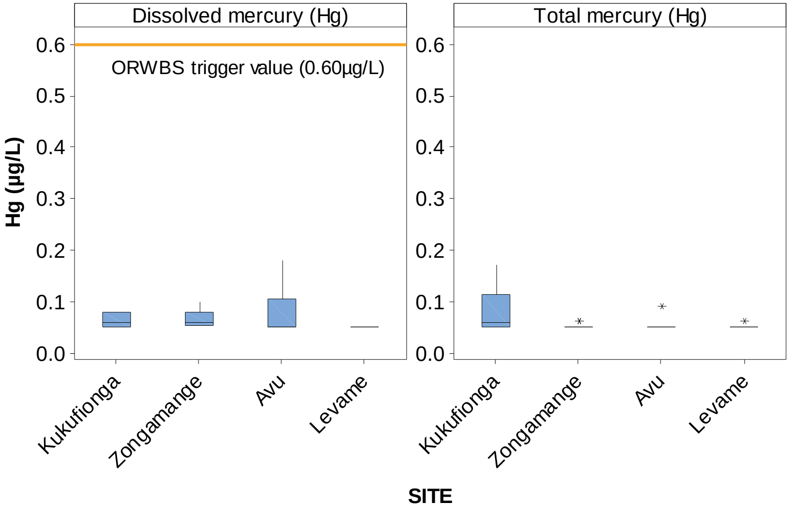

Figure D-42 Mercury in water ORWB test sites 2019

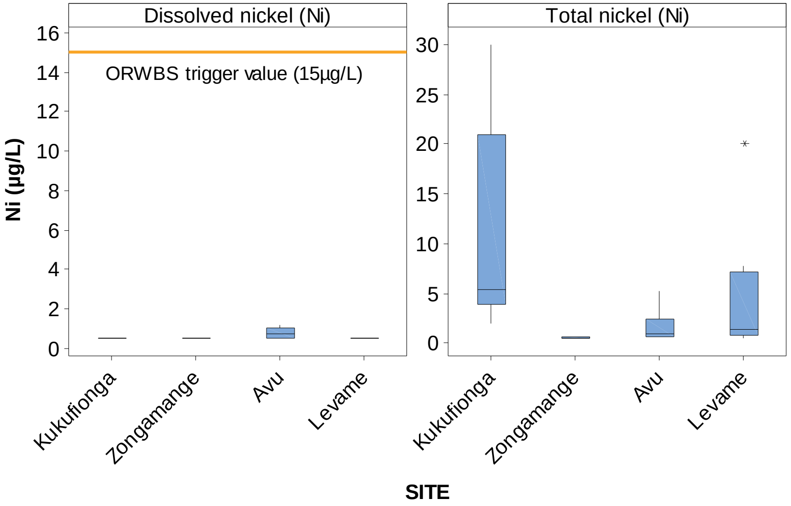

Figure D-43 Nickel in water ORWB test sites 2019

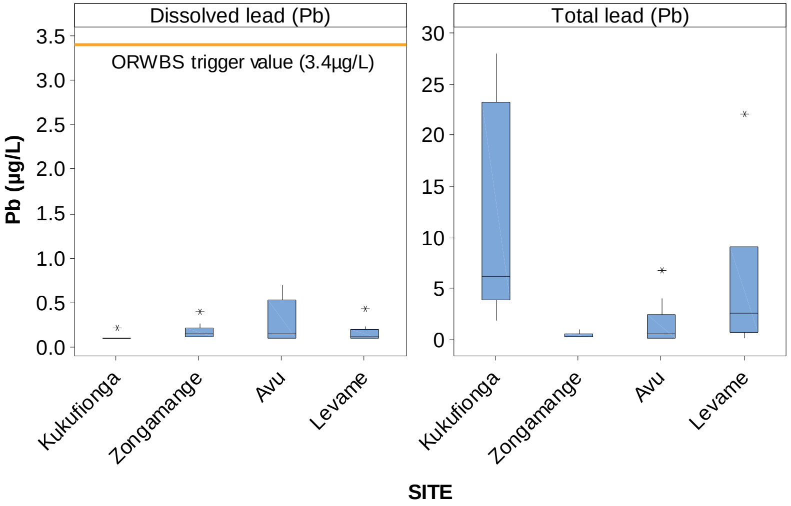

Figure D-44 Lead in water ORWB test sites 2019

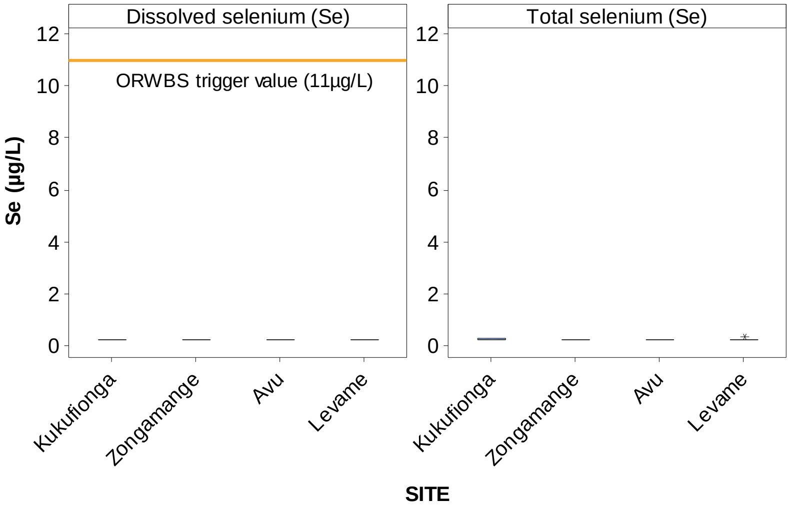

Figure D-45 Selenium in water ORWB test sites 2019

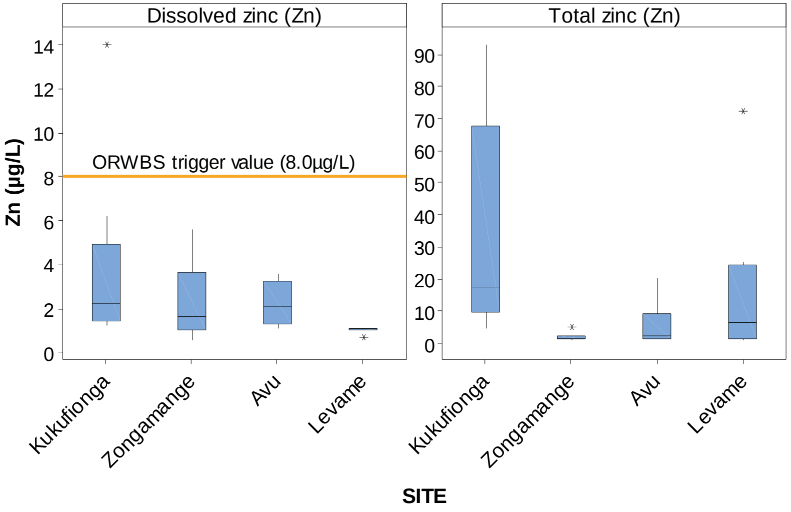

Figure D-46 Zinc in water ORWB test sites 2019

Table D-14 Performance assessment – Based on the trend of water quality indicators (all data) at upper river test sites between 2010 and 2019 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2010 - 2019
SG1 (Trend of all data 2010 - 2015) Monitoring not conducted since 2015	pH	-0.066	0.578	No change over time
	EC	-0.601	<0.001	Reduced over time
	TSS	-0.426	<0.001	Reduced over time
	Ag-D*	-0.362	0.002	No change over time
	As-D	-0.579	<0.001	Reduced over time
	Cd-D	-0.089	0.455	No change over time
	Cr-D*	-0.714	<0.001	No change over time
	Cu-D	-0.123	0.300	No change over time
	Fe-D	0.058	0.626	No change over time
	Hg-D*	-0.520	<0.001	No change over time
	Ni-D	-0.138	0.246	No change over time
	Pb-D*	-0.254	0.030	No change over time
	Se-D*	-0.663	0.001	No change over time
	Zn-D	-0.088	0.457	No change over time
SG2 (Trend of all data 2010 - 2019)	pH	-0.193	0.038	Reduced over time
	EC	-0.341	<0.001	Reduced over time
	TSS	-0.153	0.096	No change over time
	Ag-D*	-0.865	<0.001	No change over time
	As-D*	-0.381	<0.001	No change over time
	Cd-D*	-0.370	<0.001	No change over time
	Cr-D*	-0.587	<0.001	No change over time
	Cu-D*	-0.319	<0.001	No change over time
	Fe-D	-0.098	0.287	No change over time
	Hg-D*	-0.626	<0.001	No change over time
	Ni-D*	-0.272	0.003	No change over time
	Pb-D*	-0.597	<0.001	No change over time
	Se-D*	-0.623	<0.001	No change over time
	Zn-D	-0.163	0.077	No change over time
Wasiba (Trend of all data 2010 - 2019)	pH	0.295	0.006	Increased over time
	EC	-0.306	0.004	Reduced over time
	TSS	0.163	0.132	No change over time
	Ag-D*	-0.711	<0.001	No change over time
	As-D	-0.297	0.004	Reduced over time
	Cd-D*	-0.267	0.011	No change over time
	Cr-D	-0.017	0.874	No change over time
	Cu-D	-0.204	0.053	No change over time
	Fe-D	0.310	0.003	Increased over time
	Hg-D	0.231	0.029	Increased over time
	Ni-D*	-0.244	0.02	No change over time
	Pb-D	-0.075	0.485	No change over time
	Se-D*	-0.287	0.006	No change over time
	Zn-D	0.028	0.793	No change over time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2010 - 2019
Wankipe (Trend of all data 2010 - 2019)	pH	-0.309	<0.001	Reduced over time
	EC	-0.371	<0.001	Reduced over time
	TSS	0.006	0.942	No change over time
	Ag-D*	-0.844	<0.001	No change over time
	As-D*	-0.417	<0.001	No change over time
	Cd-D*	-0.568	<0.001	No change over time
	Cr-D*	-0.525	<0.001	No change over time
	Cu-D	0.017	0.842	No change over time
	Fe-D	0.215	0.013	Increased over time
	Hg-D*	-0.533	<0.001	No change over time
	Ni-D*	-0.477	<0.001	No change over time
	Pb-D*	-0.483	<0.001	No change over time
	Se-D*	-0.584	<0.001	No change over time
	Zn-D	0.172	0.049	Increased over time
SG3 (Trend of all data 2010 - 2019)	pH	-0.503	<0.001	Reduced over time
	EC	-0.249	<0.001	Reduced over time
	TSS	0.006	0.812	No change over time
	Ag-D*	-0.860	<0.001	No change over time
	As-D*	-0.369	<0.001	No change over time
	Cd-D*	-0.614	<0.001	No change over time
	Cr-D*	-0.664	<0.001	No change over time
	Cu-D*	-0.172	<0.001	No change over time
	Fe-D	0.241	<0.001	Increased over time
	Hg-D*	-0.645	<0.001	No change over time
	Ni-D*	-0.644	<0.001	No change over time
	Pb-D*	-0.630	<0.001	No change over time
	Se-D*	-0.667	<0.001	No change over time
	Zn-D	0.122	<0.001	Increased 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.

Table D-15 Performance assessment – Based on the trend of water quality indicators (all data) at lower river test sites between 2010 and 2019 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend 2010 - 2019
Bebelubi (Trend of all data 2010 - 2019)	pH	-0.328	0.006	Reduced over time
	EC	0.074	0.547	No change over time
	TSS	-0.275	0.022	Reduced over time
	Ag-D*	-0.845	<0.001	No change over time
	As-D*	-0.351	0.002	No change over time
	Cd-D*	-0.713	<0.001	No change over time
	Cr-D*	-0.685	<0.001	No change over time
	Cu-D	-0.200	0.08	No change over time
	Fe-D	0.027	0.818	No change over time
	Hg-D*	-0.688	<0.001	No change over time
	Ni-D*	-0.655	<0.001	No change over time
	Pb-D*	-0.782	<0.001	No change over time
	Se-D*	-0.756	<0.001	No change over time
	Zn-D	0.304	0.007	Increased over time
SG4 (Trend of all data 2010 - 2019)	pH	-0.277	0.018	Reduced over time
	EC	0.210	0.074	No change over time
	TSS	-0.128	0.277	No change over time
	Ag-D*	-0.700	<0.001	No change over time
	As-D*	-0.611	<0.001	No change over time
	Cd-D*	-0.798	<0.001	No change over time
	Cr-D*	-0.555	<0.001	No change over time
	Cu-D	-0.165	0.145	No change over time
	Fe-D	0.060	0.599	No change over time
	Hg-D*	-0.780	<0.001	No change over time
	Ni-D*	-0.593	<0.001	No change over time
	Pb-D*	-0.713	<0.001	No change over time
	Se-D*	-0.750	<0.001	No change over time
	Zn-D	0.144	0.205	No change over time
SG5 (Trend of all data 2010 - 2019)	pH	0.227	0.098	No change over time
	EC	0.237	0.084	No change over time
	TSS	0.078	0.585	No change over time
	Ag-D*	-0.901	<0.001	No change over time
	As-D*	-0.297	0.028	No change over time
	Cd-D*	-0.694	<0.001	No change over time
	Cr-D	-0.010	0.941	No change over time
	Cu-D	-0.114	0.408	No change over time
	Fe-D	-0.083	0.545	No change over time
	Hg-D*	-0.629	<0.001	No change over time
	Ni-D*	-0.406	0.002	No change over time
	Pb-D*	-0.404	0.002	No change over time
	Se-D	≤LOR	≤LOR	No change over time
	Zn-D	0.117	0.400	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.

Table D-16 Performance assessment – Based on the trend of water quality indicators (all data) at ORWB test sites between 2010 and 2019 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend 2010 - 2019
Kukufionga (Trend of all data 2010 - 2019)	pH	-0.031	0.862	No change over time
	EC	-0.630	<0.001	Reduced over time
	TSS	0.591	<0.001	Increased over time
	Ag-D*	-0.887	<0.001	No change over time
	As-D*	-0.574	<0.001	No change over time
	Cd-D*	-0.551	<0.001	No change over time
	Cr-D	0.088	0.609	No change over time
	Cu-D	0.322	0.056	No change over time
	Fe-D	0.338	0.044	Increased over time
	Hg-D*	-0.532	0.001	No change over time
	Ni-D*	-0.551	<0.001	No change over time
	Pb-D	-0.306	0.069	No change over time
	Se-D	-0.302	0.088	No change over time
	Zn-D	0.248	0.146	No change over time
Zongamange (Trend of all data 2010 - 2019)	pH	0.023	0.904	No change over time
	EC	-0.520	0.040	Reduced over time
	TSS	-0.667	<0.001	Reduced over time
	Ag-D*	-0.846	<0.001	No change over time
	As-D*	-0.814	<0.001	No change over time
	Cd-D*	-0.577	0.001	No change over time
	Cr-D	-0.319	0.075	No change over time
	Cu-D*	-0.476	0.006	No change over time
	Fe-D	0.040	0.830	No change over time
	Hg-D	-0.257	0.155	No change over time
	Ni-D*	-0.494	0.004	No change over time
	Pb-D	0.146	0.427	No change over time
	Se-D	-0.319	0.091	No change over time
	Zn-D	-0.034	0.856	No change over time
Avu (Trend of all data 2010 - 2019)	pH	0.014	0.937	No change over time
	EC	-0.413	0.012	Reduced over time
	TSS	-0.172	0.323	No change over time
	Ag-D*	-0.873	<0.001	No change over time
	As-D	-0.162	0.324	No change over time
	Cd-D*	-0.531	0.001	No change over time
	Cr-D	0.130	0.428	No change over time
	Cu-D	-0.123	0.457	No change over time
	Fe-D	0.235	0.151	No change over time
	Hg-D*	-0.494	0.001	No change over time
	Ni-D	0.150	0.363	No change over time
	Pb-D	-0.023	0.888	No change over time
	Se-D	-0.288	0.088	No change over time
	Zn-D	0.237	0.147	No change over time

Water Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend 2010 - 2019
Levame (Trend of all data 2015 - 2019)	pH	-0.258	0.286	No change over time
	EC	0.260	0.283	No change over time
	TSS	-0.724	<0.001	Reduced over time
	Ag-D	-0.394	0.095	No change over time
	As-D	0.347	0.146	No change over time
	Cd-D	≤LOR	≤LOR	No change over time
	Cr-D	0.223	0.359	No change over time
	Cu-D	0.062	0.801	No change over time
	Fe-D	0.313	0.192	No change over time
	Hg-D	0.347	0.145	No change over time
	Ni-D	≤LOR	≤LOR	No change over time
	Pb-D	0.664	0.002	Increased over time
	Se-D	≤LOR	≤LOR	No change over time
	Zn-D	-0.788	<0.001	Reduced over time

Insufficient data – Insufficient number of data points within the historical data set to support trend analysis.

* 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.

Table D-17 Water quality Lake Murray test sites - Central Lake Murray 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Central Lake	N	N (Test)	Median	Result	Go to			
pH	15	15	5.4	Lower TV < TSM < Upper TV	Step 1 / 2	5.0-8.0	<0.001 / 0.004	LOW
EC	15	15	16	TSM < Upper TV	Step 1	21	0.001	LOW
TSS	15	15	2.0	TSM < Upper TV	Step 1	13	<0.001	LOW
Ag-D	15	15	0.01	TSM < Upper TV	Step 1	0.05	<0.001	LOW
As-D	15	15	0.15	TSM < Upper TV	Step 1	24	<0.001	LOW
Cd-D	15	15	0.05	TSM < Upper TV	Step 1	0.72	<0.001	LOW
Cr-D	15	14	0.50	TSM < Upper TV	Step 1	1.0	0.004	LOW
Cu-D	15	15	0.37	TSM < Upper TV	Step 1	1.4	0.001	LOW
Fe-D	15	15	81	TSM < Upper TV	Step 1	340	0.004	LOW
Hg-D	15	15	0.06	TSM < Upper TV	Step 1	0.60	<0.001	LOW
Ni-D	15	15	0.57	TSM < Upper TV	Step 1	11	<0.001	LOW
Pb-D	15	15	0.10	TSM < Upper TV	Step 1	3.4	<0.001	LOW
Se-D	15	15	0.20	TSM < Upper TV	Step 1	11	<0.001	LOW
Zn-D	15	15	3.9	TSM < Upper TV	Step 1	8.1	0.001	LOW

Table D-18 Water quality Lake Murray test sites - South Lake Murray 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Southern Lake	N	N (Test)	Median	Result	Go to			
pH	22	22	6.3	Lower TV < TSM < Upper TV	Step 1 / 2	5.0-8.0	<0.001 / < 0.001	LOW
EC	22	22	23	TSM ≥ Upper TV	Step 2	21	0.032	POTENTIAL
TSS	22	22	2.0	TSM < Upper TV	Step 1	13	<0.001	LOW
Ag-D	22	22	0.01	TSM < Upper TV	Step 1	0.05	<0.001	LOW
As-D	22	22	0.23	TSM < Upper TV	Step 1	24	<0.001	LOW
Cd-D	22	22	0.05	TSM < Upper TV	Step 1	0.72	<0.001	LOW
Cr-D	22	22	0.33	TSM < Upper TV	Step 1	1.0	0.001	LOW
Cu-D	22	22	0.41	TSM < Upper TV	Step 1	1.4	<0.001	LOW
Fe-D	22	22	78	TSM < Upper TV	Step 1	340	<0.001	LOW
Hg-D	22	22	0.07	TSM < Upper TV	Step 1	0.60	<0.001	LOW
Ni-D	22	22	0.50	TSM < Upper TV	Step 1	11	<0.001	LOW
Pb-D	22	22	0.15	TSM < Upper TV	Step 1	3.4	<0.001	LOW
Se-D	22	22	0.20	TSM < Upper TV	Step 1	11	<0.001	LOW
Zn-D	22	22	2.9	TSM < Upper TV	Step 1	8.1	<0.001	LOW

Table D-19 Water quality Lake Murray test sites - SG6 2019 median (µg/L for metals, std pH units for pH, µS/cm for EC and mg/L for TSS)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG6	N	N (Test)	Median	Result	Go to			
pH	14	13	6.7	Lower TV < TSM < Upper TV	Step 1 / 2	5.0-8.0	0.001 / 0.001	LOW
EC	14	14	84	TSM ≥ Upper TV	Step 2	21	0.999	POTENTIAL
TSS	14	12	19	TSM ≥ Upper TV	Step 2	13	0.985	POTENTIAL
Ag-D	14	14	0.01	TSM < Upper TV	Step 1	0.05	0.001	LOW
As-D	14	14	0.45	TSM < Upper TV	Step 1	24	0.001	LOW
Cd-D	14	14	0.05	TSM < Upper TV	Step 1	0.72	0.001	LOW
Cr-D	14	14	0.18	TSM < Upper TV	Step 1	1.0	0.001	LOW
Cu-D	14	14	0.66	TSM < Upper TV	Step 1	1.4	0.001	LOW
Fe-D	14	14	71	TSM < Upper TV	Step 1	340	0.001	LOW
Hg-D	14	14	0.05	TSM < Upper TV	Step 1	0.60	0.001	LOW
Ni-D	14	14	0.50	TSM < Upper TV	Step 1	11	0.001	LOW
Pb-D	14	14	0.18	TSM < Upper TV	Step 1	3.4	0.001	LOW
Se-D	14	14	0.20	TSM < Upper TV	Step 1	11	0.001	LOW
Zn-D	14	14	1.7	TSM < Upper TV	Step 1	8.1	0.001	LOW

