PORGERA
JOINT VENTURE

ANNUAL ENVIRONMENT REPORT 2018

ISO 14001 Certified Environmental Management System

ERMCVS CERTIFIED ENVIRONMENTAL MANAGEMENT SYSTEM

UKAS MANAGEMENT SYSTEMS 067

ISO 14001 Certificate 489

Barrick Niugini Limited - Porgera Joint Venture

June 2019

POR ENV 1/19

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PAPUA NEW GUINEA

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Cover Photo: Strickland River, SG3 compliance monitoring station, January 2019

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CSIRO

James Versluis
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Porgera Joint Venture
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Papua New Guinea

17 June 2019

Dear James,

Re: Porgera Joint Venture 2018 Annual Environment Report

Dr Graeme Batley and Dr Simon Apte reviewed a draft of the 2018 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 recommendations were made for improvement. Porgera Joint Venture responded positively to the review team's recommendations and the report was satisfactorily revised in the light of the comments made.

Both the CSIRO review team and Dr Andrew Storey (Wetlands Research & Management Pty Ltd.) who independently reviewed the report, also made a number of observations and suggestions relating to improving laboratory quality assurance, monitoring data interpretation and the identification of long term trends. We note that Porgera Joint Venture have agreed to hold a workshop later this year to discuss these matters with a view to incorporation in the next Annual Environment Report.

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 2028, with an annual production of approximately 500 koz of gold. The site employs 3,400 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, mitigation of potential environmental risks and continual improvement of environmental performance. The EMS was first certified to the ISO14001 standard in December 2012, it was re-certified in December 2015 and again in August 2018.

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, to identify those which require attention to improve their 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, 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 area of land held by the PJV and the quantity of ore and gold production in 2018 were comparable with the previous five years. Water and energy efficiencies also were comparable with previous years and the trend of moderately improving efficiency over time has continued.

Tailings production was marginally lower than previous years due to production constraints associated with the February 2018 earthquake which damaged the Hides Power Station. Discharged volumes were, however, still consistent with previous years, and a significant proportion (9.4% by volume) was diverted from riverine disposal and used for cemented backfill in the underground mine.

Tailings quality achieved 100% compliance with the internal site-developed end-of-pipe criteria for cyanide and pH.

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 showed increased trends over the preceding ten-year period (2009-2018), while other metals either remained unchanged or decreased. The median concentrations of TSS, dissolved cadmium, copper, nickel and zinc were elevated when compared against the trigger values (TVs) for the upper river system in 2018.

The median concentrations of weak-acid-extractable arsenic, cadmium, copper, mercury, nickel, lead selenium and zinc in tailings solids were elevated in relation to the upper river trigger values in 2018.

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 2018 were higher than previous years despite less rainfall, which is attributable to more accurate runoff calculations.

Background Environmental Conditions

The Porgera Valley and downstream catchments experienced average annual rainfall during 2018. This, consequently, resulted in 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 (i.e. baseline data), and since operations began from sites that are not influenced by the operation (i.e. 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 and ORWB reference sites and trends of dissolved zinc at upper and lower river reference sites and Lake Murray and ORWB reference sites displayed statistically significant increases over the past decade.

The February 2018 earthquake caused landslides in the headwaters of the Baia, Nomad and Rintoul Rivers, which flow into the Strickland River on the Strickland River floodplain. The landslides caused large volumes of sediment and organic matter to enter the rivers, increasing TSS, reducing dissolved oxygen and causing fish kills. Baia is one of the PJV monitoring program's reference sites and Bebelubi and SG4 are test sites on the Strickland River downstream of the landslide-affected areas. Elevated TSS was observed at reference site Baia and test sites Bebelubi and SG4 as a result of the earthquake and subsequent landslides.

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 99% of legal and other obligations throughout 2018. Non-compliance was related to a short-duration event of elevated TSS in discharge from two (2) of the five (5) sewage treatment plants (STP). The events did not result in any environmental or human health risk.

PJV complied with all other water extraction and waste discharge permit conditions, including water quality at compliance point at SG3 on the Strickland River, which was compliant with all permit requirements throughout 2018.

Environmental Risk, Impact and Performance

Methodology

The methodology for risk and impact assessment has been developed by PJV in accordance with international guidelines and in consultation with external technical experts.

The risk assessment stage is based on the comparison of physical and chemical environmental indicators at sites potentially impacted by the mine (test sites) against trigger values (TVs) 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. It should be noted that the derivation of trigger values from the statistical distribution of baseline and reference site data, rather than "effects-based" TVs, limits the assessment to only a "screening level" for identification of risk and potential impacts. TVs act as a benchmark to determine whether conditions at test sites pose a risk of causing impact to aquatic ecosystems or human health. Exceeding a TV prompts further investigation to determine whether impact is actually occurring.

Impact assessment is based on the comparison of biological indicators at test sites against biological indicators at reference sites or appropriate baseline indicators to determine whether environmental aspects of the mine are impacting aquatic ecosystems.

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, cadmium, nickel, lead and selenium in tailings and mine 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 SG3 on the Strickland River. There was low risk to aquatic ecosystems downstream of SG3 in the lower river, Lake Murray and ORWBs.

The proportion of mine derived sediment at SG3 in 2018 was estimated to be 41%, which was higher than recent years and higher than the long-term median of approximately 23%, although it should be noted that there is low confidence in the 2018 estimate due to poor quality flow data from SG3 for a portion of the year. This 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 of impact to the receiving environment.

There was low risk posed to human health through consumption of water from known drinking water sources, contact with water in rivers downstream of the tailings discharge point and consumption of fish and prawns within the Lagaip and Strickland Rivers and Lake Murray. Contact with undiluted tailings did pose a potential human health risk due to elevated concentrations of dissolved cadmium, nickel and zinc. It should be noted that the only mechanism for exposure to undiluted tailings is through illegally accessing the tailings discharge point within the mining area.

The impact assessment concluded that there was no significant mine-related aquatic ecosystem impact within the upper or lower river during 2018. An analysis of the trends of biological environmental indicators showed a significantly decreasing trend in the biomass of prawn species *M. lorentzi* at upper river test site Wasiba between 2015 and 2018, and while this does not show impact it does provide an indication that impact may be detected in future years if the decreasing trend continues. No mine-related change to other biological environmental indicators were observed at any of the upper river, lower river or Lake Murray test sites. Change to biological indicators were observed at lower river test site Tiumsinawam on the Strickland River, however, this was likely to have been driven by non-mine related pressure on fish populations, primarily due to population growth within the nearby villages.

Overall, the condition of the receiving aquatic ecosystem remained consistent with predictions made prior to operations commencing in 1990.

Recommendations for Improvement

Recommendations are proposed 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 2017 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 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 Strickland River 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. Apply improved standardised fishing methods at Lake Murray.
5. Investigate the ions that contribute to elevated EC values.

Reduce Environmental Risk and Impact and Improve Performance

6. Continue to investigate options for reducing the concentrations of bioavailable metals and mass loads of metals in mine discharges.
7. 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.
8. Investigate the apparent trend of increasing pH and metals concentrations from non-mine related sources in the lower river system (e.g. zinc at concentrations slightly above the analytical LOR).

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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 (ANZECC/ARMCANZ 2000). 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.

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. (ANZECC/ARMCANZ 2000)

SAG: Semi-autogenous Grinding.

SML: Special Mining Lease.

SOP: Standard Operating Procedure.

SQGV: 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 630km 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%) 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 2028 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 sites 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 sites 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, 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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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 (ANZECC/ARMCANZ 2000) 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 45 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 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 35 m 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 – 100 mg/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 6.3 – 7.0.

A portion (nominally 8%) 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 15 km 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 20 km 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 a 12MW diesel power stations at the mine site.

1.1.3.1 Modified operations during earthquake recovery 2018

On the 26th February 2018 a magnitude 7.5 earthquake occurred in the Hela province of PNG, approximately 10km west of the town of Komo, 30km south of the Hides Power Station and 75km southwest of Porgera.

The earthquake caused extensive damage to the Hides Power Station which is the main power supply for the Porgera Mine. The Porgera Mine itself did not sustain any damage.

To maintain production while the Hides Power Station was repaired, additional onsite power generation was commissioned and the processing plant was modified to operate on a lower power supply. Key changes to the process were:

- Throughput was reduced from 20 kt/d to 8 kt/d meaning the tailings discharge rate was also reduced accordingly.
- The pressure oxidation circuit was taken offline and bypassed, meaning:
  - Ore, and associated sulfides were not oxidised and the low pH acid-wash tailings stream from the pressure oxidation circuit was no longer produced.
  - Without the low pH acid-wash tailings stream, the overall pH of the combined tailings stream at discharge was raised from pH 6.3 to pH 8, and the need to add lime to the tailings stream to raise the pH was negated. As a result, the concentration of bioavailable metals in the tailings stream was reduced between 26th February and 12th June 2018, compared to normal operations.
- Sulfide flotation concentrate was sent from the float circuit directly to the leach circuit (CIP/CIL). The leach circuit was run at a higher CN concentration to improve recovery. The CN detoxification plant reagent dosing was increased accordingly to maintain WAD CN in tailings discharge at <0.2 mg/L.

The Hides Power Station was restored on 4th June 2018 and the ore processing plant was returned to normal operations by 12th June.

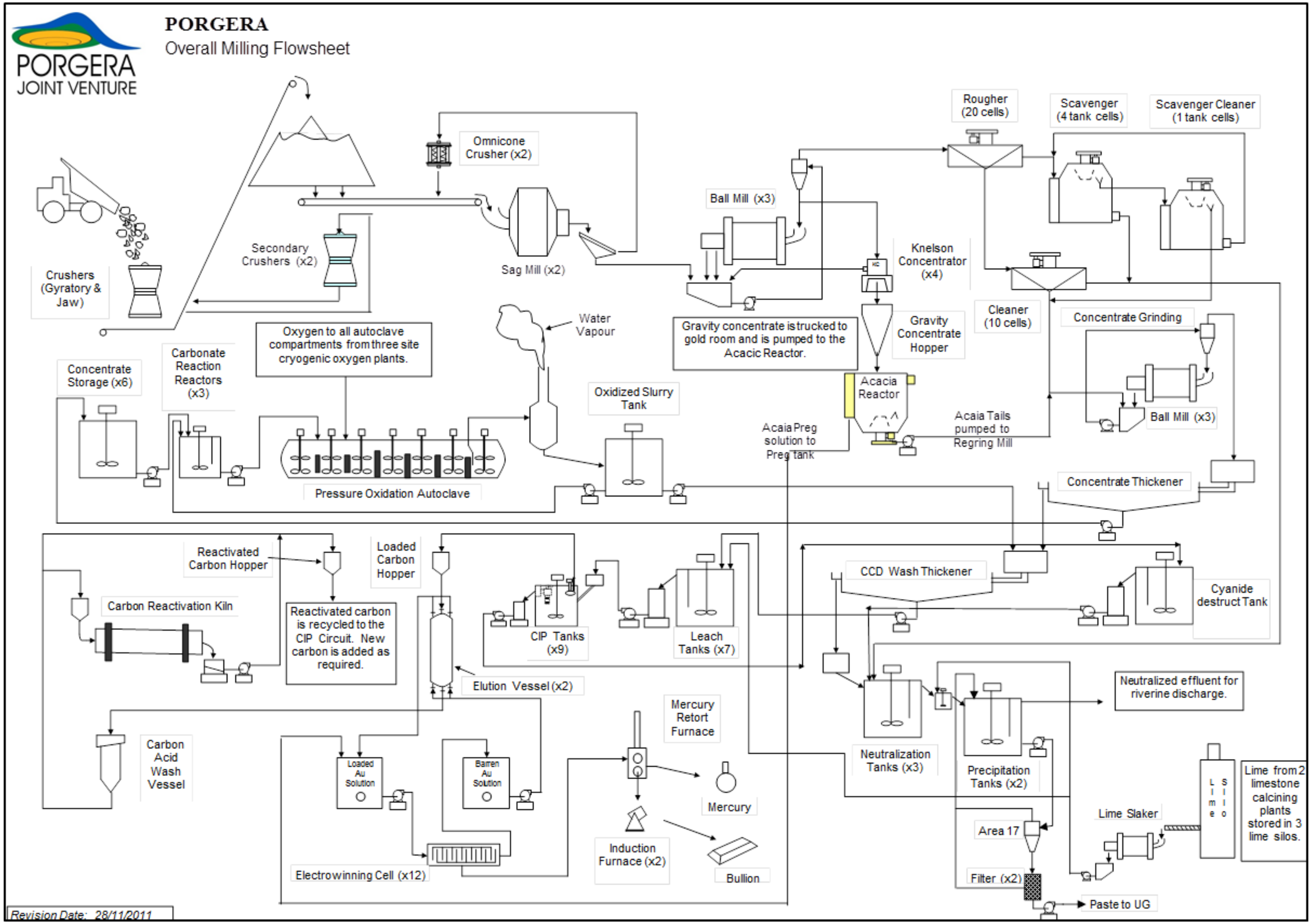


Figure 1-2 Process flow chart

2 AER METHODOLOGY

The PJV AER uses a risk-based framework for assessment and reporting of environmental compliance, risk, impact and performance of the Porgera mine operations and associated infrastructure. The report is structured in accordance with the 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 receiving environment (Section 3.2.1).
3. Identify locations within the receiving environment where mine-related environmental impact may occur, known as test sites and identify locations where mine-related environmental impact will not occur, known as reference sites (Section 3.2.2),
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 conditions and establish TVs for each indicator parameter (Section 5).
6. Assess compliance against legal requirements (Section 6).
7. Perform risk assessment to determine the potential that mine-related environmental impact has or is occurring (Section 7).
8. Perform impact assessment to confirm whether mine-related environmental impact has or is occurring (Section 8).
9. Discuss findings, draw conclusions and make a determination of the operation’s overall environmental performance (Section 9).
10. Make recommendations for improving environmental performance and the environmental monitoring program (Section10).

2.1 Risk Assessment Methodology

The purpose of the risk assessment stage is to determine the potential or likelihood that mine-related environmental impact has occurred or is occurring 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 within the receiving environment exceed the TV, it indicates a risk that impact may have or may be occurring. Exceedance then triggers further and more detailed environmental impact assessment to determine whether impact has occurred or is actually occurring.

Impact assessment requires a holistic and detailed investigation of ecosystem function based on the interactions between chemical and physical parameters and biological functions within the environment. Risk assessment based on physical and chemical parameters 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 the application of impact assessment.

The PJV AER risk assessment framework has been developed in accordance with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000) framework. It should be noted that while the ANZECC/ARMCANZ guidelines have been developed specifically for use in assessing risk and managing environmental values associated with water resources, PJV considers it an appropriate model for assessing risks to all environmental values through the development of appropriate TVs. The ANZECC/ARMCANZ (2000) framework is presented Figure 2-1.

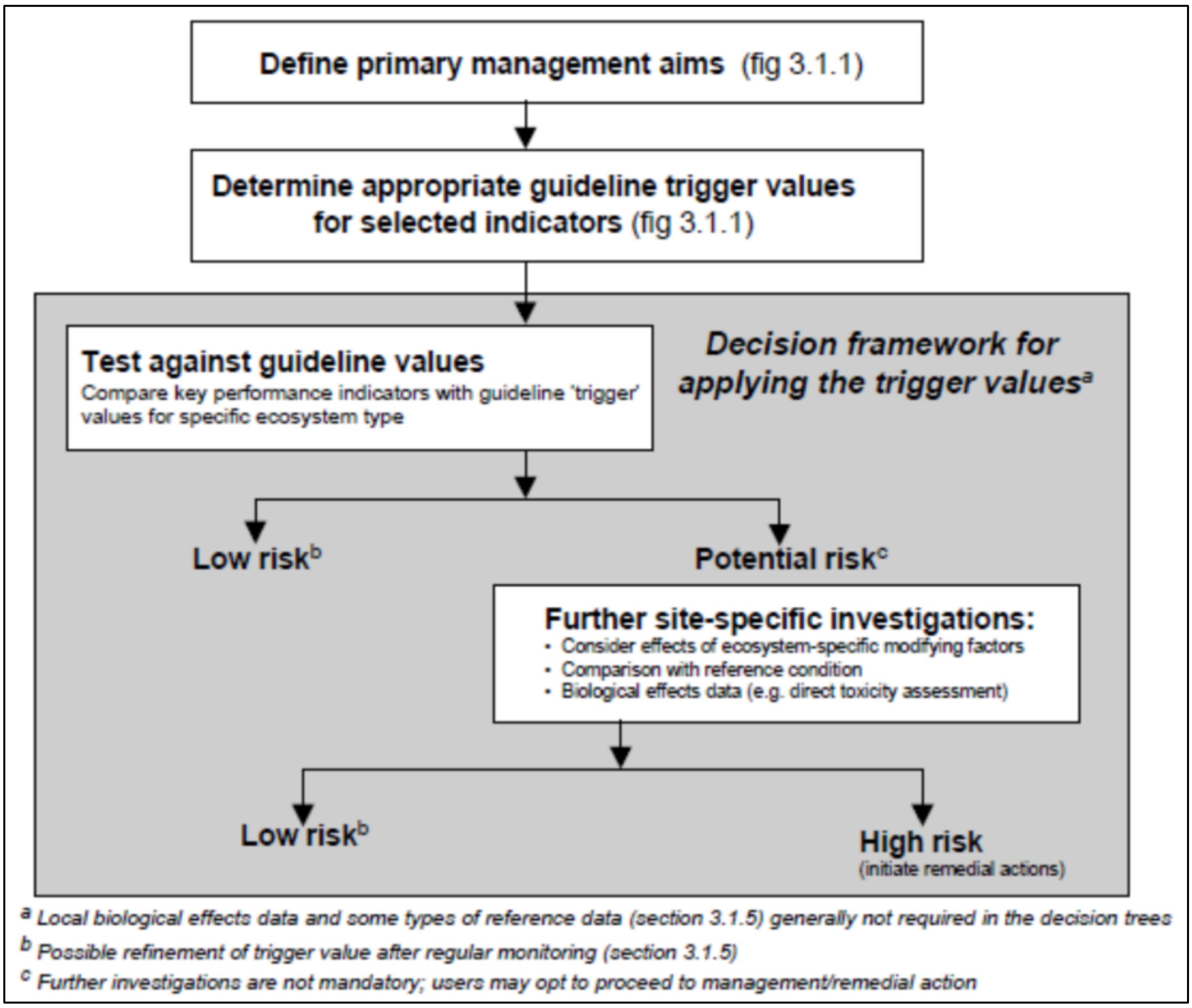


Figure 2-1 ANZECC/ARMCANZ risk assessment framework (ANZECC/ARMCANZ, 2000: Fig 3.3.1)

2.2 Establishing TVs

ANZECC/ARMCANZ (2000) nominates the following order of preference when establishing 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. Then define the TV as the level of key physical or chemical stressors below which ecologically or biologically meaningful changes do not occur (ANZECC/ARMCANZ 2000 Section 3.3.2.4).

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 (ANZECC/ARMCANZ 2000 Section 3.3.2.4). Reference data are gained from either baseline data or from 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 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 (ANZECC/ARMCANZ 2000 Section 3.1.4.1).

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), ANZECC/ARMCANZ (2000) 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 (ANZECC/ARMCANZ 2000 Section 3.3.2.6). The 80^{th}%ile and 20^{th}%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 (ANZECC/ARMCANZ 2000). 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 80^{th}%ile or 20^{th}%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. 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 provide by ANZECC/ARMCANZ (2000) are site specific and would not 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	ANZECC/ARMCANZ (2000)
	Benthic sediment quality	Simpson et. al (2013) – Revised ANZECC/ARMCANZ (2000) sediment quality guidelines.
	Tissue metal	USEPA (2016) – Selenium only
Drinking water	Water quality	*WHO Drinking Water Guidelines (2017)*
Aquatic recreation	Water quality	ANZECC/ARMCANZ (2000) Guidelines for recreational water quality and aesthetics (Chapter 5) *WHO Drinking Water Guidelines (2017)*
Fish and prawn consumption	Tissue metal	As – Australia New Zealand Food Standards Code – Standard 1.4.1 – Contaminants and natural toxicants (ANZFS 2016) Cd, Hg, Pb – European Food Safety Authority (EC 2006) Cr – Hong Kong Food Adulteration (Metallic Contamination) Regulations (HK 1997) Cu, Se, Zn – Food Standards Australia New Zealand GEL for Metal Contaminants 90th%ile (ANZFA 2001)
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. ANZECC/ARMCANZ, 2000), and then adopting whichever is highest.

Where the baseline or reference site TV is higher than the default guideline TV, it indicates that pre-disturbance levels of those indicators are naturally higher than the dataset upon which the guideline TVs are 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 80^{th}%ile value from baseline data, the 80^{th}%ile value from the most recent 24-months regional reference site data and the respective ANZECC/ARMCANZ (2000) default guideline for 95% species protection, and then adopting the highest of the three values as the TV.

The ANZECC/ARMCANZ (2000) 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. (ANZECC/ARMCANZ 2000 Section 1.3)

ANZECC/ARMCANZ (2000) default TVs for physical parameters have been derived from the statistical distribution of reference data collected within five geographical regions across Australia and New Zealand (ANZECC/ARMCANZ 2000, Section 3.3.2.5).

Most of the ANZECC/ARMCANZ (2000) default trigger values for chemical parameters (referred to by ANZECC/ARMCANZ (2000) 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 trigger values were calculated from chronic 'no observable effect concentration' tests (NOEC). However, the majority of trigger values 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 (ANZECC/ARMCANZ 2000, Section 3.4.2.1).

The ANZECC/ARMCANZ (2000) default trigger values 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 (ANZECC/ARMCANZ 2000, Section 3.4.2.4). The 95% species protection level is most commonly used in monitoring programs.

The guideline TVs 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 (ANZECC/ARMCANZ 2000, Section 3.4.3).

TVs for metals are based on dissolved metal concentrations as it is the dissolved fraction that is most bioavailable and therefore has the potential to cause a toxic effect. Where applicable, the ANZECC/ARMCANZ (2000) default guidelines for 95% species protection have been hardness-modified prior to comparison with the baseline and reference site data in accordance with Section 3.3.4.2 of ANZECC/ARMCANZ (2000). Hardness modification is done separately for the upper river, lower river, Lake Murray and ORWBs, and conservatively uses the 20^{th}%ile hardness value from all test sites within each of the respective groups. Adoption of the 20^{th}%ile value is considered a conservative approach as it assumes low buffering capacity throughout the entire year, and calculating a specific hardness modified trigger value for each of the different regions will account for the different hardness within the upper river, lower river, Lake Murray and off-river water bodies (ORWBs) such as oxbow lakes.

The comparisons between baseline data, reference site data and the ANZECC/ARMCANZ (2000) default guidelines for 95% species protection in the upper river, lower river, Lake Murray and ORWBs are presented in Section 5.3.

A summary of the TV development method is provided in Table 2-2 and the decision matrix is shown in Figure 2-2 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 80^{th}%ile (full data set) - Regional reference site 80^{th}%ile (most recent 24-month data set), or - ANZECC/ARMCANZ default guideline for 95% species protection (hardness-modified where appropriate)

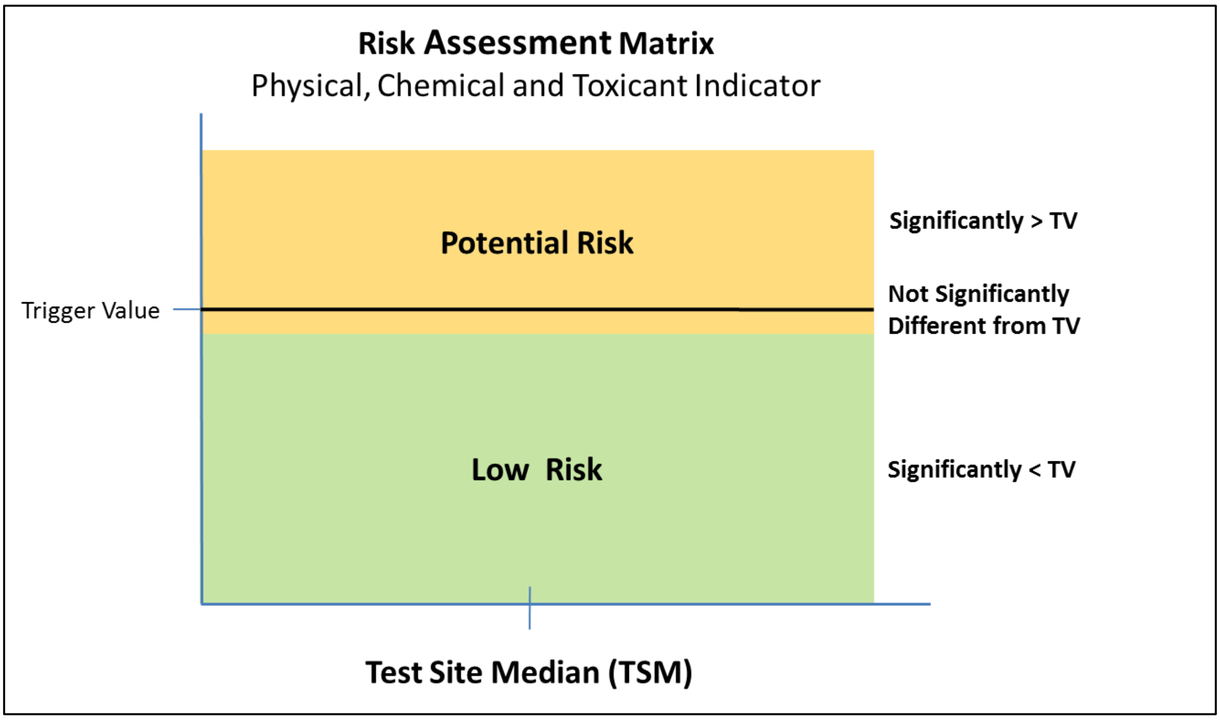


Figure 2-2 Risk assessment matrix – physical, chemical and toxicant indicators in water

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

<table>
<tr><th>Assessment Result</th><th>Risk Rating</th><th>Action</th></tr>
<tr><td>TSM significantly > TV</td><td rowspan="2">Potential Risk</td><td rowspan="4">Confirm whether impact has or is occurring by conducting an impact assessment based on biological indicators.</td></tr>
<tr><td>TSM not significantly different from TV

And TV, TSM and TSM data set not all ≤ LOR.</td></tr>
<tr><td>TSM not significantly different from TV

And TV, TSM and TSM data set all ≤ LOR.</td><td rowspan="2">Low Risk</td></tr>
<tr><td>TSM significantly < TV</td></tr>
</table>

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 ANZECC/ARMCANZ (2000) 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 ANZECC/ARMCANZ (2000) upper and lower limit respectively for pH for lowland rivers in tropical Australia.

Comparisons between upper river baseline data, reference site data and the ANZECC/ARMCANZ (2000) default guidelines for upland rivers in Tropical Australia are presented in Section 5.3.

Comparisons between test site baseline data, lower river reference site data and the ANZECC/ARMCANZ (2000) default guidelines for lowland rivers in Tropical Australia are presented in Section 5.3.

A summary of the TV development method is provided in Table 2-4, and the decision matrix is shown in Figure 2-3 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 - ANZECC/ARMCANZ 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 - ANZECC/ARMCANZ lower limit for upland rivers in tropical Australia

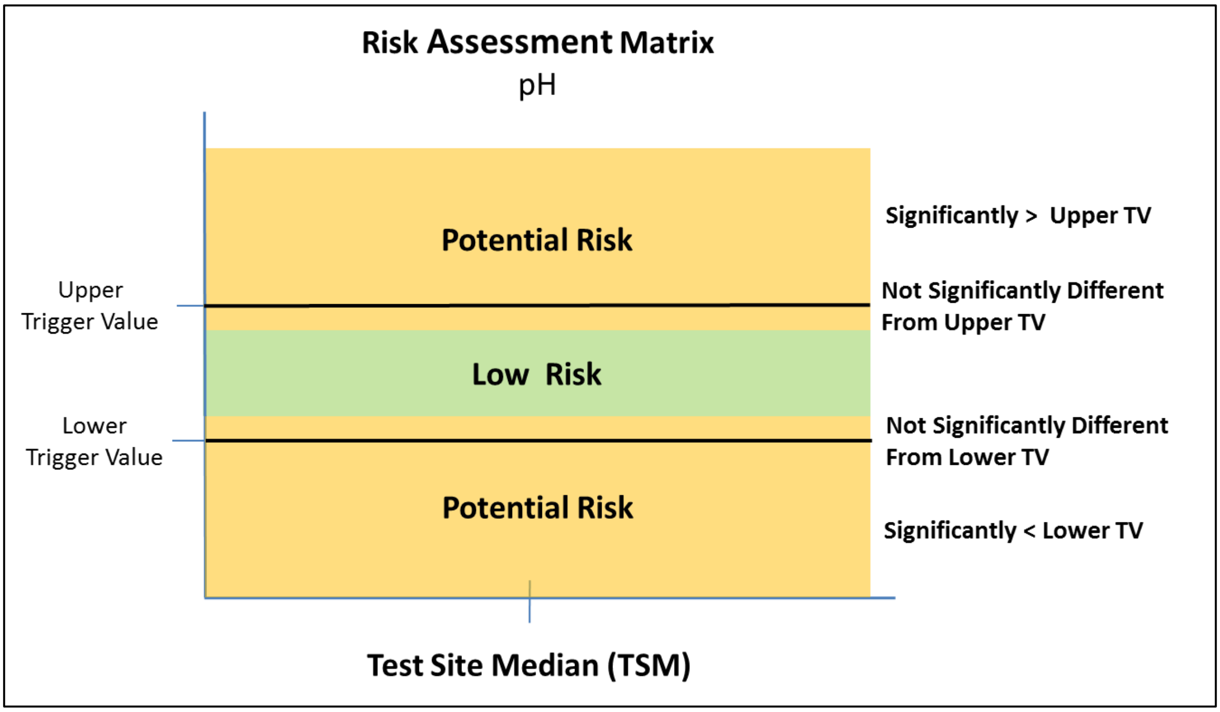


Figure 2-3 Risk assessment matrix – pH in water

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 ANZECC/ARMCANZ (2000) Sediment Quality Guideline Values (SQGV) (Simpson et al 2013). The guidelines include Sediment Quality Guideline Values (SQGVs) and SQGV-High, which represent the 10th percentile (10^{th}%ile) and 50th percentile (50^{th}%ile) values for chemical concentrations associated with acute toxicity effects respectively.