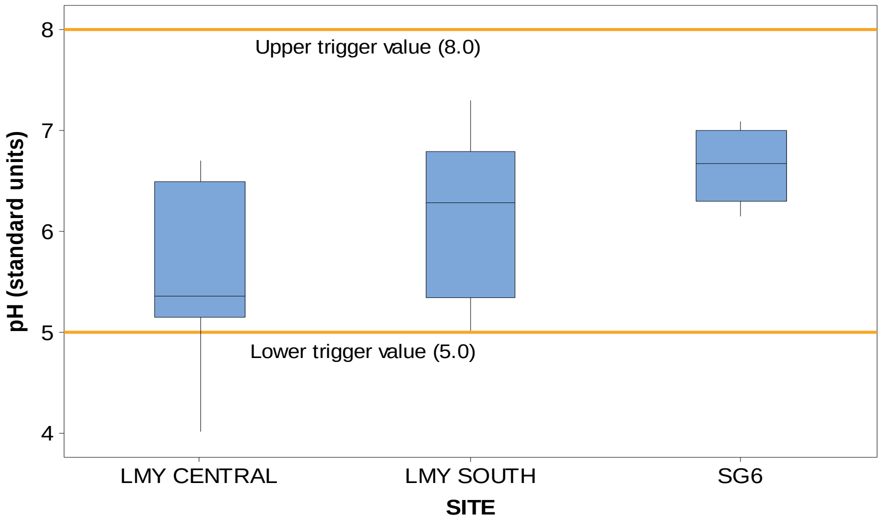

Figure D-47 pH in water Lake Murray test sites 2019

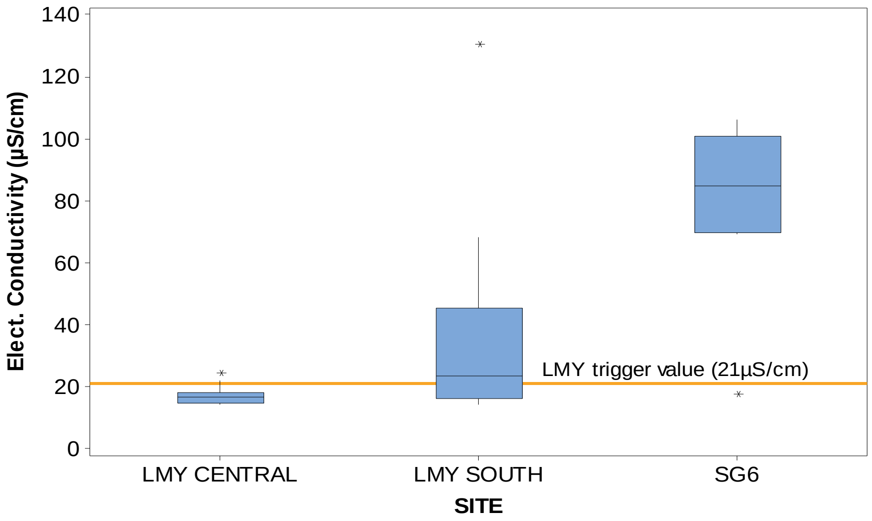

Figure D-48 Electrical conductivity in water Lake Murray test sites 2019

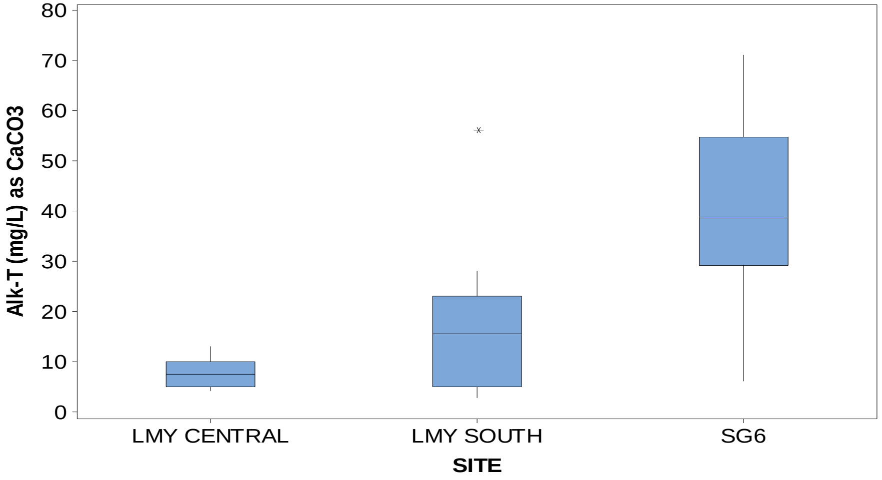

Figure D-49 Alkalinity in water Lake Murray test sites 2019

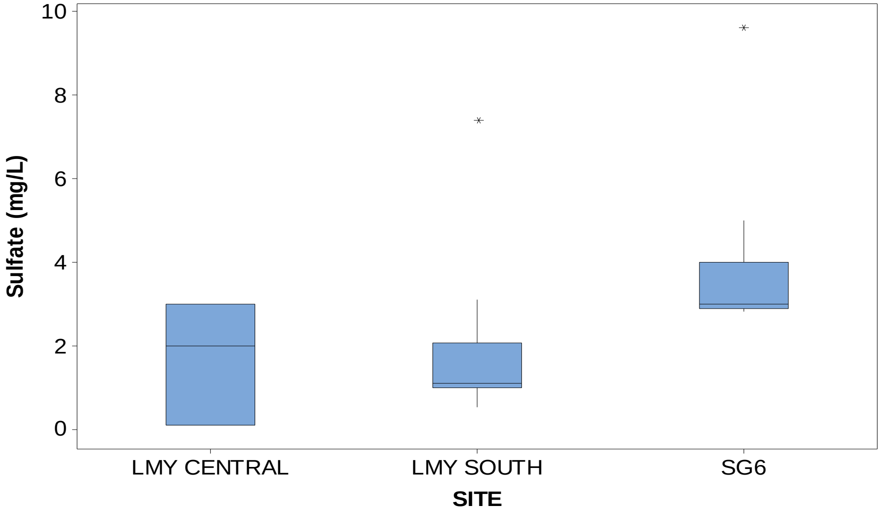

Figure D-50 Sulfate in water Lake Murray test sites 2019

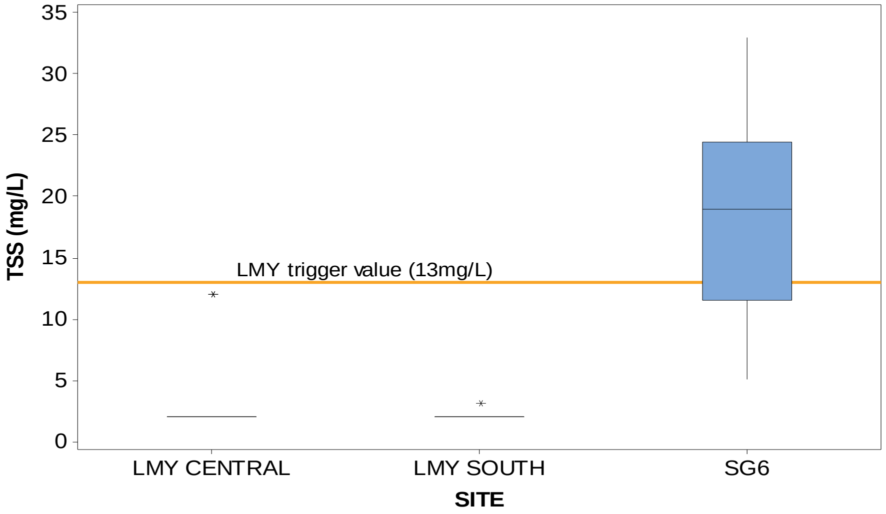

Figure D-51 TSS in water Lake Murray test sites 2019

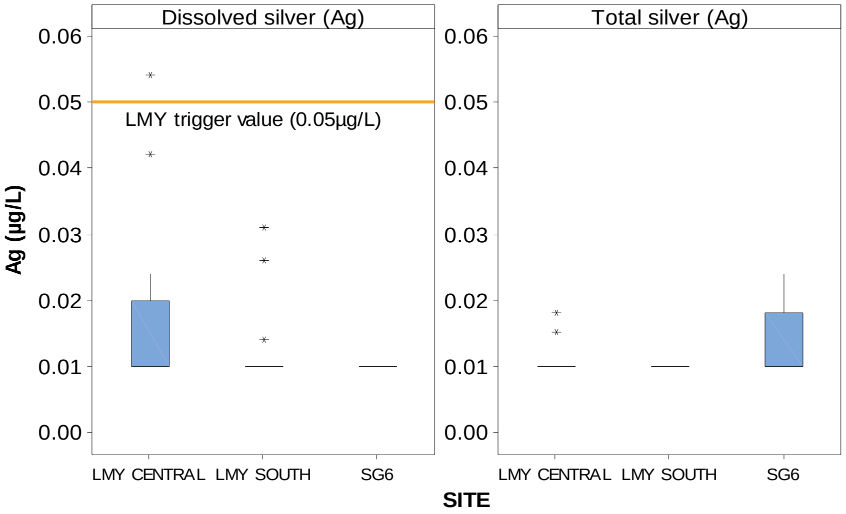

Figure D-52 Silver in water Lake Murray test sites 2019

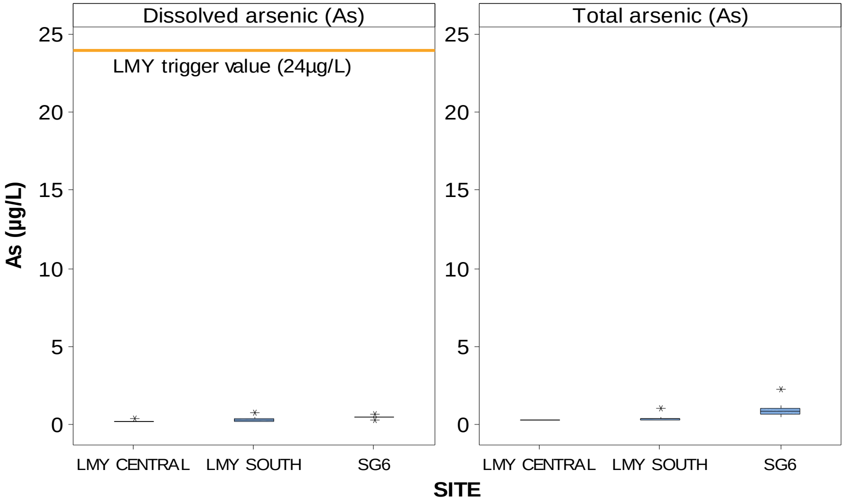

Figure D-53 As in water Lake Murray test sites 2019

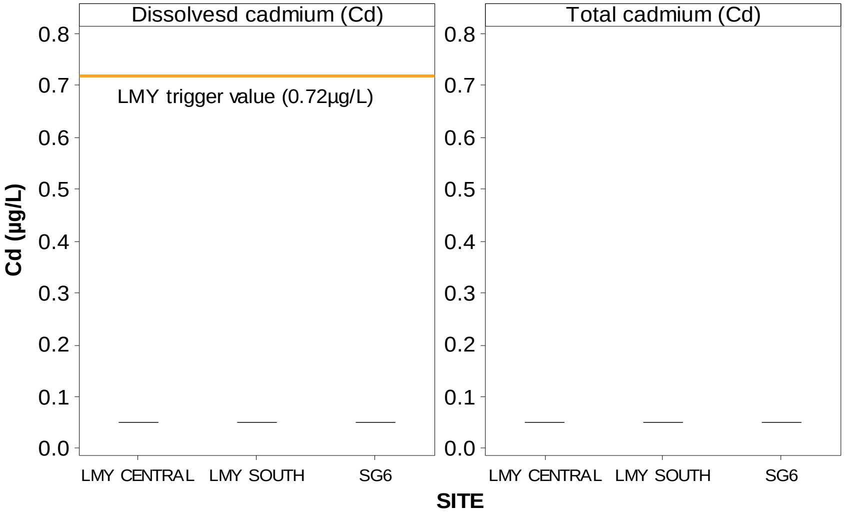

Figure D-54 Cadmium in water Lake Murray test sites 2019

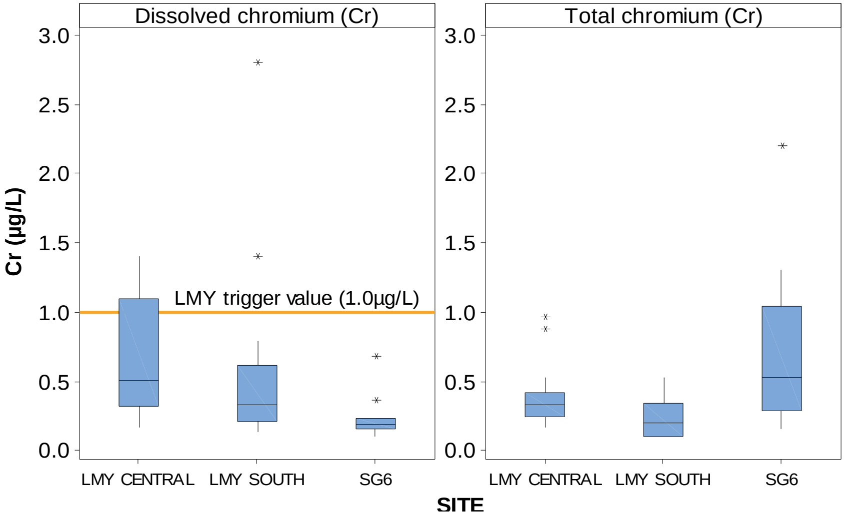

Figure D-55 Cr in water Lake Murray test sites 2019

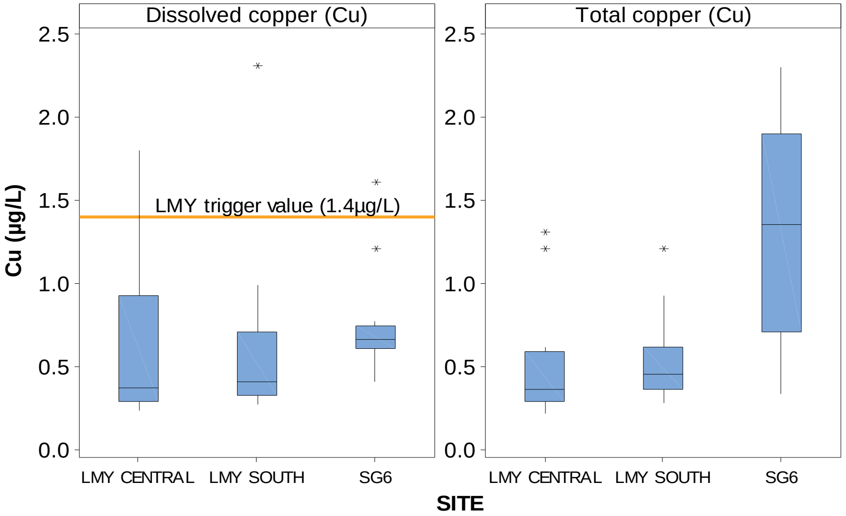

Figure D-56 Copper in water Lake Murray test sites 2019

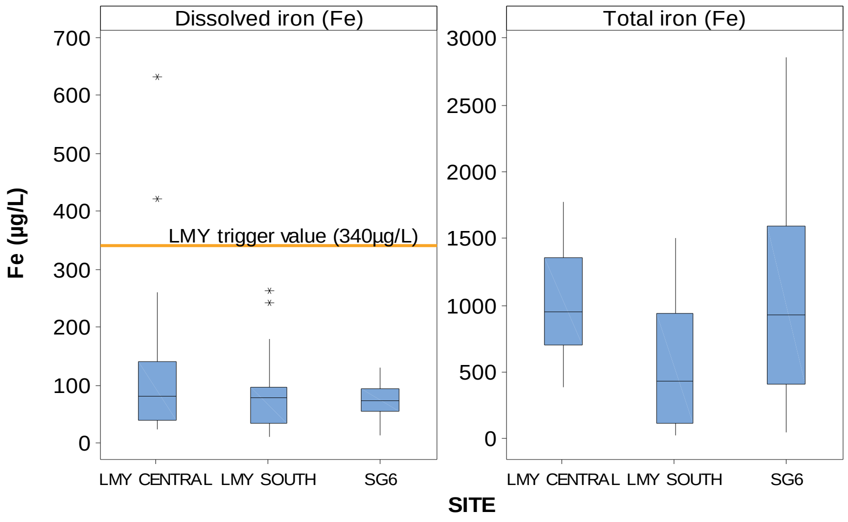

Figure D-57 Iron in water Lake Murray test sites 2019

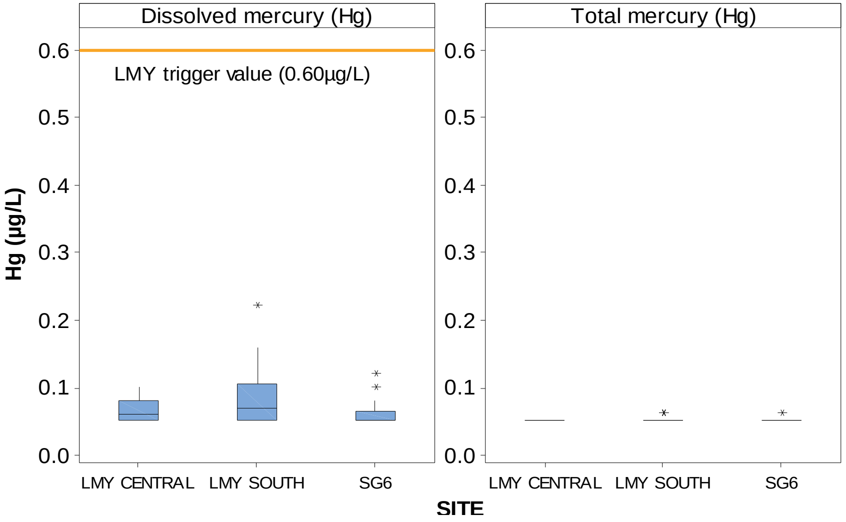

Figure D-58 Mercury in water Lake Murray test sites 2019

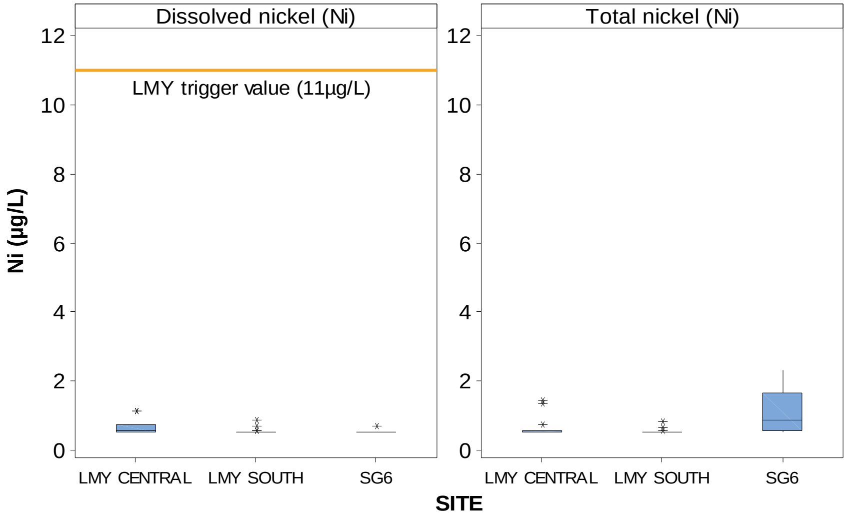

Figure D-59 Nickel in water Lake Murray test sites 2019

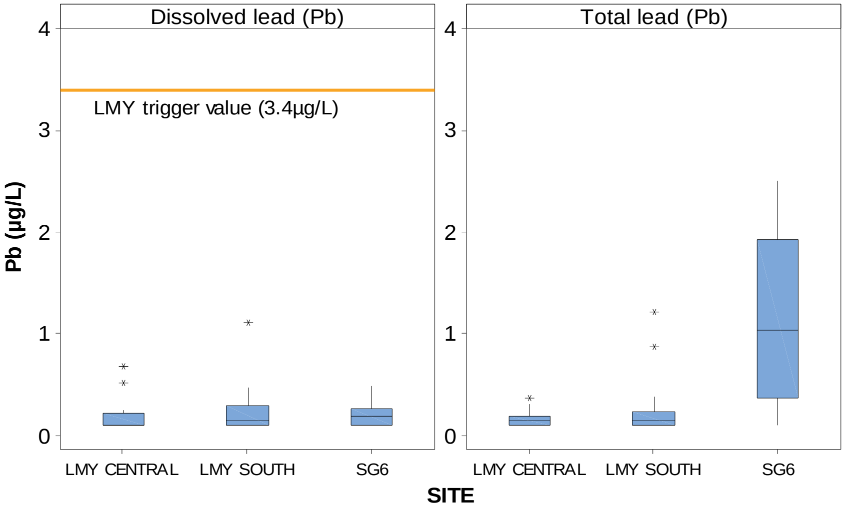

Figure D-60 Lead in water Lake Murray test sites 2019

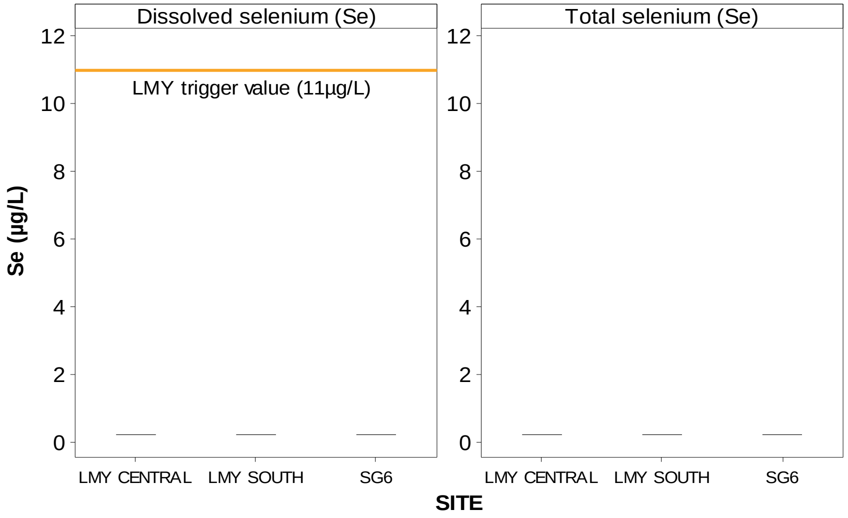

Figure D-61 Selenium in water Lake Murray test sites 2019

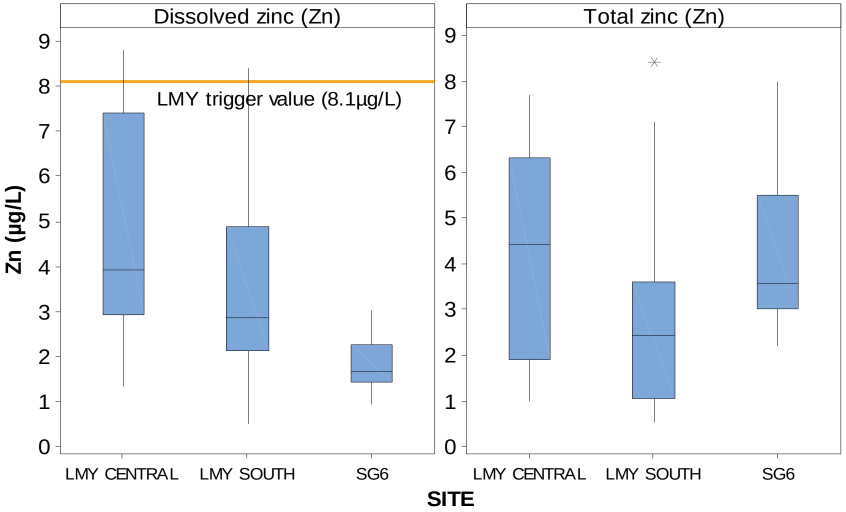

Figure D-62 Zinc in water Lake Murray test sites 2019

Table D-20 Performance assessment – Based on the trend of water quality indicators (all data) at Lake Murray test sites between 2010 and 2019 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend 2010 - 2019
Central (Trend of all data 2010 - 2019)	pH	0.110	0.359	No change over time
	EC	-0.366	0.002	Reduced over time
	TSS	-0.046	0.711	No change over time
	Ag-D*	-0.664	<0.001	No change over time
	As-D*	-0.362	0.002	No change over time
	Cd-D*	-0.402	0.001	No change over time
	Cr-D	0.291	0.014	Increased over time
	Cu-D*	-0.334	0.004	No change over time
	Fe-D	-0.147	0.222	No change over time
	Hg-D	-0.191	0.110	No change over time
	Ni-D	0.146	0.225	No change over time
	Pb-D	0.230	0.053	No change over time
	Se-D*	-0.354	0.003	No change over time
	Zn-D	0.488	<0.001	Increased over time
Southern (Trend of all data 2010 - 2019)	pH	0.106	0.306	No change over time
	EC	0.048	0.646	No change over time
	TSS	-0.165	0.132	No change over time
	Ag-D*	-0.868	<0.001	No change over time
	As-D*	-0.531	<0.001	No change over time
	Cd-D*	-0.724	<0.001	No change over time
	Cr-D*	-0.220	0.032	No change over time
	Cu-D*	-0.532	<0.001	No change over time
	Fe-D*	-0.509	<0.001	No change over time
	Hg-D*	-0.255	0.012	No change over time
	Ni-D*	-0.620	<0.001	No change over time
	Pb-D*	-0.330	0.001	No change over time
	Se-D*	-0.571	<0.001	No change over time
	Zn-D	0.292	0.004	Increased over time
SG6 (Trend of all data 2010 - 2019)	pH	0.466	0.003	Increased over time
	EC	0.352	0.026	Increased over time
	TSS	0.384	0.017	Increased over time
	Ag-D*	-0.846	<0.001	No change over time
	As-D	0.065	0.679	No change over time
	Cd-D*	-0.507	0.001	No change over time
	Cr-D	0.075	0.634	No change over time
	Cu-D	0.014	0.931	No change over time
	Fe-D	-0.277	0.073	No change over time
	Hg-D	-0.255	0.099	No change over time
	Ni-D*	-0.355	0.019	No change over time
	Pb-D	0.176	0.26	No change over time
	Se-D	-0.273	0.089	No change over time
	Zn-D	0.040	0.800	No change over time

APPENDIX E. SEDIMENT QUALITY – RISK AND PERFORMANCE ASSESSMENT – DETAILS OF STATISTICAL ANALYSIS AND BOX PLOTS

Table E-1 Expanded risk matrix – sediment quality

Initial Assessment Result	Go To
TSM < TV	Step 1
TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR	Step 2
TSM = TV and TV, TSM and full TSM data set ≤ LOR	Step 3

Step	Alt Hypothesis	Null Hypothesis	Sig Test Result		Risk Assessment
1	TSM < TV	TSM = TV	p < 0.05	Accept Alt	LOW
			p > 0.05	Accept Null	POTENTIAL
			Error	Accept Neither	ND
2	TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR				POTENTIAL
3	TSM = TV and TV, TSM and full TSM data set are ≤ LOR				LOW

TSM = Test Site Median

ND = No determination

Table E-2 Sediment quality upper river test sites - SG2 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG2	N	N (Test)	Median	Result	Go to			
Ag-WAE	12	12	0.16	TSM < Upper TV	Step 1	1.0	0.001	LOW
As-WAE	12	12	4.7	TSM < Upper TV	Step 1	20	0.001	LOW
Cd-WAE	12	10	0.97	TSM < Upper TV	Step 1	1.5	0.042	LOW
Cr-WAE	12	12	6.8	TSM < Upper TV	Step 1	80	0.001	LOW
Cu-WAE	12	12	12	TSM < Upper TV	Step 1	65	0.001	LOW
Hg-WAE	12	12	0.01	TSM < Upper TV	Step 1	0.15	0.001	LOW
Ni-WAE	12	12	11	TSM < Upper TV	Step 1	22	0.001	LOW
Pb-WAE	12	12	115	TSM > Upper TV	Step 2	50	0.997	POTENTIAL
Se-WAE	12	9	0.15	TSM = Upper TV	Step 1	0.15	0.297	POTENTIAL
Zn-WAE	12	11	140	TSM < Upper TV	Step 1	200	0.115	POTENTIAL