The SQGV 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 SQGV-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 (ANZECC/ARMCANZ 2000).

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 ANZECC/ARMCANZ (2000) SQGVs.

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 ANZECC/ARMCANZ (2000) SQGV.

TVs for sediment quality for all parameters except selenium (Se) have been established by comparing the WAE whole sediment 80^{th}%ile value from the most recent 24-month reference site data against the ANZECC/ARMCANZ (2000) interim sediment quality low guideline value (SQGV), and adopting whichever is higher.

ANZECC/ARMCANZ (2000) does not provide sediment quality TVs for selenium, therefore the TV for selenium has been established from the most recent 24-month 80^{th}%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 ANZECC/ARMCANZ (2000) SQGV 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 upon which the TSM is based 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 2-4 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 - ANZECC/ARMCANZ (2000) revised SQGV Simpson et. al (2013)

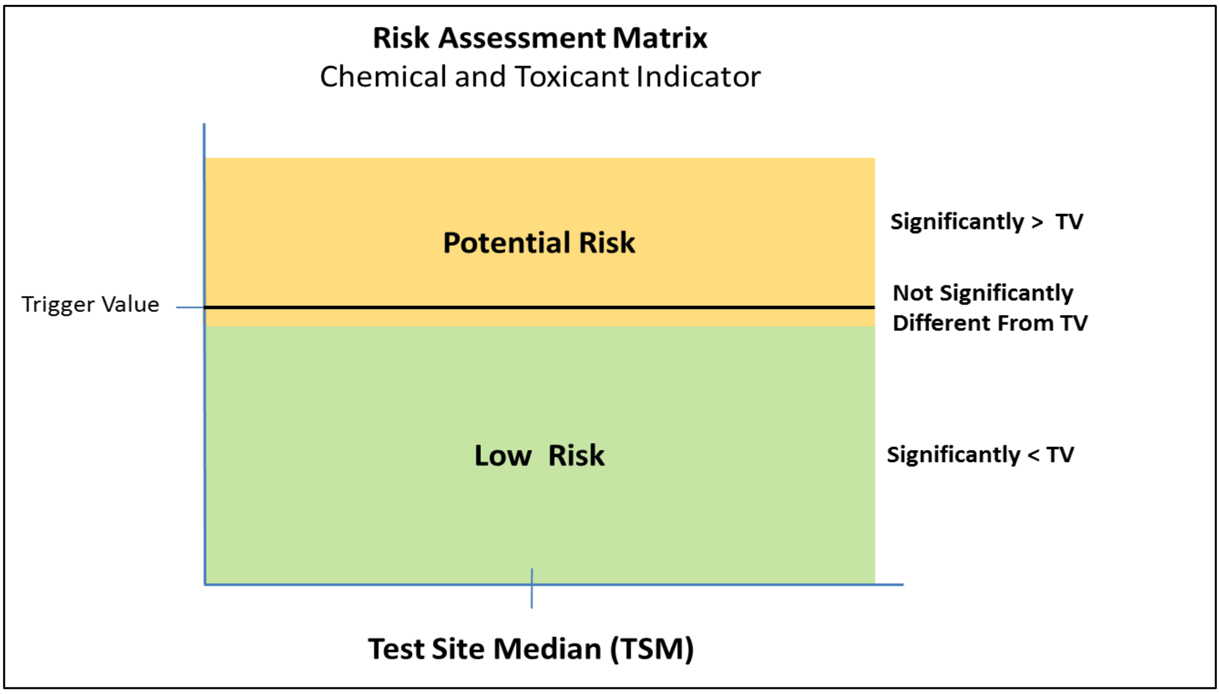


Figure 2-4 Risk assessment matrix – chemical and toxicant indicators in benthic sediment

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 and ORWBs 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,* groove-snouted catfish, *Arius berneyi*, and Papuan herring, *Nematalosa papuensis*.

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 80^{th}%ile value from the most recent 24-month data against the 80^{th}%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 80^{th}%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 80^{th}%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 to the reference sites.

The TV for selenium in fish flesh has been established by comparing the reference site 80^{th}%ile value from the most recent 24-month data, the 80^{th}%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 2-5 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)

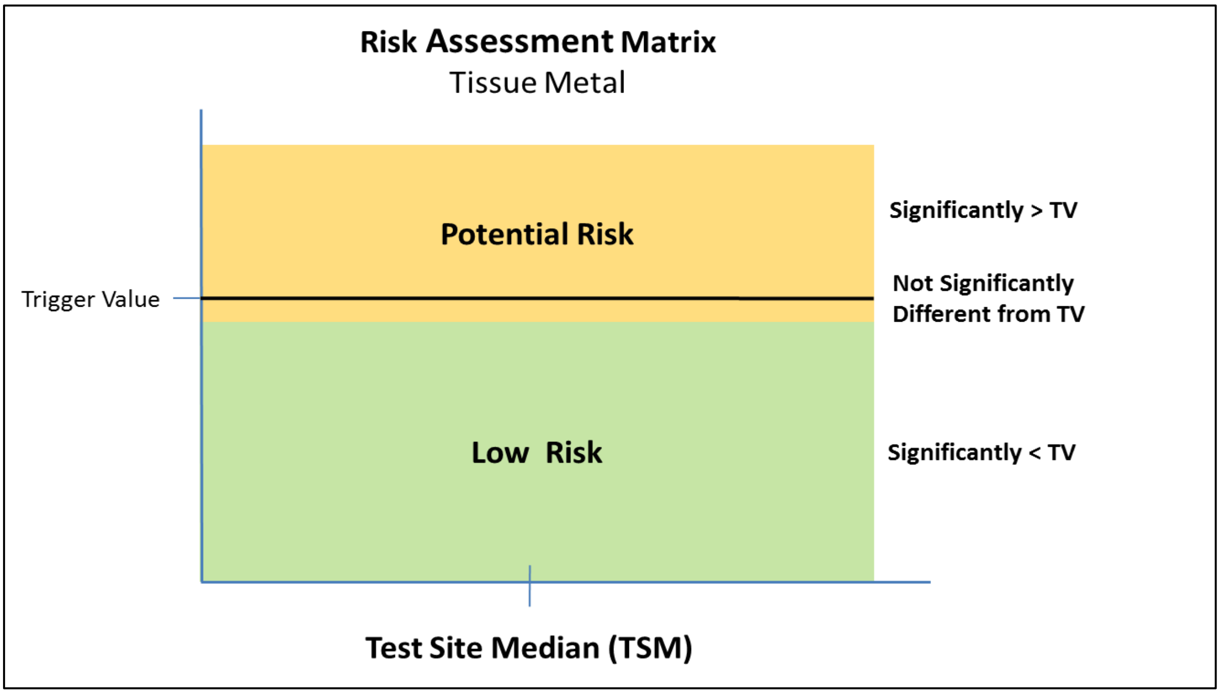


Figure 2-5 Risk assessment matrix – tissue metal concentrations

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 (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 ANZECC/ARMCANZ (2000) recreational water quality guidelines as TVs to support the risk assessment. The ANZECC/ARMCANZ (2000) 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 Drinking Water Guidelines (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 and the Victoria State Environment Protection Policy (Air Quality Management) 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	ANZECC/ARMCANZ (2000) 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)

Indicator Parameter	Risk Assessment Trigger Value (TV) Derivation
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 ANZECC/ARMCANZ (2000) 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. 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 ANZECC/ARMCANZ (2000). 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 change 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.

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. (WRM 2017)

To overcome these challenges the TVs recommended by WRM (2017) 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 (2017) 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 2018 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 the lower river and Lake Murray; this is due to non-standardised sampling methods being historically used to catch prawns, meaning the data are not suitable for supporting statistical analysis.

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 TV 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 biomas 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 80^{th}%ile values for Ok Om were therefore considered more appropriate for use as TVs for total species abundance and total biomass, as using 20^{th}%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 80^{th}%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 80^{th}%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 20^{th}%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 Tiumsinawam, and Baia the more appropriate reference site for Bebelubi. Therefore, TVs for Tiumsinawam 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 Tiumsinawam 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 Tiumsinawam. Because of these trends and the inter-dependence of reference and test site, it was not considered valid to derive TVs for Tiumsinawam 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 period post-commencement of mining shown to have a high and stable species composition at both Tomu and Tiumsinawam was 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 no 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 Tiumsinawam for the period 1989 - 1999. These early records possibly better represent pre-mine conditions at Tiumsinawam, than do later records for reference Tomu. As such, they were used to develop an alternate set of TVs for Tiumsinawam.

The same approach used for developing TVs from reference Tomu data, was used to develop TVs for Bebelubi from reference Baia data. 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 Tiumsinawam, 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 20^{th}%ile values would be too low to be protective of existing populations at Tiumsinawam. For biomass however, the 20^{th}%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 Tiumsinawam.

For alternative TVs for Tiumsinawam, 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 20^{th}%ile values as TVs would be too low to be protective of existing populations at Tiumsinawam. 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 80^{th}%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 20^{th}%ile or even the average values, as the numerous low values in the Baia reference data meant using 20^{th}%ile or average values as TVs would be too low to be protective of existing populations at Bebelubi. The 80^{th}%ile was also less conservative than 90^{th}%ile or 95^{th}%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. 2017 – 2018) data from Baia was also used. (WRM 2017)

2.6.1.3 Deriving impact assessment TVs for Lake Murray

In Laker Murray, impact assessment was conducted by testing changes in fish species richness, abundance and biomass derived from replicated gill netting on a single, annual sampling cmapaign. 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 20^{th}%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 20^{th}%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 species Abundance Total Biomass	OKOM REFERENCE - 80^{th}%ile of the most recent 24-months from upper river reference site Ok Om.
			N.equinus Abundance *N.equinus* Biomass	OKOM REFERENCE - Average of the most recent 24-months from upper river reference site Ok Om.
		Prawns	Total Prawn Abundance	OKOM REFERENCE - Average of the most recent 24-months from upper river reference site Ok Om.
			Total prawn Biomass	
			M. handschini Abundance	
			M. handschini Biomass	
			M. lorentzi Abundance	
			M. lorentzi Biomass	

Region	Test Site	Species	Indicator	Trigger Value Source
Lower River	Bebelubi	Fish	Species Richness Abundance Biomass	OPTION A1 BAIA 'BASELINE' - 80th%ile 2006-2008 OPTION A2 BAIA REFERENCE - Average previous 24 months
	Tium-sinawam	Fish	Species Richness Abundance	OPTION B1 TOMU 'BASELINE' - Average 1999-2004 OPTION B2 TIUM BASELINE - 80th%ile 1989-1998 OPTION B3 TOMU REFERENCE - Average previous 24 months
			Biomass	OPTION B1 TOMU 'BASELINE' - 20th%ile 1999-2004 OPTION B2 TIUM BASELINE - 20%ile 1989-1998 OPTION B3 TOMU REFERENCE - Average previous 24 months
Lake Murray	Miwa & Pangoa	Fish	Species Richness Abundance Biomass	OPTION C1 MAKA 'BASELINE' - 20%ile 2001-2006 OPTION C2 MIWA 'BASELINE' - Average 1989-2000

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 the t-Test with a probability threshold of $p = 0.05$. The t-test is a parametric statistical hypothesis test used to determine if there is a significant difference between the averages of two groups of data, based on the absolute values.

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 (POR ENV PRO 0006) 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 effective in 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, WAD CN Total hydrocarbons Free chlorine BOD_5 Total N and P	Faecal coliforms
Waste rock disposal to land	Area disturbed Volume of waste disposed to land (solid waste and competent waste rock)	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 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.

3.2.1 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

3.2.2 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, where 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.

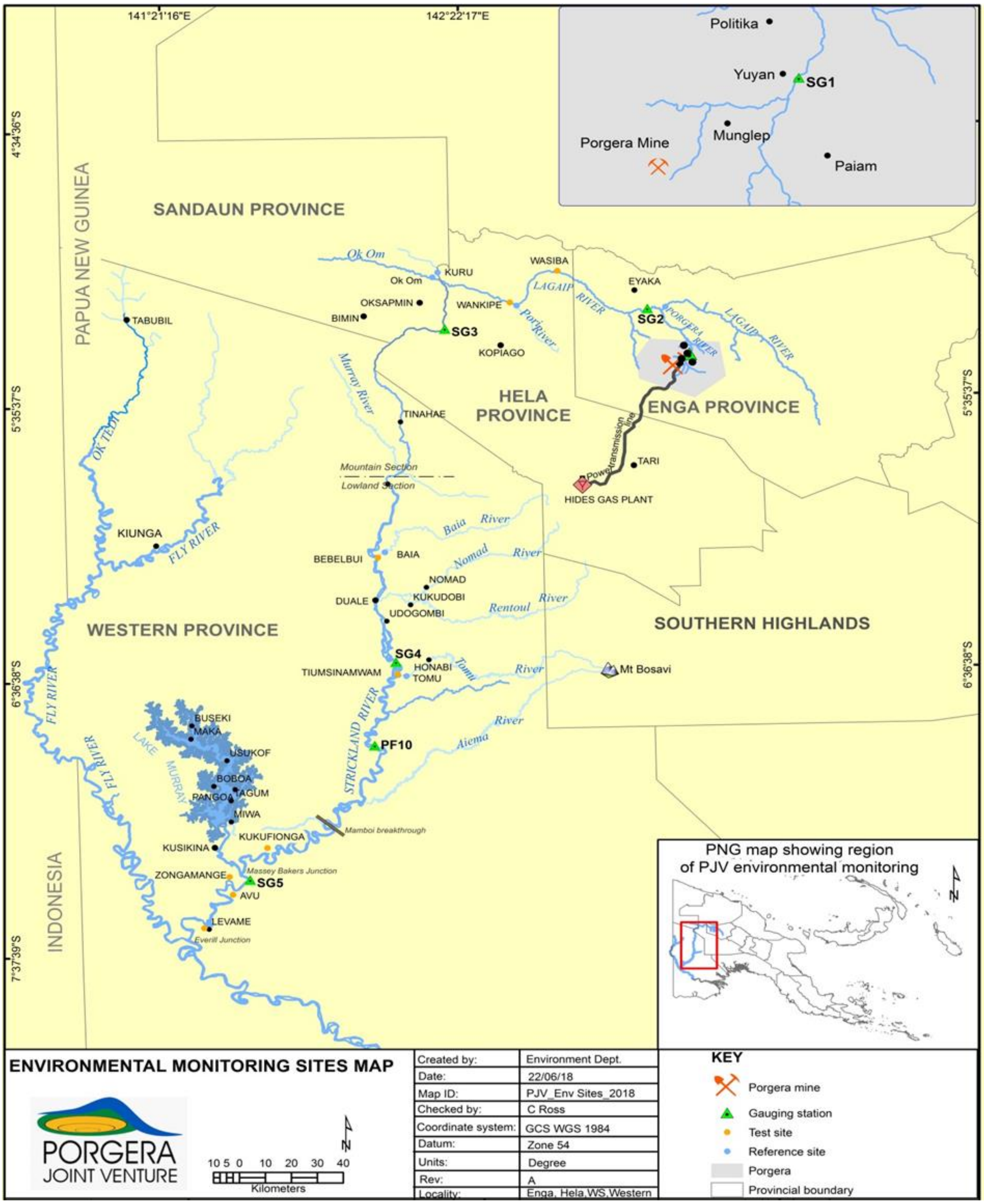


Figure 3-1 Receiving environment monitoring sites

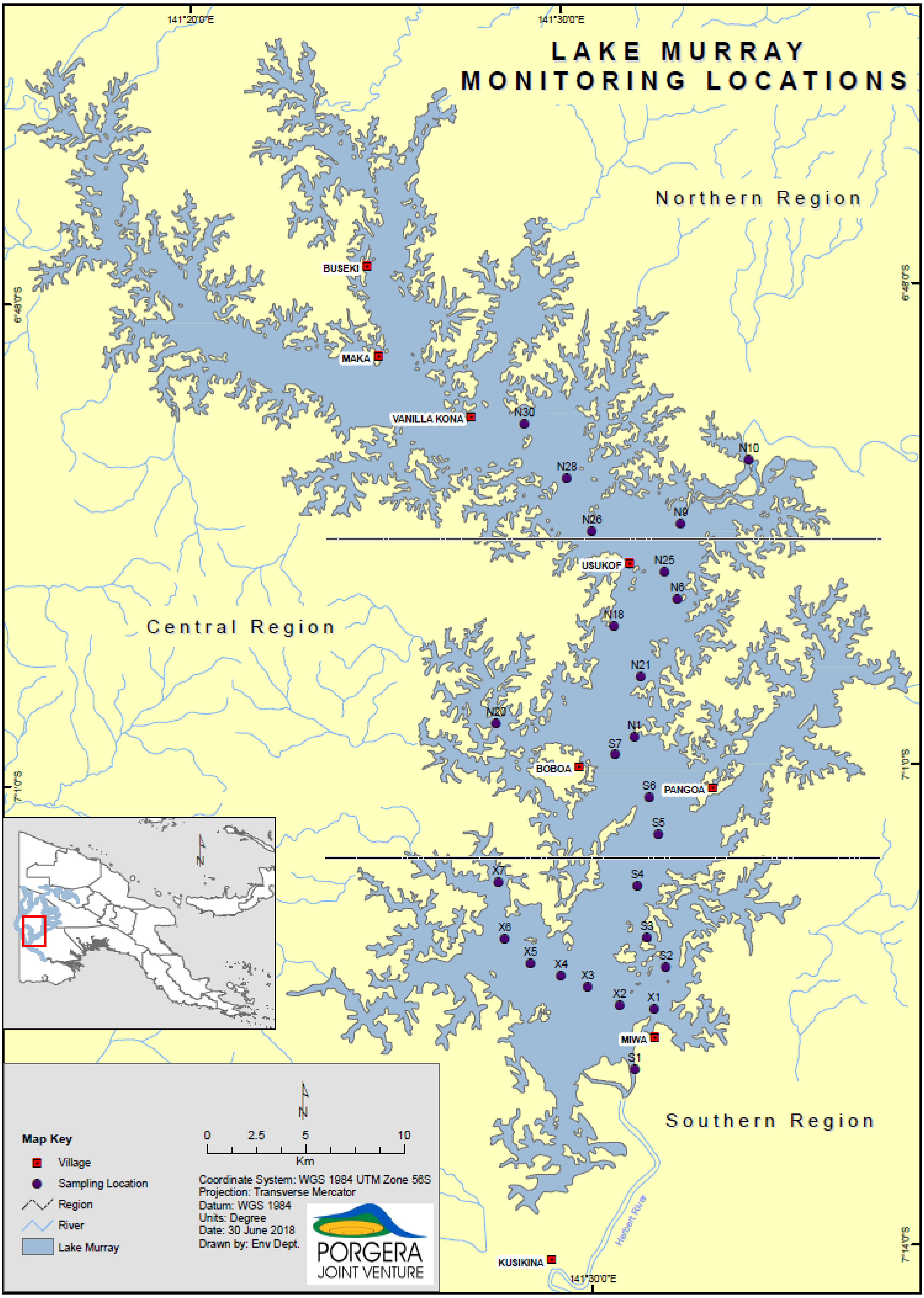


Figure 3-2 Lake Murray monitoring locations

Table 3-3 Test sites, applicable reference sites and indicator parameters

Receiving Environment Test Site		Reference Sites and Parameters				
		Profile	Water and/or Sediment	Tissue Metal	Fish & Prawn Parameters	Macro-invertebrate
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	
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	
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	Good	Good	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

3.2.4 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 2018

Discipline	Compliance to Plan (%)
Biology	99
Hydrology	98
Chemistry	98

3.2.5 QA & QC

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

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 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 and tissue metal 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;
- Commissioning of a new water deioniser;
- Change from latex to nitrile gloves;
- 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 an SOP for performing PTA analysis and ensuring the results are double-checked prior to submission.

Tissue metal field duplicate results for chromium and copper did not meet PJVs internal criteria. This issue is being resolved by adopting the use of plastic cutting instruments, to replace stainless steel, and also by ensuring the field duplicate samples are effectively homogenised before splitting, to reduce intra-sample variation that is inherently observed in tissue metal samples.

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 2019.

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 2018 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 2018

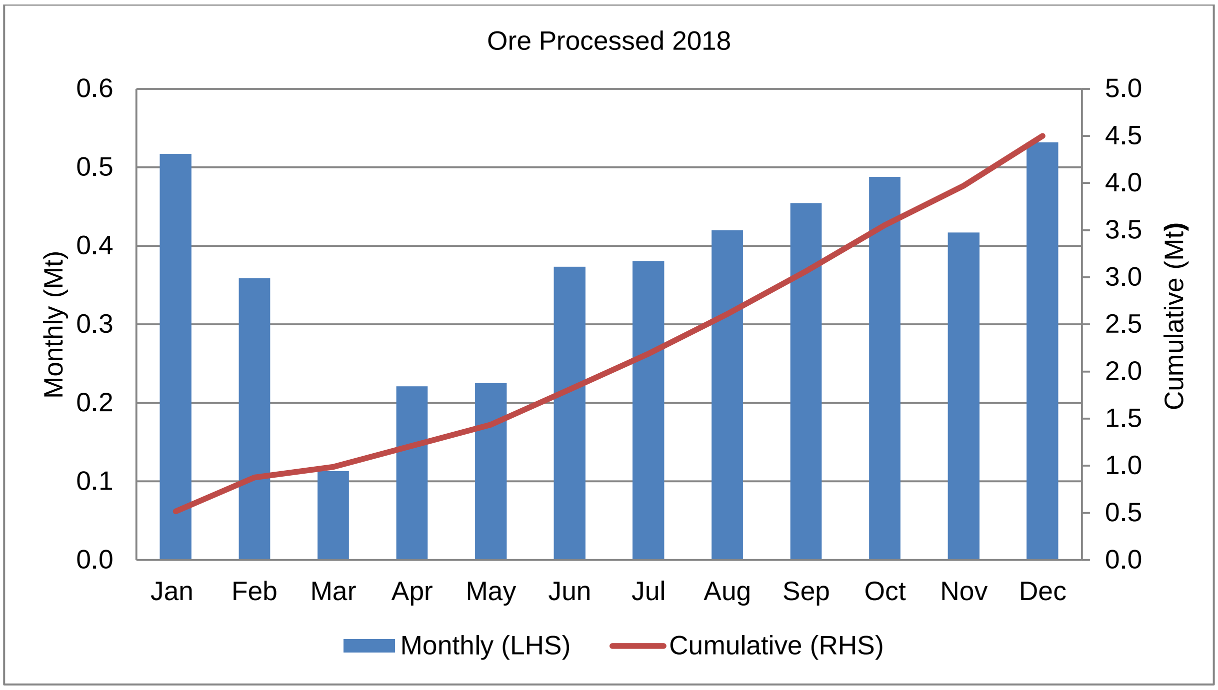
Operational and Environmental Aspects	2018	Life of Mine Total	Comments
Ore processed (Mt)	4.50	135.47	Below target compared to previous year due to earthquake event.
Gold production (oz)	428,972	20,631,700	Below 2018 guidance.
Competent waste rock produced (Mt)	4.40	433.22	Lower than previous year.
Incompetent waste rock produced – Anawe (Mt)	3.34	237.54	Lower than previous year.
Incompetent waste rock produced – Anjolek (Mt)	8.91	241.75	Slightly higher than previous year.
Tailings to underground paste (% total tailings volume)	9.40	NA	Below 2018 guidance.
Tailings discharged (Mt)	4.01	131.30	Slightly below previous year.
Total sediment discharged to river (Mt) (from tailings and erodible dumps)	13	NA	No significant change compared to previous year.
Sewage discharge (m^3)	184, 600	NA	Slightly below previous years due to improvements
Mine contact rainfall runoff (Mm^3)	33.5	NA	Higher than previous year due to improvement in calculation.
Greenhouse gas and energy efficiency (kg CO2-e / t processed ore)	83	NA	2.3 % increased emission rate compared to 2017, but downward trend maintained
Water use and efficiency (L / t processed ore)	4,866	NA	3.5 % increase consumption compared to 2017
Area land disturbed (ha)	2,364	60% of total leased area is disturbed.	
Area of disturbed land under rehab (ha)	239.2	10% of total disturbed land.	

4.1 Production

4.1.1 Mining and processing operations

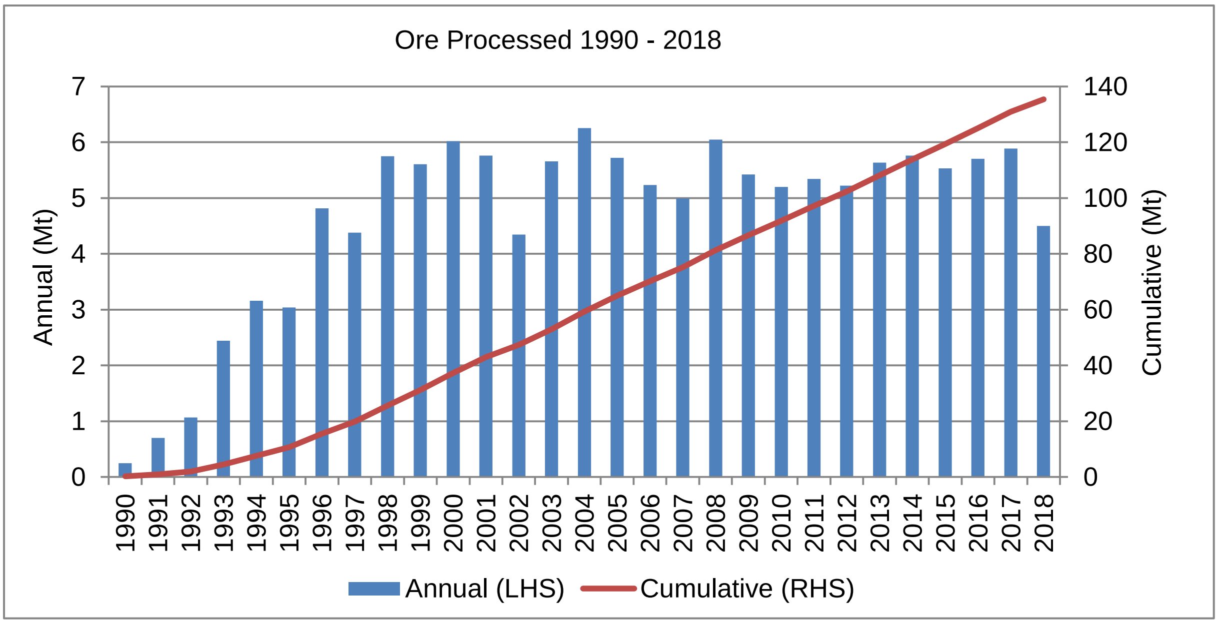
4.1.1.1 Total ore processed

The total quantity of ore processed in 2018 was 4.5 million tonnes (Mt). Figure 4-1 shows the monthly and cumulative quantities of ore processed in 2018, February to May were influenced by the earthquake recovery. The cumulative quantity of ore processed from 1990 to 2018 was 135.5 Mt (Figure 4-2).



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

Figure 4-1 Monthly and cumulative ore processed in 2018

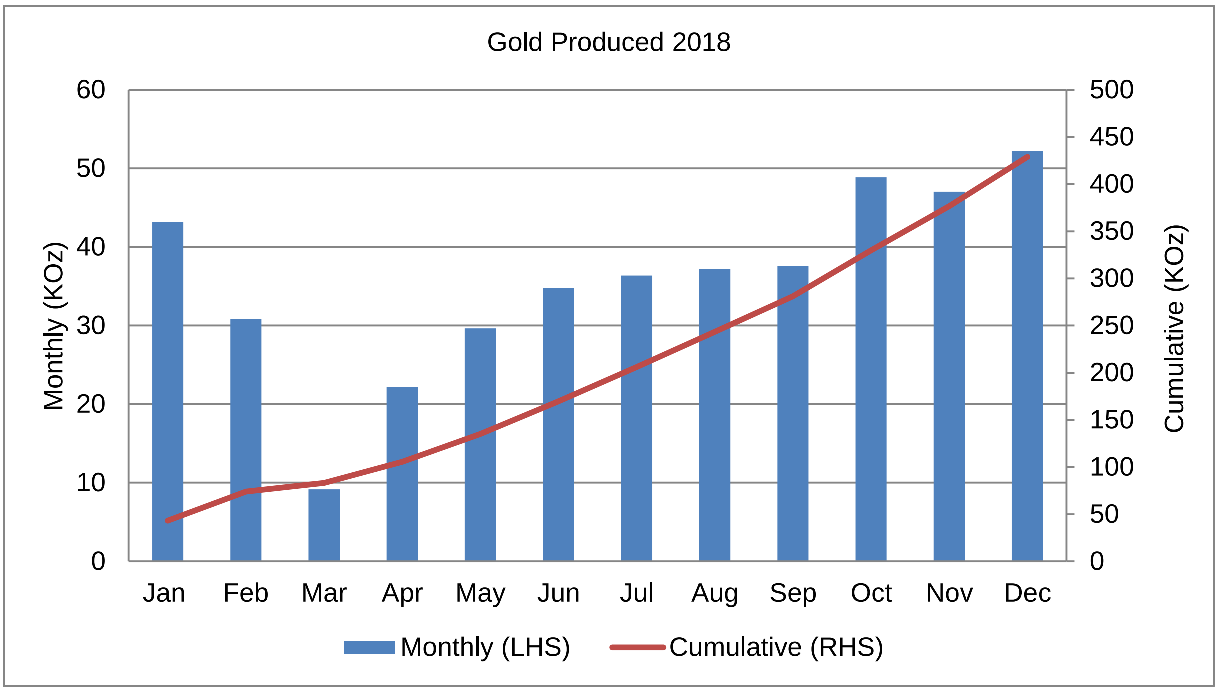


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-2 Yearly and cumulative ore processed 1990 - 2018

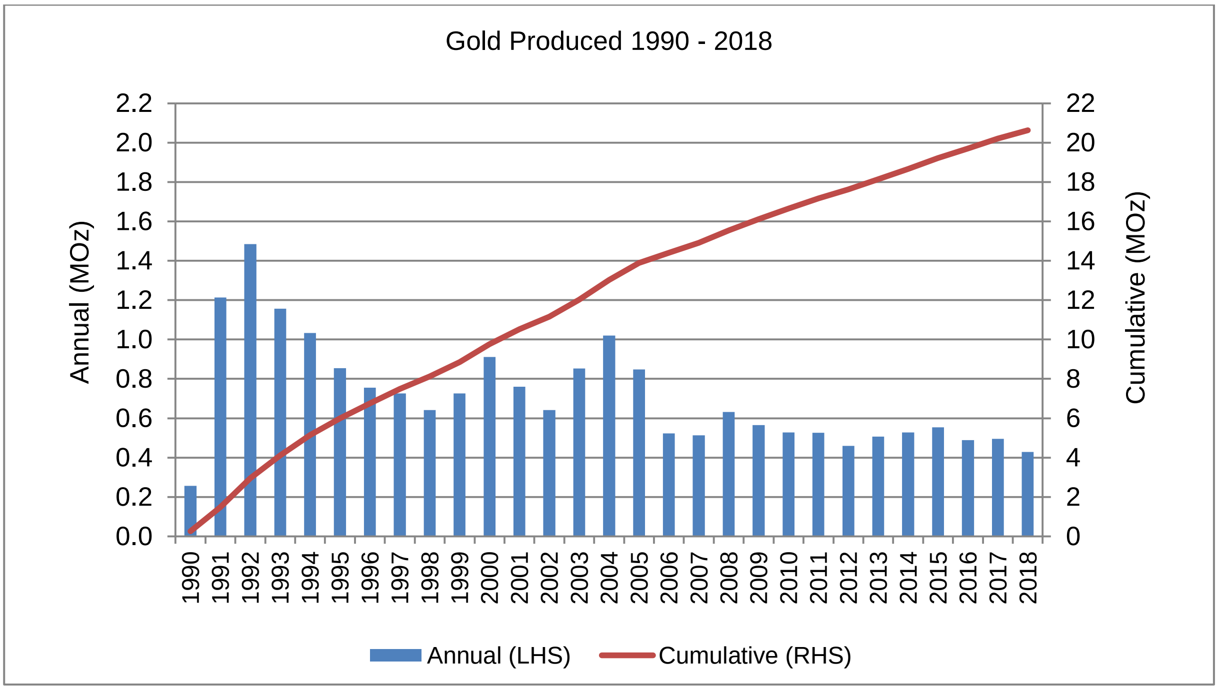
4.1.1.2 Gold production

Total gold production in 2018 was 429 koz. Figure 4-3 shows monthly and cumulative gold production during 2018. Total gold production from 1990 to 2018 was 20.6 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 2018



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

Figure 4-4 Yearly and cumulative gold production 1990 – 2018

4.2 Water Use

Figure 4-5 shows water use efficiency between 2009 and 2018. The overall water use efficiency for the year was below the annual target due to lower tonnes of ore processed and planned maintenance shutdowns and power outages. However, the water use efficiency in 2018 was 3.5 % which was slightly higher compared to 2017, due to high water consumption in the mining and processing operational areas.

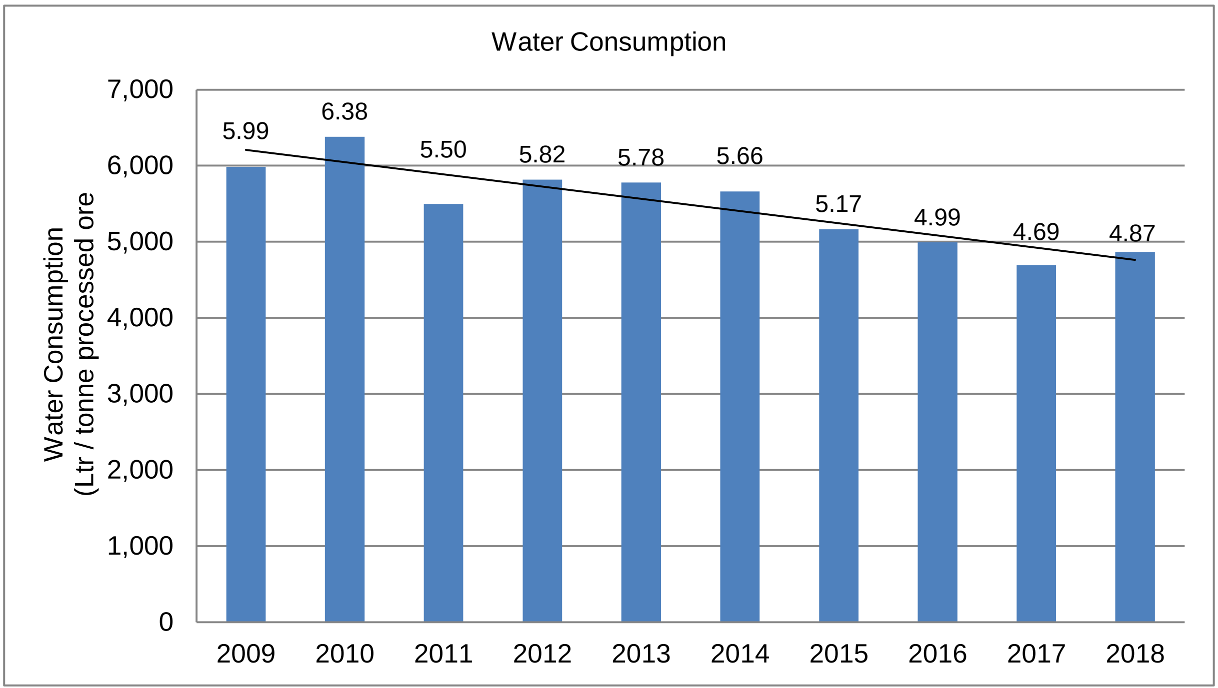


Figure 4-5 Water use efficiency 2009 - 2018

4.3 Land Disturbance

Porgera mine holds eight leases with a total area of 3,932.6 ha as listed in Table 4-2 and shown in Figure 4-6. The Special Mining Lease (SML) includes the mine and project infrastructure. The other Leases for Mining Purposes (LMP) correspond to land use 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 here.

The total area disturbed by mining and related activities as at 31 December 2018 was 2,364.4 ha, equating to approximately 60% of the total leased areas. The total area of disturbance increased by 22.3 ha during 2018, comprising; 0.015 ha due to expansion of the erodible dumps, 0.8 ha due to expansion of the Kogai competent dump, 9.4 ha due to mining expansion at the Open Pit and project works at 28 level area, 3.6 ha due to expansion of the Pangalita limestone quarry, 3.5 ha expansion of Anawe North bypass road and 4.8 ha of construction of new water harvest site at Aipulungu Creek located upstream of the Lime Plant.

Table 4-2 Areas of cumulative land disturbance and reclamation to December 2018

Lease	Total Lease Area (ha)	Disturbed (ha)	Undisturbed (ha)	Under Progressive Reclamation (ha)
SML	2107	1376	731	240
Kogai LMP	424	181	243	0
Kaiya LMP	602	345	257	0
Anawe North LMP 72	219	121	103	0
Anawe South LMP 77	204	132	72	0
Anawe LMP3	81	81	0.0	0
Suyan LMP	69	45	25	0
Pangalita LMP	135	67	68	0
Waile LMP	85	16	69	0
Aipulungu Weir LMP	5.8	5.8	0.0	0
TOTAL	**3,9267**	**2364**	**1562**	**239 (10.1% of disturbed)**

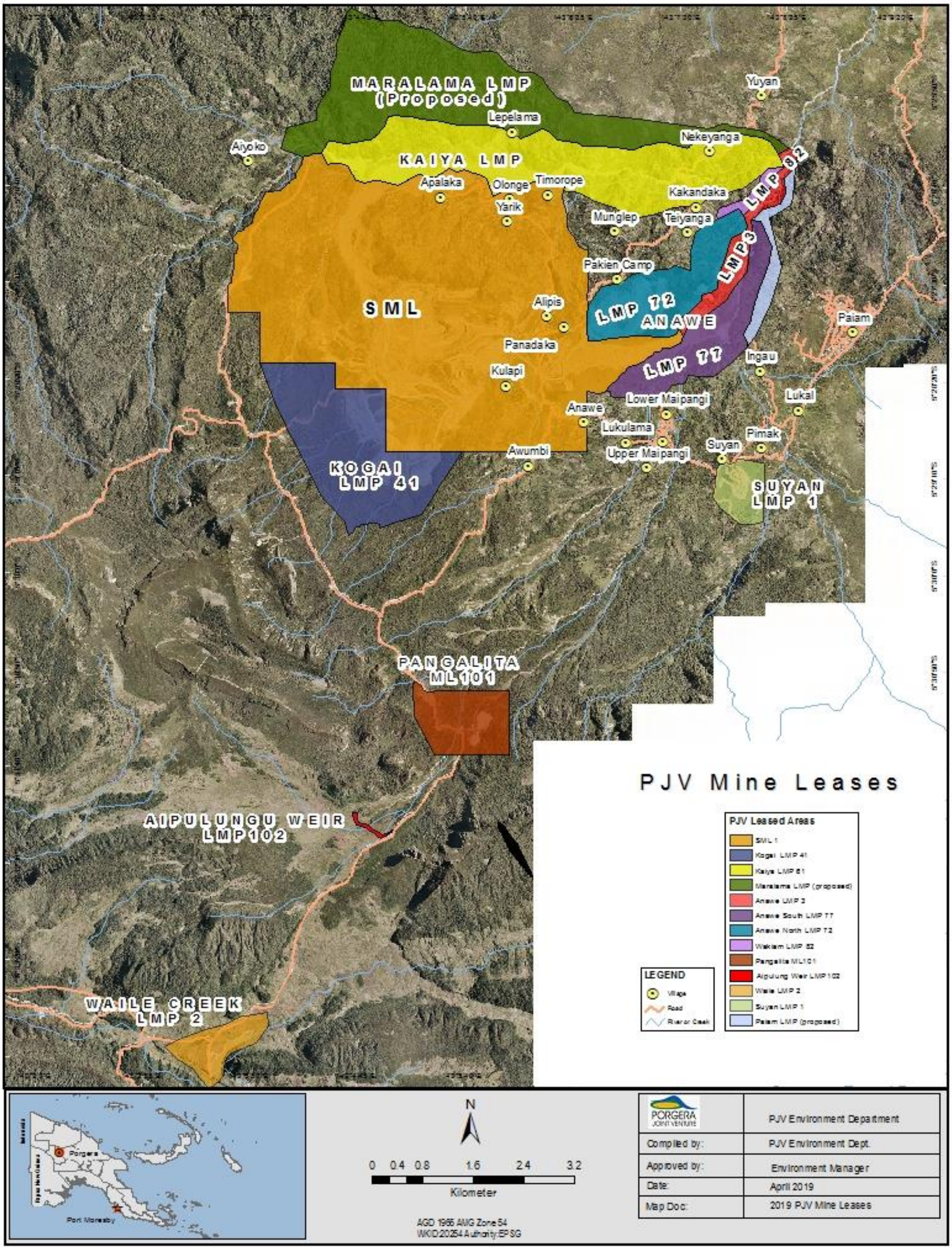


Figure 4-6 Boundaries of special mining lease and other leases for mining purposes

4.4 Waste Rock Production

The mine generates two types of waste rock with very different physical characteristics. Competent or hard rock has high shear strength and is not prone to weathering, and therefore does not rapidly break down into smaller particles after mining. Incompetent waste 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. Competent rock is selectively mined and stored in engineered waste rock dumps 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.

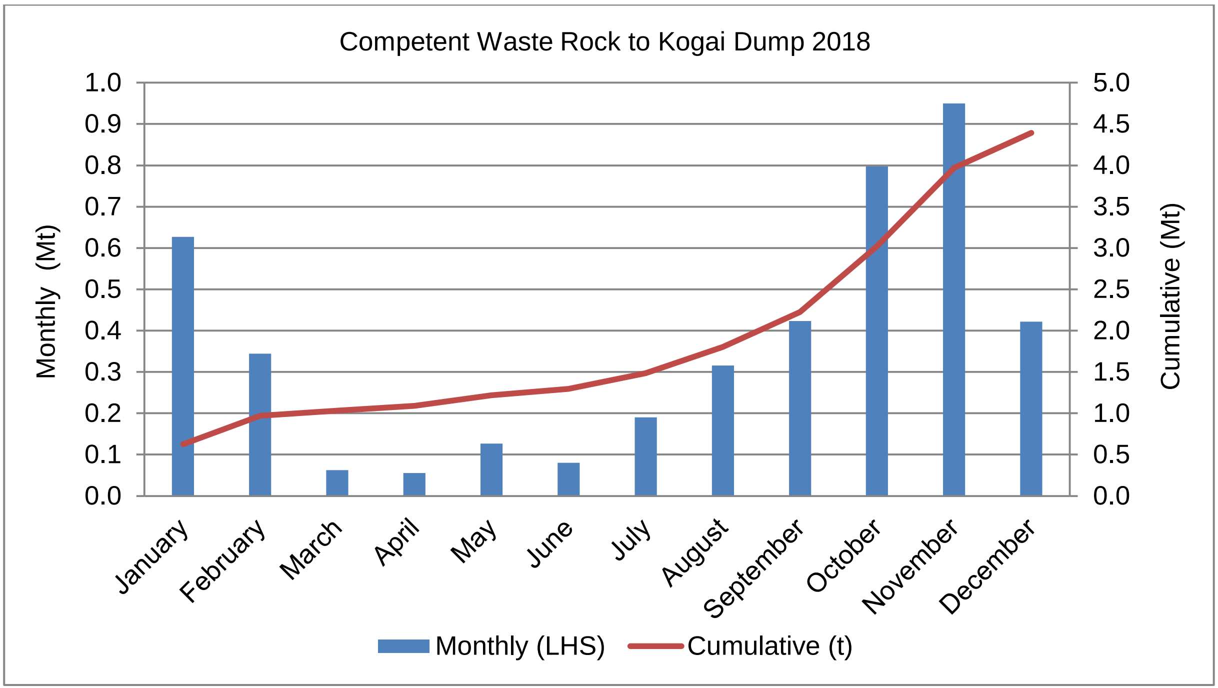
The mass of competent and incompetent waste rock mined between 1989 and 2018 and the disposal locations are presented in Table 4-3. The data show that to date, the quantity of competent waste rock placed at Kogai dump is approximately twice the total amount placed at Anawe North competent dump since 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 – 2018

Waste Dump	Total Quantity (Mt)
Anawe North Competent	134.36
Kogai Competent	298.86
Competent Sub-Total	**433.22**
Anawe Erodible	237.55
Anjolek Erodible	241.75
Erodible Sub-Total	**479.30**
TOTAL	**912.52**

4.4.1 Kogai competent dump

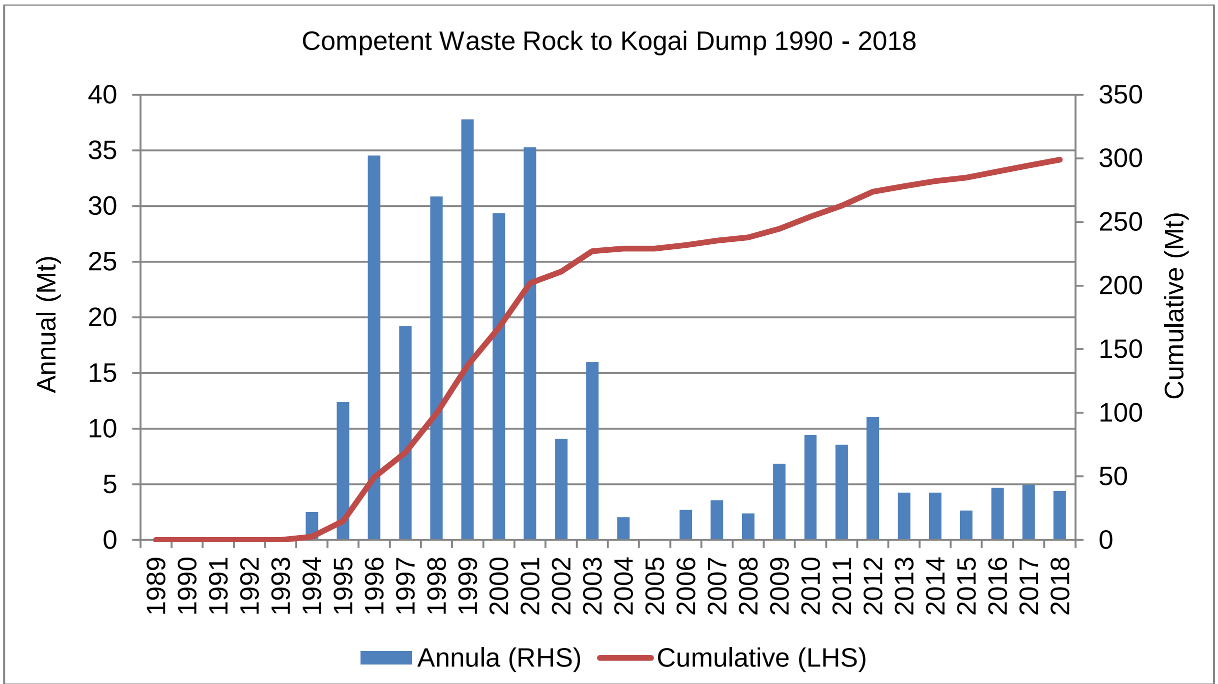
The total quantity of competent waste rock placed at the Kogai dump in 2018 was 4.39 Mt as shown in Figure 4-7. The competent waste rock mined from Stage 5C of the Open Pit during the year was placed at the dump due to shorter haulage distance.



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 2018

The total quantity of competent waste rock placed at Kogai dump since 1992 was 298.9 million tonnes. 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.

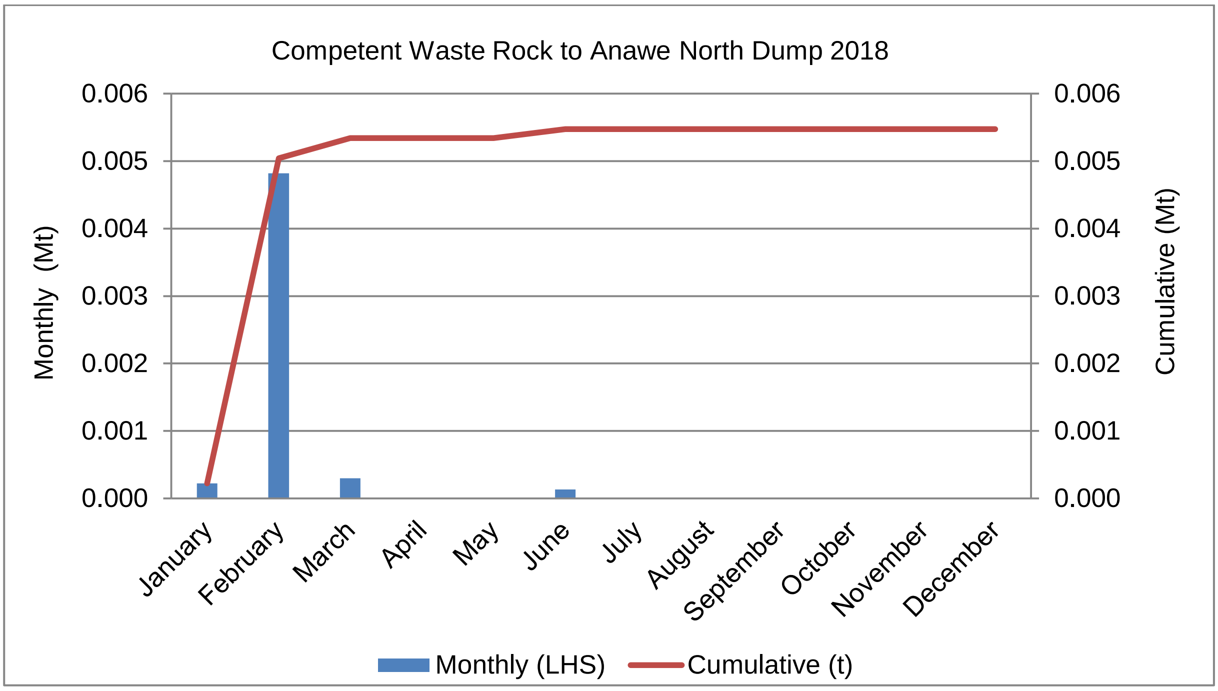


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-8 Yearly tonnages of competent waste rock placed at Kogai Dump 1989 – 2018

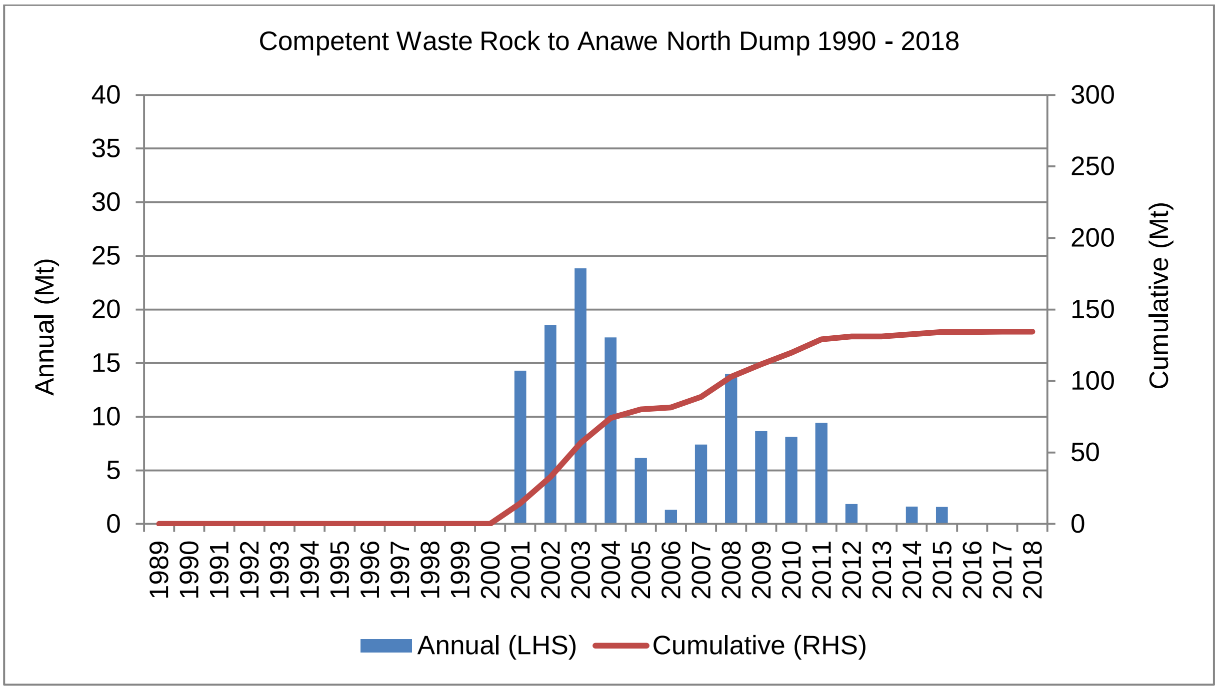
4.4.2 Anawe North competent dump

The Anawe North stable dump received 5,500 t of competent waste rock in 2018 as shown in Figure 4-9. The total quantity of competent waste rock placed at Anawe North dump since construction began in 2001 was 134.4 Mt. 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 2018



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

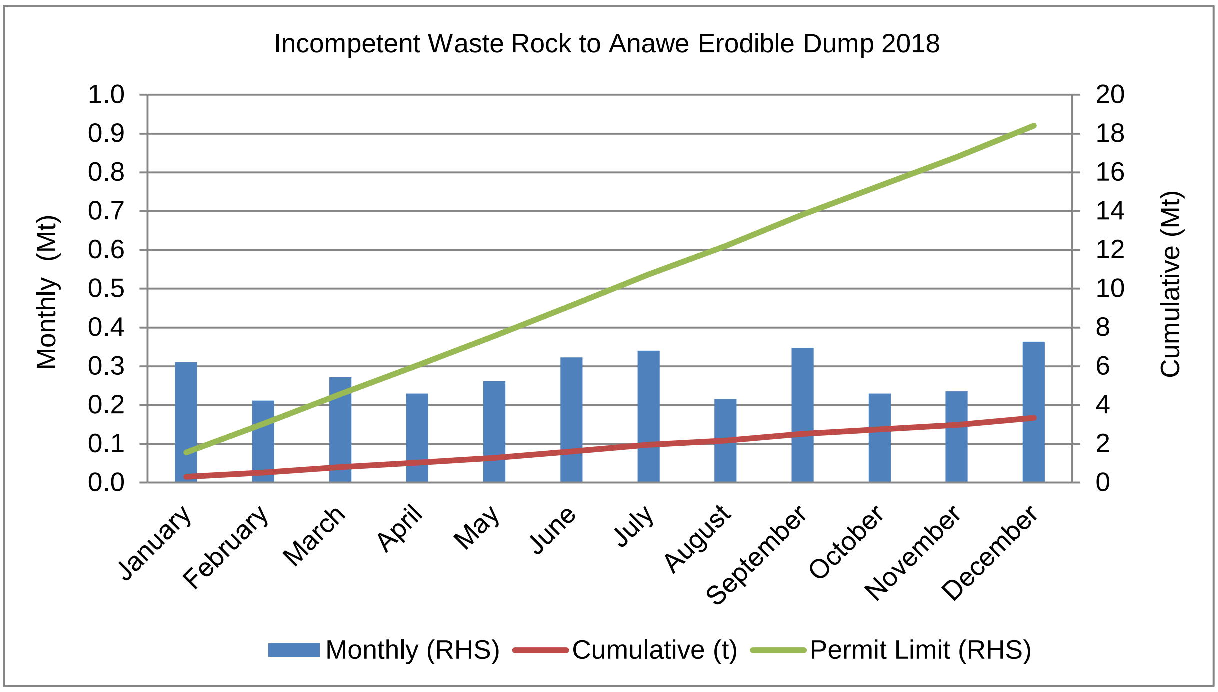
Figure 4-10 Yearly tonnages of competent waste rock placed at Anawe North Dump 2001-2018

4.5 Incompetent Waste Rock Disposal

Incompetent waste rock is disposed in either the Anawe or Anjolek erodible dumps. Fluvial processes from rainfall runoff erode unconsolidated waste from the dumps and this is discharged as sediment to the receiving river system. The total quantities of incompetent waste rock placed during 2018 were slightly less than previous years due to decreased mining of incompetent material from the bottom of the open pit.