Table E-3 Sediment quality upper river test sites - Wasiba 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Wasiba	N	N (Test)	Median	Result	Go to			
Ag-WAE	15	15	0.05	TSM < Upper TV	Step 1	1.0	<0.001	LOW
As-WAE	15	15	3.8	TSM < Upper TV	Step 1	20	<0.001	LOW
Cd-WAE	15	15	0.69	TSM < Upper TV	Step 1	1.5	0.001	LOW
Cr-WAE	15	15	4.2	TSM < Upper TV	Step 1	80	<0.001	LOW
Cu-WAE	15	15	10	TSM < Upper TV	Step 1	65	<0.001	LOW
Hg-WAE	15	15	0.01	TSM < Upper TV	Step 1	0.15	<0.001	LOW
Ni-WAE	15	15	11	TSM < Upper TV	Step 1	22	0.001	LOW
Pb-WAE	15	15	33	TSM < Upper TV	Step 1	50	0.078	POTENTIAL
Se-WAE	15	15	0.13	TSM < Upper TV	Step 1	0.15	0.002	LOW
Zn-WAE	15	15	110	TSM < Upper TV	Step 1	200	0.020	LOW

Table E-4 Sediment quality upper river test sites - Wankipe 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment			Statistical Test Result (p=0.05)	Risk Assessment
Wankipe	N	N (Test)	Median	Result	Go to	TV		
Ag-WAE	17	17	0.05	TSM < Upper TV	Step 1	1.0	<0.001	LOW
As-WAE	17	17	3.6	TSM < Upper TV	Step 1	20	<0.001	LOW
Cd-WAE	17	17	0.44	TSM < Upper TV	Step 1	1.5	<0.001	LOW
Cr-WAE	17	17	3.5	TSM < Upper TV	Step 1	80	<0.001	LOW
Cu-WAE	17	17	9.5	TSM < Upper TV	Step 1	65	<0.001	LOW
Hg-WAE	17	17	0.01	TSM < Upper TV	Step 1	0.15	<0.001	LOW
Ni-WAE	17	17	13	TSM < Upper TV	Step 1	22	0.021	LOW
Pb-WAE	17	17	31	TSM < Upper TV	Step 1	50	<0.001	LOW
Se-WAE	17	15	0.13	TSM < Upper TV	Step 1	0.15	0.030	LOW
Zn-WAE	17	15	68	TSM < Upper TV	Step 1	200	0.006	LOW

Table E-5 Sediment quality upper river test sites - SG3 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG3	N	N (Test)	Median	Result	Go to			
Ag-WAE	14	14	0.05	TSM < Upper TV	Step 1	1.0	0.001	LOW
As-WAE	14	14	3.6	TSM < Upper TV	Step 1	20	0.001	LOW
Cd-WAE	14	14	0.47	TSM < Upper TV	Step 1	1.5	0.001	LOW
Cr-WAE	14	14	6.3	TSM < Upper TV	Step 1	80	0.001	LOW
Cu-WAE	14	14	9.5	TSM < Upper TV	Step 1	65	0.001	LOW
Hg-WAE	14	14	0.01	TSM < Upper TV	Step 1	0.15	0.001	LOW
Ni-WAE	14	14	18	TSM < Upper TV	Step 1	22	0.028	LOW
Pb-WAE	14	14	29	TSM < Upper TV	Step 1	50	0.006	LOW
Se-WAE	14	14	0.13	TSM < Upper TV	Step 1	0.15	0.116	POTENTIAL
Zn-WAE	14	14	88	TSM < Upper TV	Step 1	200	0.001	LOW

Table E-6 Sediment quality lower river test sites - Bebelubi 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Bebelubi	N	N (Test)	Median	Result	Go to			
Ag-WAE	7	7	0.05	TSM < Upper TV	Step 1	1.0	0.011	LOW
As-WAE	7	7	2.8	TSM < Upper TV	Step 1	20	0.011	LOW
Cd-WAE	7	7	0.28	TSM < Upper TV	Step 1	1.5	0.011	LOW
Cr-WAE	7	7	2.5	TSM < Upper TV	Step 1	80	0.011	LOW
Cu-WAE	7	7	6.3	TSM < Upper TV	Step 1	65	0.011	LOW
Hg-WAE	7	7	0.01	TSM < Upper TV	Step 1	0.15	0.011	LOW
Ni-WAE	7	7	10	TSM < Upper TV	Step 1	21	0.011	LOW
Pb-WAE	7	7	15	TSM < Upper TV	Step 1	50	0.011	LOW
Se-WAE	7	3	0.10	TSM = Upper TV	Step 1	0.10	0.969	POTENTIAL
Zn-WAE	7	7	47	TSM < Upper TV	Step 1	200	0.011	LOW

Table E-7 Sediment quality lower river test sites - SG4 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Tium/SG4	N	N (Test)	Median	Result	Go to			
Ag-WAE	8	8	0.05	TSM < Upper TV	Step 1	1.0	0.007	LOW
As-WAE	8	8	2.5	TSM < Upper TV	Step 1	20	0.007	LOW
Cd-WAE	8	8	0.22	TSM < Upper TV	Step 1	1.5	0.007	LOW
Cr-WAE	8	8	3.4	TSM < Upper TV	Step 1	80	0.007	LOW
Cu-WAE	8	8	7.1	TSM < Upper TV	Step 1	65	0.007	LOW
Hg-WAE	8	8	0.01	TSM < Upper TV	Step 1	0.15	0.007	LOW
Ni-WAE	8	8	10	TSM < Upper TV	Step 1	21	0.007	LOW
Pb-WAE	8	8	13	TSM < Upper TV	Step 1	50	0.007	LOW
Se-WAE	8	6	0.12	TSM > Upper TV	Step 2	0.10	0.989	POTENTIAL
Zn-WAE	8	8	38	TSM < Upper TV	Step 1	200	0.007	LOW

Table E-8 Sediment quality lower river test sites - SG5 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG5	N	N (Test)	Median	Result	Go to			
Ag-WAE	14	14	0.05	TSM < Upper TV	Step 1	1.0	0.001	LOW
As-WAE	14	14	3.4	TSM < Upper TV	Step 1	20	0.001	LOW
Cd-WAE	14	14	0.29	TSM < Upper TV	Step 1	1.5	0.001	LOW
Cr-WAE	14	14	2.2	TSM < Upper TV	Step 1	80	0.001	LOW
Cu-WAE	14	14	12	TSM < Upper TV	Step 1	65	0.001	LOW
Hg-WAE	14	14	0.01	TSM < Upper TV	Step 1	0.15	0.001	LOW
Ni-WAE	14	14	6.4	TSM < Upper TV	Step 1	21	0.001	LOW
Pb-WAE	14	14	15	TSM < Upper TV	Step 1	50	0.001	LOW
Se-WAE	14	11	0.12	TSM > Upper TV	Step 2	0.10	0.999	POTENTIAL
Zn-WAE	14	14	41	TSM < Upper TV	Step 1	200	0.001	LOW

Table E-9 Sediment quality ORWB test site Kukufionga 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Kukufionga	N	N (Test)	Median	Result	Go to			
Ag-WAE	10	10	0.05	TSM < TV	Step 1	1.0	0.003	LOW
As-WAE	10	10	3.7	TSM < TV	Step 1	20	0.003	LOW
Cd-WAE	10	10	0.34	TSM < TV	Step 1	1.5	0.003	LOW
Cr-WAE	10	10	2.3	TSM < TV	Step 1	80	0.003	LOW
Cu-WAE	10	10	12	TSM < TV	Step 1	65	0.003	LOW
Hg-WAE	10	10	0.01	TSM < TV	Step 1	0.15	0.003	LOW
Ni-WAE	10	10	6.6	TSM < TV	Step 1	21	0.003	LOW
Pb-WAE	10	10	16	TSM < TV	Step 1	50	0.003	LOW
Se-WAE	10	8	0.12	TSM > TV	Step 2	0.10	0.995	POTENTIAL
Zn-WAE	10	10	47	TSM < TV	Step 1	200	0.003	LOW

Table E-10 Sediment quality ORWB test site Zongamange 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Zongamange	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
Ag-WAE	12	12	0.17	TSM < TV	Step 1	1.0	0.001	LOW
As-WAE	12	12	9.1	TSM < TV	Step 1	20	0.001	LOW
Cd-WAE	12	12	0.33	TSM < TV	Step 1	1.5	0.001	LOW
Cr-WAE	12	12	2.8	TSM < TV	Step 1	80	0.001	LOW
Cu-WAE	12	12	22	TSM < TV	Step 1	65	0.001	LOW
Hg-WAE	12	12	0.01	TSM < TV	Step 1	0.15	0.001	LOW
Ni-WAE	12	12	9.6	TSM < TV	Step 1	21	0.001	LOW
Pb-WAE	12	12	33	TSM < TV	Step 1	50	0.001	LOW
Se-WAE	12	12	0.21	TSM > TV	Step 2	0.10	0.999	POTENTIAL
Zn-WAE	12	12	64	TSM < TV	Step 1	200	0.001	LOW

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

Table E-11 Sediment quality ORWB test site Avu 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Avu	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
Ag-WAE	12	12	0.06	TSM < TV	Step 1	1.0	0.001	LOW
As-WAE	12	12	4.0	TSM < TV	Step 1	20	0.001	LOW
Cd-WAE	12	12	0.25	TSM < TV	Step 1	1.5	0.001	LOW
Cr-WAE	12	12	1.6	TSM < TV	Step 1	80	0.001	LOW
Cu-WAE	12	12	18	TSM < TV	Step 1	65	0.001	LOW
Hg-WAE	12	12	0.01	TSM < TV	Step 1	0.15	0.001	LOW
Ni-WAE	12	12	8.3	TSM < TV	Step 1	21	0.001	LOW
Pb-WAE	12	12	18	TSM < TV	Step 1	50	0.001	LOW
Se-WAE	12	11	0.20	TSM > TV	Step 2	0.10	0.999	POTENTIAL
Zn-WAE	12	12	53	TSM < TV	Step 1	200	0.001	LOW

Table E-12 Sediment quality ORWB test site Levame 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Levame	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
Ag-WAE	12	12	0.11	TSM < TV	Step 1	1.0	0.001	LOW
As-WAE	12	12	6.2	TSM < TV	Step 1	20	0.001	LOW
Cd-WAE	12	12	0.27	TSM < TV	Step 1	1.5	0.001	LOW
Cr-WAE	12	12	2.7	TSM < TV	Step 1	80	0.001	LOW
Cu-WAE	12	12	18	TSM < TV	Step 1	65	0.001	LOW
Hg-WAE	12	12	0.01	TSM < TV	Step 1	0.15	0.001	LOW
Ni-WAE	12	12	7.0	TSM < TV	Step 1	21	0.001	LOW
Pb-WAE	12	12	28	TSM < TV	Step 1	50	0.001	LOW
Se-WAE	12	11	0.19	TSM > TV	Step 2	0.10	0.999	POTENTIAL
Zn-WAE	12	12	55	TSM < TV	Step 1	200	0.001	LOW

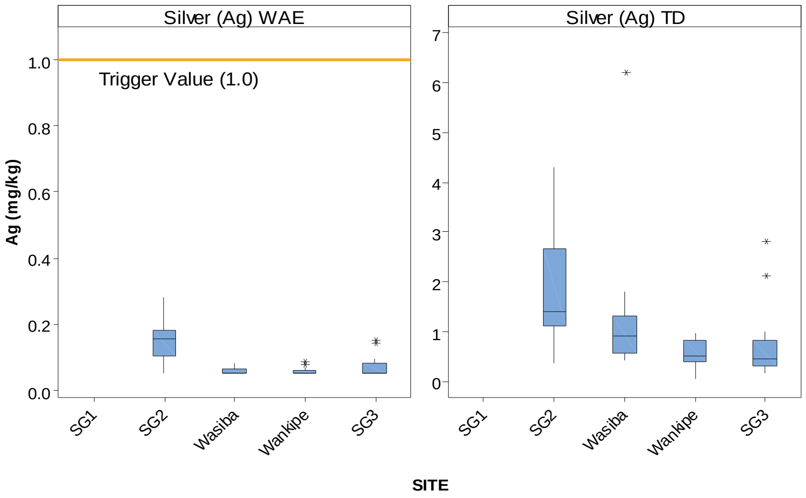

Figure E-1 Silver in sediment upper river test sites 2019

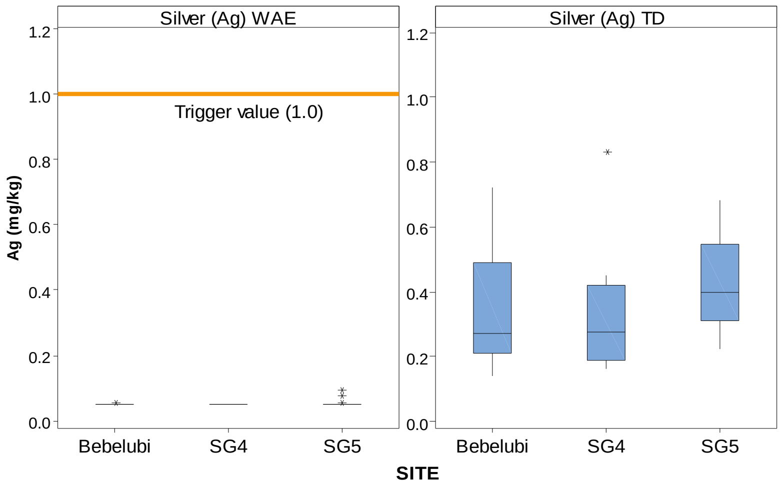

Figure E-2 Silver in sediment lower river test sites 2019

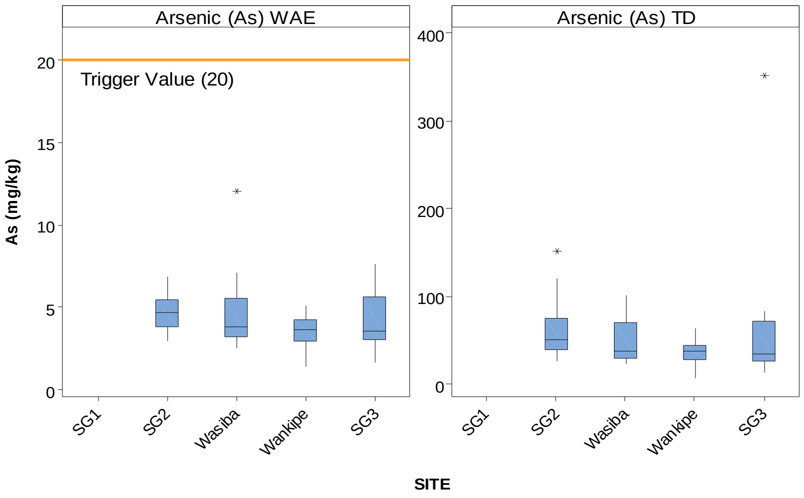

Figure E-3 Arsenic in sediment upper river test sites 2019

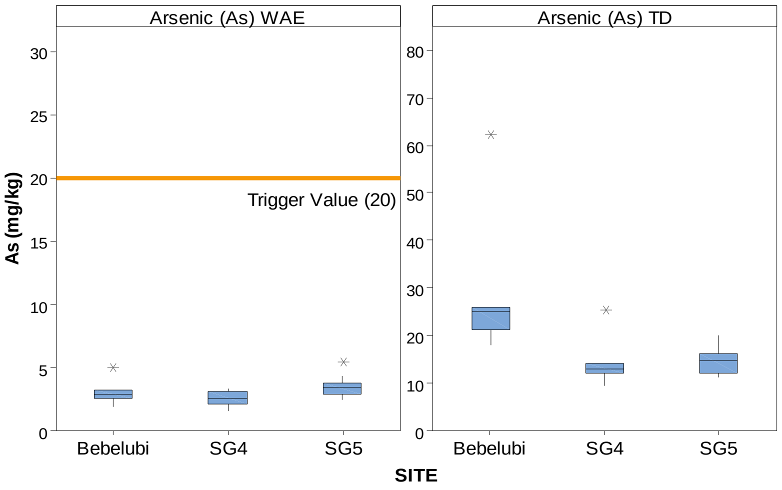

Figure E-4 Arsenic in sediment lower river test sites 2019

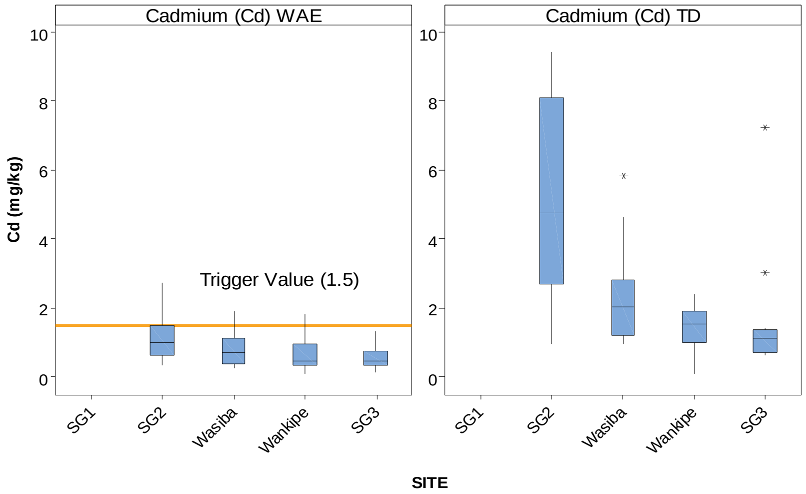

Figure E-5 Cadmium in sediment upper river test sites 2019

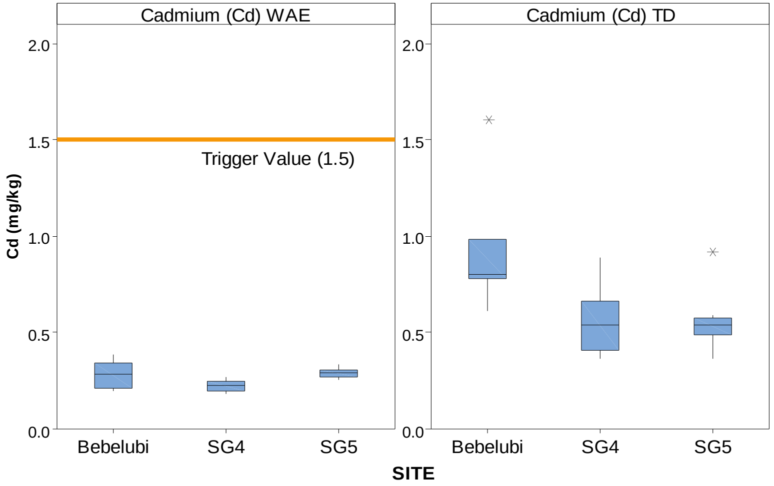

Figure E-6 Cadmium in sediment lower river test sites 2019

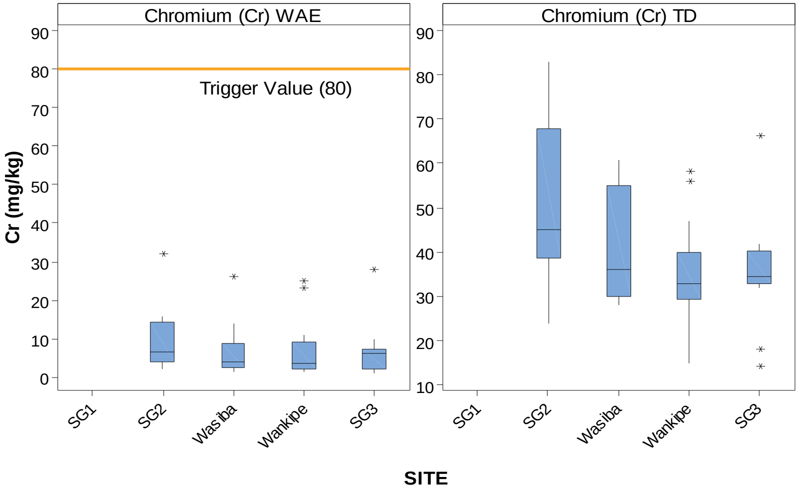

Figure E-7 Chromium in sediment upper river test sites 2019

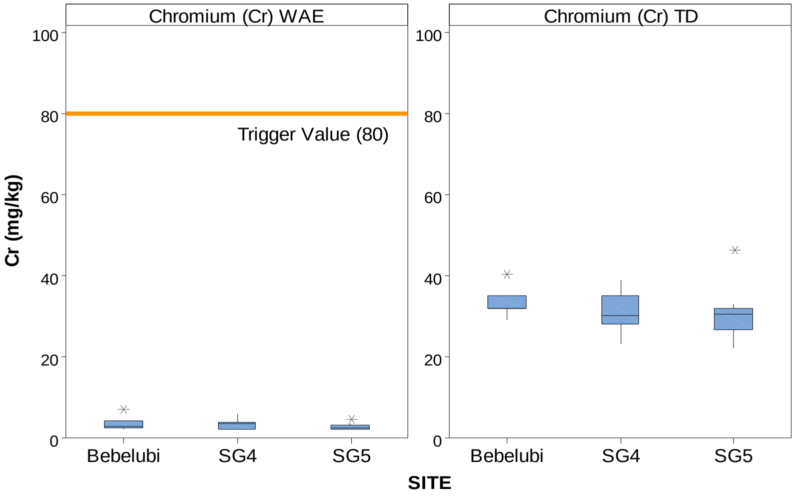

Figure E-8 Chromium in sediment lower river test sites 2019

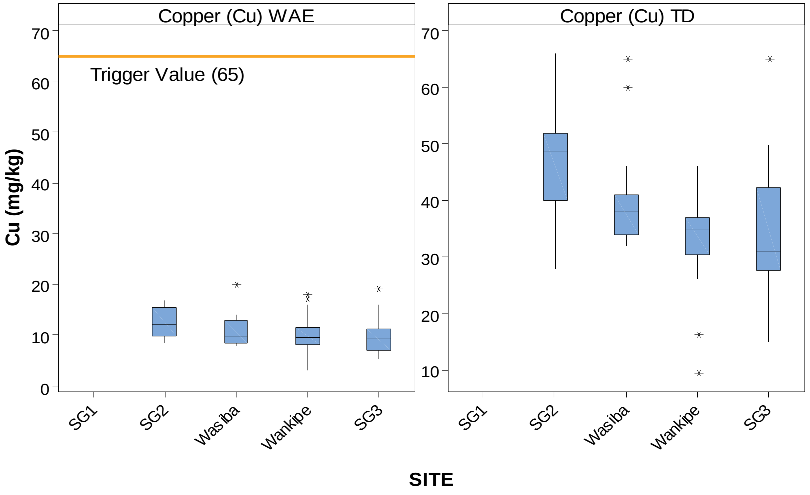

Figure E-9 Copper in sediment upper river test sites 2019

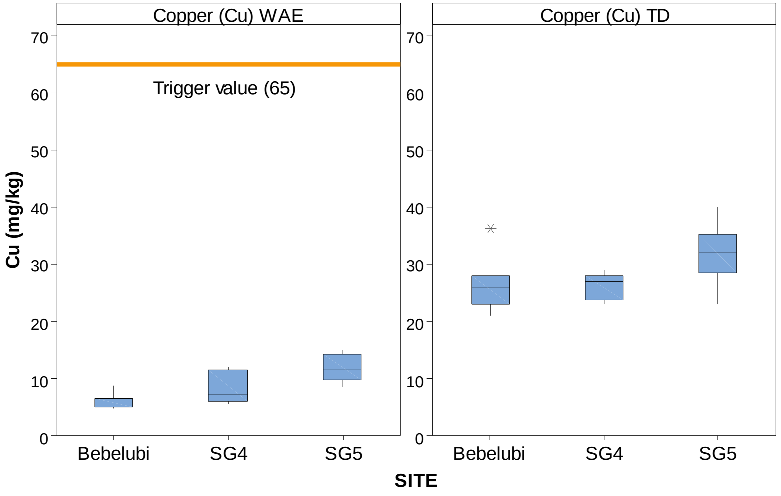

Figure E-10 Copper in sediment lower river test sites 2019

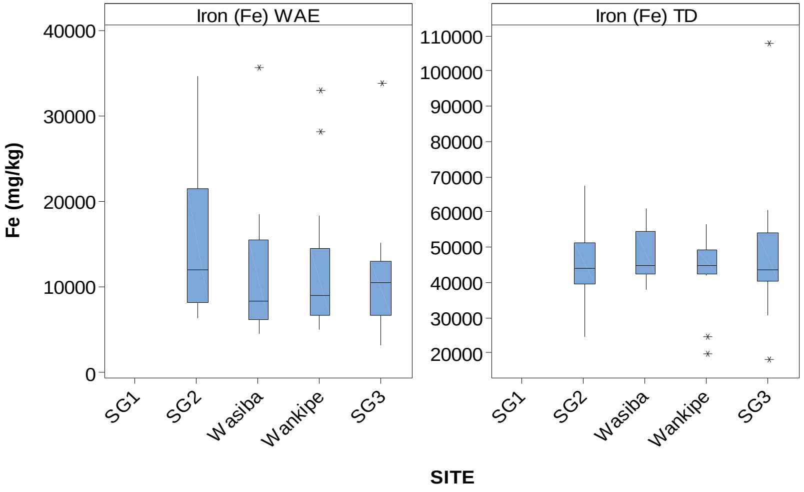

Figure E-11 Iron in sediment upper river test sites 2019

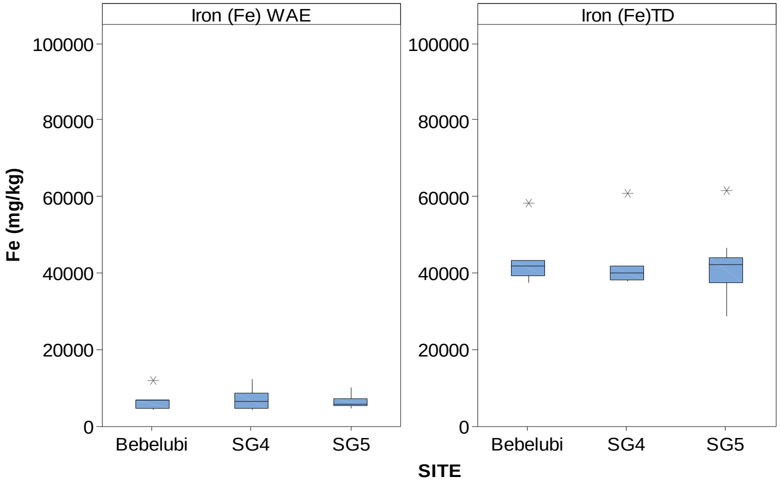

Figure E-12 Iron in sediment lower river test sites 2019

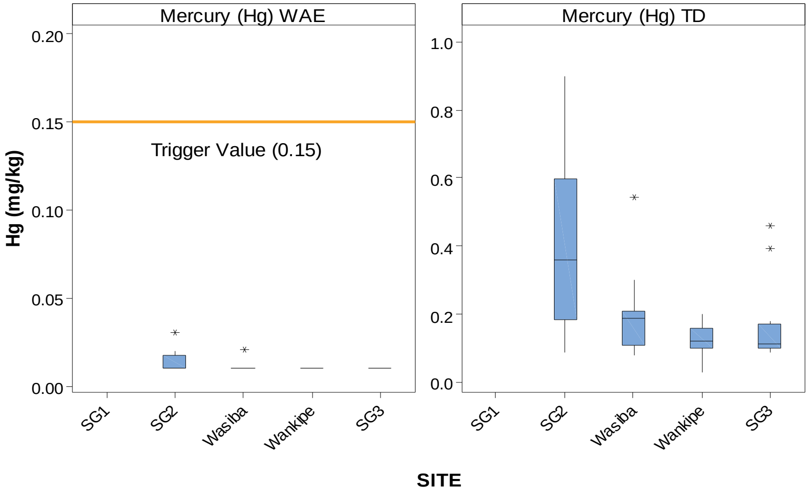

Figure E-13 Mercury in sediment upper river test sites 2019

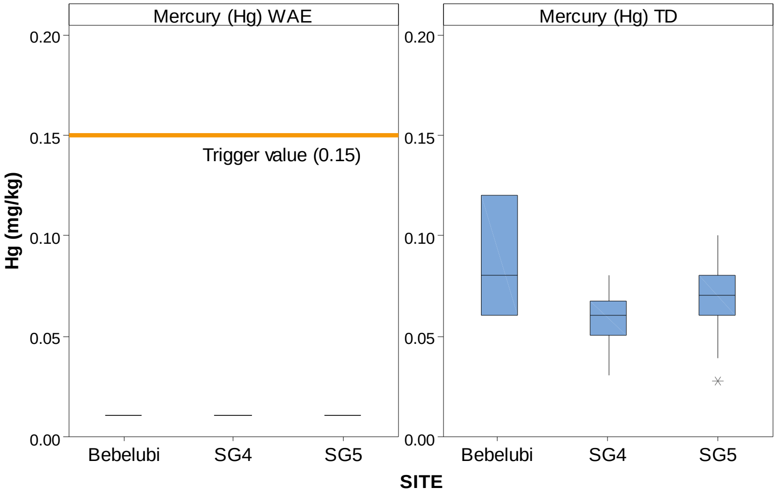

Figure E-14 Mercury in sediment lower river test sites 2019

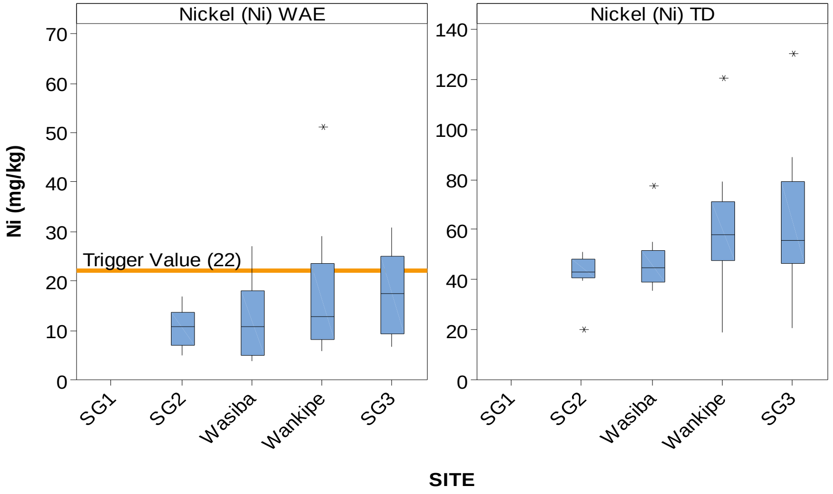

Figure E-15 Nickel in sediment upper river test sites 2019

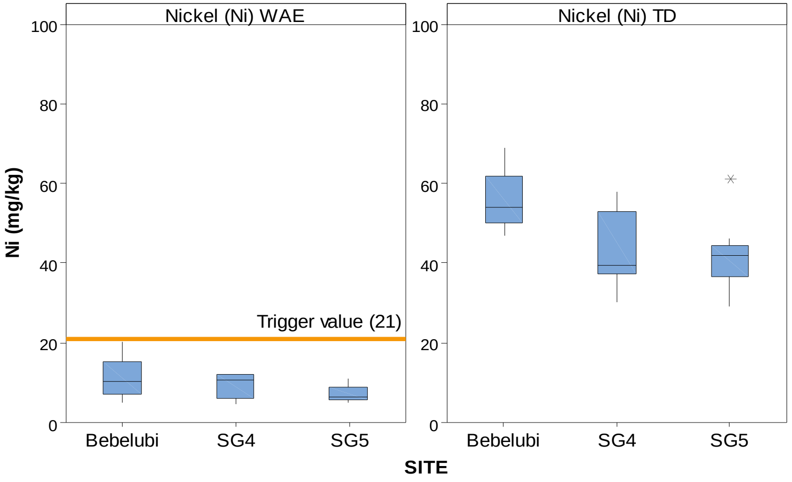

Figure E-16 Nickel in sediment lower river test sites 2019

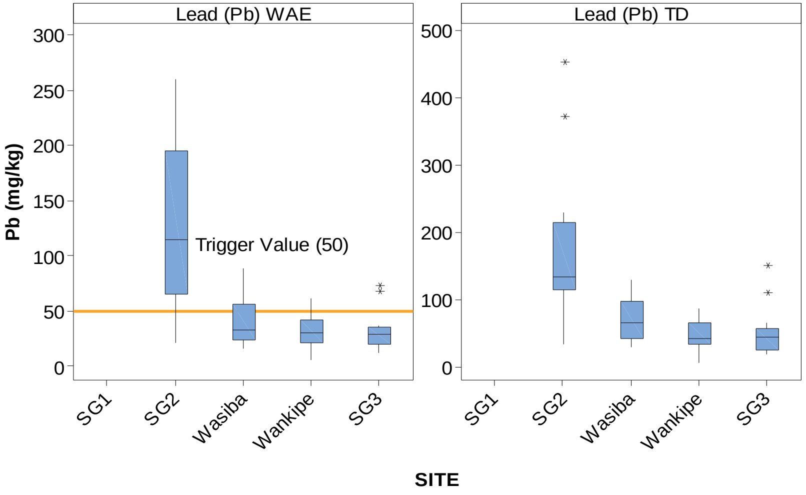

Figure E-17 Lead in sediment upper river test sites 2019

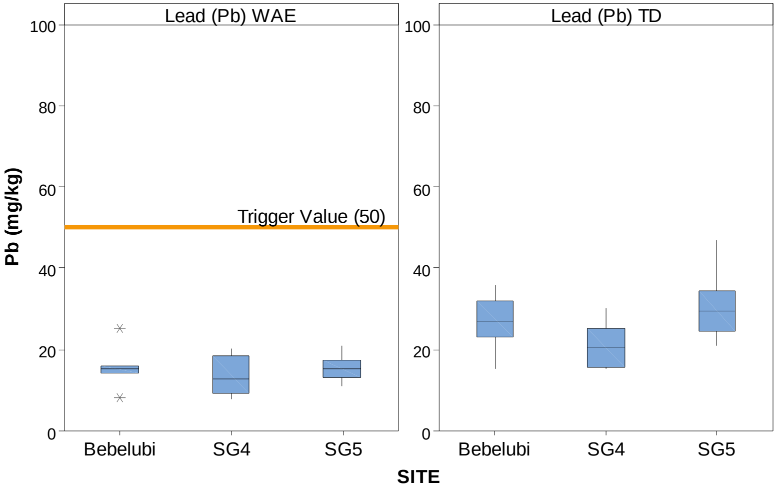

Figure E-18 Lead in sediment lower river test sites 2019

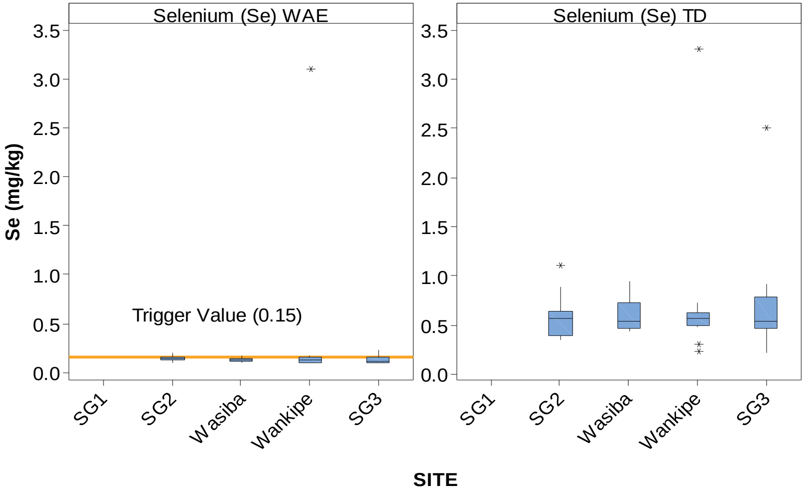

Figure E-19 Selenium in sediment upper river test sites 2019

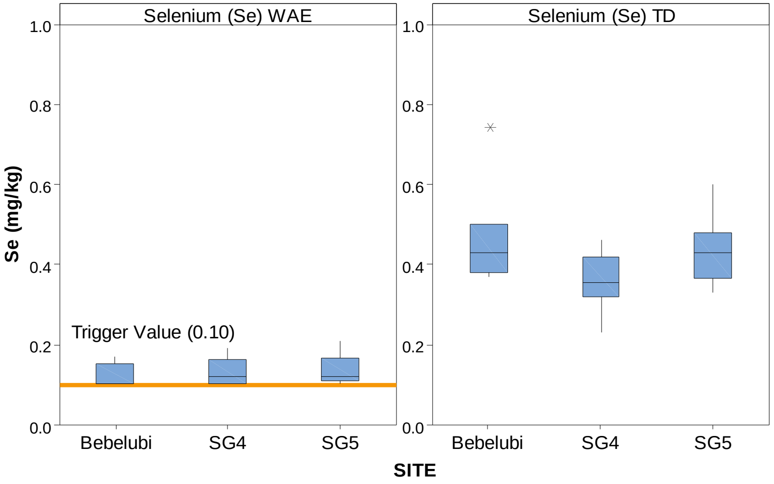

Figure E-20 Selenium in sediment lower river test sites 2019

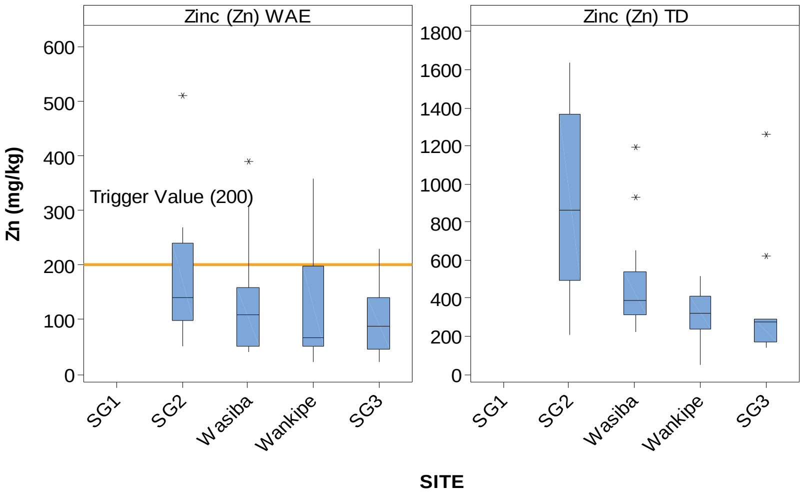

Figure E-21 Zinc in sediment upper river test sites 2019

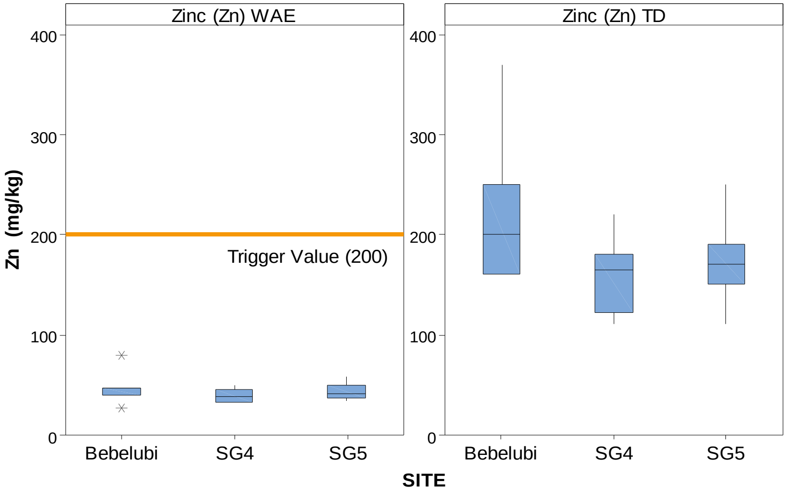

Figure E-22 Zinc in sediment lower river test sites 2019

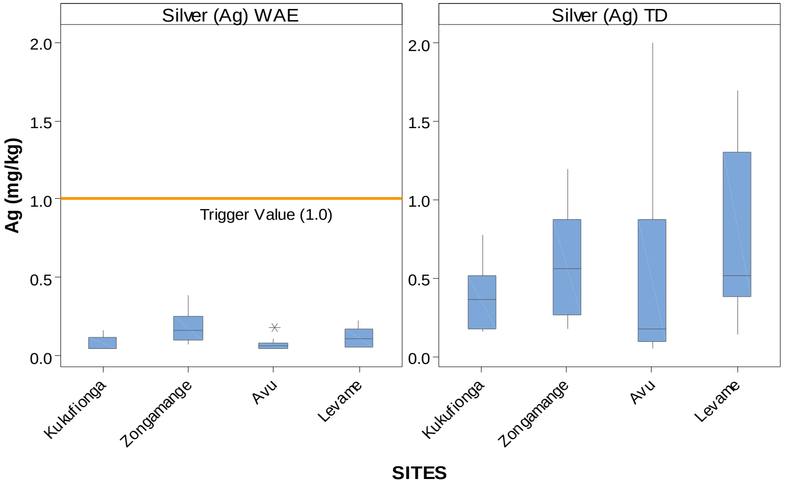

Figure E-23 Silver in sediment ORWB test sites 2019

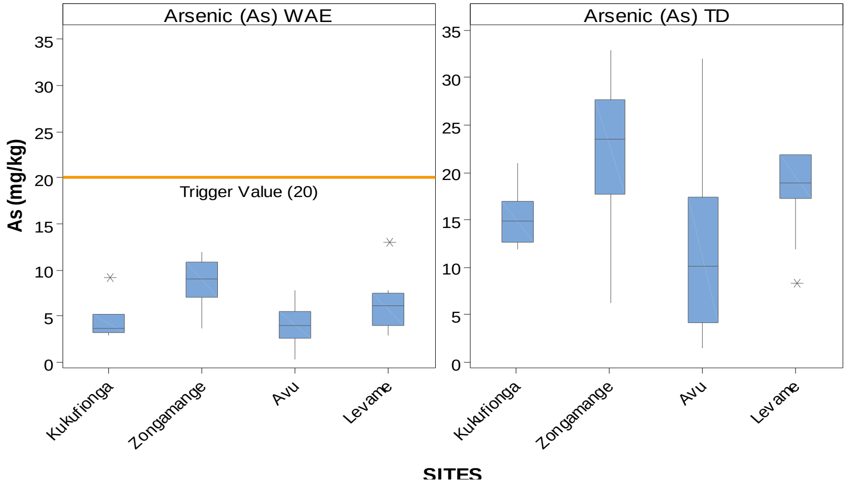

Figure E-24 Arsenic in sediment ORWB test sites 2019

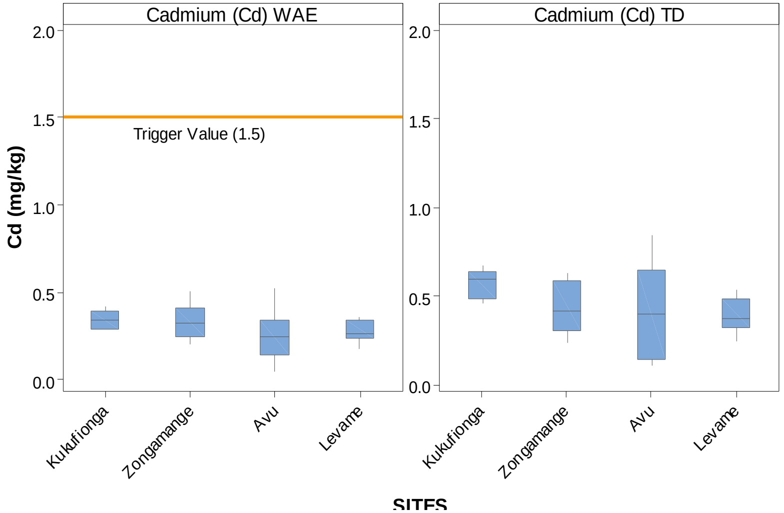

Figure E-25 Cadmium in sediment ORWB test sites 2019

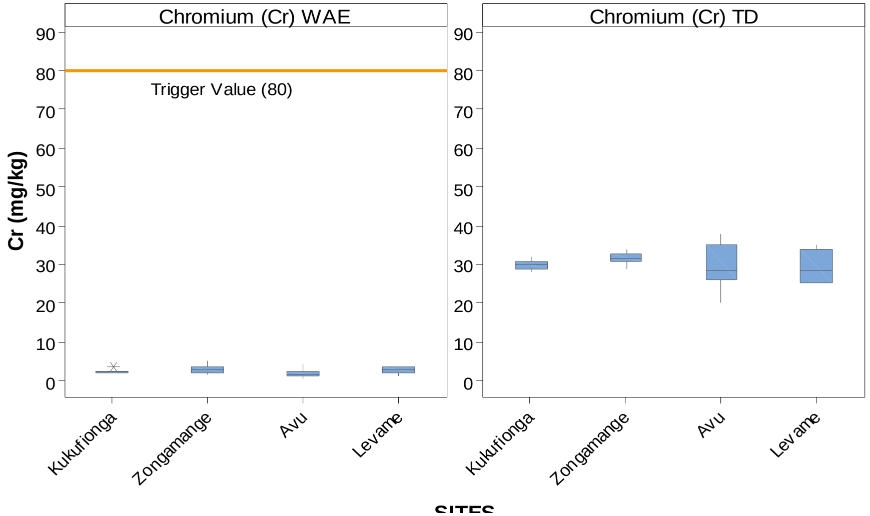

Figure E-26 Chromium in sediment ORWB test sites 2019

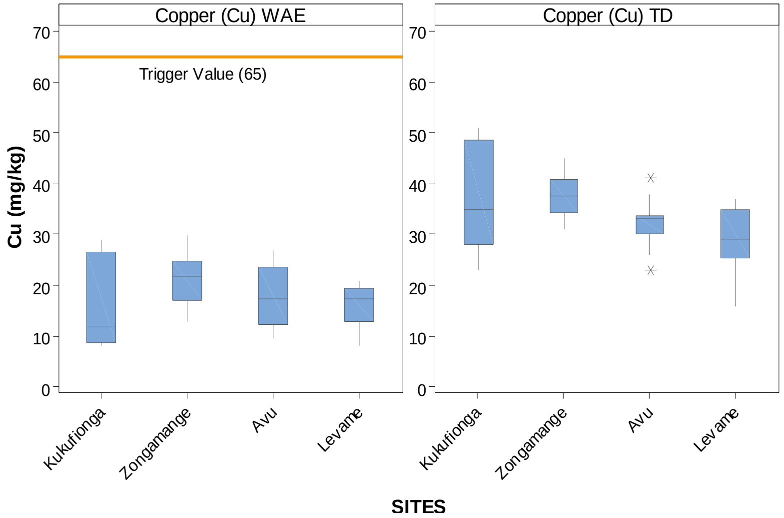

Figure E-27 Copper in sediment ORWB test sites 2019

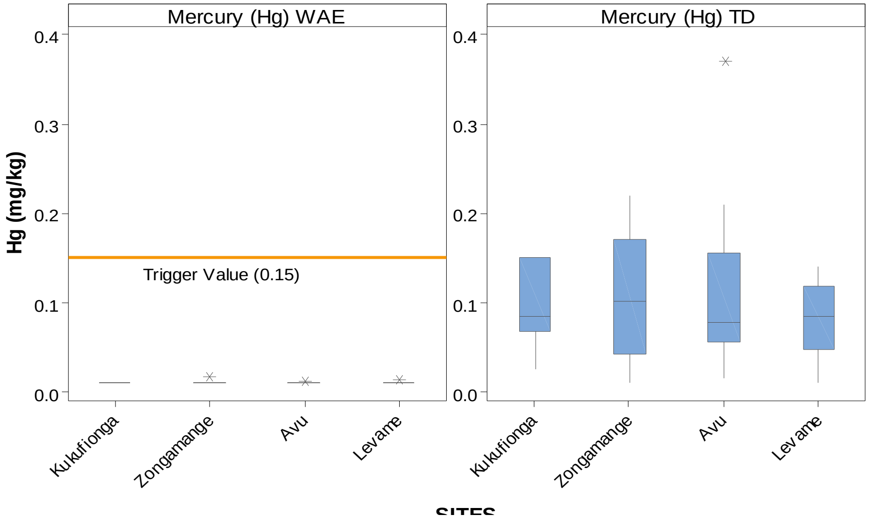

Figure E-28 Mercury in sediment ORWB test sites 2019

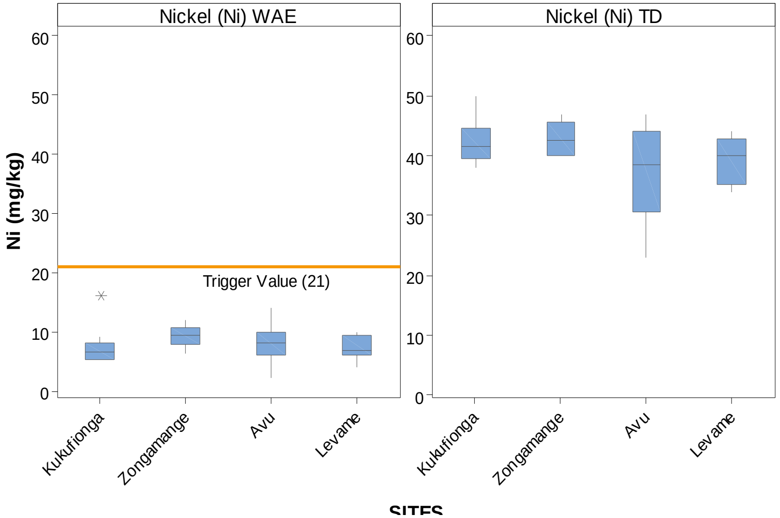

Figure E-29 Nickel in sediment ORWB test sites 2019

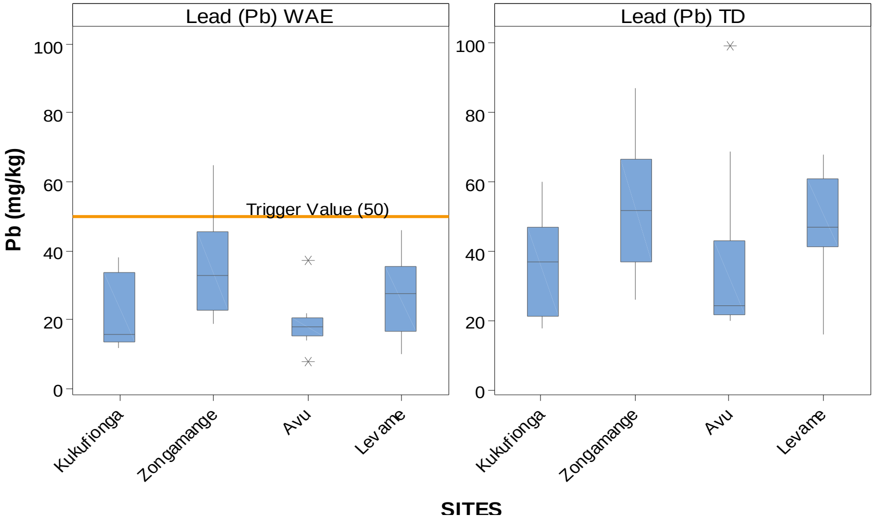

Figure E-30 Lead in sediment ORWB test sites 2019

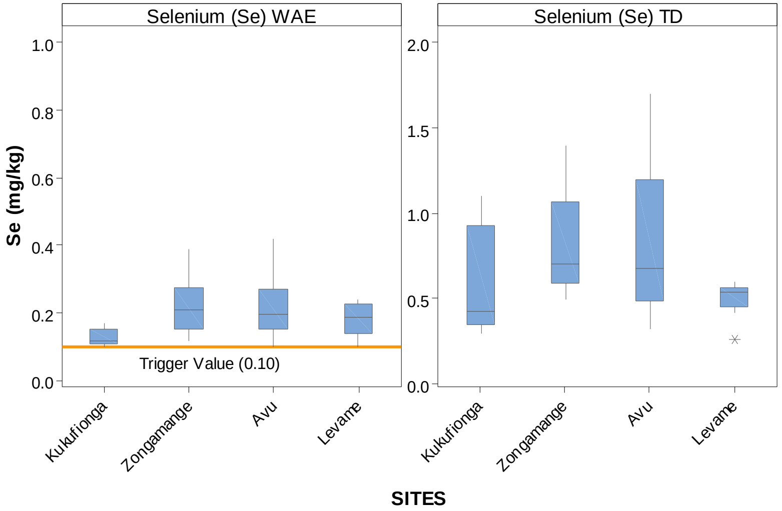

Figure E-31 Selenium in sediment ORWB test sites 2019

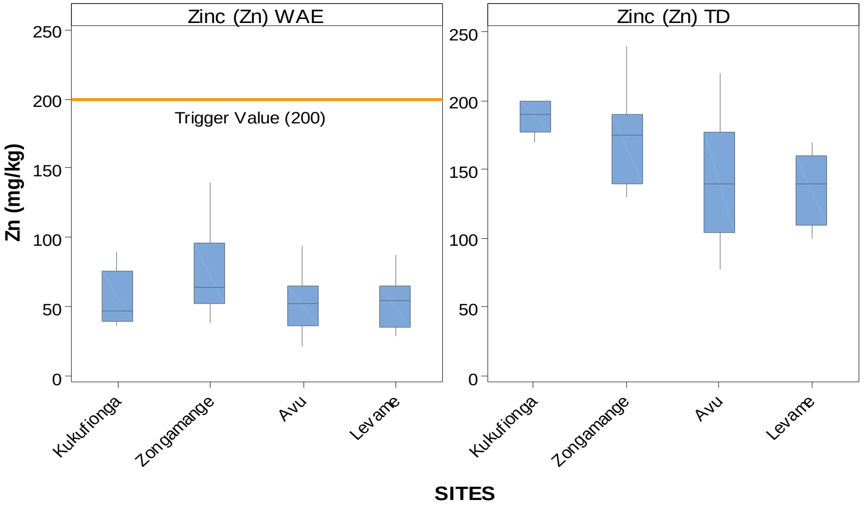

Figure E-32 Zinc in sediment ORWB test sites 2019

Table E-13 Performance assessment – Based on the trend of sediment quality indicators (all data) at upper river test sites between 2013 and 2019 using Spearman Rank Test (mg/kg dry, whole fraction)

Sediment Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend
SG1 (Trend of all data 2013 - 2015)	Ag-WAE	0.258	0.246	No change over time
	As-WAE	0.336	0.127	No change over time
	Cd-WAE	0.13	0.563	No change over time
	Cr-WAE	0.56	0.007	Increased over time
	Cu-WAE	0.27	0.224	No change over time
	Fe-WAE	0.682	<0.001	Increased over time
	Pb-WAE	0.196	0.381	No change over time
	Hg-WAE	-0.649	0.001	Reduced over time
	Ni-WAE	0.514	0.014	Increased over time
	Se-WAE	<LOR	<LOR	No change over time
	Zn-WAE	0.178	0.428	No change over time
SG2 (Trend of all data 2013 - 2019)	Ag-WAE*	-0.651	<0.001	No change over time
	As-WAE	0.03	0.809	No change over time
	Cd-WAE	0.162	0.188	No change over time
	Cr-WAE	0.452	<0.001	Increased over time
	Cu-WAE	0.034	0.783	No change over time
	Fe-WAE	0.404	0.001	Increased over time
	Pb-WAE	0.28	0.021	Increased over time
	Hg-WAE	-0.386	0.001	Reduced over time
	Ni-WAE	0.441	<0.001	Increased over time
	Se-WAE*	-0.773	<0.001	No change over time
	Zn-WAE	0.284	0.019	Increased over time
Wasiba (Trend of all data 2014 - 2019)	Ag-WAE*	-0.625	<0.001	No change over time
	As-WAE	-0.283	0.011	Reduced over time
	Cd-WAE	-0.026	0.821	No change over time
	Cr-WAE	-0.014	0.903	No change over time
	Cu-WAE	0.038	0.736	No change over time
	Fe-WAE	0.027	0.81	No change over time
	Pb-WAE	-0.273	0.014	Reduced over time
	Hg-WAE	-0.223	0.05	Reduced over time
	Ni-WAE	-0.071	0.533	No change over time
	Se-WAE*	-0.62	<0.001	No change over time
	Zn-WAE	0.095	0.402	No change over time
Wankipe (Trend of all data 2013 - 2019)	Ag-WAE*	-0.726	<0.001	No change over time
	As-WAE	-0.153	0.155	No change over time
	Cd-WAE	-0.26	0.015	Reduced over time
	Cr-WAE	0.203	0.058	No change over time
	Cu-WAE	0.2	0.062	No change over time
	Fe-WAE	0.208	0.052	No change over time
	Pb-WAE	-0.068	0.53	No change over time
	Hg-WAE	-0.425	<0.001	Reduced over time
	Ni-WAE	0.283	0.008	Increased over time
	Se-WAE*	-0.648	<0.001	No change over time
	Zn-WAE	0.118	0.273	No change over time
SG3 (Trend of all data 2013 - 2019)	Ag-WAE*	-0.761	<0.001	No change over time
	As-WAE	0.462	<0.001	Increased over time
	Cd-WAE	-0.082	0.228	No change over time
	Cr-WAE	0.489	<0.001	Increased over time

Sediment Quality	Parameter	Spearman's	P-Value	Trend
	Cu-WAE	0.545	<0.001	Increased over time
	Fe-WAE	0.518	<0.001	Increased over time
	Pb-WAE	0.392	<0.001	Increased over time
	Hg-WAE	-0.163	0.016	Reduced over time
	Ni-WAE	0.193	0.004	Increased over time
	Se-WAE*	-0.761	<0.001	No change over time
	Zn-WAE	0.464	<0.001	Increased over time

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.