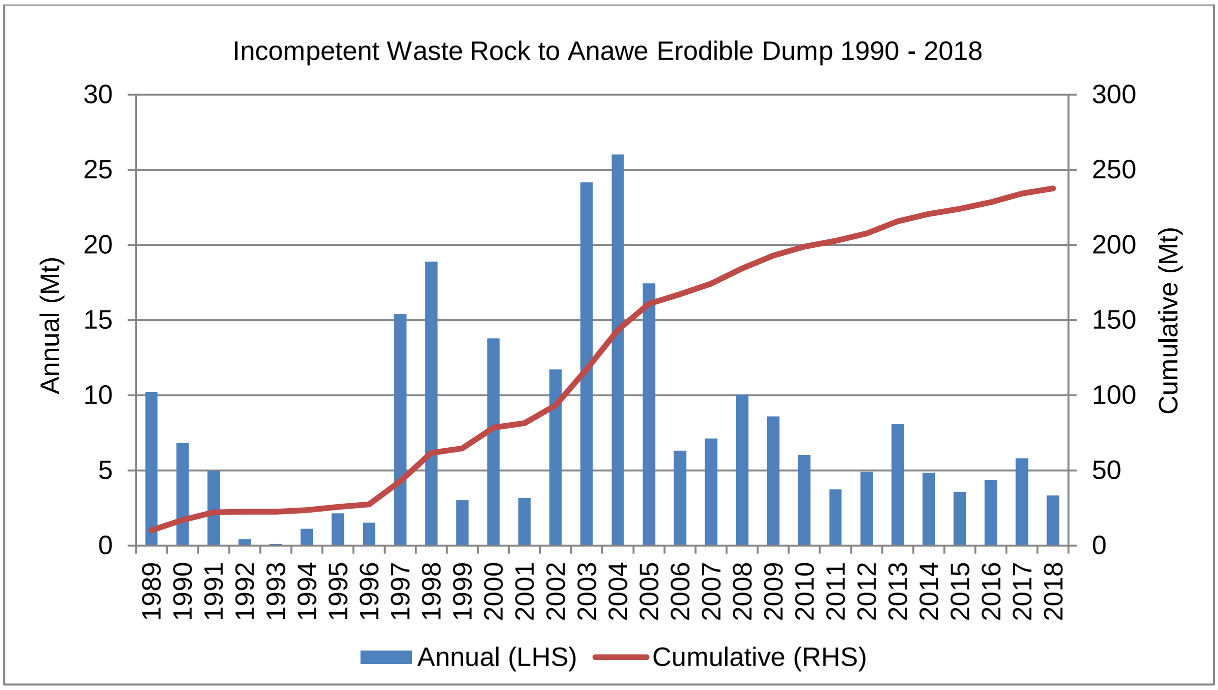
4.5.1 Anawe erodible dump

Monthly tonnages of incompetent waste rock disposed to Anawe erodible dump in 2018 are shown in Figure 4-11. A total of 3.34 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 22% of the annual permit limit of 15.07 Mt. 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 2018



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 1989-2018

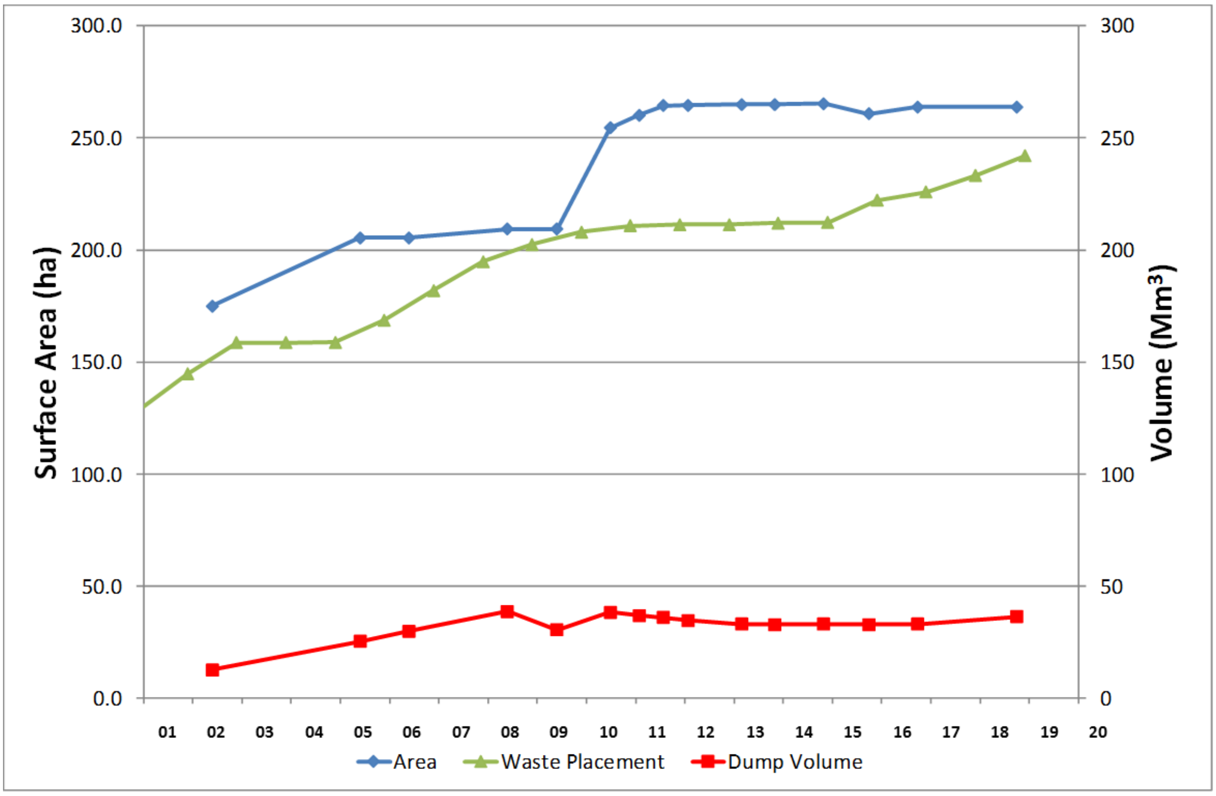
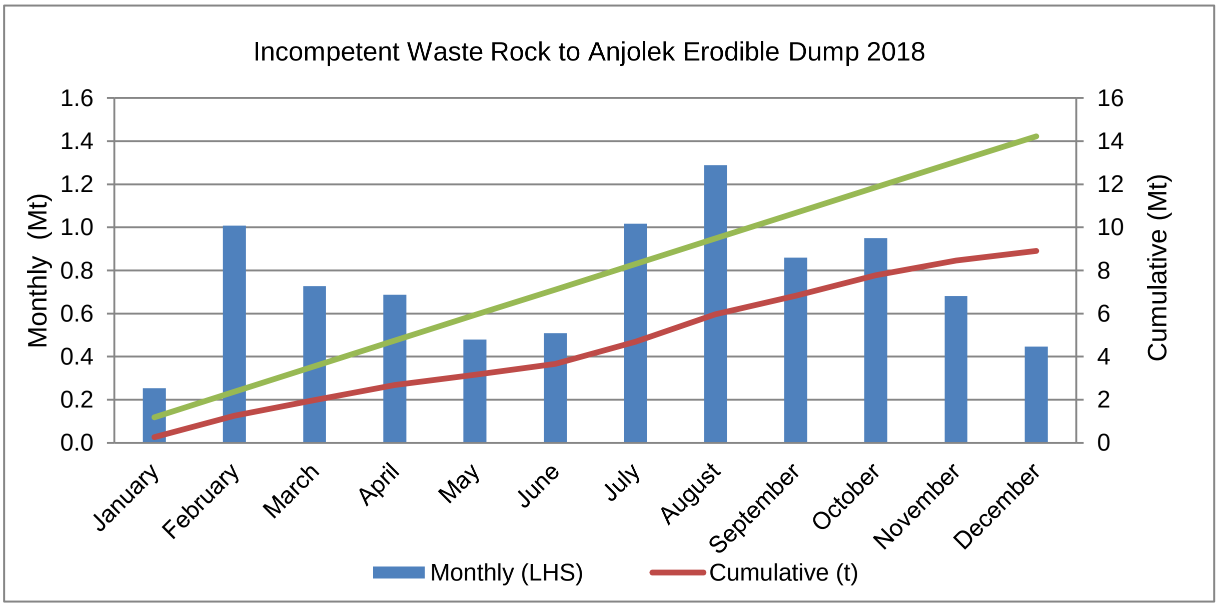


Figure 4-13 Area, volume of waste placed in the dump (Waste Placement) and volume and volume of Anawe Erodible Dump based on LiDAR survey 2001-2018

4.5.1 Anjolek erodible dump

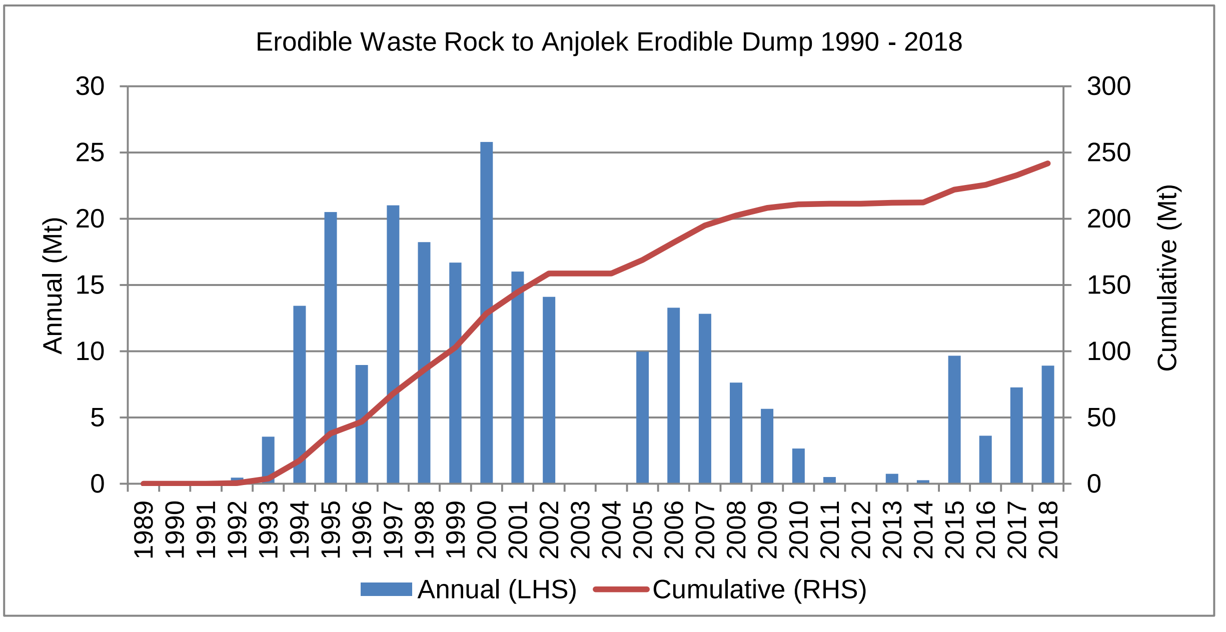
Figure 4-14 shows monthly tonnages of incompetent waste rock disposed to Anjolek erodible dump during 2018. A total of 8.91 Mt was placed during the year, the majority of which was mudstone from a cut-back of the west wall and Stage 5C operations of the open pit. This was equivalent to 63% of the annual permit limit of 14.23 Mt. The quantity dumped in 2018 was significantly higher than 2017 due to an increase in mining of the west wall cut-back and open pit mining expansion at Stage 5C during the year.

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 2018



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 1992-2018

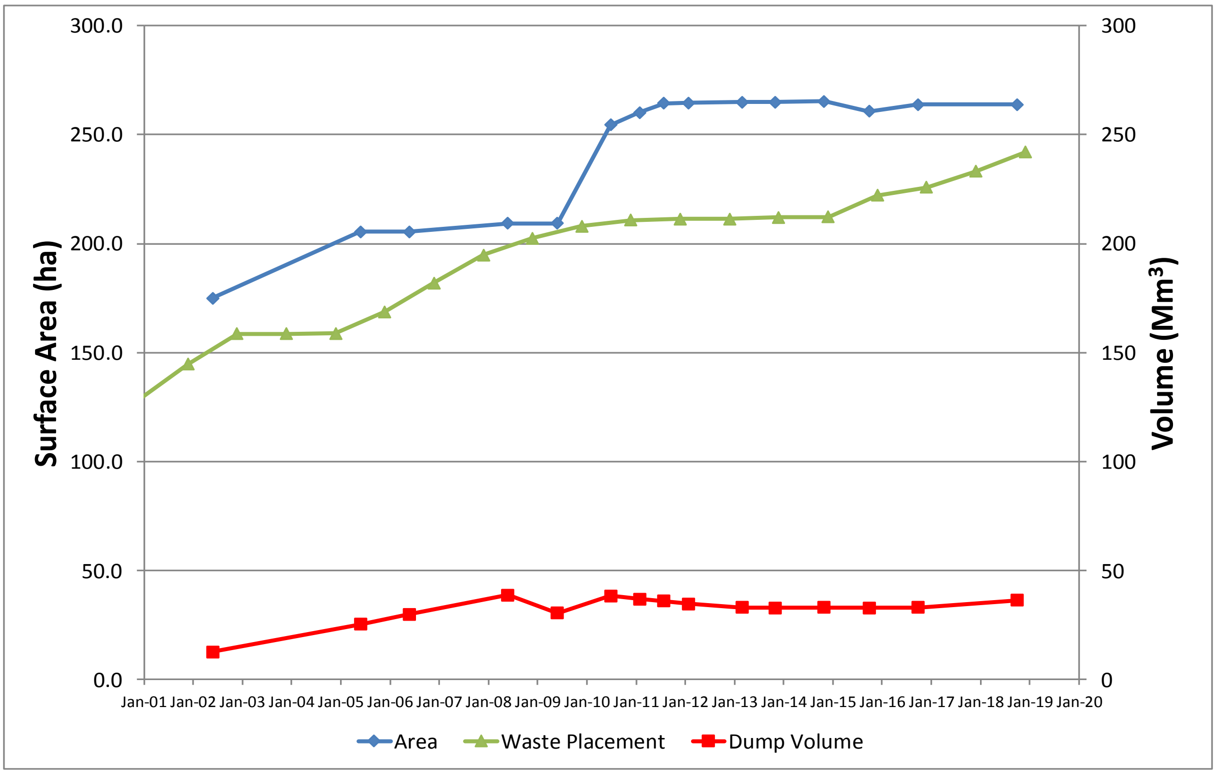


Figure 4-16 Area, volume of waste placed in the dump (Waste Placement) and volume of Anjolek Erodible Dump based on LiDAR survey 2001-2018

4.6 Status of the Erodible Dumps in 2018

Unmanned aerial vehicle (UAV) surveys of both erodible dumps were undertaken in November 2018 after the survey for 2017 was not done as described in the 2017 AER.

Rates of waste dumping continued to be relatively low in a historical context. The total amount dumped to Anawe (3.34 Mt) was the lowest recorded figure for Anawe since 2001. More waste was dumped at Anjolek (8.91 Mt) which is the second highest total reported since 2008, 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

A number of aerial inspections undertaken during the year showed that there had been relatively little change to the overall morphology of Anawe Dump which accords with survey data that indicates minimal change to both surface area and volume during the reporting period.

- Tip-heads and Upper Tract: The elevation of the dump surface continues to remain at a historically low level, and close to the original base topography in places. Some increase in depth compared to the 2016 surface was also noted.
- Maiapam Area (historical overspill area): Generally low and variable surface showing no trend of thickening.
- Confluence with Pongema River (including Pongema Fan). Thickening continues to occur between about the Pongema River Junction and the toe. Survey data show that in several locations the surface is at its highest recorded level. It was also noted from a recent flyover that a proportion of the tailings is now discharging to Pongema Creek at the Fan (Figure 4-17) and at a downstream location between the Fan and the Toe. This is due to changes to dump topography that in turn affect the flow of surface watercourses.

- Northern Flank below Anawe North Dump
- Toe area: Material is removed from the dump as dumped material 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. Survey data show that despite some thickening near the toe area, the location of the toe itself appears to have moved a very short distance upstream although the morphology is complex. (Figure 4-18).

Figure 4-17 Pongema River Fan showing tailings discharge

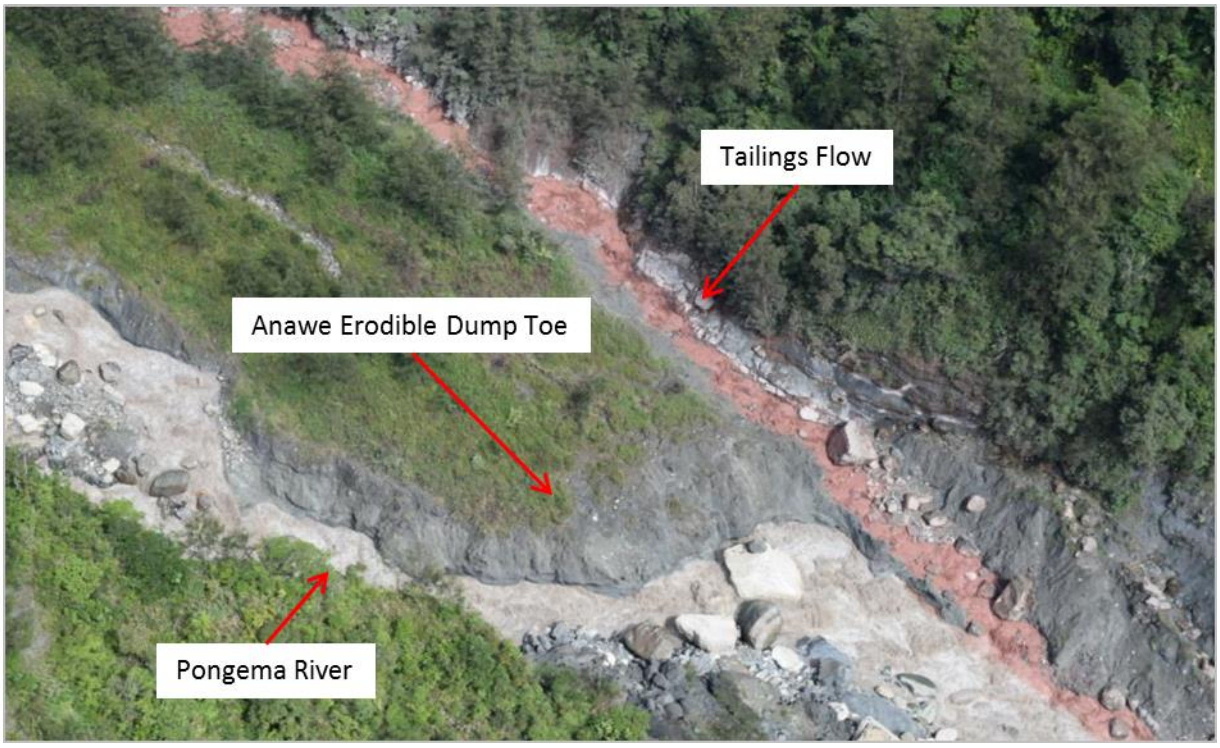


Figure 4-18 Anawe erodible dump toe

4.6.2 Anjolek erodible dump

Similar to Anawe, both aerial inspections and the survey data indicated that the overall morphology of Anjolek Dump appeared relatively unchanged compared with the 2016 survey. As previously discussed, both volume and surface area remained similar compared with 2016 data. Photographs showed that:

- In the Upper Tract below the tip-head, data show that the dump surface is at a relatively low elevation. The 2018 surface is below the 2016 surface in a number of locations.
- At approximately the Bioko Ridge location the 2018 surface increases in elevation and there is notable thickening of the dump as it encounters the Kaiya River and then swings in an easterly direction following the Kaiya River Valley. In this area of thickening (a distance of approximately 600 m), the 2018 surface is at its highest recorded elevation. This appears to have resulted in a change to the course of Anjolek Creek (Figure 4-19), which now flows into the Kaiya River in a more westerly location, upstream of the alluvial fan. Downstream of this area of thickening, the 2018 surface then reduces in elevation and is near the base level in places.
- The impact of the changed course of Anjolek Creek is that there is now dump material being transported further upstream in the Kaiya River and the developing alluvial fan is pushing the Kaiya River up against the northern valley walls.
- 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 although no substantial change to erosion patterns of the northern slopes in the lower tract is evident from visual assessment only.
- 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 2016. While some sediment deposition can be seen in Kogai Creek, it is not known to what extent this is due to the recent remediation works adjacent to the Portal.
- An area of valley wall failure was noted on the north wall of the Kaiya River immediately opposite the Kogai Creek confluence (Figure 4-20). It is not known if this is related to sediment runout from Kogai Creek.
- The toe area and runout zone to the Kaiya River showed little substantial change from 2017 although survey data suggest that surface erosion and ‘thinning’ is occurring at the toe, and the toe location is very gradually moving upstream in ‘patches’.

Figure 4-19 Change in the path of Anjolek Creek

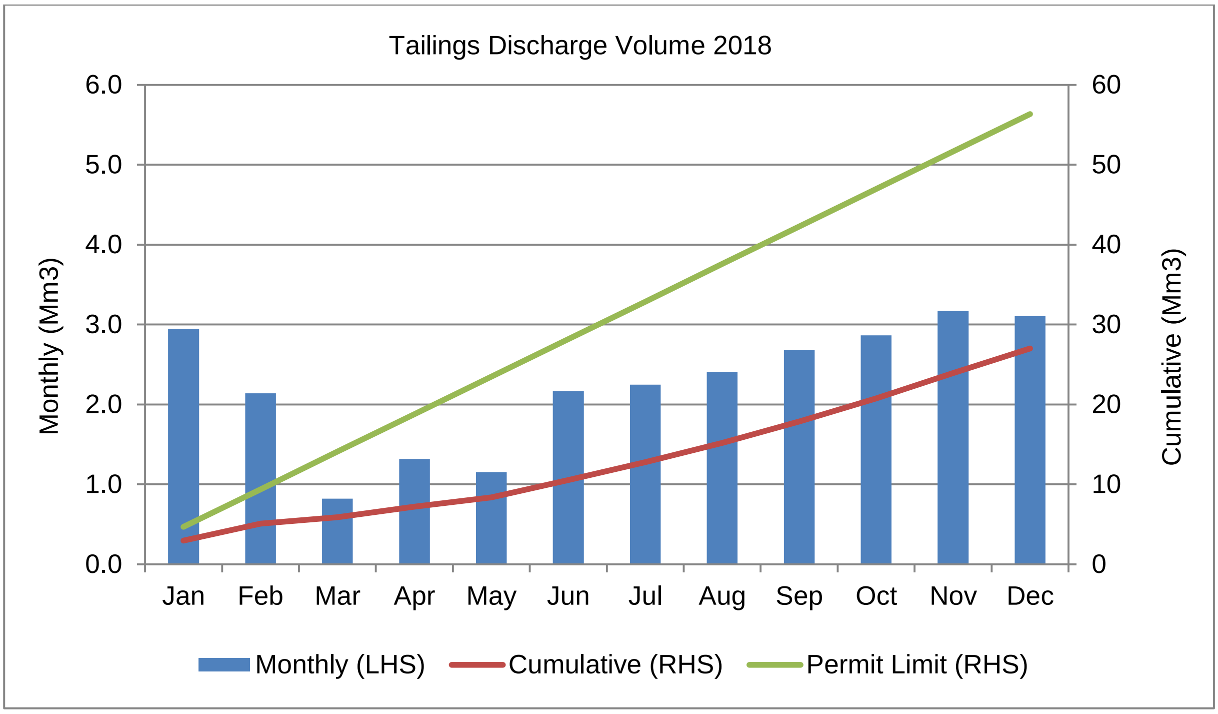
Figure 4-20 Kaiya River bank failure opposite the Kogai Creek Confluence

4.7 Tailings Disposal

4.7.1 Riverine tailings disposal

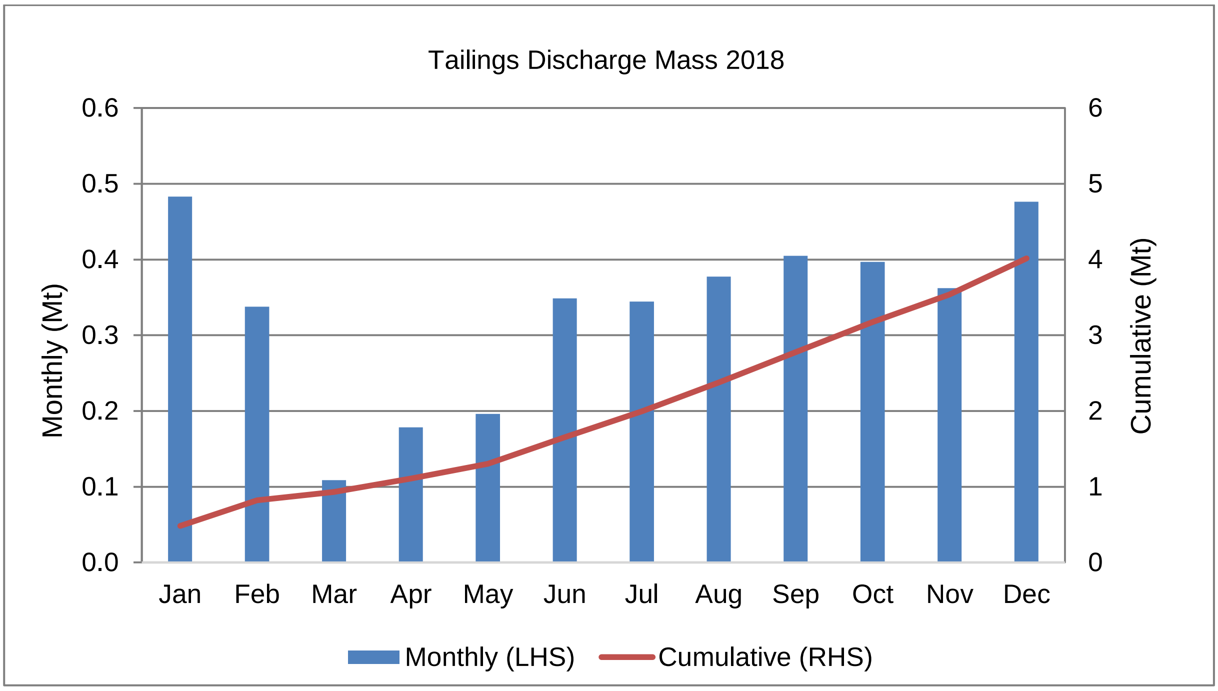
Monthly and cumulative volumes (m^3) of tailings solids and liquids discharged in 2018 and compared against the permit limits are shown in Figure 4-21. The total volume of tailings discharged in 2018 was 27 Mm^3 and is compliant with the annual environmental discharge permit limit of 56.35 Mm^3.

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 2018 was slightly lower compared to the previous year due to the earthquake event. Associated discharge rates for March, April and May were approximately 30% of normal monthly rates. The historical mass discharges are reported in tonnes for comparison with the erodible waste rock discharge mass.



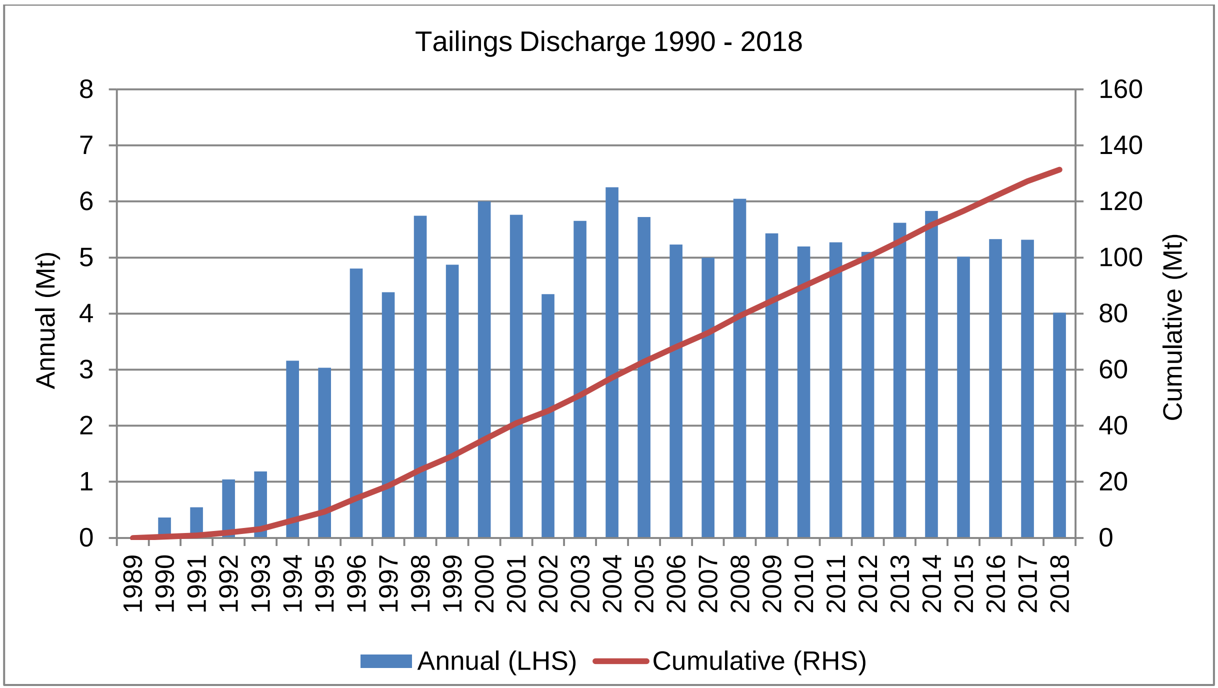
LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-21 Monthly and cumulative tailings discharge volumes (Mm^3) 2018



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

Figure 4-22 Monthly and cumulative tailings discharge mass (Mt dry solids) 2018

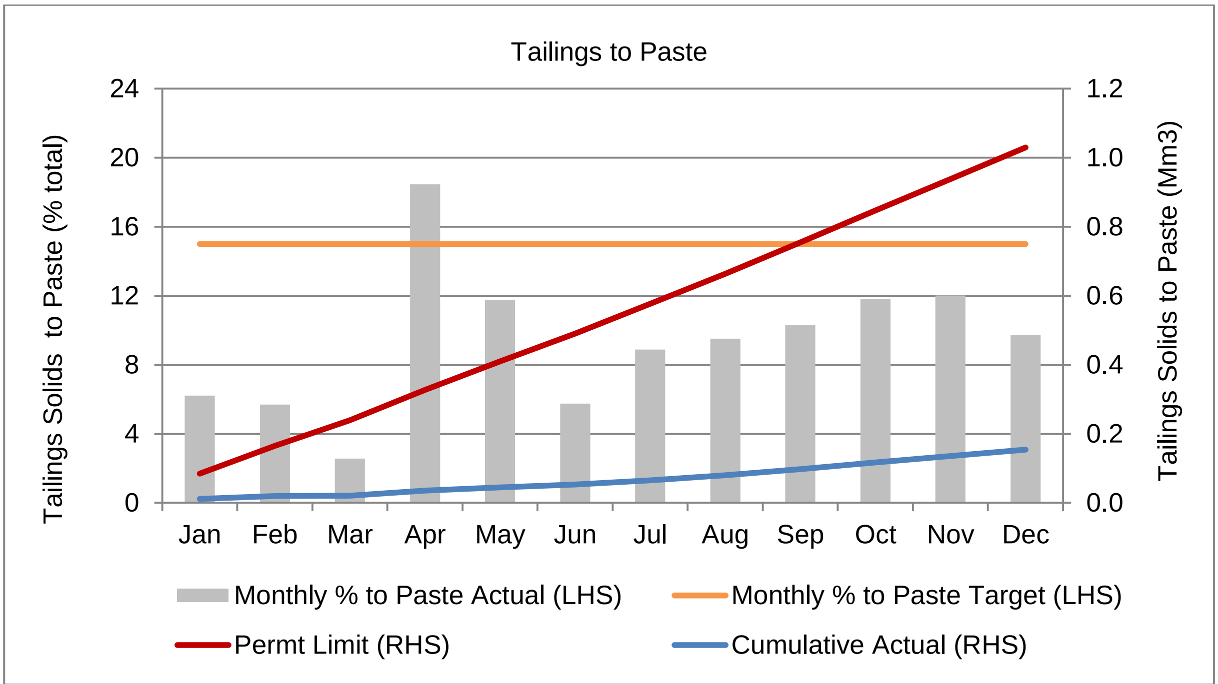


LHS = Left-hand side y-axis, RHS = Right-hand side y-axis

Figure 4-23 Annual and cumulative tailings discharge mass (Mt) (dry solids) (1990-2018)

4.7.2 Tailings used as underground mine backfill

The Paste Plant operation was slightly affected by the earthquake event. The monthly and cumulative volumes diverted to the underground mine are shown in Figure 4-24. A total of 154,255 m^3 of the coarse fraction of tailings was diverted to paste in 2018, which is approximately 9.4% of the total tailings volume produced against a revised annual guiding target of 15% the shortfall was due to the earthquake recovery.



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

Figure 4-24 Tailings diverted to underground backfill in 2018

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 operational effectiveness of 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 TSS concentration in 2018 was slightly higher than the previous year. 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 the tailings treatment stage. 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 is dissolved during the oxidation process, which reaches a pH as low as pH 1. Adding lime raises the pH of the tailings and precipitates the metals as solid forms such as hydroxides, which are less bioavailable. In addition, some metals will also adsorb to particulates as the pH increases.

Tailings discharge pH is managed primarily through the addition of hydrated lime during the tailings treatment stage. The pH target for discharge has varied throughout the history of the operation, however after reviewing historical data and along with external expert advice, in 2012 the criterion was set between pH 6.3 and pH 7.0, and modified again in 2018 to between pH 6.3 and pH 9.5. The upper limit was raised from pH 7.0 to pH 9.5 in 2018 to provide greater operating flexibility while still mitigating environmental and human health risks. Discharge during 2018 under the TARP achieved 100% compliance with the internal site-developed end-of-pipe criterion for pH. The pH was elevated in March, April and May due to changes in processing. The results for 2018 are shown in Figure 4-27, results from 2009 – 2018 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.

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 2018 were low and were in compliance with the internal site-developed end of pipe criterion with the exception of an excursion event that occurred in May when the WAD-CN concentration in the tailings discharge peaked at 17 mg/L. The excursion was caused by a malfunction of the system that controls cyanide addition to the leach circuit which led to an elevated concentration of cyanide within the leach circuit. This subsequently led to an elevated concentration of cyanide in the tailings discharge which was in excess of the site-based internal performance targets. The incident did not constitute a non-compliance with environmental permit conditions and there were no impacts to people or the environment. A subsequent investigation found the risks of detrimental environmental or health effects as a result of the elevated WAD CN to be low. The monthly WAD-CN results for 2018 are shown in Figure 4-30. The performance achieved during 2018 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.

The 20th%ile , median and 80th%ile concentrations of total and dissolved metals in the tailings slurry (water/solids mixture) during 2018 are shown in Table 4-4. Monthly concentrations for 2018 and annual concentrations between 2009 and 2018 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 March and June due the change in operating strategy during the recovery from the earthquake. 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. In the tailings discharge elevated concentrations of dissolved silver, arsenic, copper, mercury, lead and selenium were observed while concentrations of dissolved cadmium, nickel and zinc were lowered. Discharge pH rose slightly during this period due to the absence of the acid wash tailings stream while the autoclaves were not operational. Also of note was a reduction in alkalinity during this this period. In the absence of the acid wash tailings stream it was not necessary to add hydrated lime to the combined tailings stream to elevate the pH to within the TARP discharge criteria, as the natural pH of the combined tailings stream met the discharge targets. However, the natural neutralising capacity within the tailings stream is generated by carbonaceous material contained within the ore, which provides a lower level of alkalinity than the hydrated lime used for neutralisation during normal operations. The change in total concentrations of metals in the feed, combined with the absence of oxidation through the processing circuit, the associated absence of acid wash tailings stream and additional hydrated lime to the combined tailings stream were the drivers for the change in metals concentrations and speciation during this period.

Moderate proportions of cadmium (3.4%), nickel (12%) and zinc (3.9%) were present in dissolved forms throughout 2018 as shown in Table 4-5. Weak-Acid-Extractable (WAE) metals concentrations in tailings solids are presented in Table 4-6. The 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.

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 EC and 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.

Table 4-4 Tailings slurry discharge quality 2018 (µg/L except where shown), sample count (n) = 48

Parameter	UpRiv TV	20th%ile	Median	80th%ile
pH^	6.0-8.2	6.5	6.7	7.5
EC#	250	2,169	3,028	4,108
WAD-CN*	NA	0.20	0.20	0.20
Sulfate*	NA	1,252	2,525	3,630
ALK-T**	NA	125	211	270
TSS*	2837	82,000	120,000	146,000
Hardness**	NA	1,103	3,279	3,555
Ag-D	0.05	0.01	0.01	0.06
Ag-T	NA	1,140	1,950	3,000
As-D	24	0.24	0.82	9.2
As-T	NA	15,400	30,500	39,600
Cd-D	0.34	0.83	35	59
Cd-T	NA	744	1,050	1,700
Cr-D	1.0	0.10	0.14	0.65

Parameter	UpRiv TV	20th%ile	Median	80th%ile
Cr-T	NA	7,040	11,000	15,000
Cu-D	4.1	3.9	13	28
Cu-T	NA	8,940	14,000	18,000
Fe-D	75	5.5	31	832
Fe-T	NA	3,568,000	5,550,000	7,350,000
Hg-D	0.60	0.06	0.12	0.21
Hg-T	NA	63	120	160
Ni-D	21	73	565	892
Ni-T	NA	3,540	5,600	7,300
Pb-D	7.5	0.10	0.10	0.41
Pb-T	NA	46,400	72,000	116,000
Se-D	11	1.0	1.6	2.5
Se-T	NA	100	100	120
Zn-D	20	388	7,900	17,760
Zn-T	NA	134,000	190,000	298,000
	> 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 2018

	% Total in Dissolved Form 2018		
Parameter	20th%ile	Median	80th%ile
Ag-D	0.001	0.003	0.007
As-D	0.004	0.01	0.03
Cd-D	2.0	3.4	4.3
Cr-D	0.002	0.004	0.006
Cu-D	0.1	0.1	0.2
Fe-D	0.005	0.012	0.02
Hg-D	0.09	0.17	0.3
Ni-D	6.5	12	16
Pb-D	0.0002	0.001	0.002
Se-D	1.1	1.7	2.1
Zn-D	3.9	3.9	6.1

D – Dissolved fraction

Table 4-6 Tailings solids discharge quality 2018 (mg/kg dry, whole fraction), sample count (n) = 48

Parameter	UpRiv TV	20th%ile	Median	80th%ile
Ag-TD	NA	12	17	25
Ag-WAE	1.0	0.35	0.79	2.7
As-TD	NA	210	250	316
As-WAE	20	27	58	110
Cd-TD	NA	8.4	13	15
Cd-WAE	1.5	1.9	6.8	8.9

Parameter	UpRiv TV	20th%ile	Median	80th%ile
Cr-TD	NA	80	96	110
Cr-WAE	80	15	24	30
Cu-TD	NA	110	120	150
Cu-WAE	65	54	79	106
Fe-TD	NA	42,980	50,150	55,580
Fe-WAE	NA	8,474	13,200	20,440
Hg-TD	NA	0.90	1.3	1.5
Hg-WAE	0.15	0.06	0.15	0.26
Ni-TD	NA	39	48	54
Ni-WAE	21	8.4	22	32
Pb-TD	NA	500	775	990
Pb-WAE	50	83	150	260
Se-TD	NA	0.58	0.82	1.2
Se-WAE	0.16	0.10	0.22	0.50
Zn-TD	NA	1,436	2,075	2,558
Zn-WAE	200	222	1,100	1,572
	> UpRiv TV = Potential Risk			

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

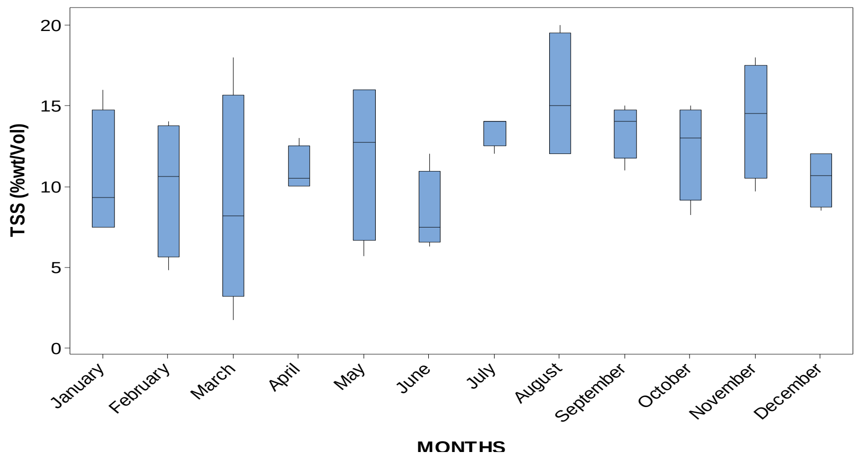


Figure 4-25 Monthly TSS in tailings discharge in 2018

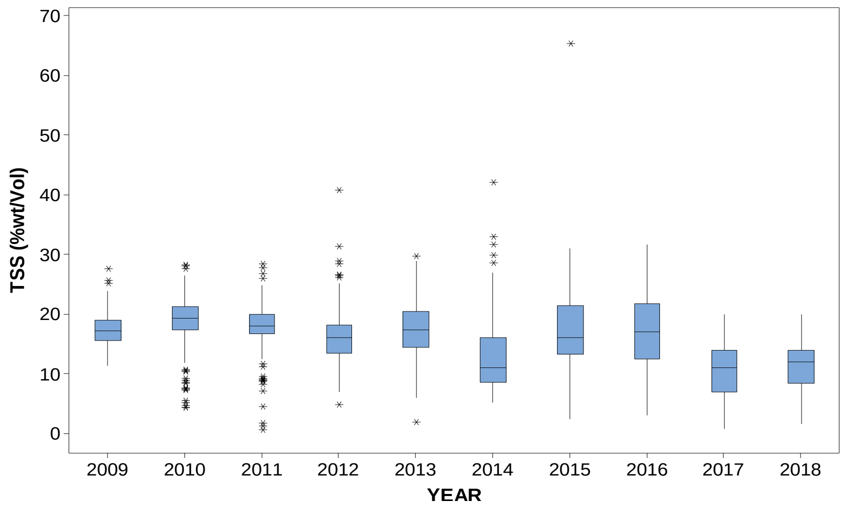


Figure 4-26 Annual TSS in tailings discharge 2009-2018

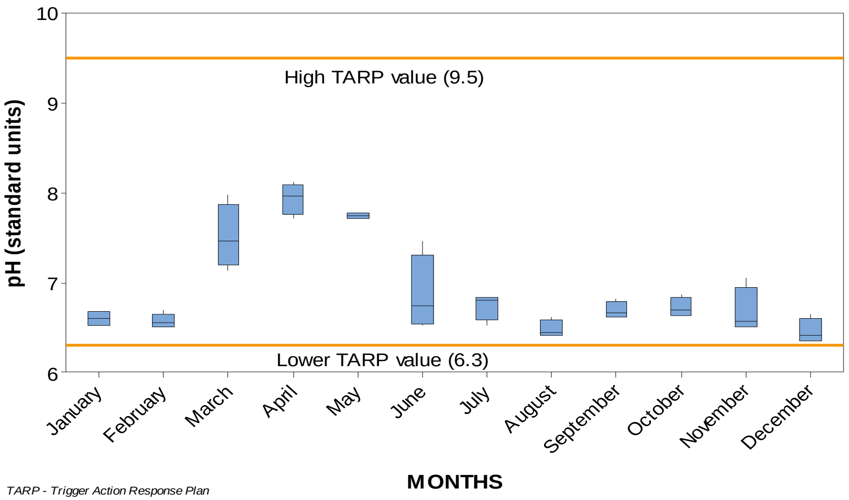


Figure 4-27 Monthly pH in tailings discharge in 2018

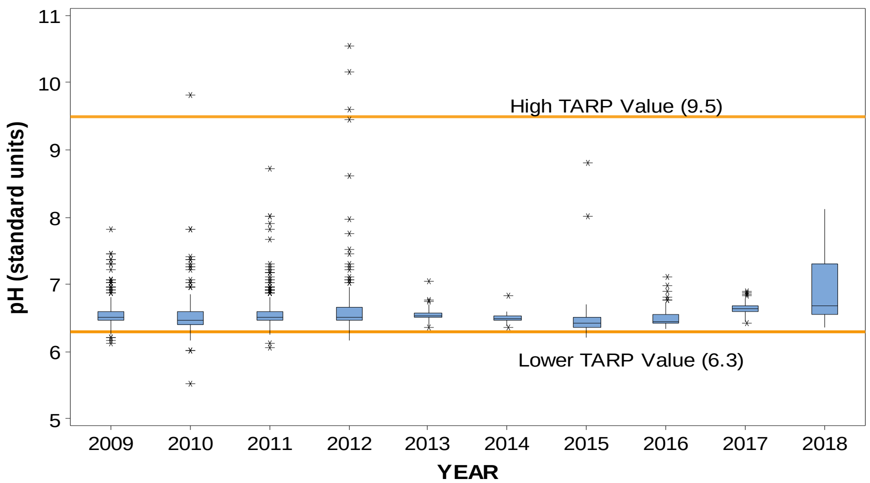


Figure 4-28 Annual pH in tailings discharge 2009-2018

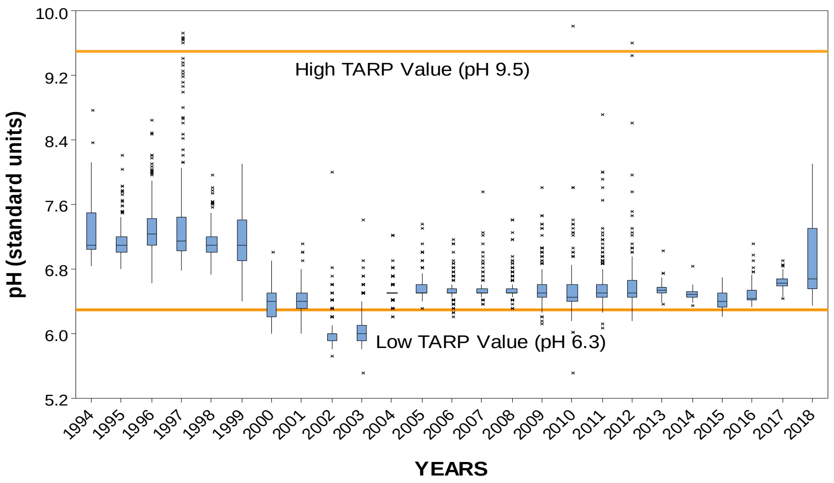


Figure 4-29 pH in tailings discharge 1994-2018

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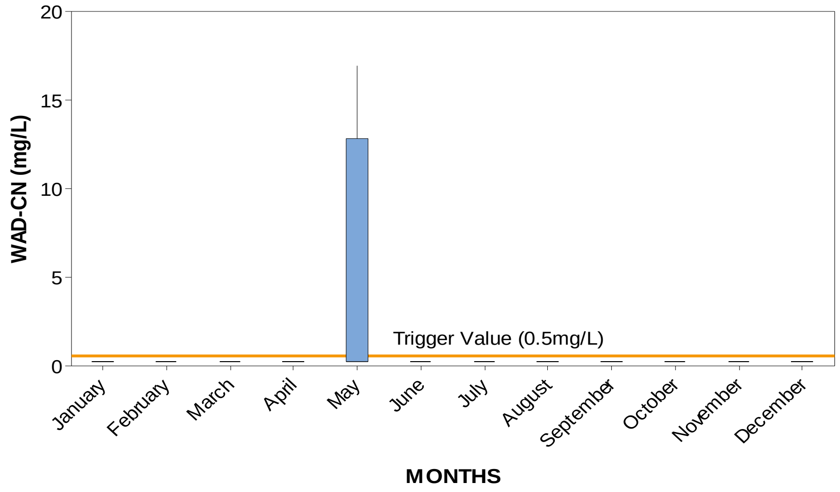

Figure 4-30 Monthly WAD-CN concentration in tailings discharge in 2018 (mg/L)

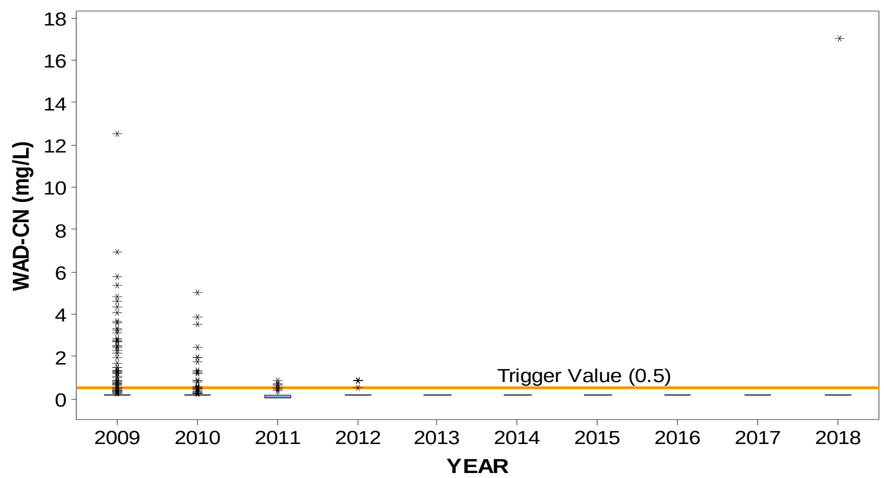

Figure 4-31 Annual WAD-CN concentration in tailings discharge 2009-2018 (mg/L)

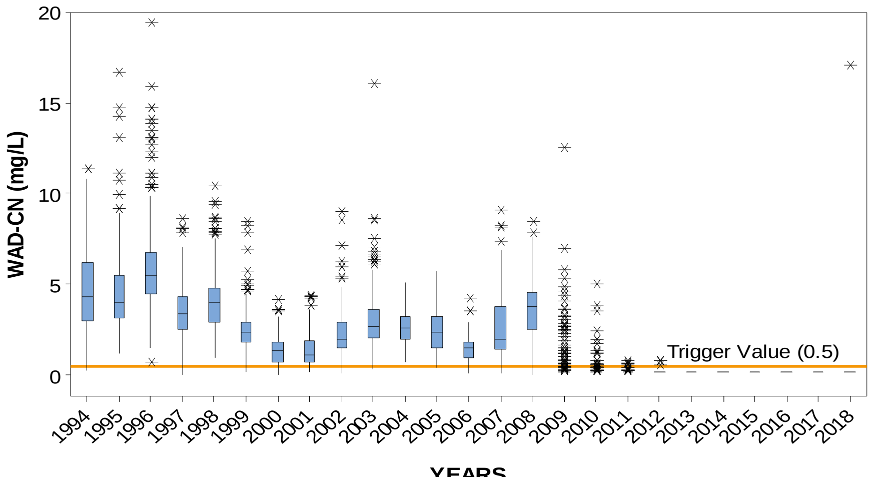

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Figure 4-32 WAD-CN in tailings discharge 1994-2018

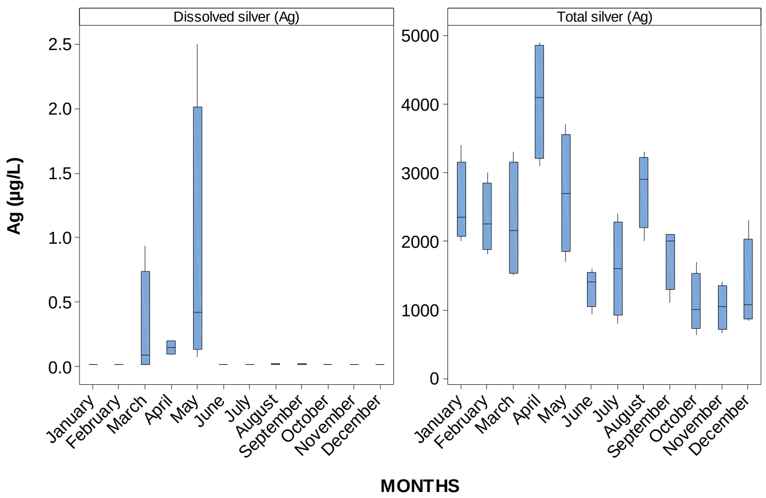


Figure 4-33 Monthly dissolved and total silver concentrations in tailings 2018 (µg/L)

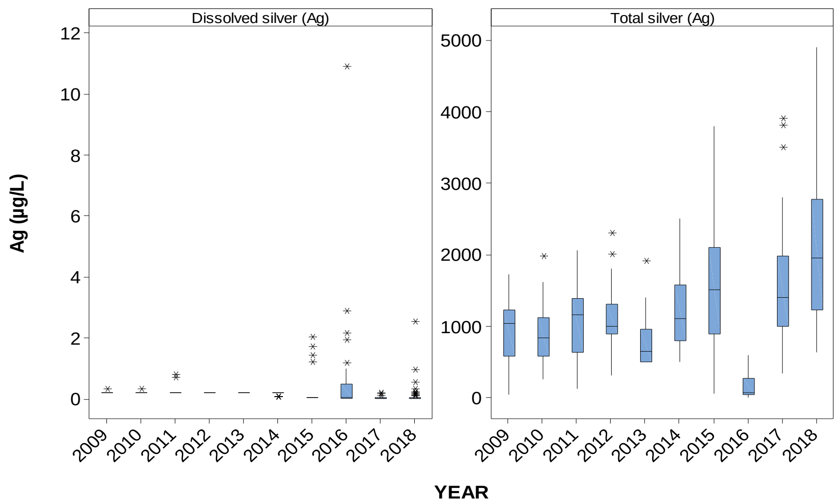


Figure 4-34 Annual dissolved and total silver concentrations in tailings 2009-2018 (µg/L)

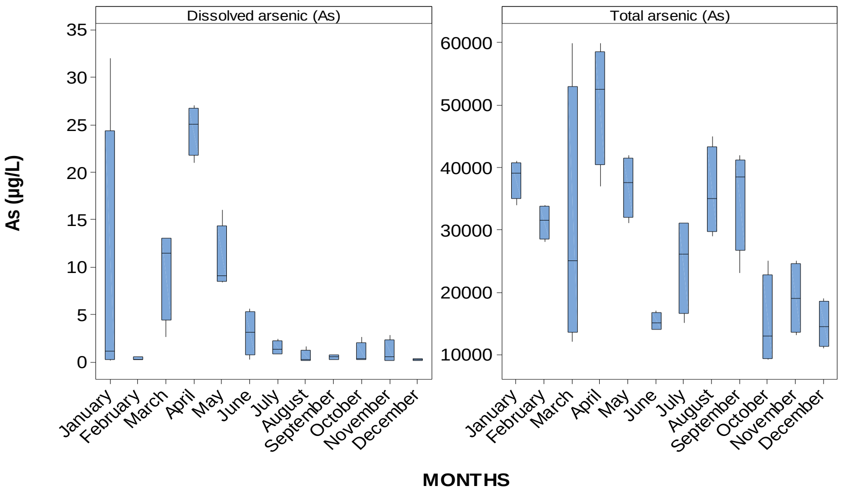


Figure 4-35 Monthly dissolved and total arsenic concentrations in tailings 2018 (µg/L)

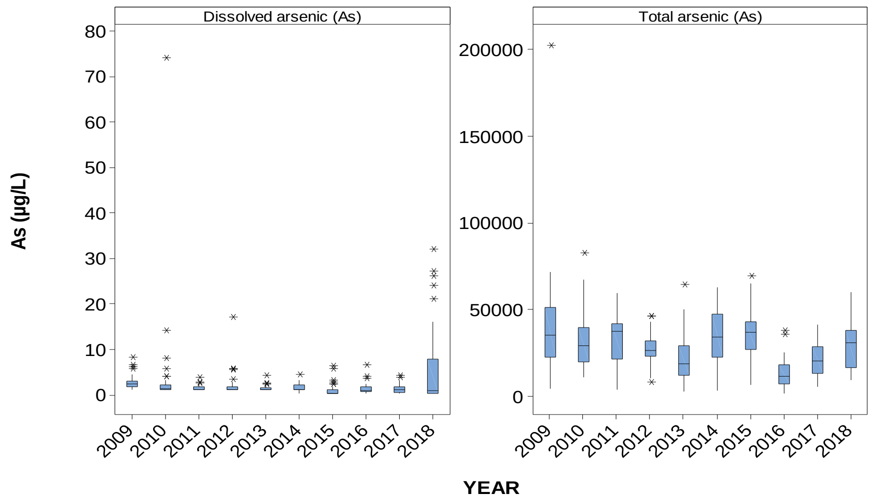


Figure 4-36 Annual dissolved and total arsenic concentrations in tailings 2009-2018 (µg/L)

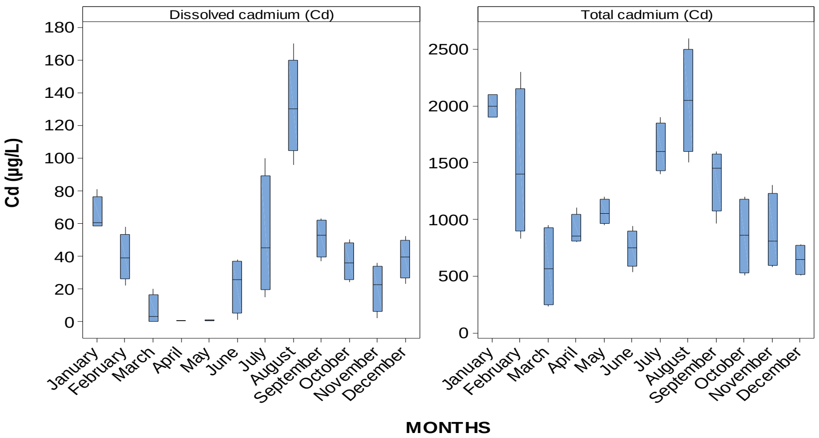


Figure 4-37 Monthly dissolved and total cadmium concentrations in tailings 2018 (µg/L)

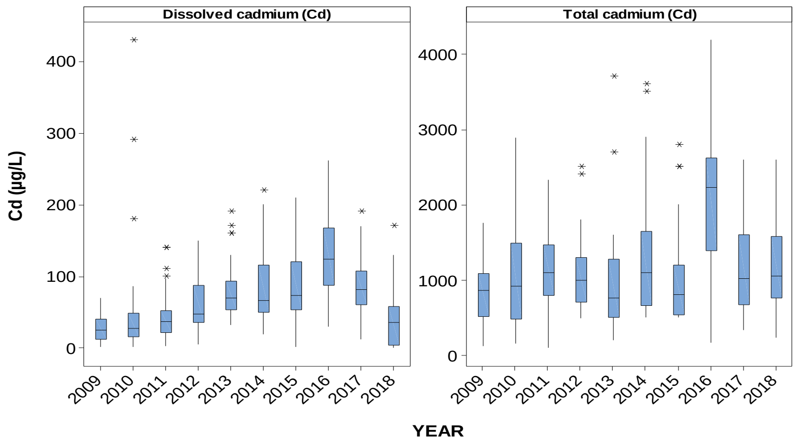


Figure 4-38 Annual dissolved and total cadmium concentrations in tailings 2009-2018 (µg/L)

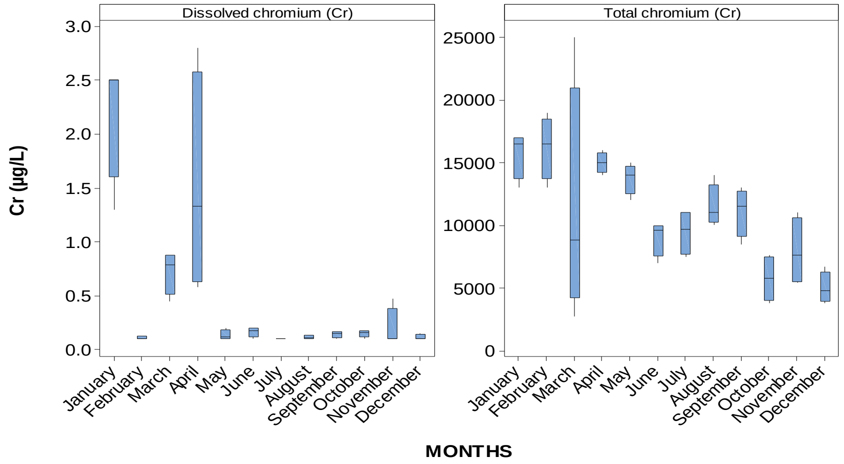


Figure 4-39 Monthly dissolved and total chromium concentrations in tailings 2018 (µg/L)

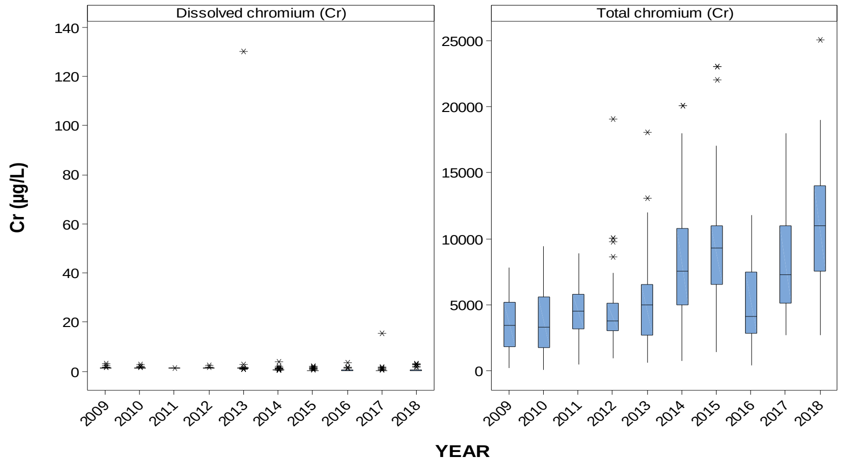


Figure 4-40 Annual dissolved and total chromium concentrations in tailings 2009-2018 (µg/L)