Table E-14 Performance assessment – Based on the trend of sediment quality indicators (all data) at lower river test sites between 2013 and 2019 using Spearman Rank Test (mg/kg dry, whole fraction)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend
Bebelubi (Trend of all data 2013 - 2019)	Ag-WAE*	-0.805	<0.001	No change over time
	As-WAE	-0.224	0.202	No change over time
	Cd-WAE*	-0.717	<0.001	No change over time
	Cr-WAE	-0.038	0.833	No change over time
	Cu-WAE	-0.155	0.382	No change over time
	Fe-WAE	-0.073	0.681	No change over time
	Hg-WAE	-0.275	0.115	No change over time
	Ni-WAE	-0.062	0.727	No change over time
	Pb-WAE	-0.154	0.386	No change over time
	Se-WAE*	-0.774	<0.001	No change over time
	Zn-WAE	0.105	0.556	No change over time
SG4 (Trend of all data 2013 - 2019)	Ag-WAE*	-0.823	<0.001	No change over time
	As-WAE	-0.004	0.982	No change over time
	Cd-WAE*	-0.794	<0.001	No change over time
	Cr-WAE	-0.023	0.894	No change over time
	Cu-WAE	0.385	0.019	Increased over time
	Fe-WAE	-0.003	0.987	No change over time
	Hg-WAE	-0.337	0.041	Reduced over time
	Ni-WAE	-0.066	0.699	No change over time
	Pb-WAE	0.066	0.699	No change over time
	Se-WAE*	-0.765	<0.001	No change over time
	Zn-WAE	0.235	0.162	No change over time
SG5 (Trend of all data 2013 - 2019)	Ag-WAE*	-0.728	<0.001	No change over time
	As-WAE	-0.204	0.184	No change over time
	Cd-WAE*	-0.721	<0.001	No change over time
	Cr-WAE	-0.603	<0.001	Reduced over time
	Cu-WAE	0.316	0.036	Increased over time
	Fe-WAE	-0.578	<0.001	Reduced over time
	Hg-WAE	-0.254	0.097	No change over time
	Ni-WAE	-0.543	<0.001	Reduced over time
	Pb-WAE	-0.026	0.866	No change over time
	Se-WAE*	-0.63	<0.001	No change over time
	Zn-WAE	-0.557	<0.001	Reduced 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.

Table E-15 Performance assessment – Based on the trend of the annual median of sediment quality indicators at ORWB test sites throughout the history of the operation using Spearman Rank Test. (mg/kg dry, whole fraction)

Sediment Quality	Parameter	Spearman's rho	P-Value (P=0.05)	Trend
Site				
Kukufionga (Trend of all data 2013 - 2019)	Ag-WAE*	-0.729	<0.001	No change over time
	As-WAE	-0.586	<0.001	Reduced over time
	Cd-WAE	-0.877	<0.001	Reduced over time
	Cr-WAE	-0.739	<0.001	Reduced over time
	Cu-WAE	-0.311	0.078	No change over time
	Fe-WAE	-0.708	<0.001	Reduced over time
	Pb-WAE	-0.559	0.001	Reduced over time
	Hg-WAE	-0.159	0.377	No change over time
	Ni-WAE	-0.681	<0.001	Reduced over time
	Se-WAE*	-0.760	<0.001	No change over time
	Zn-WAE	-0.602	<0.001	Reduced over time
Zongamange (Trend of all data 2013 - 2019)	Ag-WAE*	-0.431	0.020	No change over time
	As-WAE	0.480	0.008	Increased over time
	Cd-WAE*	-0.646	<0.001	No change over time
	Cr-WAE	-0.459	0.012	Reduced over time
	Cu-WAE	0.335	0.076	No change over time
	Fe-WAE	0.269	0.159	No change over time
	Pb-WAE	0.138	0.475	No change over time
	Hg-WAE*	-0.669	<0.001	No change over time
	Ni-WAE	-0.356	0.058	No change over time
	Se-WAE*	-0.326	0.084	No change over time
	Zn-WAE	-0.323	0.087	No change over time
Avu (Trend of all data 2013 - 2019)	Ag-WAE*	-0.631	<0.001	No change over time
	As-WAE	-0.326	0.064	No change over time
	Cd-WAE*	-0.642	<0.001	No change over time
	Cr-WAE	-0.604	<0.001	Reduced over time
	Cu-WAE	-0.025	0.889	No change over time
	Fe-WAE	-0.419	0.015	Reduced over time
	Pb-WAE	-0.392	0.024	Reduced over time
	Hg-WAE*	-0.755	<0.001	No change over time
	Ni-WAE	-0.534	0.001	Reduced over time
	Se-WAE*	-0.499	0.003	No change over time
	Zn-WAE	-0.457	0.007	Reduced over time
Levame (Trend of all data 2015 - 2019)	Ag-WAE	0.219	0.328	No change over time
	As-WAE	0.464	0.030	Increased over time
	Cd-WAE	-0.394	0.070	No change over time
	Cr-WAE	-0.021	0.928	No change over time
	Cu-WAE	0.509	0.016	Increased over time
	Fe-WAE	0.113	0.616	No change over time
	Pb-WAE	0.230	0.303	No change over time
	Hg-WAE	-0.449	0.036	Reduced over time
	Ni-WAE	-0.288	0.194	No change over time
	Se-WAE	0.331	0.132	No change over time
	Zn-WAE	-0.028	0.900	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.

Table E-16 Sediment quality Lake Murray test sites Central Lake 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Central	N	N (Test)	Median	Result	Go to			
Ag-WAE	15	15	0.06	TSM < TV	Step 1	1.0	<0.001	LOW
As-WAE	15	15	1.7	TSM < TV	Step 1	20	<0.001	LOW
Cd-WAE	15	15	0.10	TSM < TV	Step 1	1.5	<0.001	LOW
Cr-WAE	15	15	5.3	TSM < TV	Step 1	80	<0.001	LOW
Cu-WAE	15	15	12	TSM < TV	Step 1	65	<0.001	LOW
Hg-WAE	15	15	0.03	TSM < TV	Step 1	0.15	<0.001	LOW
Ni-WAE	15	15	11	TSM < TV	Step 1	21	<0.001	LOW
Pb-WAE	15	15	9.8	TSM < TV	Step 1	50	<0.001	LOW
Se-WAE	15	15	0.14	TSM < TV	Step 1	0.27	0.001	LOW
Zn-WAE	15	15	46	TSM < TV	Step 1	200	<0.001	LOW

Table E-17 Sediment quality Lake Murray test sites South Lake 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Southern	N	N (Test)	Median	Result	Go to			
Ag-WAE	22	22	0.15	TSM < TV	Step 1	1.0	<0.001	LOW
As-WAE	22	22	3.7	TSM < TV	Step 1	20	<0.001	LOW
Cd-WAE	22	22	0.21	TSM < TV	Step 1	1.5	<0.001	LOW
Cr-WAE	22	22	4.4	TSM < TV	Step 1	80	<0.001	LOW
Cu-WAE	22	22	15	TSM < TV	Step 1	65	<0.001	LOW
Hg-WAE	22	22	0.01	TSM < TV	Step 1	0.15	<0.001	LOW
Ni-WAE	22	22	11	TSM < TV	Step 1	21	<0.001	LOW
Pb-WAE	22	22	27	TSM < TV	Step 1	50	<0.001	LOW
Se-WAE	22	21	0.22	TSM < TV	Step 1	0.27	<0.001	LOW
Zn-WAE	22	22	64	TSM < TV	Step 1	200	<0.001	LOW

Table E-18 Sediment quality Lake Murray test site SG6 2019 median (mg/kg dry, whole fraction)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG6	N	N (Test)	Median	Result	Go to			
Ag-WAE	16	16	0.15	TSM < TV	Step 1	1.0	<0.001	LOW
As-WAE	16	16	5.5	TSM < TV	Step 1	20	<0.001	LOW
Cd-WAE	16	16	0.32	TSM < TV	Step 1	1.5	<0.001	LOW
Cr-WAE	16	16	3.6	TSM < TV	Step 1	80	<0.001	LOW
Cu-WAE	16	16	18	TSM < TV	Step 1	65	<0.001	LOW
Hg-WAE	16	16	0.01	TSM < TV	Step 1	0.15	<0.001	LOW
Ni-WAE	16	16	9.7	TSM < TV	Step 1	21	<0.001	LOW
Pb-WAE	16	16	29	TSM < TV	Step 1	50	<0.001	LOW
Se-WAE	16	16	0.20	TSM < TV	Step 1	0.27	<0.001	LOW
Zn-WAE	16	16	59	TSM < TV	Step 1	200	<0.001	LOW

*Small sample size (n) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians. Risk assessment is based on direct comparison.