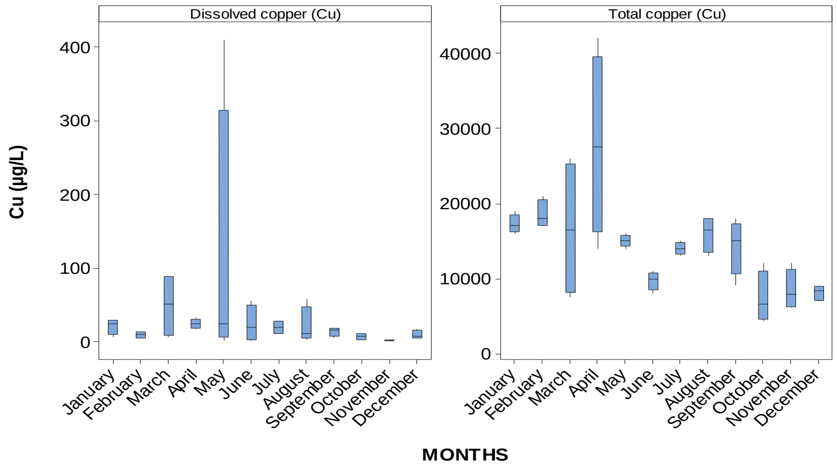


Figure 4-41 Monthly dissolved and total copper concentrations in tailings 2018 (µg/L)

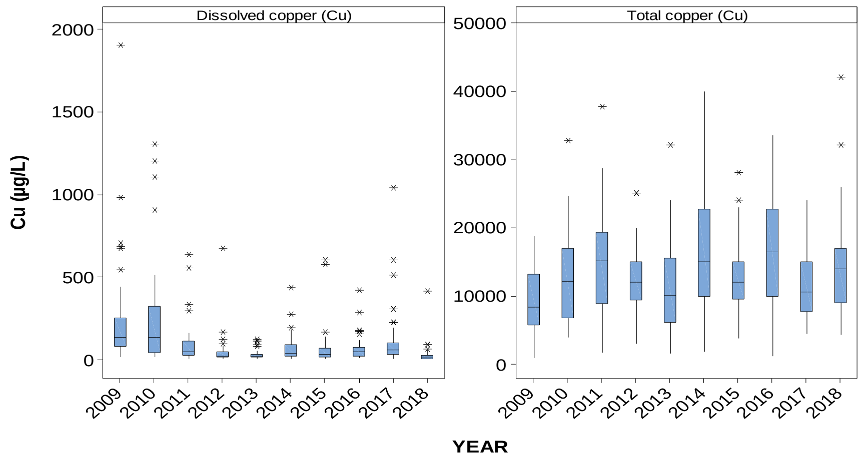


Figure 4-42 Annual dissolved and total copper concentrations in tailings 2009-2018 (µg/L)

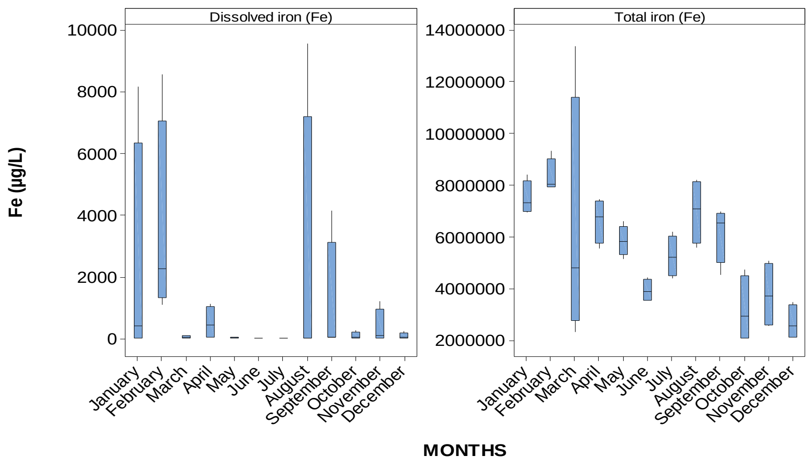


Figure 4-43 Monthly dissolved and total iron concentrations in tailings 2018 (µg/L)

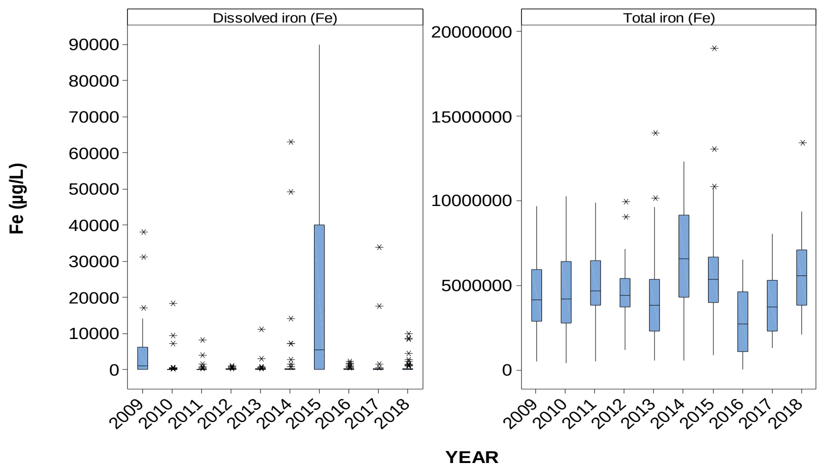


Figure 4-44 Annual dissolved and total iron concentrations in tailings 2009-2018 (µg/L)

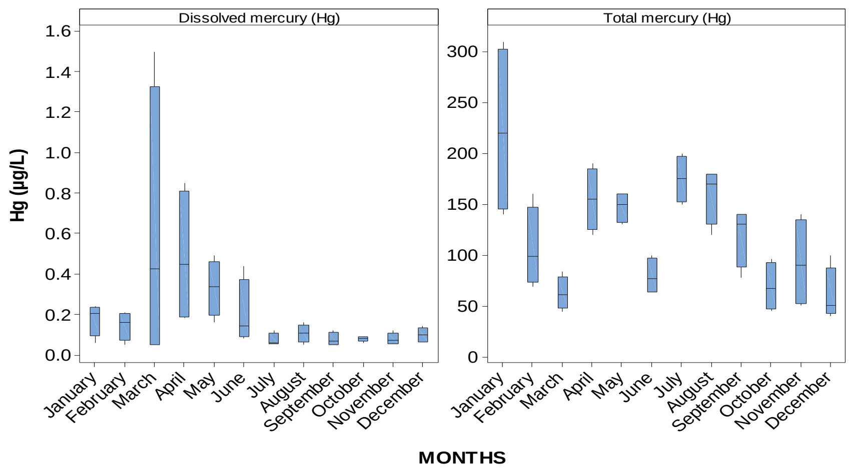


Figure 4-45 Monthly dissolved and total mercury concentrations in tailings 2018 (µg/L)

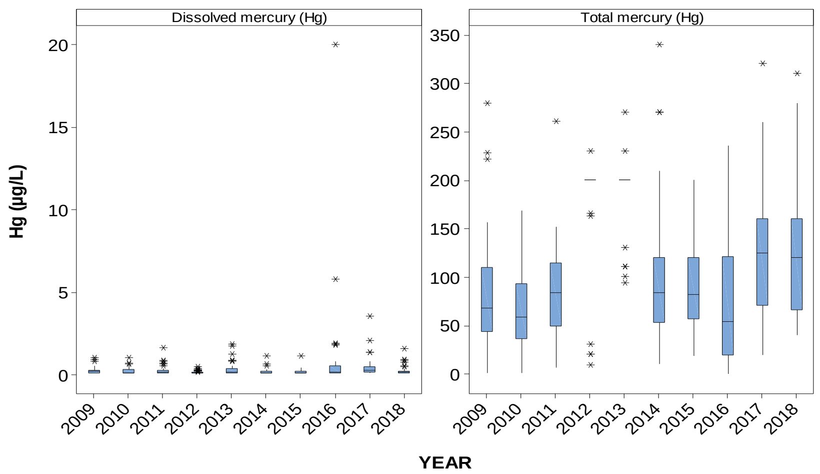


Figure 4-46 Annual dissolved and total mercury concentrations in tailings 2009-2018 (µg/L)

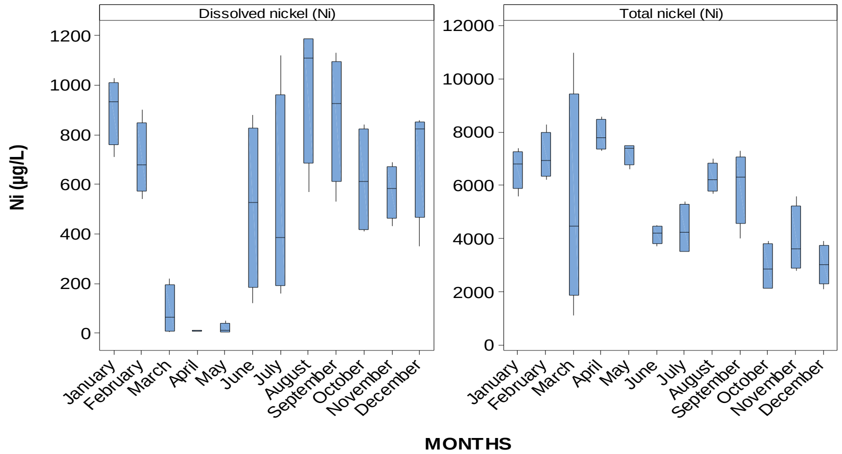


Figure 4-47 Monthly dissolved and total nickel concentrations in tailings 2018 (µg/L)

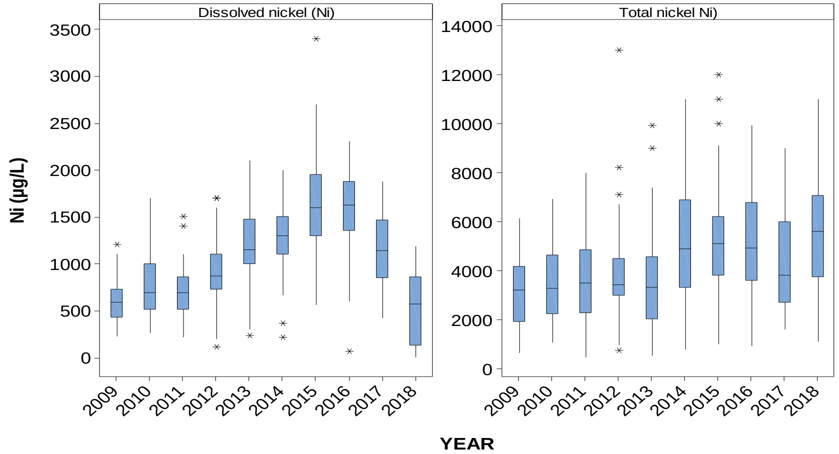


Figure 4-48 Annual dissolved and total nickel concentrations in tailings 2009-2018 (µg/L)

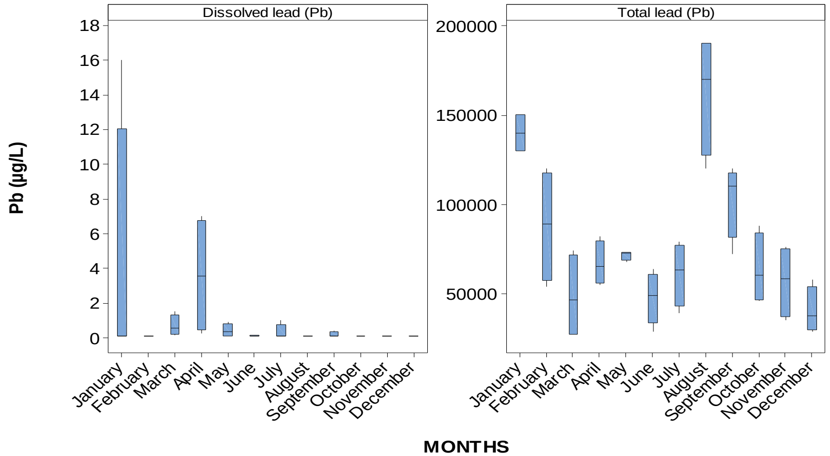


Figure 4-49 Monthly dissolved and total lead concentrations in tailings 2018 (µg/L)

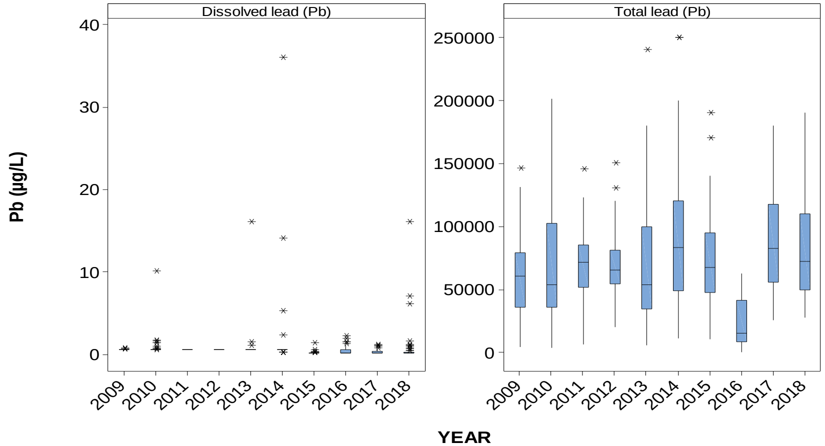


Figure 4-50 Annual dissolved and total lead concentrations in tailings 2009-2018 (µg/L)

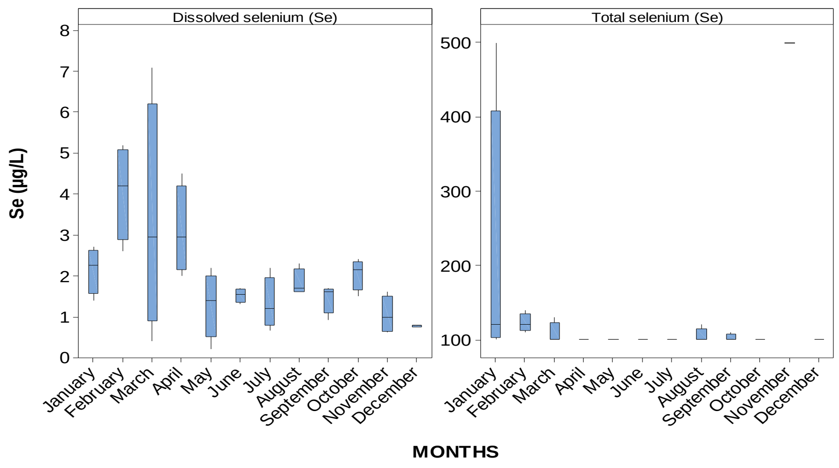


Figure 4-51 Monthly dissolved and total selenium concentration in tailings 2018 (µg/L)

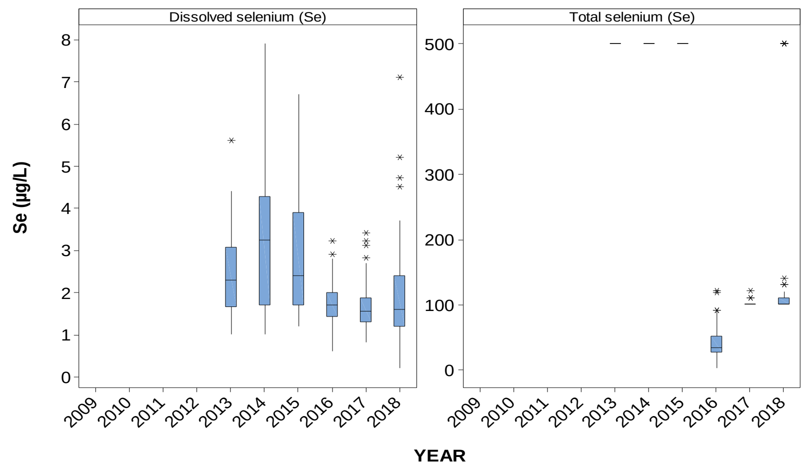


Figure 4-52 Annual dissolved and total selenium concentrations in tailings discharge 2009-2018 (µg/L)

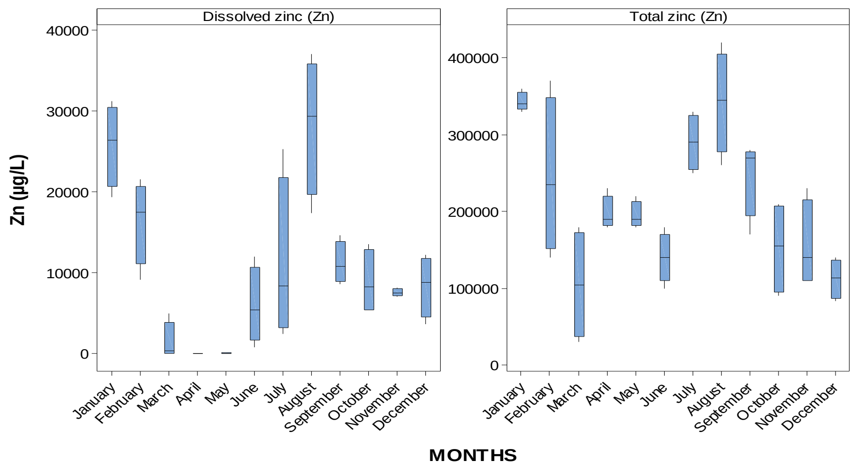


Figure 4-53 Monthly dissolved and total zinc concentrations in tailings 2018 (µg/L)

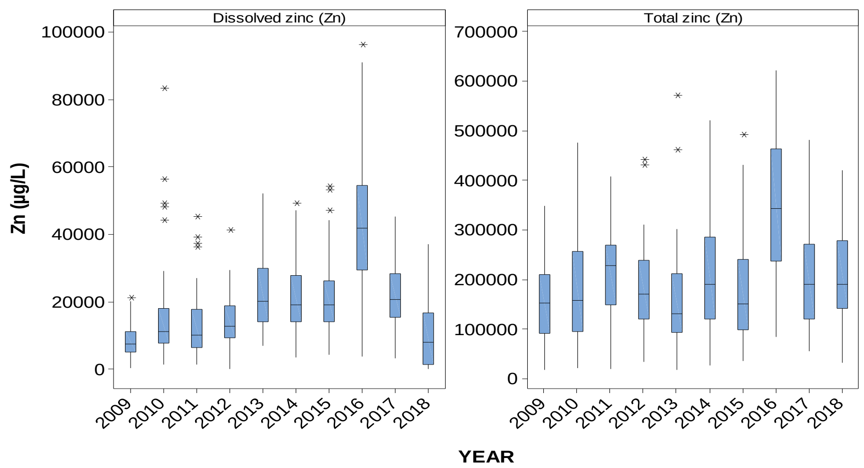


Figure 4-54 Annual dissolved and total zinc concentrations in tailings 2009-2018 (µg/L)

Statistical analysis of the trends of parameters in tailings discharge between 2009 and 2018 was performed using the Spearman Rank Test. The results are presented in Table 4-7. The results show a statistically significant increase in the pH level, concentrations of alkalinity, total silver, dissolved and total cadmium, total chromium, total copper, dissolved iron, dissolved and total nickel and dissolved and total zinc between 2009 and 2018. 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 2009 – 2018

Indicator	Spearman's rho	p-Value (p=0.05)	Trend (2009 – 2018)
pH	0.083	0.001	Increased over time
EC	-0.046	0.059	No change over time
WAD-CN	-0.173	<0.001	Reduced over time
Sulfate	-0.340	<0.001	Reduced over time
ALK-T	0.305	<0.001	Increased over time
TSS	-0.265	<0.001	Reduced over time
Hardness	-0.128	0.032	Reduced over time
Ag-D*	-0.681	<0.001	No change over time
Ag-T	0.215	<0.001	Increased over time
As-D*	-0.339	<0.001	No change over time
As-T	-0.212	<0.001	Reduced over time
Cd-D	0.354	<0.001	Increased over time
Cd-T	0.188	<0.001	Increased over time
Cr-D*	-0.698	<0.001	No change over time
Cr-T	0.501	<0.001	Increased over time
Cu-D	-0.341	<0.001	Reduced over time
Cu-T	0.142	0.002	Increased over time
Fe-D	0.108	0.019	Increased over time
Fe-T	-0.007	0.885	No change over time
Hg-D	-0.036	0.433	No change over time
Hg-T	0.078	0.090	No change over time
Ni-D	0.307	<0.001	Increased over time
Ni-T	0.336	<0.001	Increased over time
Pb-D*	-0.542	<0.001	No change over time
Pb-T	0.004	0.931	No change over time
Se-D*	-0.329	<0.001	No change over time
Se-T	-0.695	<0.001	No change over time
Zn-D	0.293	<0.001	Increased over time
Zn-T	0.199	<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.

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 variables 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 flow rates 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 dumps and the associated response of the river system is 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:

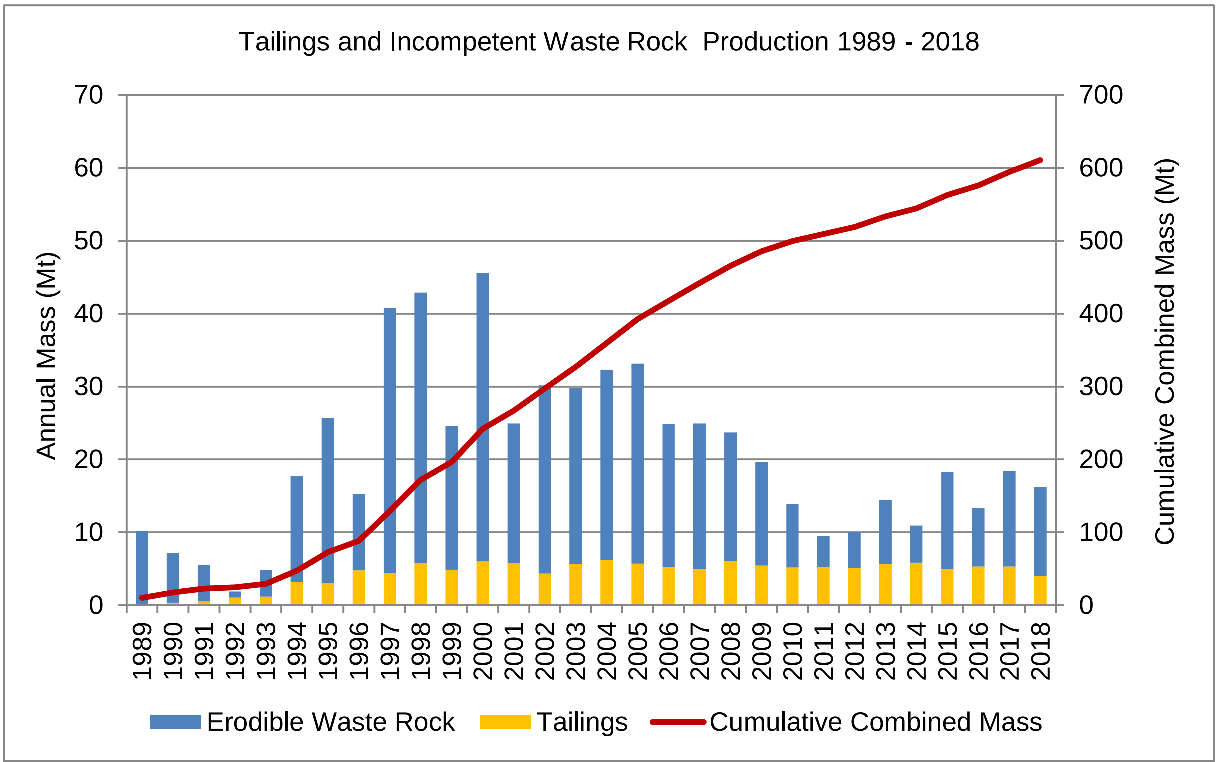
- Discharge of sediment from the toes of the erodible dumps. This is largely controlled by the fluvial action of the Kaiya River (Anjolek erodible waste rock dump) and Pongema River (Anawe erodible waste rock dump), but is also influenced by existing dump morphology, rainfall and flow rates, land sliding activity along valley walls and the like. 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 and flow, observational data on dump behaviour, observations on river impacts and recovery during periods of operational shutdown or low waste placement rates.
- Results from targeted studies such as mine sediment fingerprinting 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 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 2018 and 1989 - 2018

Discharge Location	Total for 2018 (Mt)	Total 1989 – 2018 (Mt)
Anawe erodible dump	3.3	238
Anjolek erodible dump	8.9	242
Tailings discharge (dry solids)	4.0	131
TOTAL	**16.2**	**611**



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

Figure 4-55 Production of incompetent rock and tailings 1989-2018

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 dumps are intersected by higher flowing rivers (specifically the Pongema River and Kaiya River). 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. Table 4-9 also shows the adopted size distribution used for the purposes of sediment discharge calculations.

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 (2002-2018) and mass-balance calculations for the dumps were used to indicate that approximately 50-60% of erodible waste rock input has been lost downstream as a long-term average. More recent survey data, as of 2018, indicate that the amount of material exported downstream since 2010, expressed as a percentage of the amount of material dumped, was higher at approximately 69% for Anawe and 108% for Anjolek. This partly reflects the lower rates of dumping in recent years, while there has 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.

These results are consistent with results of visual inspections which suggest that the morphology of Anawe is relatively unchanged, although a gradual increase in surface area and volume over time is noted, while the area and volume characteristics of Anjolek appear relatively unchanged over recent years, although some morphological changes have occurred due mostly to changing surface drainage patterns.

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 8.7 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	49	4.5	4.3 (69%)
Total	**NA**	**7.5**	**8.7**

Based on the figures above, Table 4-11 presents estimates of suspended sediment discharge from the SML for both tailings and waste rock in 2018, based on the most recent survey data in late 2018. 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 2018

Source	Total Sediment Discharged from Dumps (Mt/y)	Suspended Sediment Component (Mt/y)	Assumptions
Erodible dumps	8.7	5.1	Assumes 59% (silt fraction) travels as suspended load
Tailings	4.3 (4.5 x 0.95)	4.1 (4.3 x 0.95)	Assumes 95% of tailings is transported to the river system and 5% remains stored in Anawe dump
TOTAL 2018	**13**	**9.2**	

4.10 Other Discharges to Water

4.10.1 Treated sewage effluent

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

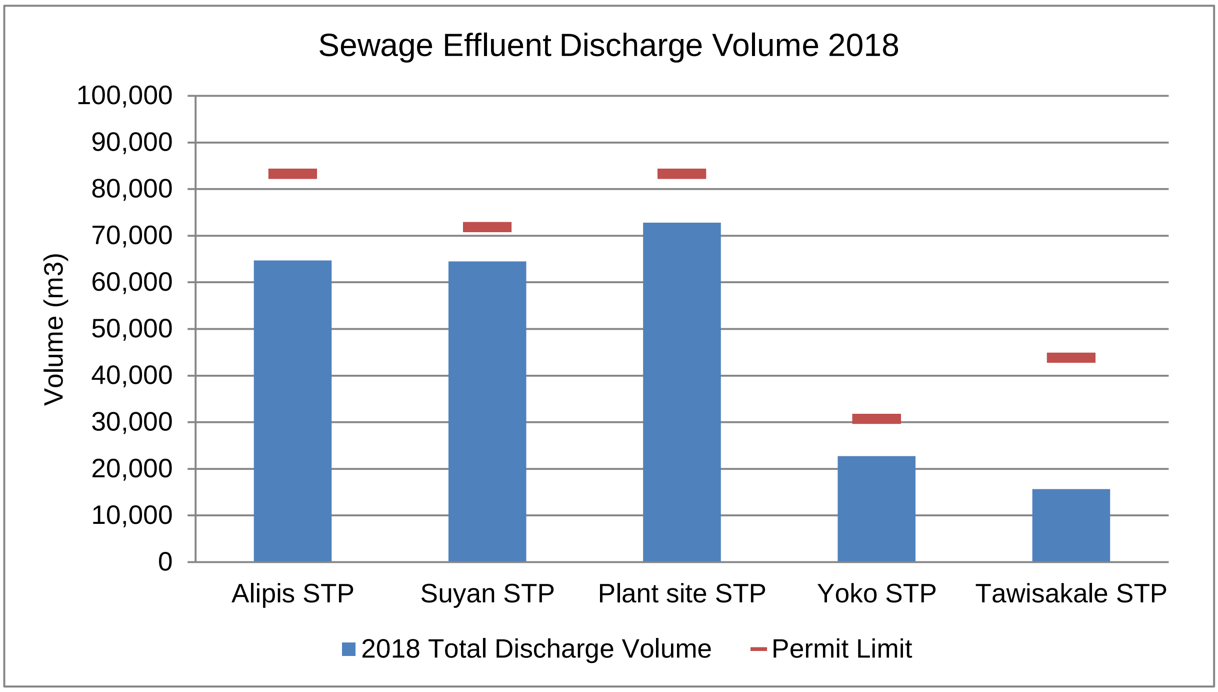


Figure 4-56 Total annual discharge volumes of treated sewage for 2018

The quality of the discharge from each STP is monitored for TSS, BOD_5 and faecal coliforms. The results of monitoring in 2018 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 two short-term excursions slightly above the permit limit at Alipis and Plant site STPs. All plants achieved compliance with the BOD_5 and faecal coliform criteria throughout the year. Both of the TSS excursions were investigated using a root-cause analysis methodology. Other excursions were caused by treatment plant operators not following SOPs. Preventative actions involved refresher training of operators and competency assessment. The consistent achievement of compliance since May confirms the success of the preventative actions.