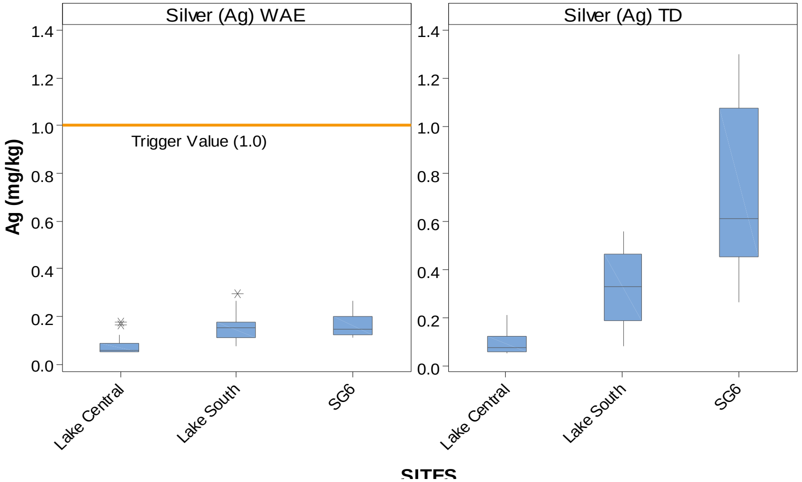

Figure E-33 Silver in sediment LMY test sites 2019

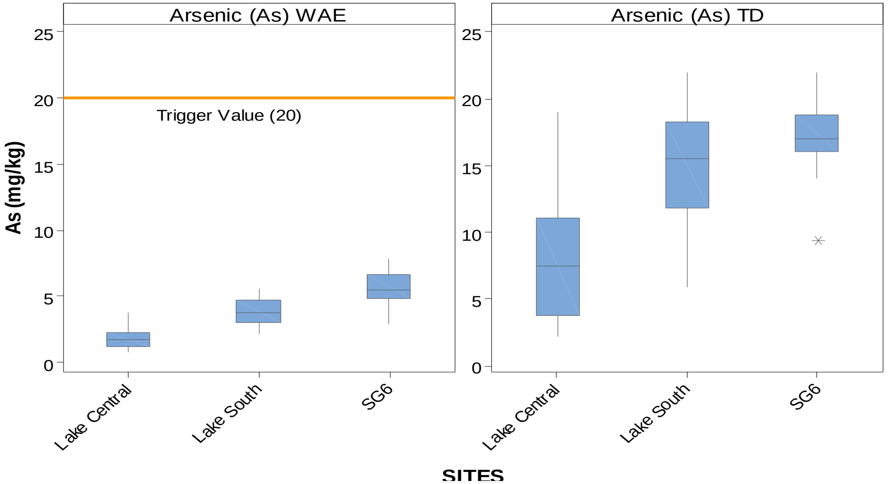

Figure E-34 Arsenic in sediment LMY test sites 2019

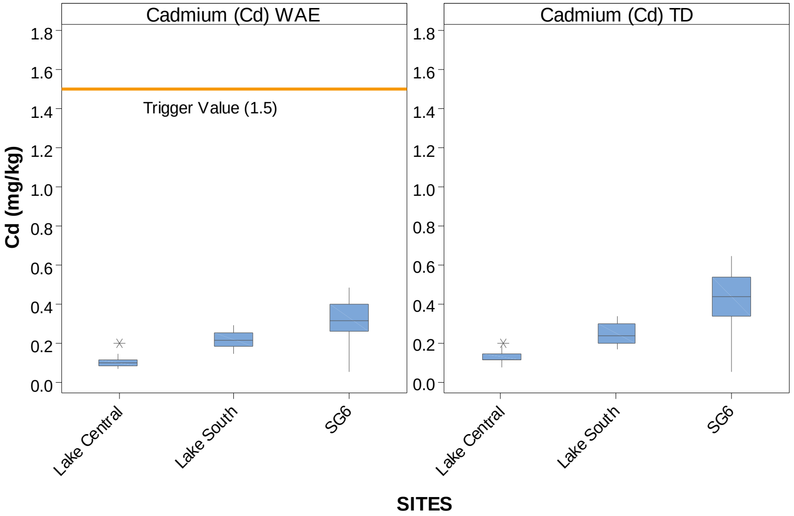

Figure E-35 Cadmium in sediment LMY test sites 2019

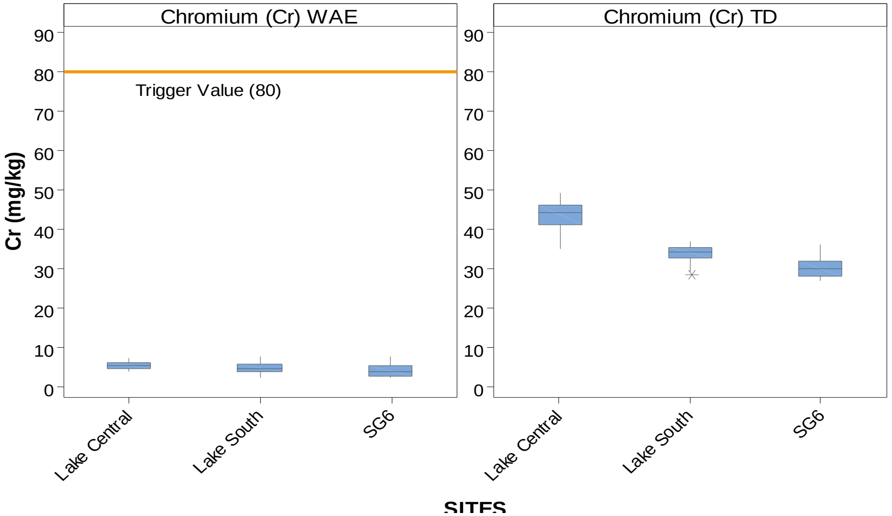

Figure E-36 Chromium in sediment LMY test sites 2019

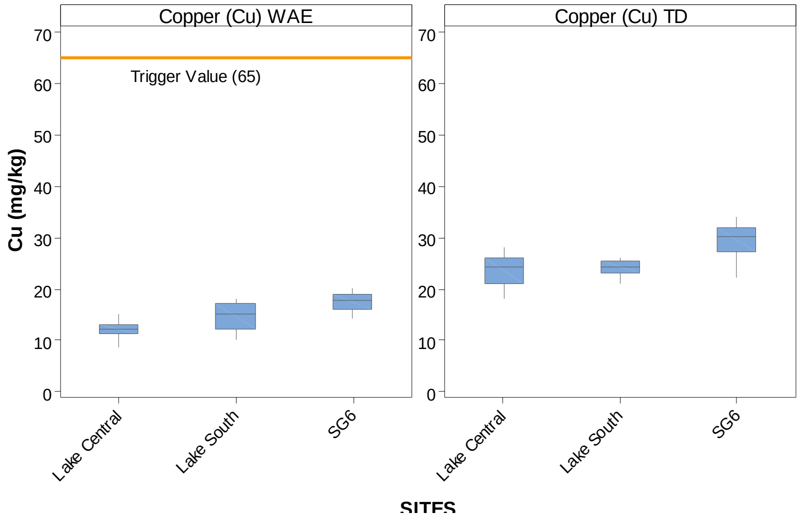

Figure E-37 Copper in sediment LMY test sites 2019

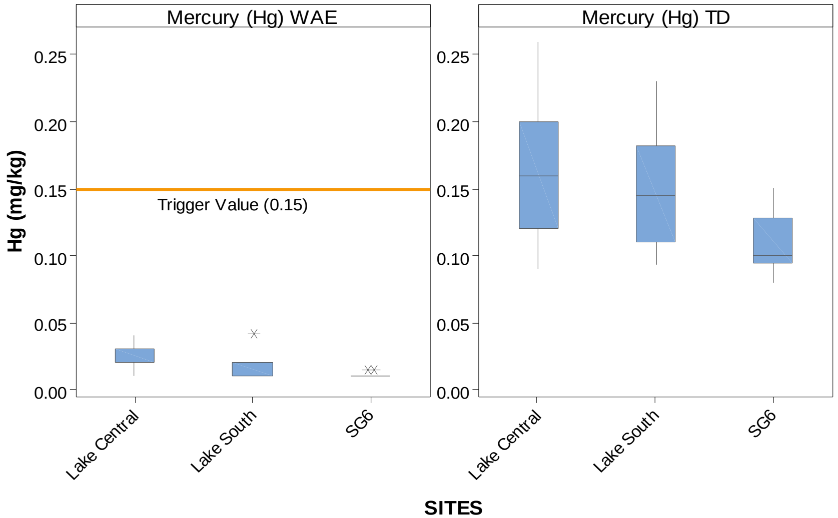

Figure E-38 Mercury in sediment LMY test sites 2019

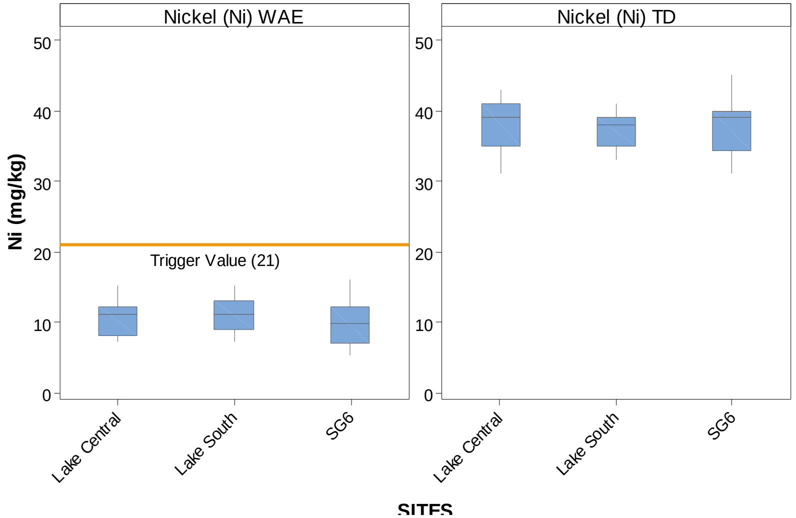

Figure E-39 Nickel in sediment LMY test sites 2019

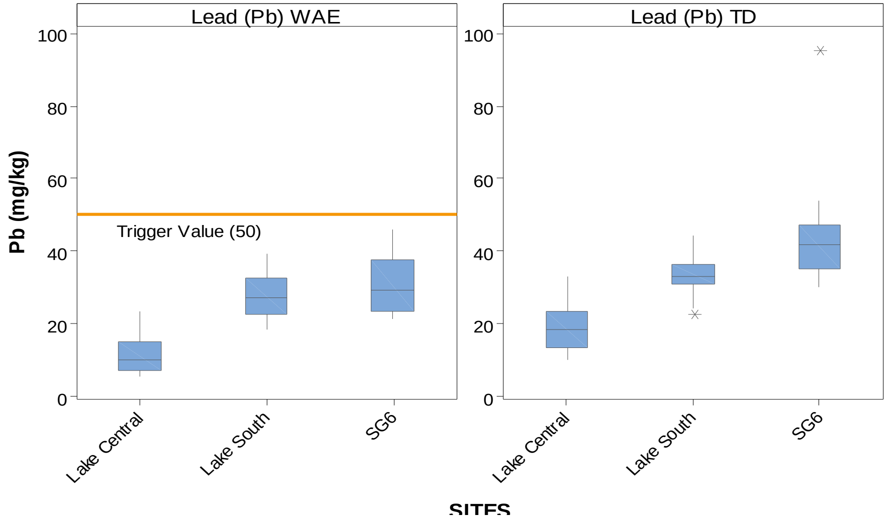

Figure E-40 Lead in sediment LMY test sites 2019

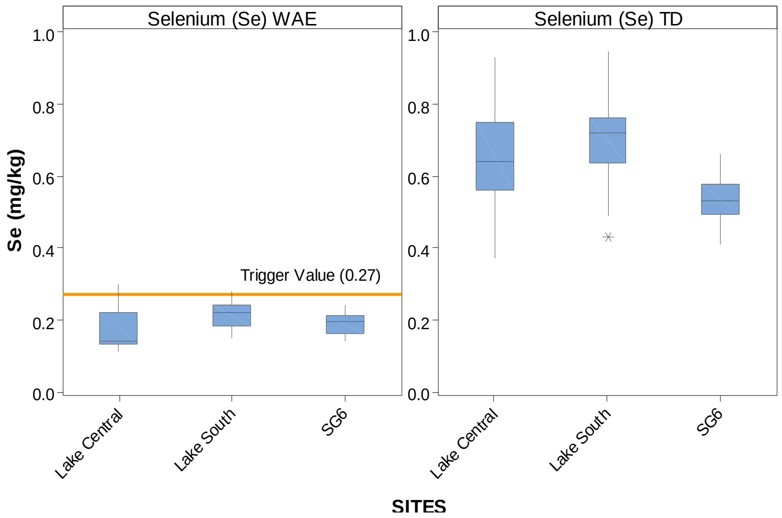

Figure E-41 Selenium in sediment LMY test sites 2019

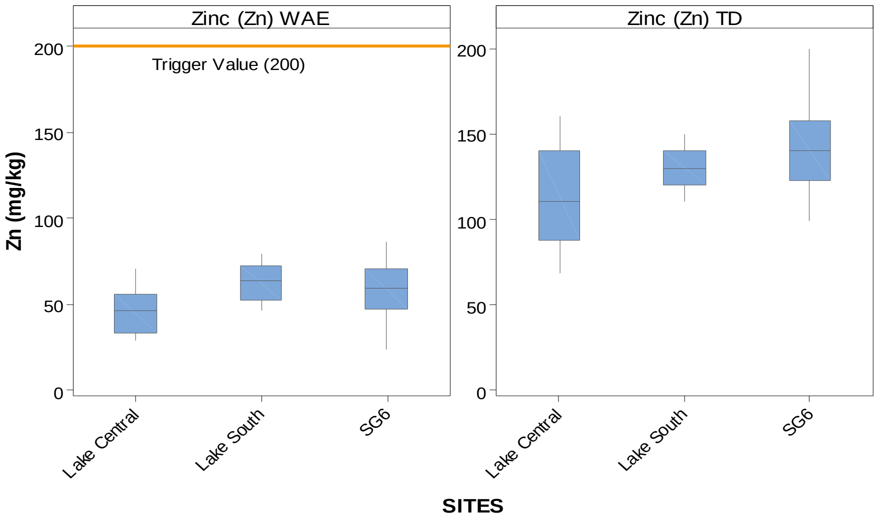

Figure E-42 Zinc in sediment LMY test sites 2019

Table E-19 Performance assessment – Based on the trend of the annual median of sediment quality indicators at Lake Murray test sites throughout the history of the operation using Spearman Rank Test. (mg/kg dry, whole fraction)

Sediment Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend
Central (Trend of all data 2013 - 2019)	Ag-WAE*	-0.612	<0.001	No change over time
	As-WAE	0.122	0.336	No change over time
	Cd-WAE*	-0.659	<0.001	No change over time
	Cr-WAE	-0.308	0.013	Reduced over time
	Cu-WAE	0.031	0.807	No change over time
	Fe-WAE	-0.331	0.007	Reduced over time
	Pb-WAE	-0.040	0.755	No change over time
	Hg-WAE*	-0.256	0.041	No change over time
	Ni-WAE	-0.140	0.269	No change over time
	Se-WAE*	-0.432	<0.001	No change over time
	Zn-WAE	-0.109	0.389	No change over time
South (Trend of all data 2013 - 2019)	Ag-WAE*	-0.480	<0.001	No change over time
	As-WAE	0.084	0.482	No change over time
	Cd-WAE*	-0.631	<0.001	No change over time
	Cr-WAE	0.058	0.623	No change over time
	Cu-WAE	0.125	0.293	No change over time
	Fe-WAE	0.162	0.172	No change over time
	Pb-WAE	-0.163	0.169	No change over time
	Hg-WAE*	-0.540	<0.001	No change over time
	Ni-WAE	0.100	0.402	No change over time
	Se-WAE*	-0.467	<0.001	No change over time
	Zn-WAE	-0.014	0.903	No change over time
SG6 (Trend of all data 2013 - 2019)	Ag-WAE*	-0.652	<0.001	No change over time
	As-WAE	0.281	0.071	No change over time
	Cd-WAE	-0.607	<0.001	Reduced over time
	Cr-WAE	-0.486	0.001	Reduced over time
	Cu-WAE	-0.109	0.493	No change over time
	Fe-WAE	-0.372	0.015	Reduced over time
	Pb-WAE	0.213	0.175	No change over time
	Hg-WAE	-0.304	0.050	Reduced over time
	Ni-WAE	-0.400	0.009	Reduced over time
	Se-WAE*	-0.535	<0.001	No change over time
	Zn-WAE	0.093	0.557	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.

APPENDIX F. TISSUE METAL – RISK AND PERFORMANCE ASSESSMENT – DETAILS OF STATISTICAL ANALYSIS & BOX PLOTS

Table F-1 Expanded risk matrix – tissue metals

Initial Assessment Result	Go To
TSM < TV	Step 1
TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR	Step 2
TSM = TV and TV, TSM and full TSM data set ≤ LOR	Step 3

Step	Alt Hypothesis	Null Hypothesis	Sig Test Result		Risk Assessment
1	TSM < TV	TSM = TV	p < 0.05	Accept Alt	LOW
			p > 0.05	Accept Null	POTENTIAL
			Error	Accept Neither	ND
2	TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR				POTENTIAL
3	TSM = TV and TV, TSM and full TSM data set are ≤ LOR				LOW

TSM = Test Site Median

ND = No determination

Table F-2 Tissue metals - fish flesh upper river test sites 2019 median (µg/g)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Wasiba	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	12	0.023	<	Step 1	0.20	0.001	LOW
Cd	12	12	0.004	<	Step 1	0.020	0.001	LOW
Cr	12	12	0.010	<	Step 1	0.021	0.027	LOW
Cu	12	12	0.14	<	Step 1	0.48	0.002	LOW
Hg	12	12	0.053	<	Step 1	0.080	0.004	LOW
Ni*	12	-	0.01	=	Step 3	0.01	-	LOW
Pb	12	12	0.01	<	Step 1	0.17	0.001	LOW
Se	12	12	0.46	<	Step 1	2.26	0.001	LOW
Zn	12	12	3.5	<	Step 1	10.4	0.001	LOW
Test Site				**Initial Assessment**		**TV**	**Statistical Test Result (p=0.05)**	**Risk Assessment**
Wankipe	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	12	0.016	<	Step 1	0.20	0.001	LOW
Cd	12	11	0.004	<	Step 1	0.020	0.002	LOW
Cr	12	12	0.010	<	Step 1	0.021	0.003	LOW
Cu	12	12	0.19	<	Step 1	0.48	0.001	LOW
Hg	12	12	0.05	<	Step 1	0.08	0.001	LOW
Ni*	12	-	0.01	=	Step 3	0.01	-	LOW
Pb	12	12	0.010	<	Step 2	0.17	0.001	LOW
Se	12	12	0.37	<	Step 1	2.26	0.001	LOW
Zn	12	12	3.7	<	Step 1	10.4	0.001	LOW

* Wilcoxon’s test returns an error when all test and reference data are equal, which usually occurs when all results are < the analytical limit of reporting. Although the result is not statistically significant the TSM is considered = TV.

Table F-3 Tissue metals - prawn abdomens from upper river test sites 2019 median (µg/g)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Wasiba	N	N (Test)	Median	Result	Go to			
As	12	12	0.030	<	Step 1	0.039	0.937	POTENTIAL
Cd	12	12	0.010	>	Step 2	0.003	0.999	POTENTIAL
Cr	12	12	0.014	<	Step 1	0.026	0.927	POTENTIAL
Cu	12	12	4.9	<	Step 1	6.3	0.937	POTENTIAL
Hg*	12	-	0.010	=	Step 3	0.010	-	LOW
Ni*	12	-	0.010	=	Step 3	0.010	-	LOW
Pb	12	12	0.016	>	Step 2	0.010	0.999	POTENTIAL
Se	12	12	0.65	>	Step 2	0.57	0.784	POTENTIAL
Zn	12	11	13	<	Step 1	14	0.950	POTENTIAL
Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Wankipe	N	N (Test)	Median	Result	Go to			
As	12	12	0.033	<	Step 1	0.039	0.927	POTENTIAL
Cd	12	12	0.010	>	Step 2	0.003	0.999	POTENTIAL
Cr	12	11	0.024	<	Step 1	0.026	0.950	POTENTIAL
Cu	12	12	8.3	>	Step 2	6.3	0.921	POTENTIAL
Hg*	12	-	0.010	=	Step 3	0.010	-	LOW
Ni*	12	-	0.010	=	Step 3	0.010	-	LOW
Pb	12	10	0.011	>	Step 2	0.010	0.998	POTENTIAL
Se	12	12	0.49	<	Step 1	0.57	0.006	LOW
Zn	12	-	14	=	Step 2	14	-	POTENTIAL

* Wilcoxon's test returns an error when all test and reference data are equal, which usually occurs when all results are < the analytical limit of reporting. Although the result is not statistically significant the TSM is considered = TV.

Table F-4 Tissue metals - fish flesh lower river test sites 2019 median (µg/g)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Bebelubi	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	12	0.015	<	Step 1	0.071	0.001	LOW
Cd*	12	-	0.003	=	Step 3	0.003	-	LOW
Cr	12	12	0.010	<	Step 1	0.030	0.001	LOW
Cu	12	12	0.065	<	Step 1	0.17	0.001	LOW
Hg	12	12	0.030	<	Step 1	0.12	0.001	LOW
Ni	12	12	0.010	<	Step 1	0.165	0.001	LOW
Pb	12	12	0.010	<	Step 1	0.03	0.001	LOW
Se	12	12	0.074	<	Step 1	2.26	0.001	LOW
Zn	12	12	2.40	<	Step 1	7.5	0.001	LOW
Test Site				**Initial Assessment**		**TV**	**Statistical Test Result (p=0.05)**	**Risk Assessment**
SG4	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	11	0.010	<	Step 1	0.071	0.001	LOW
Cd*	12	-	0.0030	=	Step 2	0.0030	-	LOW
Cr	12	12	0.010	<	Step 1	0.030	0.001	LOW
Cu	12	12	0.069	<	Step 1	0.17	0.001	LOW
Hg	12	12	0.041	<	Step 1	0.12	0.003	LOW
Ni	12	12	0.010	<	Step 1	0.165	0.001	LOW
Pb	12	12	0.010	<	Step 1	0.03	0.001	LOW
Se	12	12	0.13	<	Step 1	2.26	0.001	LOW
Zn	12	12	2.3	<	Step 1	7.5	0.001	LOW

* Wilcoxon's test returns error when all test and reference data are equal, which occurs when all results are < the analytical limit of reporting. Although the result is not statistically significant the TSM is considered = TV.

Table F-5 Tissue metals - prawn abdomens lower river test sites 2019 median (µg/g)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Bebelubi	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	12	0.077	<	Step 1	0.085	0.252	POTENTIAL
Cd	12	10	0.004	<	Step 1	0.005	0.399	POTENTIAL
Cr	12	12	0.019	<	Step 1	0.050	0.001	LOW
Cu	12	11	7.6	<	Step 1	10	0.003	LOW
Hg*	12	-	0.010	=	Step 3	0.010	-	LOW
Ni	12	3	0.010	=	Step 2	0.010	0.181	POTENTIAL
Pb	12	-	0.010	=	Step 3	0.010	-	LOW
Se	12	11	0.30	<	Step 1	0.32	0.500	POTENTIAL
Zn	12	10	12.5	<	Step 1	14	0.057	POTENTIAL
Test Site				**Initial Assessment**		**TV**	**Statistical Test Result (p=0.05)**	**Risk Assessment**
SG4	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	12	0.065	<	Step 1	0.085	0.073	POTENTIAL
Cd	12	12	0.010	>	Step 2	0.005	0.994	POTENTIAL
Cr	12	12	0.022	<	Step 1	0.050	0.004	LOW
Cu	12	12	6.9	<	Step 1	10	0.001	LOW
Hg*	12	-	0.010	=	Step 3	0.010	-	LOW
Ni	12	5	0.010	=	Step 2	0.010	0.059	POTENTIAL
Pb	12	1	0.010	=	Step 2	0.010	1	POTENTIAL
Se	12	12	0.37	>	Step 2	0.32	0.967	POTENTIAL
Zn	12	12	12	<	Step 1	14	0.005	LOW

* Wilcoxon's test returns an error when all test and reference data are equal, which usually occurs when all results are < the analytical limit of reporting. Although the result is not statistically significant the TSM is considered = TV.

Table F-6 Tissue metals - fish flesh from Lake Murray test sites 2019 median (µg/g)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Miwa	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	6	6	0.016	<	Step 1	0.0528	0.018	LOW
Cd*	6	-	0.003	=	Step 2	0.003	-	LOW
Cr	6	6	0.010	<	Step 1	0.028	0.201	POTENTIAL
Cu	6	6	0.078	<	Step 1	0.203	0.018	LOW
Hg	6	6	0.20	<	Step 1	0.328	0.018	LOW
Ni	6	6	0.010	<	Step 1	0.19	0.018	LOW
Pb	6	6	0.010	<	Step 1	0.071	0.018	LOW
Se	6	6	0.36	<	Step 1	2.26	0.018	LOW
Zn	6	6	2.40	<	Step 1	3.12	0.018	LOW
Test Site				**Initial Assessment**		**TV**	**Statistical Test Result (p=0.05)**	**Risk Assessment**
Pangoa	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	6	6	0.015	<	Step 1	0.0528	0.018	LOW
Cd*	6	-	0.003	=	Step 2	0.003	-	LOW
Cr	6	6	0.01	<	Step 1	0.028	0.018	LOW
Cu	6	6	0.080	<	Step 1	0.19	0.018	LOW
Hg	6	6	0.19	<	Step 1	0.328	0.018	LOW
Ni	6	6	0.01	<	Step 1	0.19	0.018	LOW
Pb	6	6	0.010	<	Step 1	0.071	0.018	LOW
Se	6	6	0.32	<	Step 1	2.26	0.018	LOW
Zn	6	6	2.35	<	Step 1	3.12	0.201	POTENTIAL

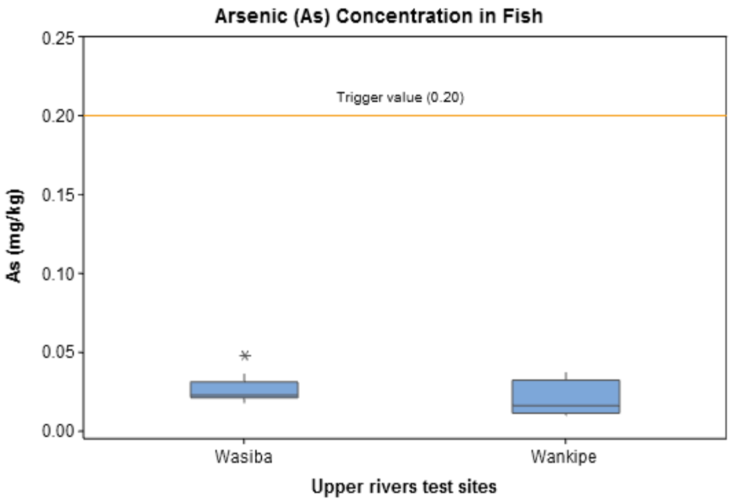

Figure F-1 Arsenic in fish flesh upper rivers test sites 2019

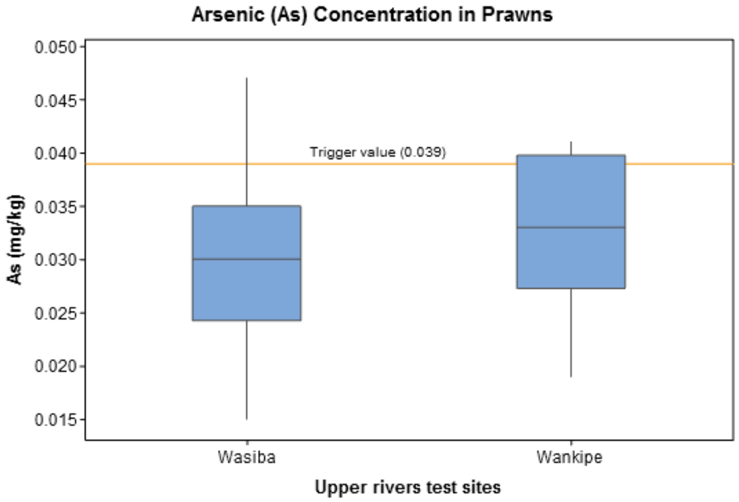

Figure F-2 Arsenic in prawn abdomen upper rivers test sites 2019

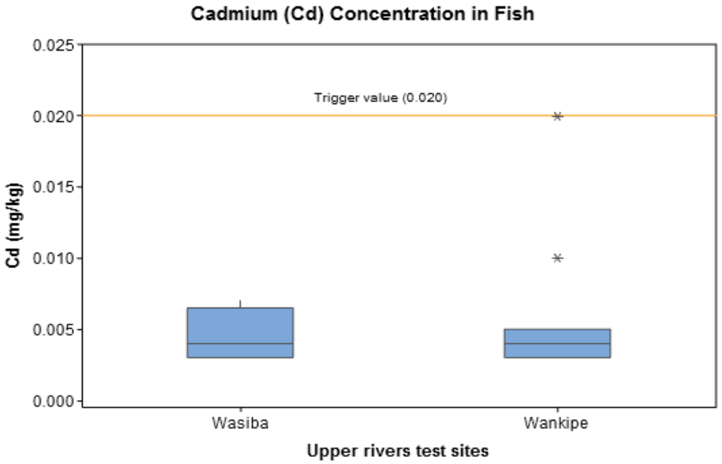

Figure F-3 Cadmium in fish flesh upper rivers test sites 2019

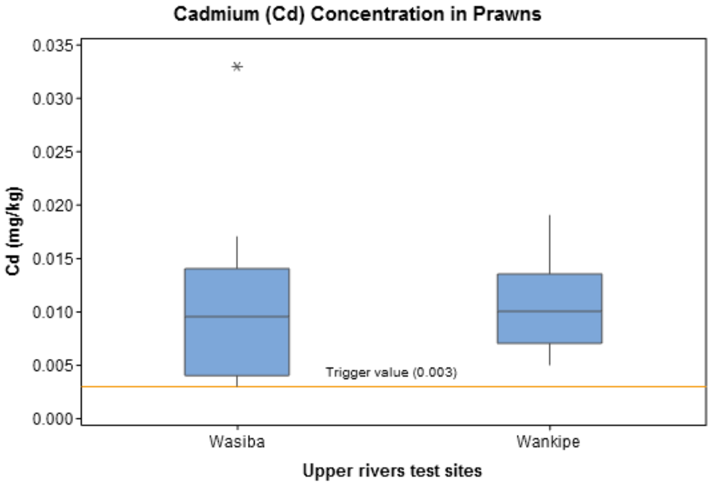

Figure F-4 Cadmium in prawn abdomen upper rivers test sites 2019

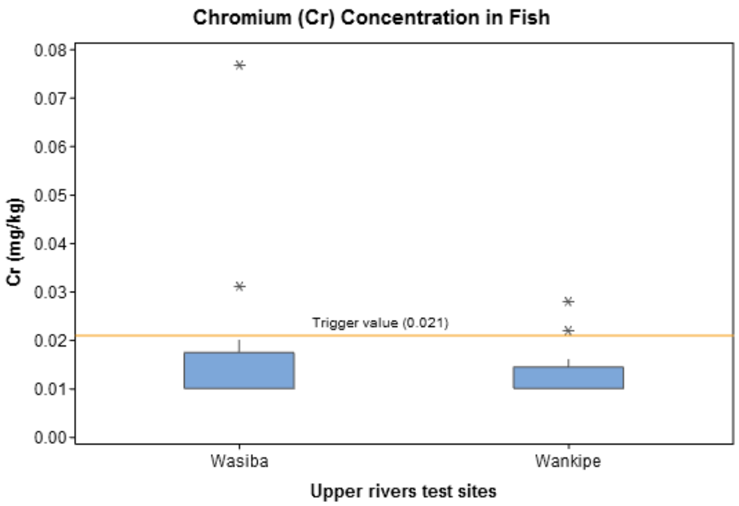

Figure F-5 Chromium in fish flesh upper rivers test sites 2019

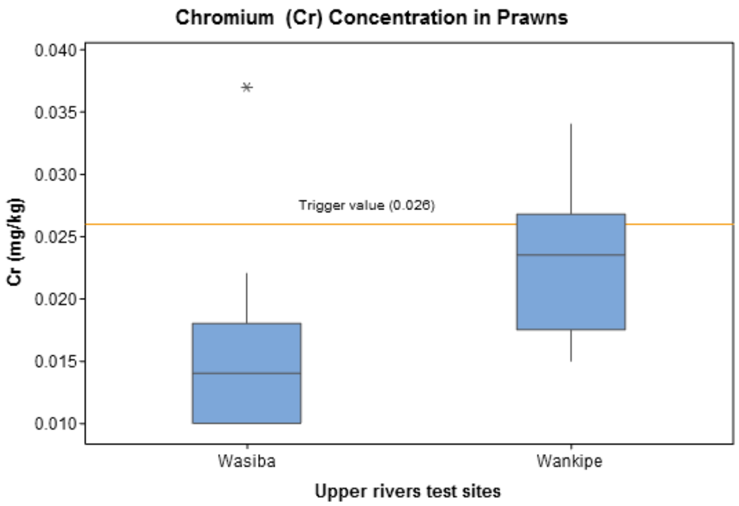

Figure F-6 Chromium in prawn abdomen upper rivers test sites 2019

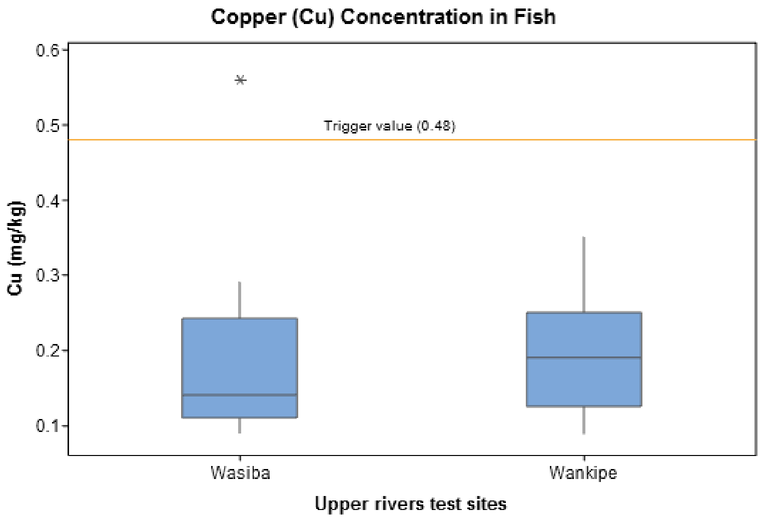

Figure F-7 Copper in fish flesh upper rivers test sites 2019

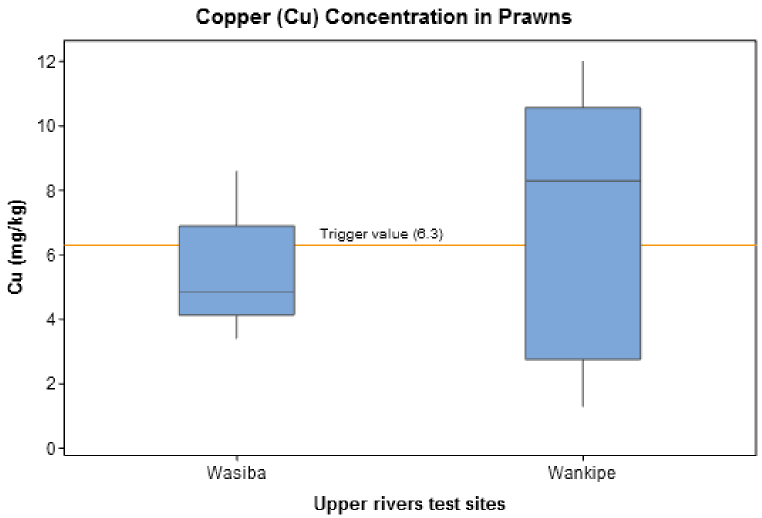

Figure F-8 Copper in prawn abdomen upper rivers test sites 2019

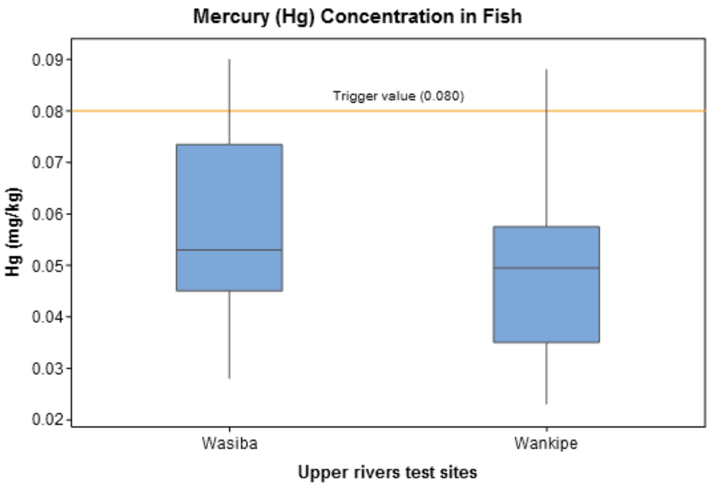

Figure F-9 Mercury in fish flesh upper rivers test sites 2019

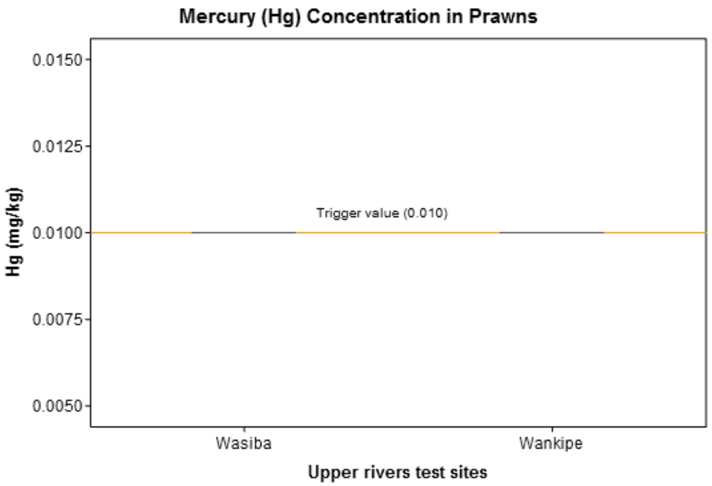

Figure F-10 Mercury in prawn abdomen upper rivers test sites 2019

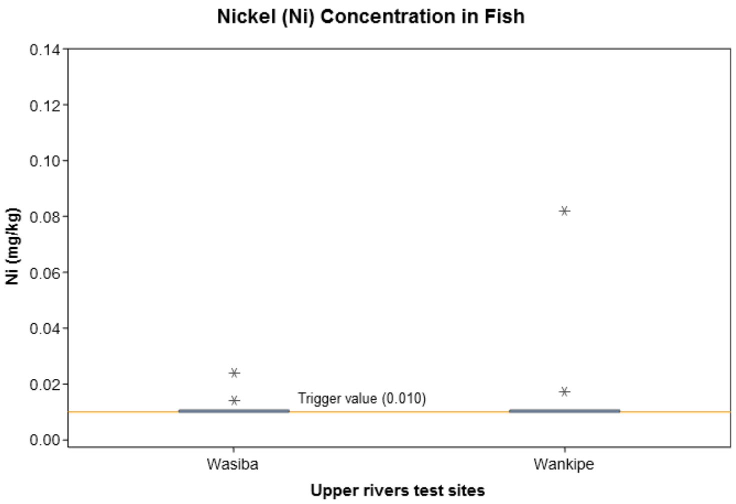

Figure F-11 Nickel in fish flesh upper rivers test sites 2019

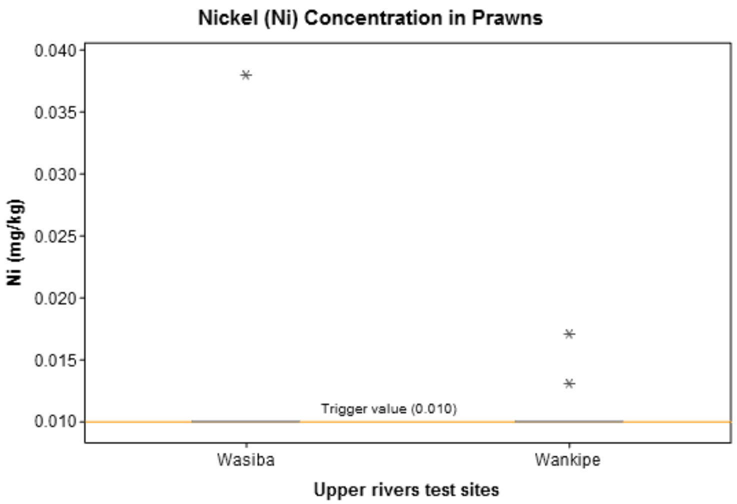

Figure F-12 Nickel in prawn abdomen upper rivers test sites 2019

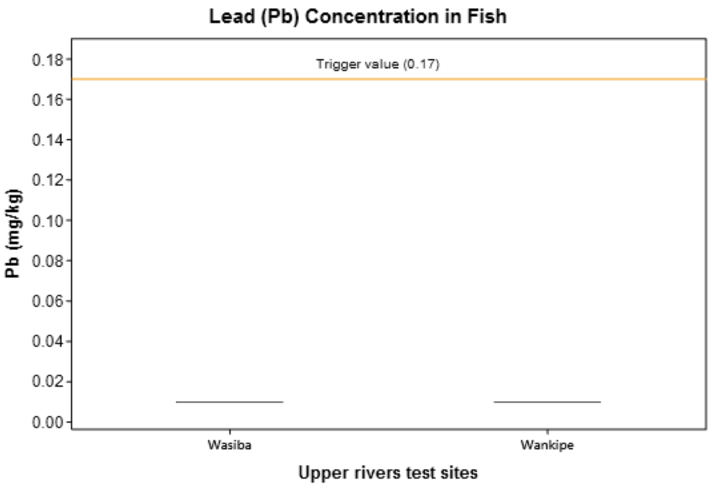

Figure F-13 Lead in fish flesh upper rivers test sites 2019

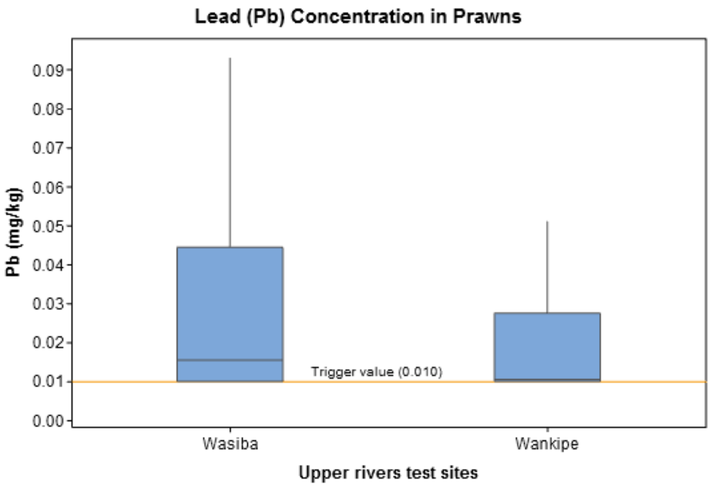

Figure F-14 Lead in prawn abdomen upper rivers test sites 2019

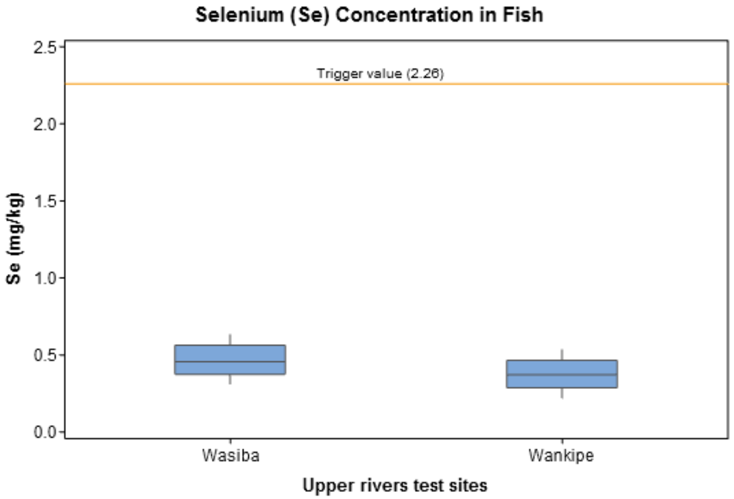

Figure F-15 Selenium in fish flesh upper rivers test sites 2019

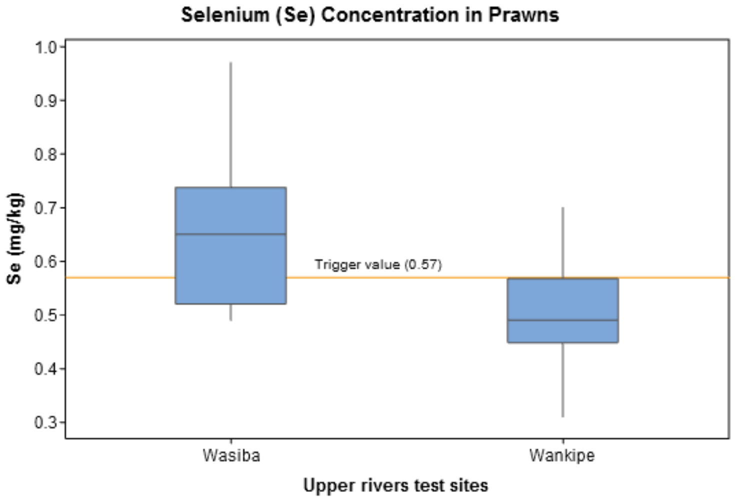

Figure F-16 Selenium in prawn abdomen upper rivers test sites 2019

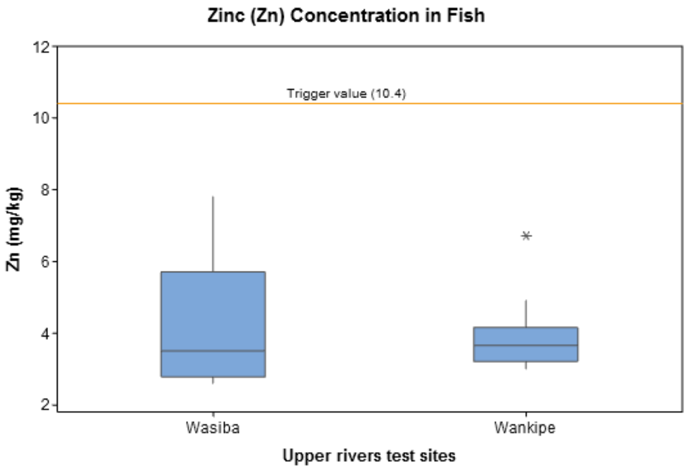

Figure F-17 Zinc in fish flesh upper rivers test sites 2019

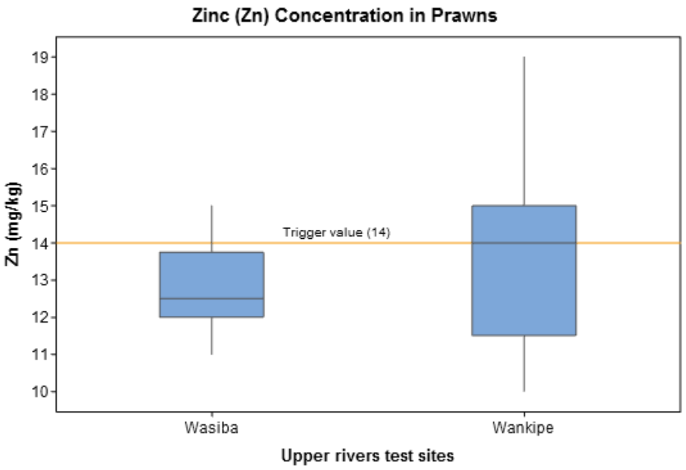

Figure F-18 Zinc in prawn abdomen upper rivers test sites 2019

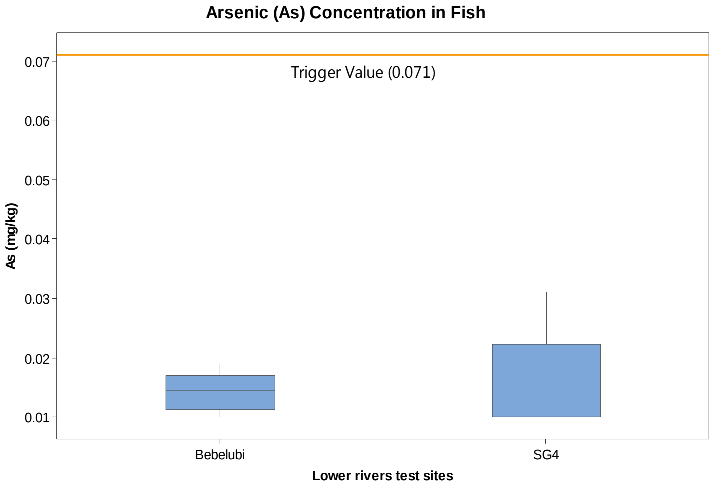

Figure F-19 Arsenic in fish flesh lower rivers test sites 2019

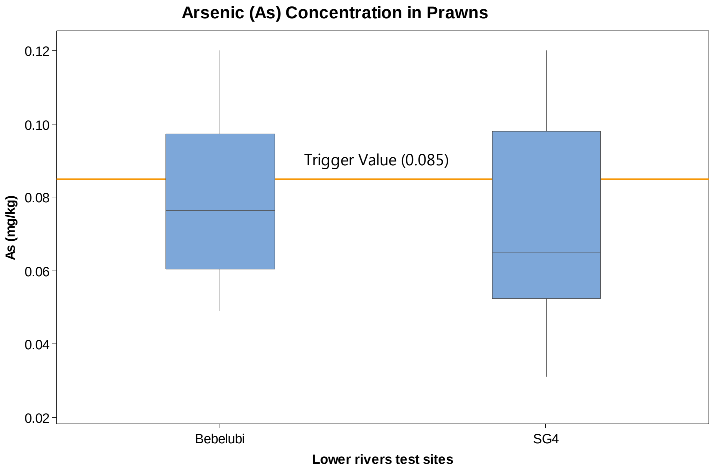

Figure F-20 Arsenic in prawn abdomen lower rivers test sites 2019

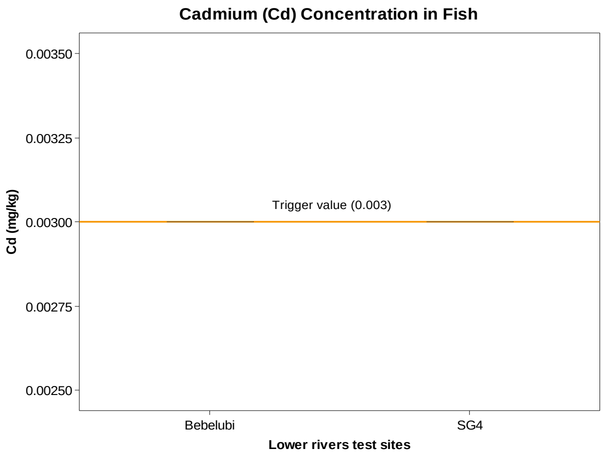

Figure F-21 Cadmium in fish flesh lower rivers test sites 2019

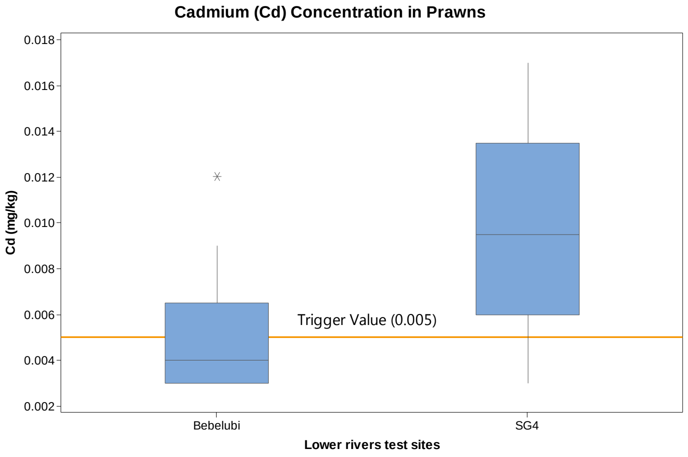

Figure F-22 Cadmium in prawn abdomen lower rivers test sites 2019

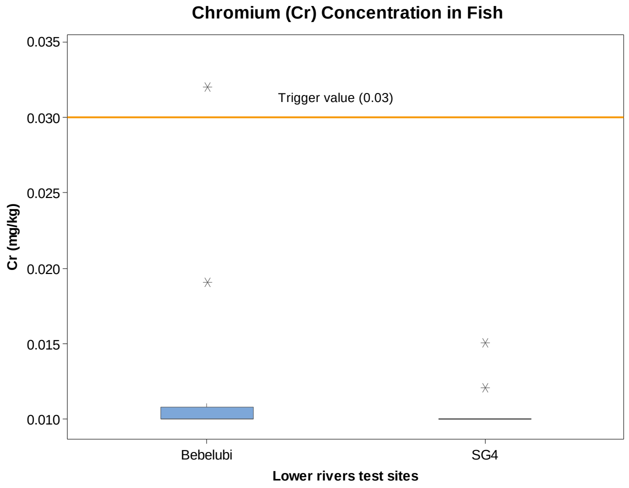

Figure F-23 Chromium in fish flesh lower rivers test sites 2019

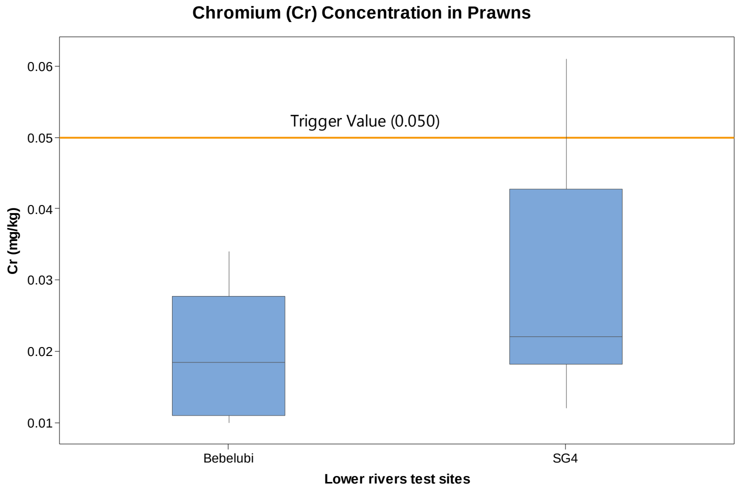

Figure F-24 Chromium in prawn abdomen lower rivers test sites 2019

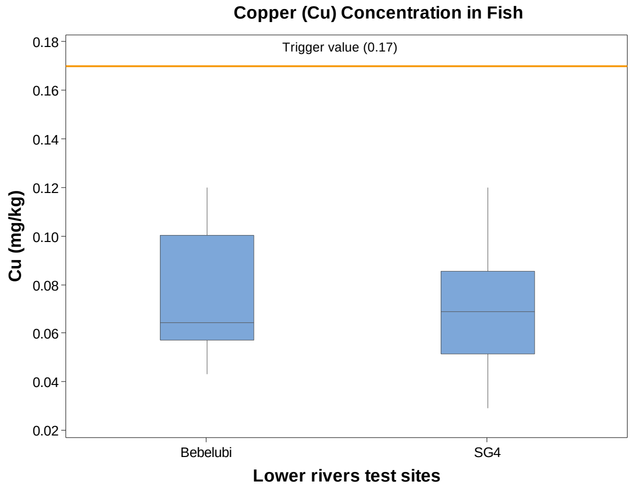

Figure F-25 Copper in fish flesh lower rivers test sites 2019

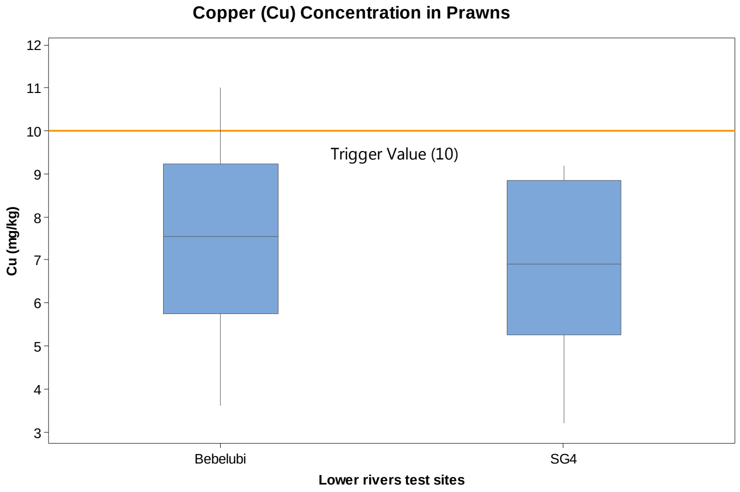

Figure F-26 Copper in prawn abdomen lower rivers test sites 2019

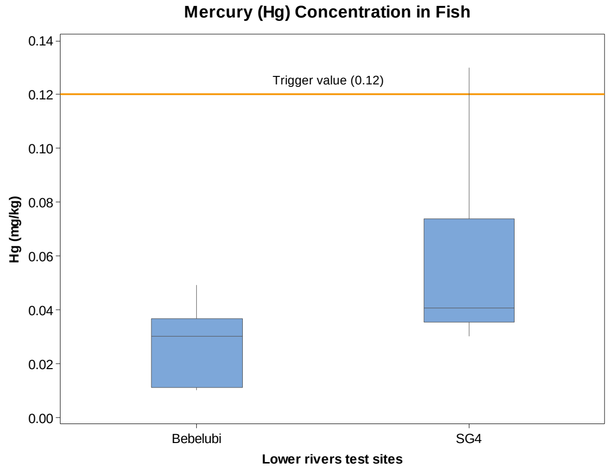

Figure F-27 Mercury in fish flesh lower rivers test sites 2019

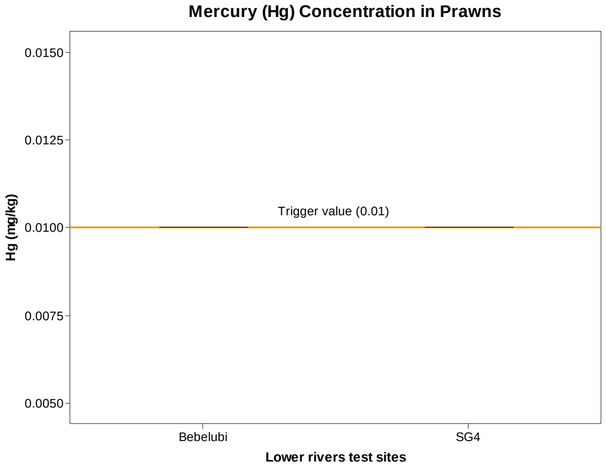

Figure F-28 Mercury in prawn abdomen lower rivers test sites 2019

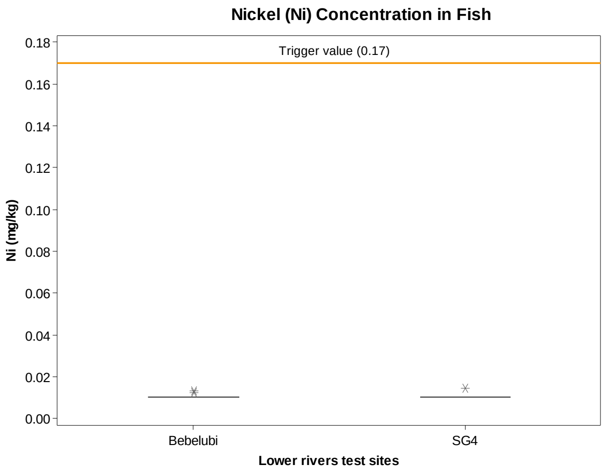

Figure F-29 Nickel in fish flesh lower rivers test sites 2019

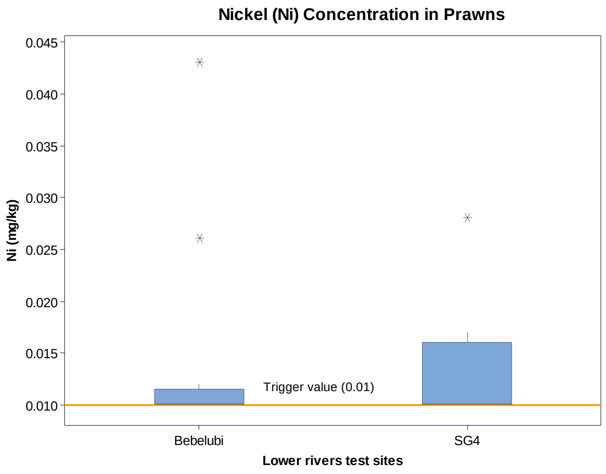

Figure F-30 Nickel in prawn abdomen lower rivers test sites 2019

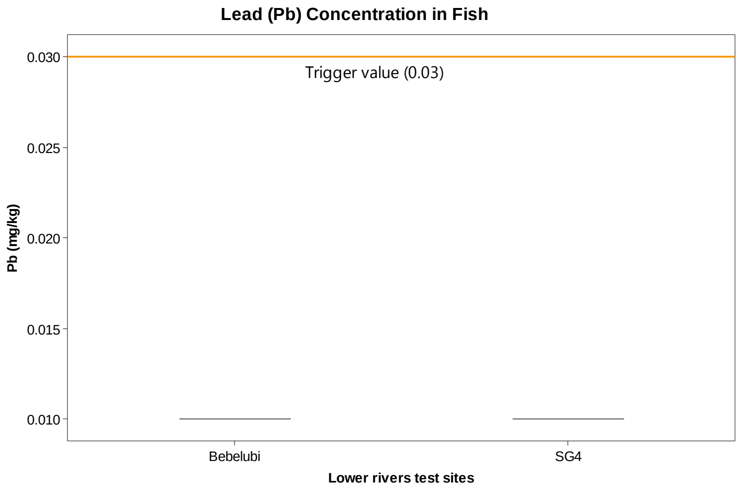

Figure F-31 Lead in fish flesh lower rivers test sites 2019

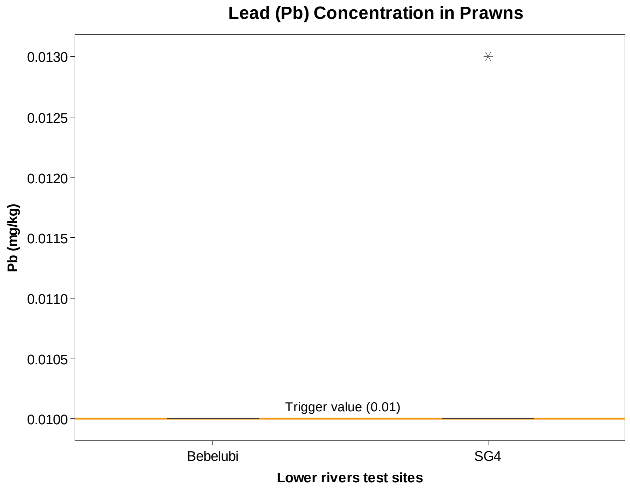

Figure F-32 Lead in prawn abdomen lower rivers test sites 2019

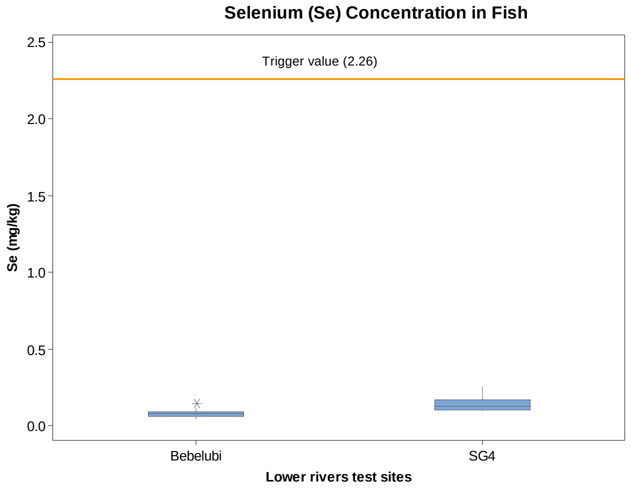

Figure F-33 Selenium in fish flesh lower rivers test sites 2019

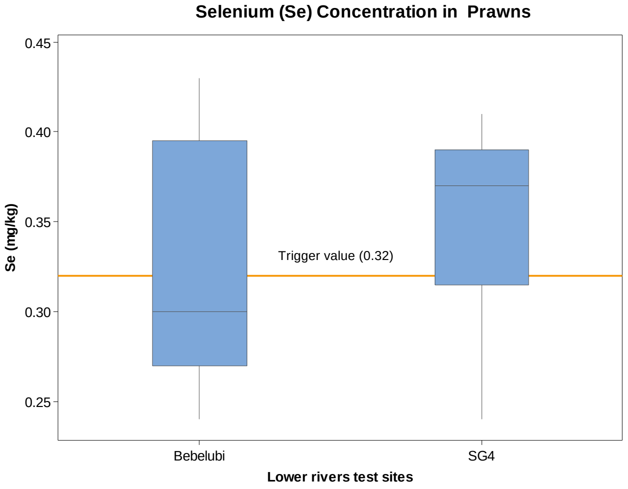

Figure F-34 Selenium in prawn abdomen lower rivers test sites 2019

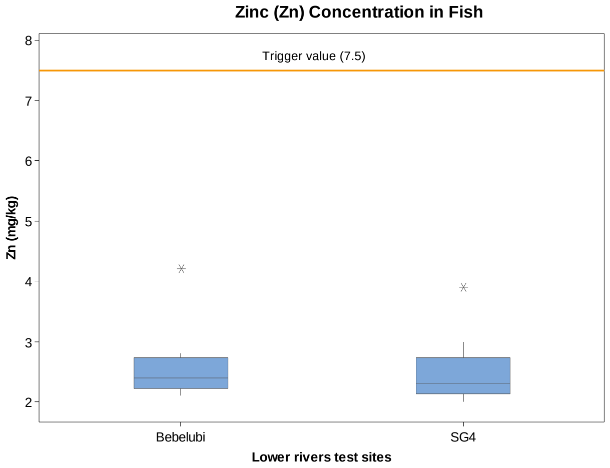

Figure F-35 Zinc in fish flesh at lower rivers test sites 2019

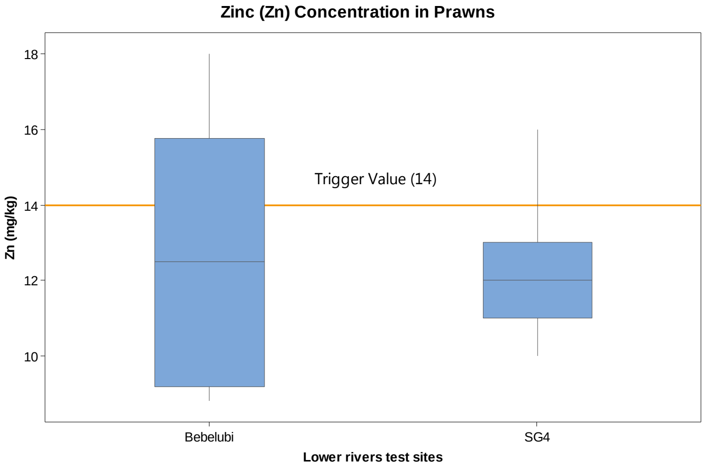

Figure F-36 Zinc in prawn abdomen lower rivers test sites 2019

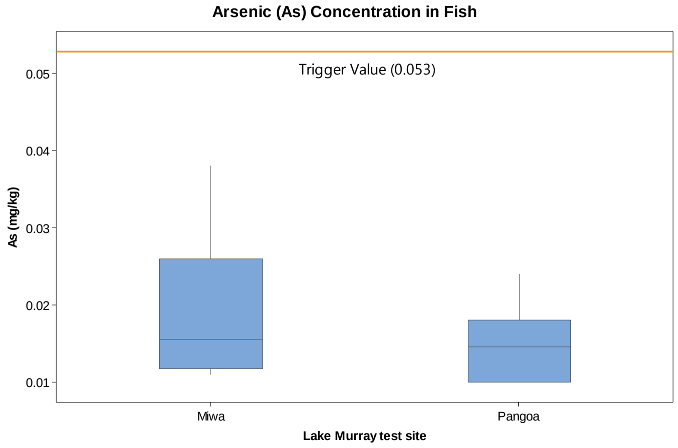

Figure F-37 Arsenic in fish flesh Lake Murray test sites 2019

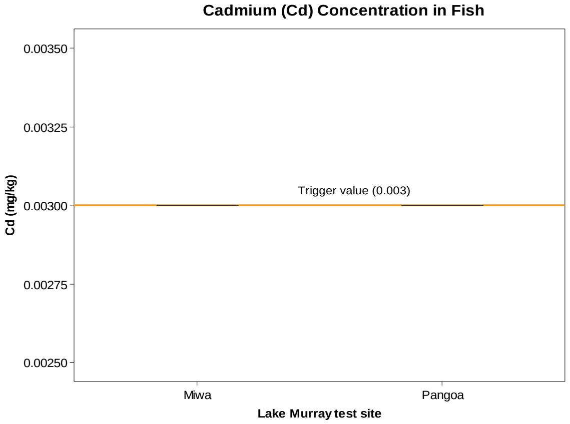

Figure F-38 Cadmium in fish flesh Lake Murray test sites 2019

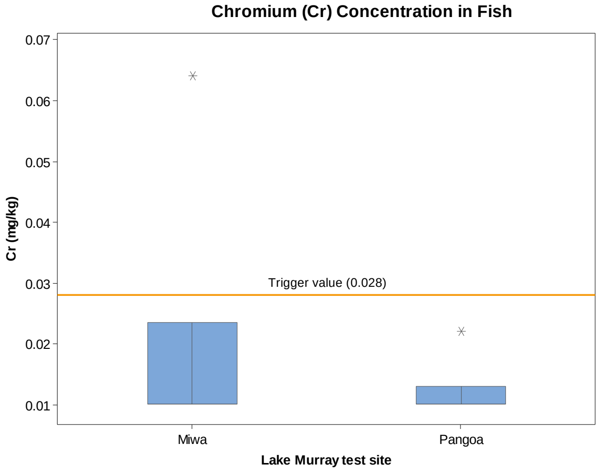

Figure F-39 Chromium in fish flesh Lake Murray test sites 2019

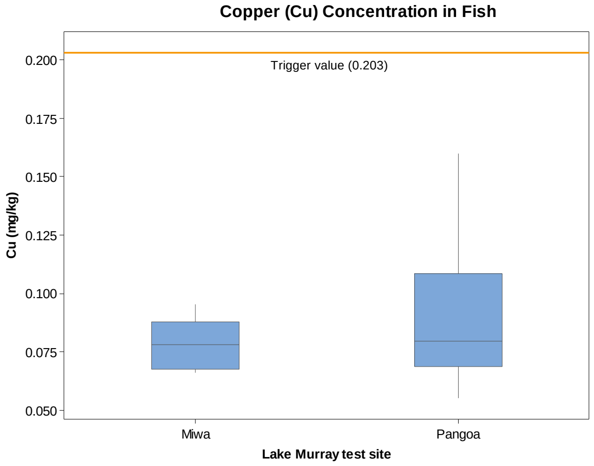

Figure F-40 Copper in fish flesh Lake Murray test sites 2019

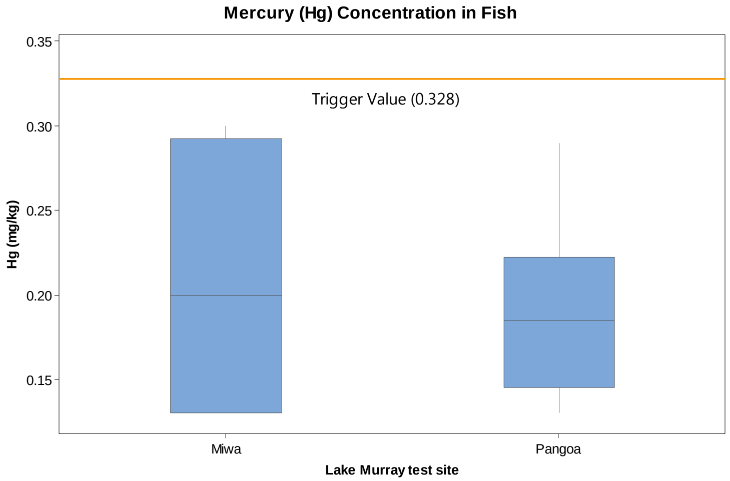

Figure F-41 Mercury in fish flesh Lake Murray test sites 2019

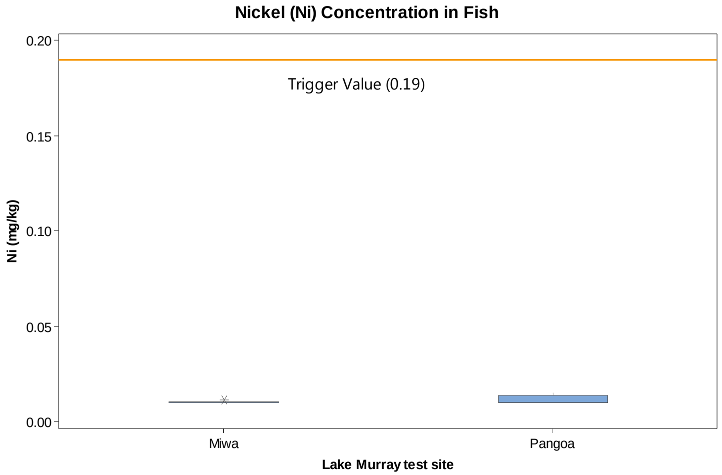

Figure F-42 Nickel in fish flesh Lake Murray test sites 2019

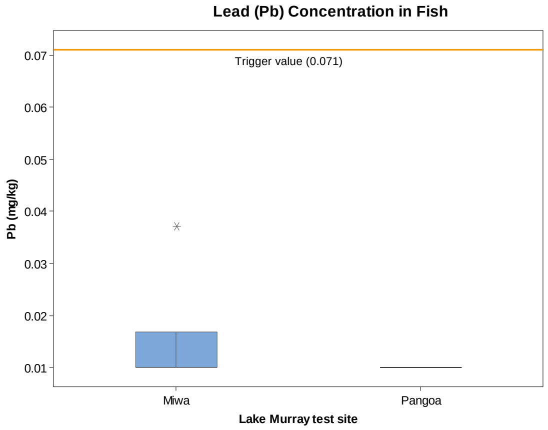

Figure F-43 Lead in fish flesh Lake Murray test sites 2019

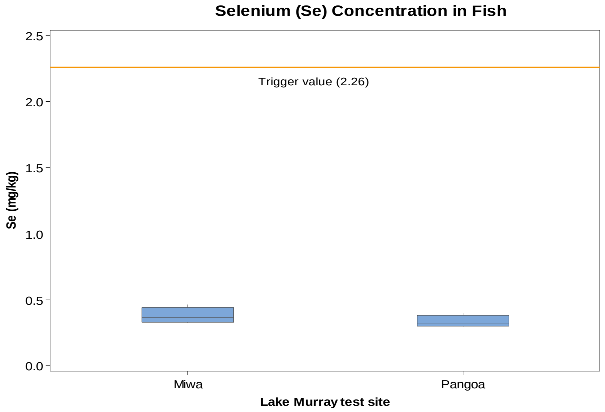

Figure F-44 Selenium in fish flesh Lake Murray test sites 2019

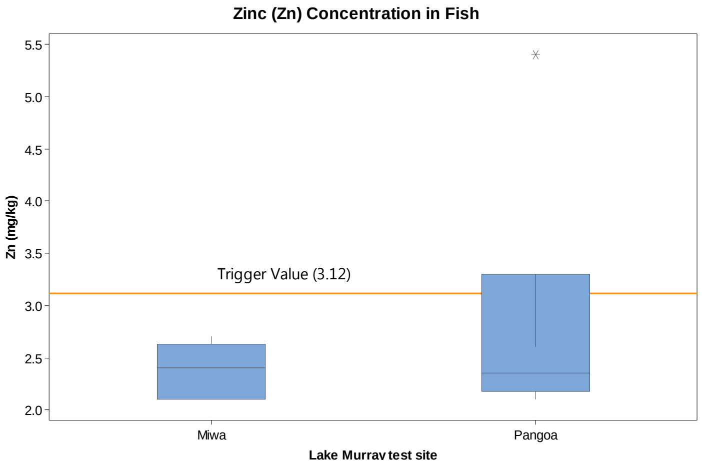

Figure F-45 Zinc in fish flesh Lake Murray test sites 2019