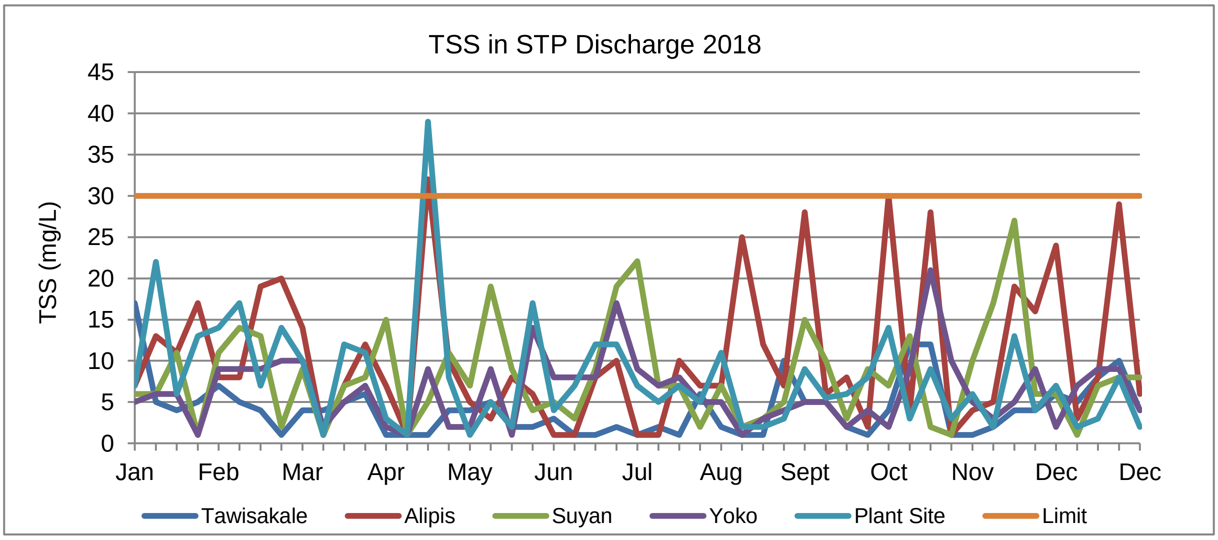


Figure 4-57 Average monthly TSS concentration in treated sewage discharge in 2018

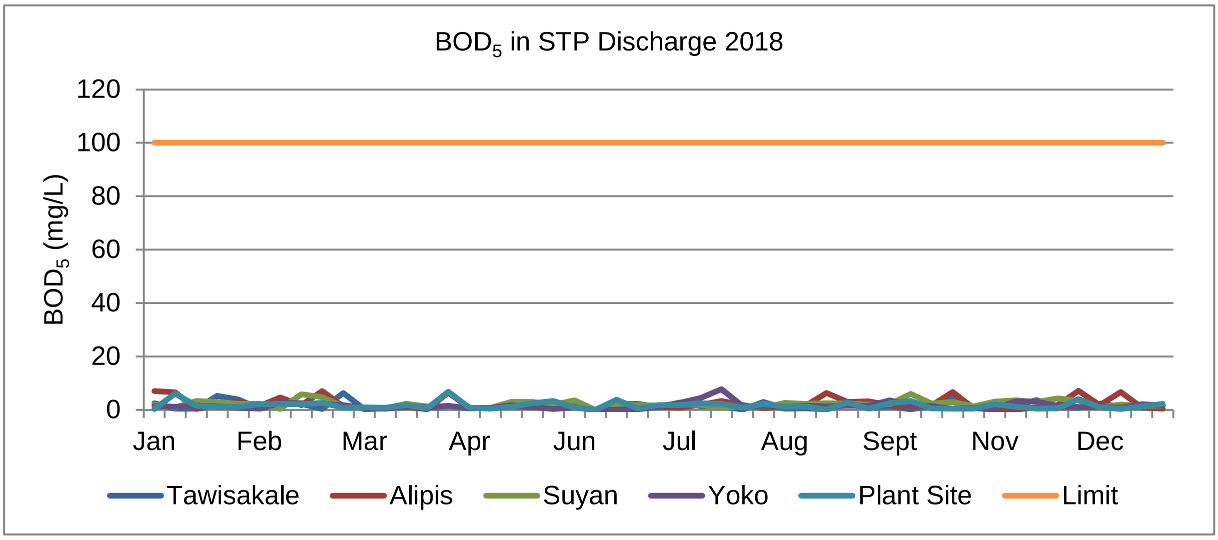


Figure 4-58 Average monthly BOD_5 concentration in treated sewage discharge in 2018

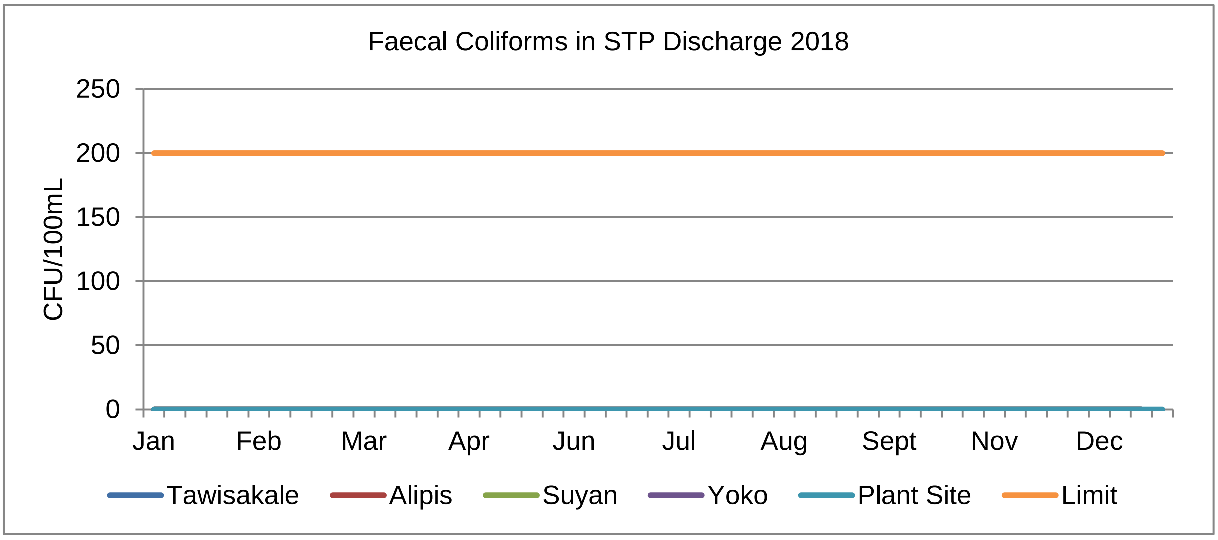


Figure 4-59 Average monthly faecal coliform count in treated sewage discharge 2018

4.10.2 Oil/water separator effluent

The mine operates 24 oil-water separators at maintenance workshops and fuel storage and refuelling installations.

Figure 4-60 shows the average monthly monitoring results for the discharge of total hydrocarbons from the oil-water separators to local streams, compared against the internal (PJV) site-developed target of 30 mg/L.

Hydrocarbons were detected in very low concentrations in contact water sampled at the mine site boundary throughout the year. PJV is continuing to implement programs to ensure the oil-water separators are designed, constructed, operated and maintained to consistently achieve the site-developed target.

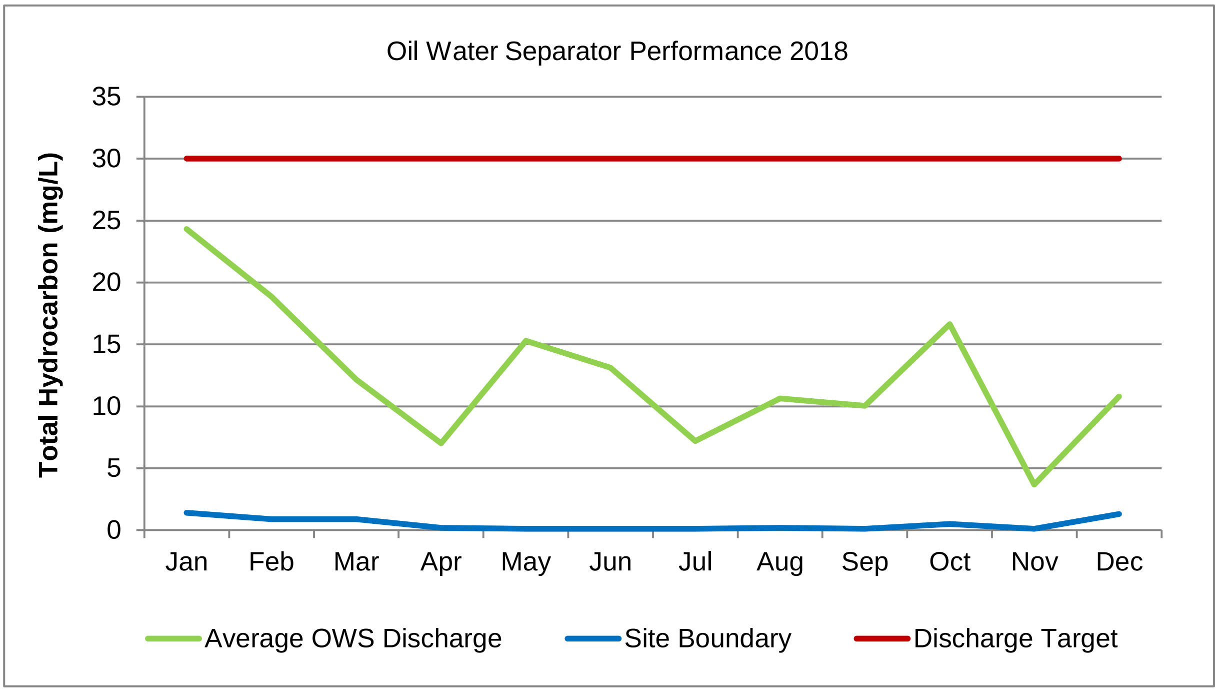


Figure 4-60 Average monthly total hydrocarbon concentrations in oil-water separator discharges in 2018

4.10.3 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.

4.10.3.1 Contact runoff volumes

Table 4-12 shows the estimated volume of contact runoff from land disturbed by mining. 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 2018

Location	Total Rainfall run off 2018 (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)	20.3	1,682
Open Pit and UG Mine drainage tunnel to Kogai Creek (DP6)	8.9	12.1
Anawe stable dump to Wendoko Creek (DP7)	3.5	4.5
Runoff from Hides to a tributary of the Tagari River (DP16)	0.04	0.1
TOTAL	**33.5**	**1,701**

4.10.3.2 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

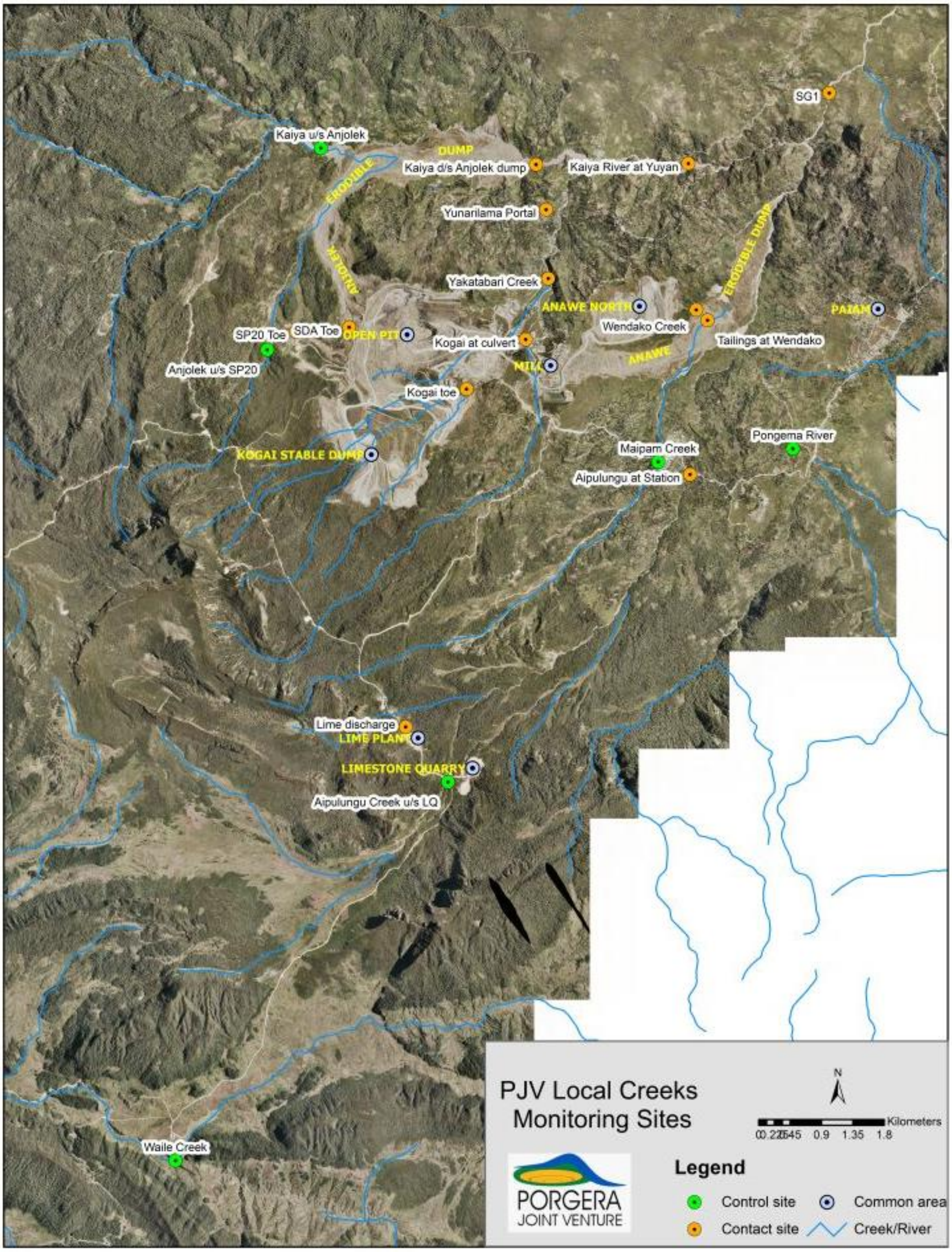


Figure 4-61 Mine contact runoff sampling location

Annual median values from monthly monitoring conducted in 2018 at mine contact runoff sites are shown in Table 4-14. An amber highlight indicates values that exceeded the upper river TV. Samples were not collected from SDA Toe and Kaiya River downstream of Anjolek erodible dump during 2018 due to community and security issues. Kogai Stable Dump Toe and Wendoko Creek downstream of Anawe Nth, which receive runoff from competent waste rock dumps, exhibited elevated concentrations of dissolved cadmium 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. Results indicated, however that there was insufficient alkalinity to fully precipitate cadmium and zinc, which typically require higher pH values than other metals to achieve complete removal from solution. Discharge from the lime plant exhibited elevated pH and dissolved chromium. Runoff from Yakatabari Crk DS of 28 Level, Yunarilama at Portal and Lime Plant exhibited elevated TSS.

A summary of trends of water quality parameters between 2009 and 2018 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 Dump Toe, 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. The results show elevated WAE 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 WAE lead was present in sediment from all sites except Lime Plant and Wendoko. 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.

Monitoring WAE metals in sediment at the contact runoff sites began in 2015 and there are insufficient data available to perform a trend analysis. This will commence in the 2019 AER, once a multi-year data set has been established.

Table 4-14 Contact water quality 2018 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	7.8	NS	NS	8.0	7.7	11.2	7.6	7.5	7.5
EC#	250	682	NS	NS	828	1628	491	2,685	674	2,890
WAD-CN*	NA	0.20	NS	NS	0.20	0.20	0.20	0.20	0.20	0.20
Sulfate*	NA	125	NS	NS	220	620	2.5	1,078	160	560
ALK-T**	NA	128	NS	NS	155	236	693	196	127	201
TSS*	2,837	27	NS	NS	270	101	500[1]	2.0	3,350	18,000
Hardness**	NA	349	NS	NS	439	1040	527	1184	303	414
Ag-D	0.05	0.01	NS	NS	0.01	0.01	0.01	0.01	0.01	0.03
Ag-T	NA	0.06	NS	NS	7.6	0.17	0.05	0.06	30	120
As-D	24	7.1	NS	NS	1.3	0.76	0.10	0.87	9.5	2.1
As-T	NA	19	NS	NS	49	4.8	0.87	2.6	405	2,800
Cd-D	0.34	0.06	NS	NS	0.23[1]	0.58	0.05	1.1	0.08	0.11
Cd-T	NA	0.24	NS	NS	5.4	2.6	0.18	1.3	30	150
Cr-D	1.0	0.12	NS	NS	0.21	0.17	4.0	0.31[1]	0.44	0.36[1]
Cr-T	NA	1.2	NS	NS	13	3.5	18	0.62	190	3,900
Cu-D	4.1	0.38	NS	NS	1.2	0.45	0.55	0.35	0.94	0.48
Cu-T	NA	1.5	NS	NS	25	4.5	5.1	1.3	380	4,100
Fe-D	75	11	NS	NS	16	9.3	3.9	10	9.3	46[1]
Fe-T	NA	670	NS	NS	11,300	2,870	2,140	505	160,900	6,150,000
Hg-D	0.60	0.05	NS	NS	0.05	0.05	0.05	0.05	0.05	0.05
Hg-T	NA	0.05	NS	NS	0.48	0.05	0.05	0.05	4.7	13
Ni-D	21	2.1	NS	NS	1.1	2.1	0.50	1.9	1.6	2.3
Ni-T	NA	5.5	NS	NS	18	6.2	4.5	4.0	215	3,400
Pb-D	7.5	0.13	NS	NS	1.2	0.53	0.11	0.15	1.0	0.46
Pb-T	NA	8.3	NS	NS	265	33	1.9	4.7	3,120	8,200
Se-D	11	0.20	NS	NS	0.20	0.21	0.20	0.56	0.21	0.9
Se-T	NA	0.20	NS	NS	0.48	0.33	0.20	0.62	3.5	100
Zn-D	20	30	NS	NS	31	155	3.9	350	11	9.6[1]
Zn-T	NA	91	NS	NS	720	420	25	425	5,240	42,000
	> UpRiv TV = Potential Risk									

^std units, #µS/cm, * mg/L, **mg $CaCO_3$/L D = Dissolved fraction, T = Total TV NA – Not applicable NS - Not sampled in 2018

[1] Although TSM falls below 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 is found to be not statistically significantly different from the TV.

Table 4-15 Trends of water quality contact runoff 2009 - 2018 (as tested using Spearman Rank Correlation)

Parameter	28 Level	SDA Toe*	Kaiya Riv D/S Anj Dump	Kogai Culvert	Kogai Dump Toe	Lime Plant	Wendoko Creek D/S Anawe Nth	Yakatabari Creek D/S 28 Level	Yunarilama / Yarik @ Portal
pH	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
EC	Increased	Decreased or no change	Increased	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
WAD-CN	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Sulfate	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
ALK-T	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Increased
TSS	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Increased	Increased	Decreased or no change	Decreased or no change	Decreased or no change
Hardness	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Ag-D	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Ag-T	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Increased
As-D	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
As-T	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Cd-D	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Cd-T	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Increased	Decreased or no change
Cr-D	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Cr-T	Decreased or no change	Increased	Decreased or no change	Increased	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Increased
Cu-D	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Cu-T	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Increased	Increased	Decreased or no change	Decreased or no change	Decreased or no change
Fe-D	Decreased or no change	Increased	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Increased
Fe-T	Decreased or no change	Increased	Decreased or no change	Increased	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change
Hg-D	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Hg-T	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Decreased or no change
Ni-D	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Ni-T	Decreased or no change	Increased	Decreased or no change	Increased	Increased	Increased	Decreased or no change	Decreased or no change	Increased
Pb-D	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Pb-T	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Increased	Increased	Decreased or no change	Decreased or no change	Decreased or no change
Se-D	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change
Se-T	Decreased or no change	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Decreased or no change
Zn-D	Increased	Decreased or no change	Increased	Decreased or no change	Increased	Decreased or no change	Decreased or no change	Increased	Increased
Zn-T	Decreased or no change	Decreased or no change	Decreased or no change	Decreased or no change	Increased	Increased	Decreased or no change	Decreased or no change	Decreased or no change

(green)	Decreased or no change over time
(orange)	Increased over time

D - Dissolved fraction, T - Total

Table 4-16 Contact Sediment Quality 2018 median values (mg/kg dry, whole fraction)

Parameter	UpRiv TV	28 Level	SDA Toe (Anjolek)	Kaiya R DS Anj Dump	Kogai Culvert	Kogai Stable Dump Toe	Lime Plant	Wendoko Creek DS Anawe Nth	Yakatabari Creek DS 28 Level	Yunarilama @ Portal
Ag-WAE	1.0	4.4	NS	NS	0.78	1.1	0.05	0.12	0.84	0.38
Ag-TD	NA	20	NS	NS	4.7	6.7	0.07	1.9	6.4	3.5
As-WAE	20	49	NS	NS	11	12	0.51	2.5	15	5.3
As-TD	NA	295	NS	NS	149	175	3.2	28	94	95
Cd-WAE	1.5	1.8	NS	NS	2.4	2.5	0.23	0.53	1.8	1.2
Cd-TD	NA	8.2	NS	NS	9.4	13	0.32	0.88	5.9	5.1
Cr-WAE	80	14	NS	NS	7.6	7.4	7.8	13	11	11
Cr-TD	NA	65	NS	NS	31	38	20	25	55	26
Cu-WAE	65	25	NS	NS	11	10	3.5	6.1	14	5.1
Cu-TD	NA	96	NS	NS	72	95	8.0	23	62	48
Hg-WAE	0.15	0.07	NS	NS	0.01	0.01	0.01	0.01	0.01	0.01
Hg-TD	NA	0.41	NS	NS	0.42	0.36	0.02	0.08	0.55	0.16
Ni-WAE	21	17	NS	NS	8.8	7.8	2.9	11	13	11
Ni-TD	NA	54	NS	NS	31	35	7.2	24	44	34
Pb-WAE	50	570	NS	NS	360	475	3.2	21	205	170
Pb-TD	NA	670	NS	NS	345	500	3.9	55	275	265
Se-WAE	0.16	0.16[1]	NS	NS	0.14	0.13	0.10	0.19	0.13	0.27
Se-TD	NA	1.0	NS	NS	0.89	1.0	0.13	0.61	0.62	1.0
Zn-WAE	200	485	NS	NS	445	405	14	135	315	235
Zn-TD	NA	1,620	NS	NS	1,620	2,065	31	235	1,210	965

(shaded)	> 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 was done in 2017, and therefore emissions were not monitoring in 2018. 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 0. PJV plans to conduct monitoring of emissions from stationary sources again in 2019.

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 slightly increased by 2.3% in 2018 compared to 2017 due to use of the extra diesel generators to generate power for the mine's operations when main power supply from Hides Power Plan was cut-off completely as a result of damage to the power plant caused by the 7.5 magnitude earthquake that struck the area on the Monday 26 February 2018. However, the declining trend since 2010 was still maintained.

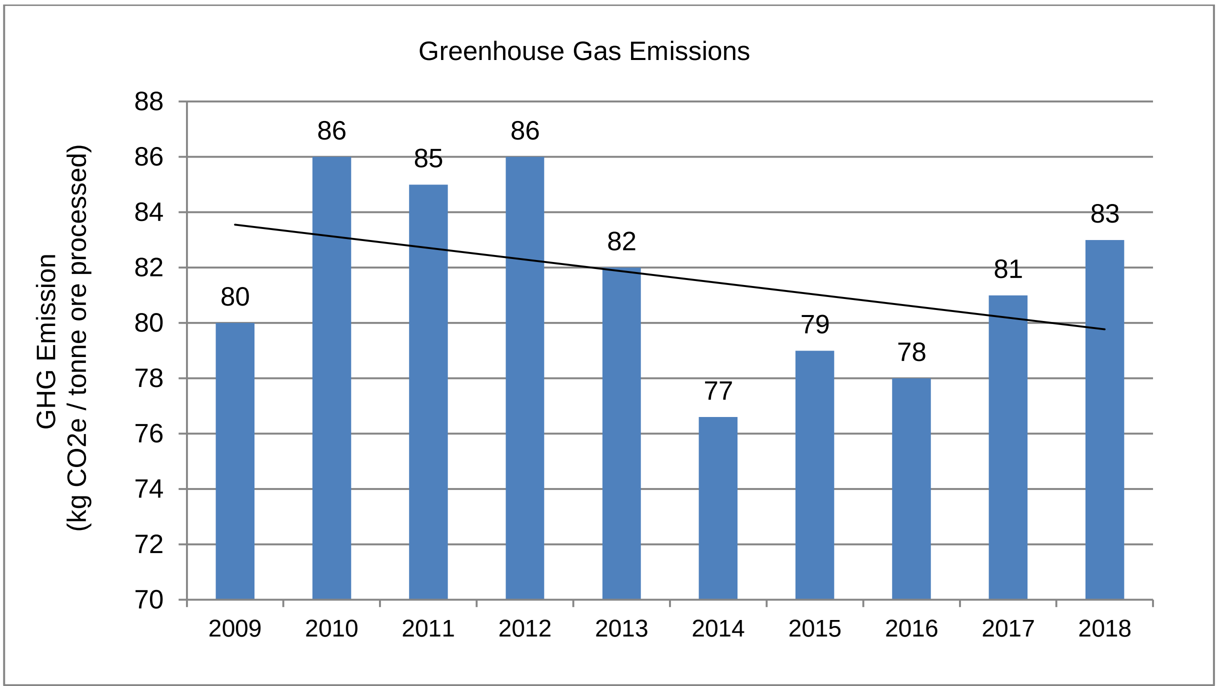


Figure 4-62 Energy efficiency 2009 – 2018

4.13 Closure Planning and Reclamation

4.13.1 Mine closure plan

In 2018, PJV revised the draft Mine Closure Plan in line with the Barrick Closure Standard and Guidelines. This plan built on previous plans produced for the project in 2007 and 2011 and highlights closure considerations for the mine infrastructure, including safety and environmental aspects during the closure process.

4.13.2 Progressive closure and reclamation

Since the start of mining at Porgera, the majority of the areas of land disturbance are still being actively used for mining operations, which has limited the land available for reclamation and revegetation. The total area reclaimed to date is 240 hectares and most of this area is on the Kogai competent waste rock dump, where the use for mining purposes was completed in 2003. The area was reclaimed by placement of a soil cover of brown mudstone and colluvium, and then revegetated. The soil cover was stabilized to protect it from erosion by planting with a range of grasses and legumes. Following the establishment of the groundcover of grasses and legumes, local lower montane tree species were planted.

Very limited areas of disturbed land became available for reclamation in 2018 as mining and related activities were still progressing.

The revegetation activities for the year included planting the reclaimed area with a grass and legume seed mix to stabilize soil as the first phase of vegetation establishment. The hydroseeder was used to seed failed areas within the open pit mining area during the year especially on the west wall cutback areas. Approximately 4.5 hectares of the area was hydroseeded.

A total of 678 tree seedlings were planted on the Kogai dump at the K65 bench, K69 slope and environmental office yard. Tree seedlings were purchased from local suppliers and raised at the nursery for hardening before transplanting. The numbers and species planted are shown in Table 4-17.

Table 4-17 Species of tree seedlings planted in 2018

Type	Scientific Name	Local Name	Number Planted 2018
Hardwood	*Castanopsis acuminatissima*	Pai	121
	Dacrydilium nidilium	Pawa	48
	Litsea timorauna	Mara	69
	Nothofagus sp.	Taro	81
	Syzgium richardsonianum	Pip	354
Softwood	*Libocedrus papuanus*	Pulapia	5
		TOTAL	**678**

4.14 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 2018, 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, 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.

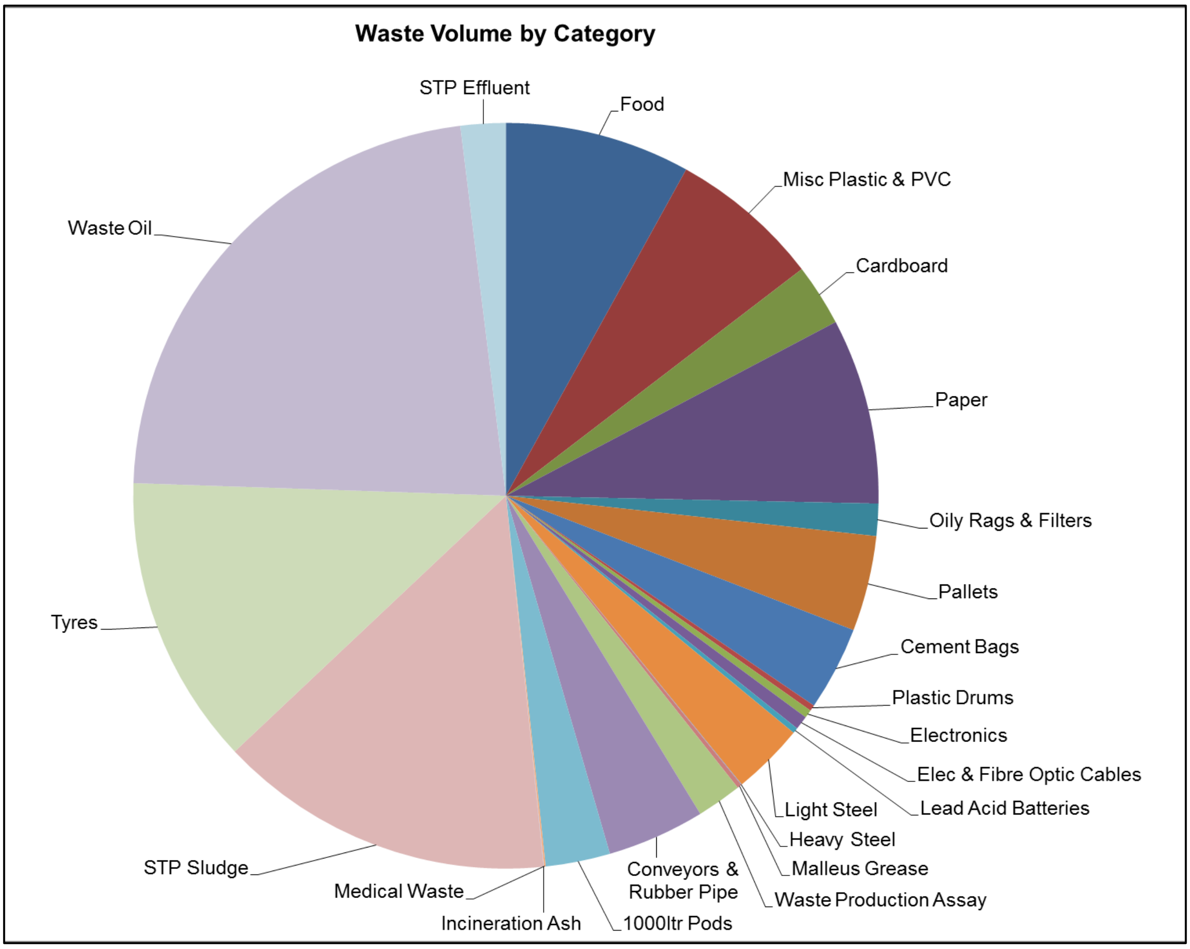


Figure 4-63 Non-mineralised waste production proportions by volume

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), 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.