Table F-7 Performance assessment – Based on the trend of tissue metals in fish flesh at upper river test sites from 2010-2019 using Spearman Rank Test.

Fish Flesh Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2010 - 2019
Wasiba (Trend of Annual Median 2010 - 2019)	As	0.076	0.262	No change over time
	Cd	-0.736	<0.001	Reduced over time
	Cr	0.048	0.478	No change over time
	Cu	-0.18	0.007	Reduced over time
	Hg	0.033	0.63	No change over time
	Ni	-0.029	0.667	No change over time
	Pb	-0.158	0.019	Reduced over time
	Se	-0.263	<0.001	Reduced over time
	Zn	-0.206	0.002	Reduced over time
Wankipe (Trend of Annual Median 2010 - 2019)	As	-0.1	0.122	No change over time
	Cd	-0.726	<0.001	Reduced over time
	Cr	0.018	0.778	No change over time
	Cu	-0.095	0.142	No change over time
	Hg	0.018	0.777	No change over time
	Ni	-0.1	0.121	No change over time
	Pb	0.018	0.776	No change over time
	Se	-0.129	0.046	Reduced over time
	Zn	-0.195	0.002	Reduced over time

Table F-8 Performance assessment – Based on the trend of tissue metals in prawn abdomen at upper river test sites from 2010-2019 using Spearman Rank Test.

Prawn Abdomen Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2010 - 2019
Wasiba (Trend of Annual Median 2010 - 2019)	As	-0.262	<0.001	Reduced over time
	Cd	-0.52	<0.001	Reduced over time
	Cr	0.159	0.014	Increased over time
	Cu	-0.15	0.021	Reduced over time
	Hg*	-	-	No change over time
	Ni	-0.101	0.12	No change over time
	Pb	0.171	0.008	Increased over time
	Se	0.302	<0.001	Increased over time
	Zn	-0.205	0.002	Reduced over time
Wankipe (Trend of Annual Median 2010 - 2019)	As	-0.322	<0.001	Reduced over time
	Cd	-0.511	<0.001	Reduced over time
	Cr	-0.082	0.19	No change over time
	Cu	-0.058	0.359	No change over time
	Hg*	-	-	No change over time
	Ni	0.074	0.239	No change over time
	Pb	0.029	0.647	No change over time
	Se	0.034	0.586	No change over time
	Zn	-0.285	<0.001	Reduced over time

Table F-9 Performance assessment – Based on the trend of tissue metals in fish flesh at lower river test sites from 2010-2019 using Spearman Rank Test.

Fish flesh	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2010 - 2019
Site				
Bebelubi (Trend of Annual Median 2010 - 2019)	As	0.033	0.776	No change over time
	Cd	-0.862	<0.001	Reduced over time
	Cr	-0.105	0.366	No change over time
	Cu	-0.394	<0.001	Reduced over time
	Hg	-0.617	<0.001	Reduced over time
	Ni	-0.27	0.018	Reduced over time
	Pb*	-	-	No change over time
	Se	-0.577	<0.001	Reduced over time
	Zn	-0.333	0.003	Reduced over time
SG4 (Trend of Annual Median 2010 - 2019)	As	-0.028	0.667	No change over time
	Cd	-0.819	<0.001	Reduced over time
	Cr	0.089	0.17	No change over time
	Cu	-0.102	0.116	No change over time
	Hg	0.037	0.573	No change over time
	Ni	0.002	0.981	No change over time
	Pb	0.003	0.965	No change over time
	Se	0.034	0.596	No change over time
	Zn	-0.016	0.810	No change over time

Table F-10 Performance assessment – Based on the trend of tissue metals in prawn abdomen at lower river test sites from 2010-2019 using Spearman Rank Test.

Prawn Abdomen	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2010 - 2019
Site				
Bebelubi (Trend of Annual Median 2010 - 2019)	As	-0.048	0.419	No change over time
	Cd	-0.558	<0.001	Reduced over time
	Cr	0.026	0.667	No change over time
	Cu	0.257	<0.001	Increased over time
	Hg*	-	-	No change over time
	Ni	-0.012	0.835	No change over time
	Pb	-0.025	0.67	No change over time
	Se	0.11	0.064	No change over time
	Zn	0.105	0.077	No change over time
SG4 (Trend of Annual Median 2010 - 2019)	As	-0.132	0.019	Reduced over time
	Cd	-0.265	<0.001	Reduced over time
	Cr	0.03	0.597	No change over time
	Cu	0.287	<0.001	Increased over time
	Hg*	-	-	No change over time
	Ni	0.024	0.672	No change over time
	Pb	0.086	0.131	No change over time
	Se	0.291	<0.001	Increased over time
	Zn	0.091	0.107	No change over time

Table F-11 Performance assessment – Based on the trend of tissue metals in fish flesh at Lake Murray test sites from 2003-2019 using Spearman Rank Test.

Fish Flesh Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2003 - 2019
Miwa (Trend of Annual Median 2011 - 2019)	As	0.23	0.552	No change over time
	Cd	-0.655	0.056	No change over time
	Cr	-0.068	0.862	No change over time
	Cu	-0.64	0.063	No change over time
	Hg	-0.851	0.004	Reduced over time
	Ni	0.245	0.524	No change over time
	Pb	0.245	0.524	No change over time
	Se	0.84	0.005	Increased over time
	Zn	-0.448	0.227	No change over time
Pangoa (Trend of Annual Median 2002 - 2019)	As	0.142	0.255	No change over time
	Cd	-0.508	<0.001	Reduced over time
	Cr	0.273	0.027	Increased over time
	Cu	-0.675	<0.001	Reduced over time
	Hg	-0.406	0.001	Reduced over time
	Ni	-0.26	0.035	Reduced over time
	Pb	0.173	0.166	No change over time
	Se	-0.068	0.586	No change over time
	Zn	-0.511	<0.001	Reduced 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.