Parts of the operation 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 2018;
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 2018 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 and Lakes and Off-River Water Bodies 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 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 2018 was approximately 1% above the long-term mean in the upper reach, 6.4% above average in the middle reach (SG2, Ok Om and SG3) and 8.2% above average in the lower reach (SG4, SG5).

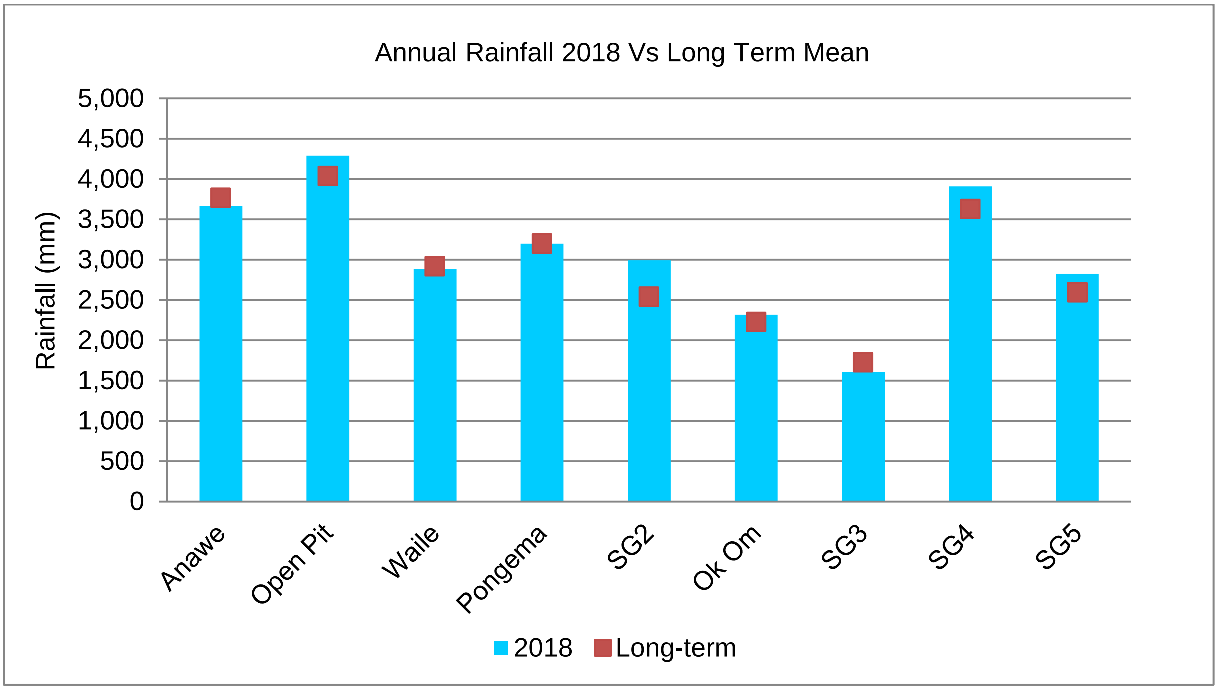


Figure 5-1 Comparison of annual rainfall (2018 data versus long-term means) at sites in the Strickland Catchment

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.

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 2018 was 0.95, indicating the 2017-2018 La Nina event, which typically exhibits above average rainfall, has ended and there has been a return to neutral conditions.

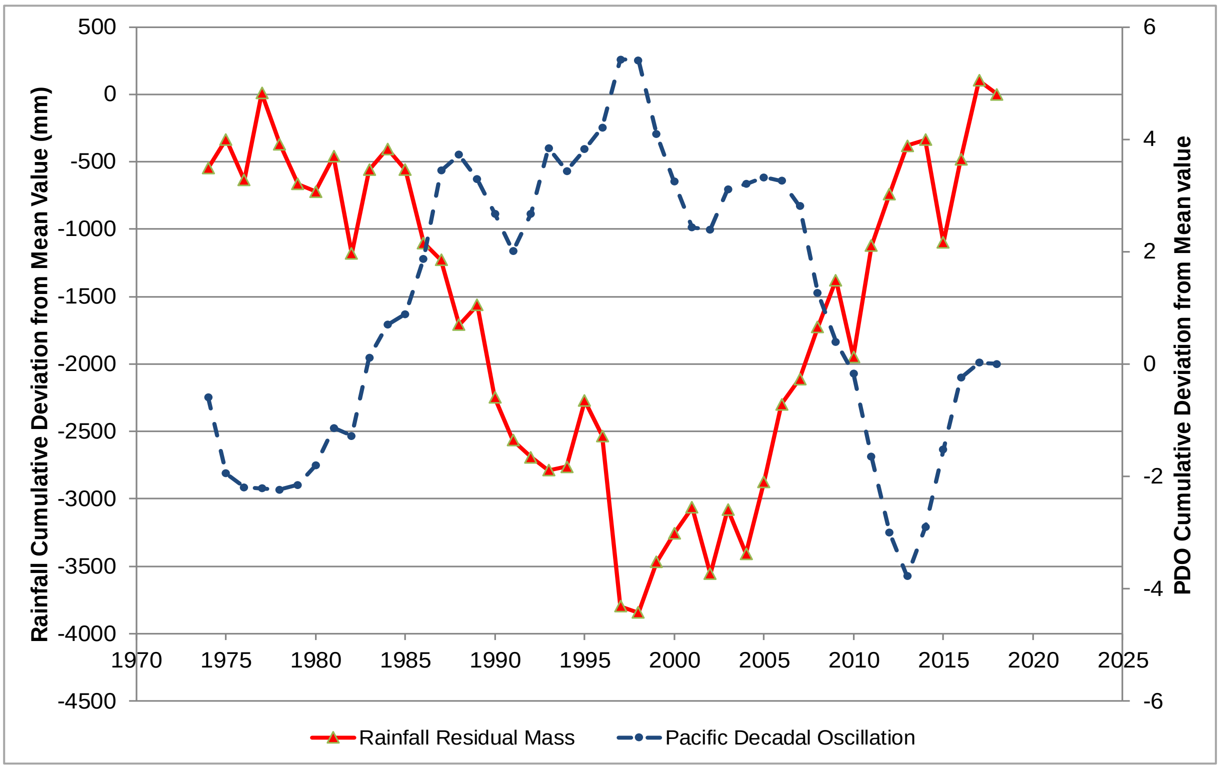


Figure 5-2 Residual mass plots Anawe rainfall station data

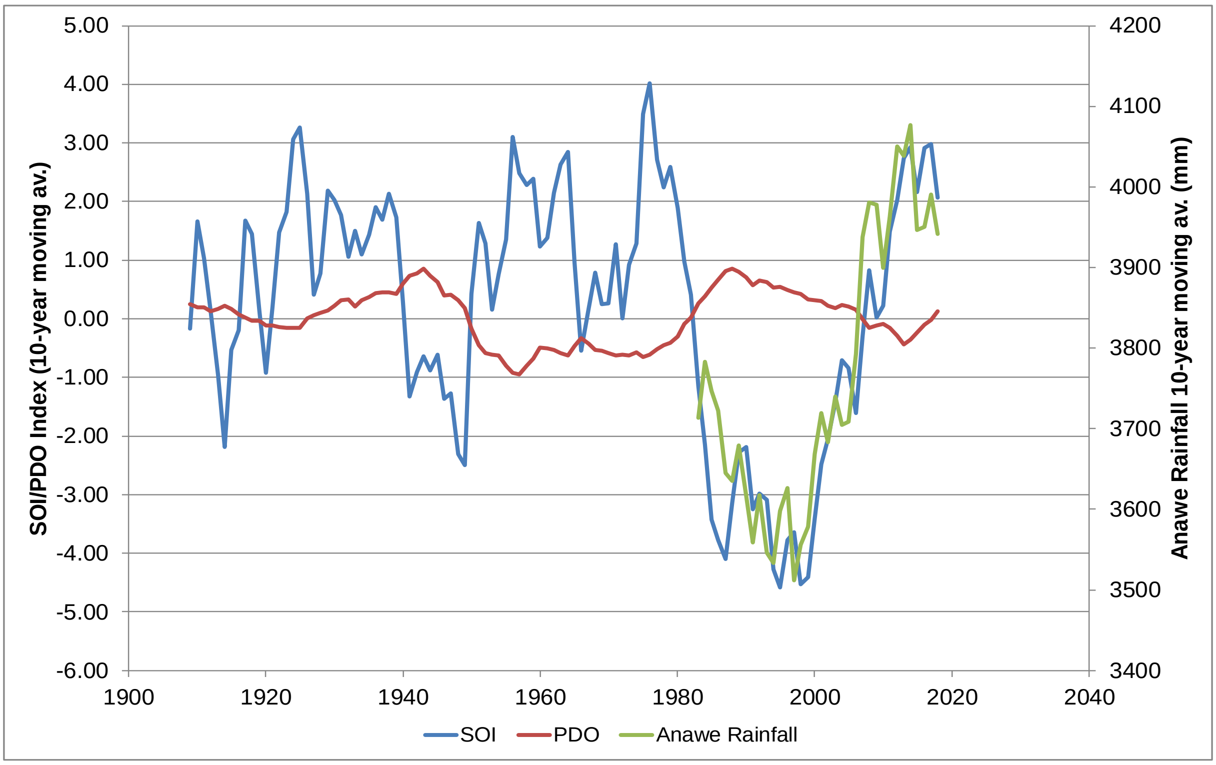


Figure 5-3 Anawe rainfall, SOI and PDO indices on 10-y moving average

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 orographic influence of the surrounding mountains there is minimal seasonal variability 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 2018

Parameter	Yearly total	Daily max	Daily min	Daily mean	Long-term daily mean
Rainfall (mm)	3,666	65.5	0.0	10	10.2
Max/Min Temp. (^{o}C)	-	19.3	9.0	-	-
Mean Daily Temp.(^{o}C)	-	21.5	11.6	15.8	16
Sunshine (h)	1,097	9.0	0.0	3.2	4.1
Evaporation (mm)	1,033	9.9	0.2	3.0	2.9
Wind run (km)	12,461	80.4	5.6	37	47

Figure 5-4 shows monthly total rainfall at Anawe in 2018 against long-term monthly means. Annual rainfall in 2018 was 3,683 mm on 315 wet days against a long-term mean annual total of 3,769 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.

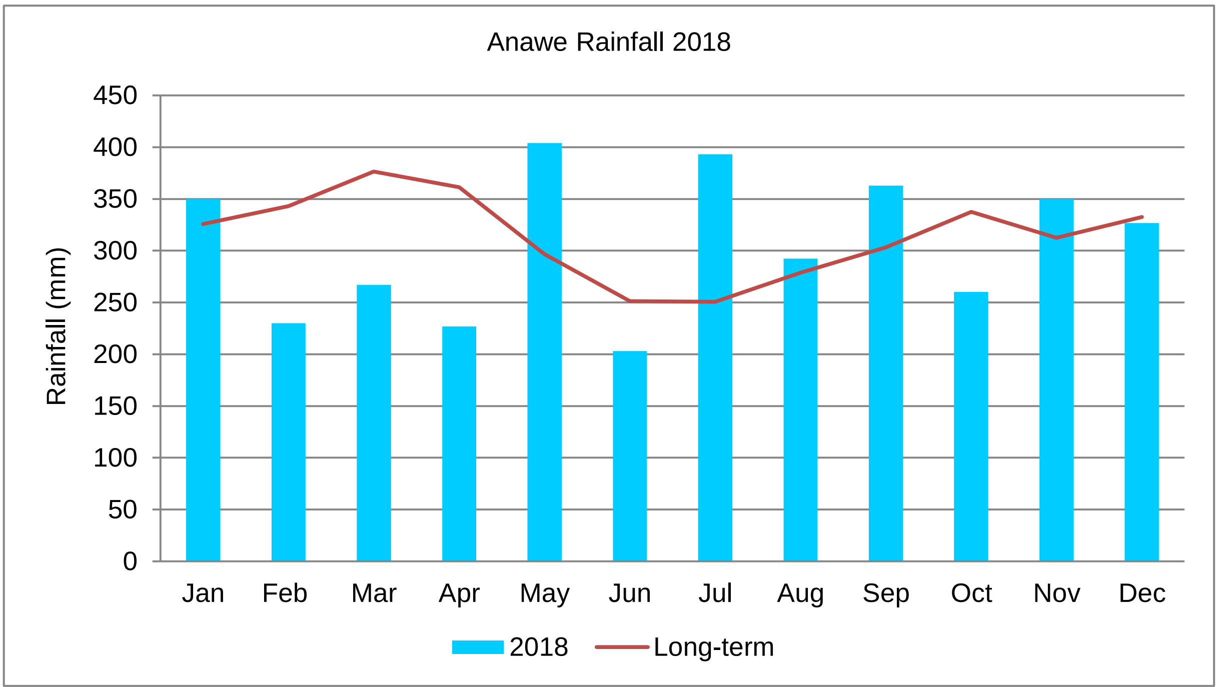


Figure 5-4 Monthly rainfall at Anawe Plant site during 2018 compared to long-term monthly means

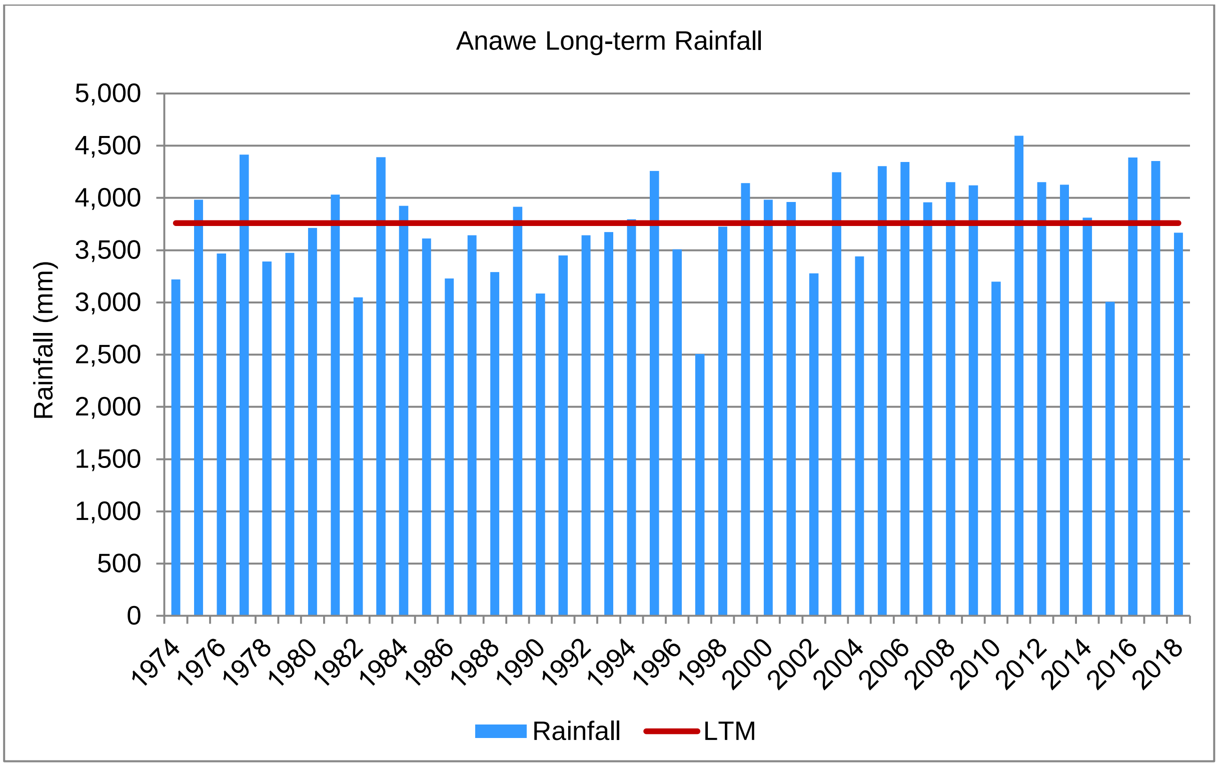


Figure 5-5 Comparison of annual rainfall at Anawe Plant site with long-term mean 1974 - 2018

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 4,292 mm on 318 wet days. The long-term mean annual total was 4040 mm. Figure 5-7 shows the historical annual totals.

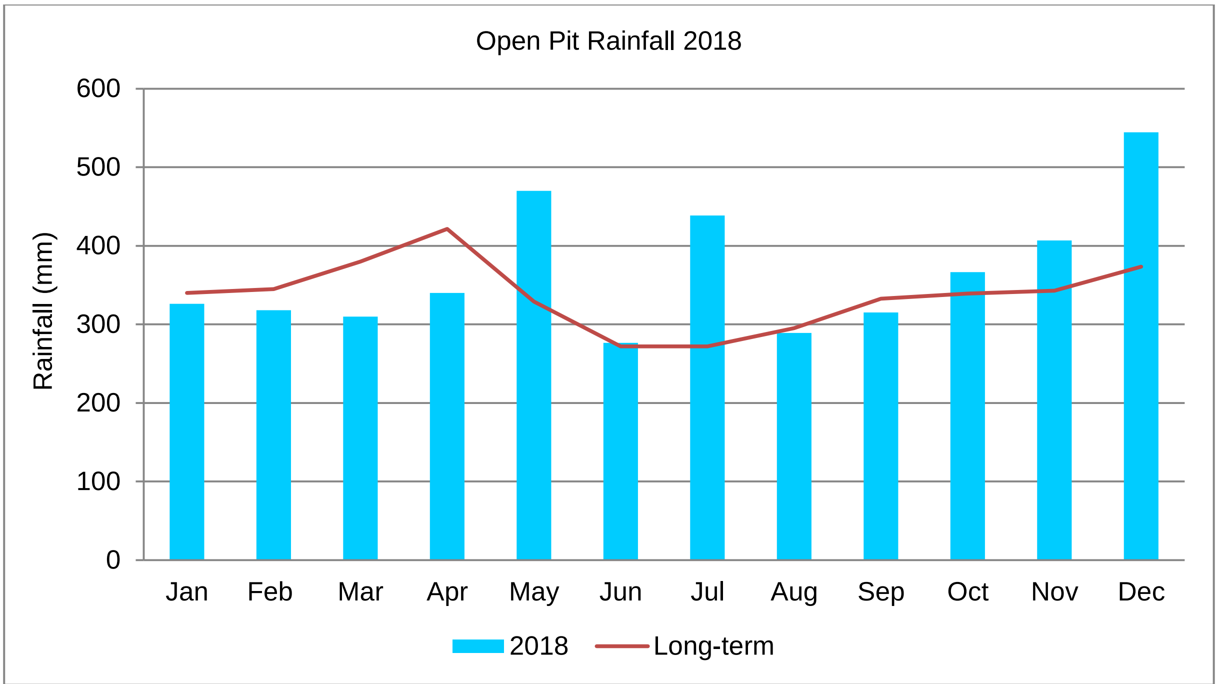


Figure 5-6 Rainfall at the Open Pit during 2018 compared to long-term monthly means

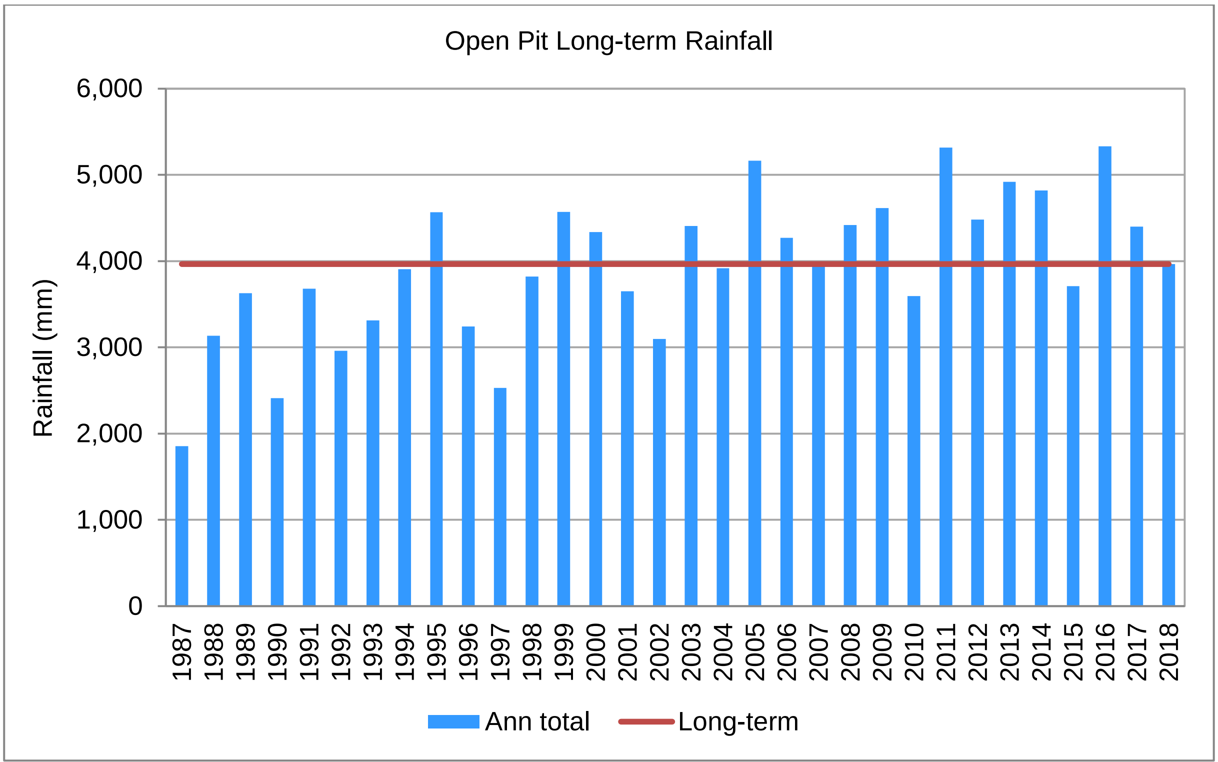


Figure 5-7 Annual rainfall at the Open Pit 1987–2018

5.1.3.3 Waile Creek

Figure 5-8 shows rainfall at Waile Dam during 2018 compared to long-term monthly means. It should be noted that records for March – September were affected due to infrequent visits to the site as a result of community issues and logger failure. Rainfall records for the affected months have been reconstructed by calculating the average ratio of rainfall in unaffected months against the long term means, and applying this factor to the long term mean of the affected months. This is considered a reasonable approach to providing a best estimate of monthly rainfall in affected months.

Annual recorded rainfall was 2,880mm compared to the long-term mean annual total was 2,919 mm.

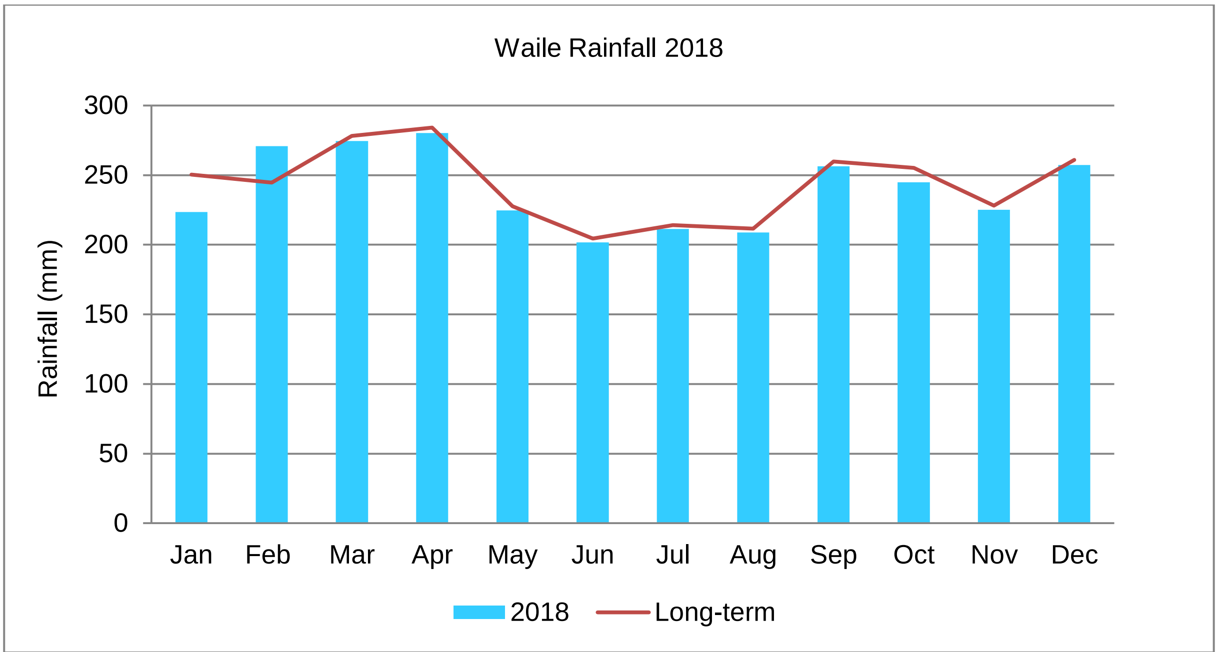


Figure 5-8 Rainfall at Waile Dam during 2018 compared to long-term monthly means

5.1.3.4 Pongema

Figure 5-9 shows rainfall recorded at Suyan Camp during 2018 against long-term monthly means. Annual rainfall was 3,666 mm which occurred on 310 wet days. The long-term mean annual total was 3,769mm.

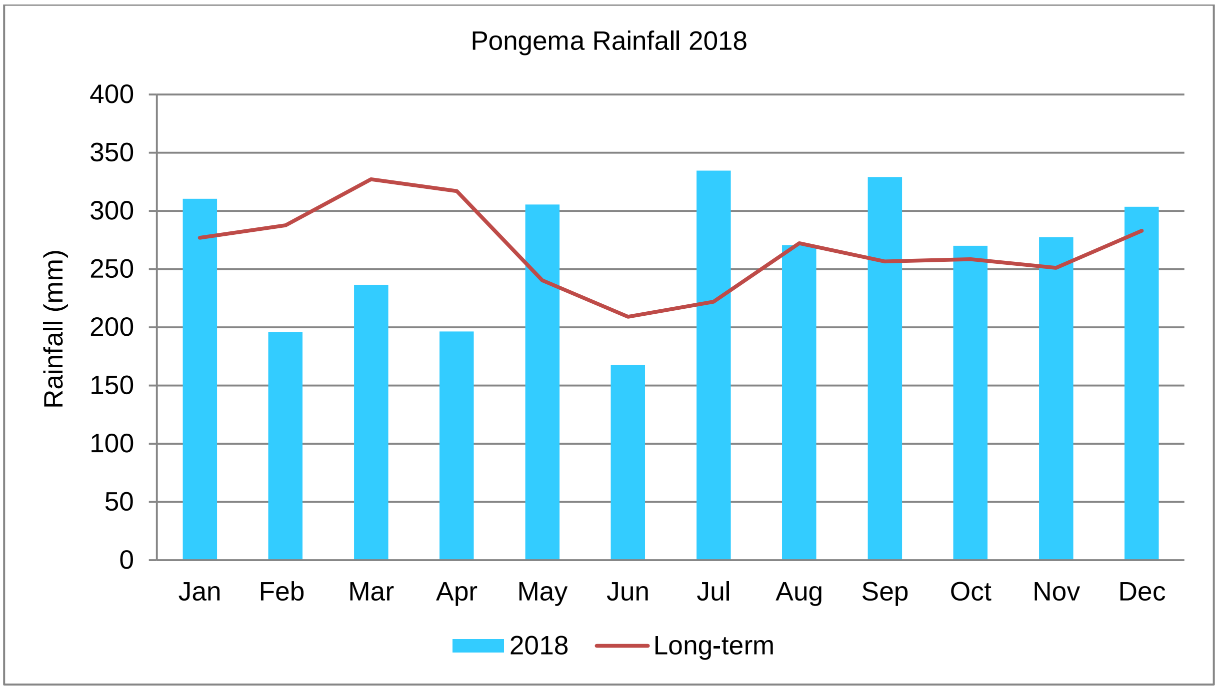


Figure 5-9 Rainfall at Suyan Camp during 2018 compared to long-term monthly means

5.1.3.5 SG2

Figure 5-10 shows available rainfall data at SG2 (Lagaip River) during the year plotted against long-term monthly means. Annual rainfall was 2,991 mm on 295 wet days. The long-term mean annual total was 2,540 mm.

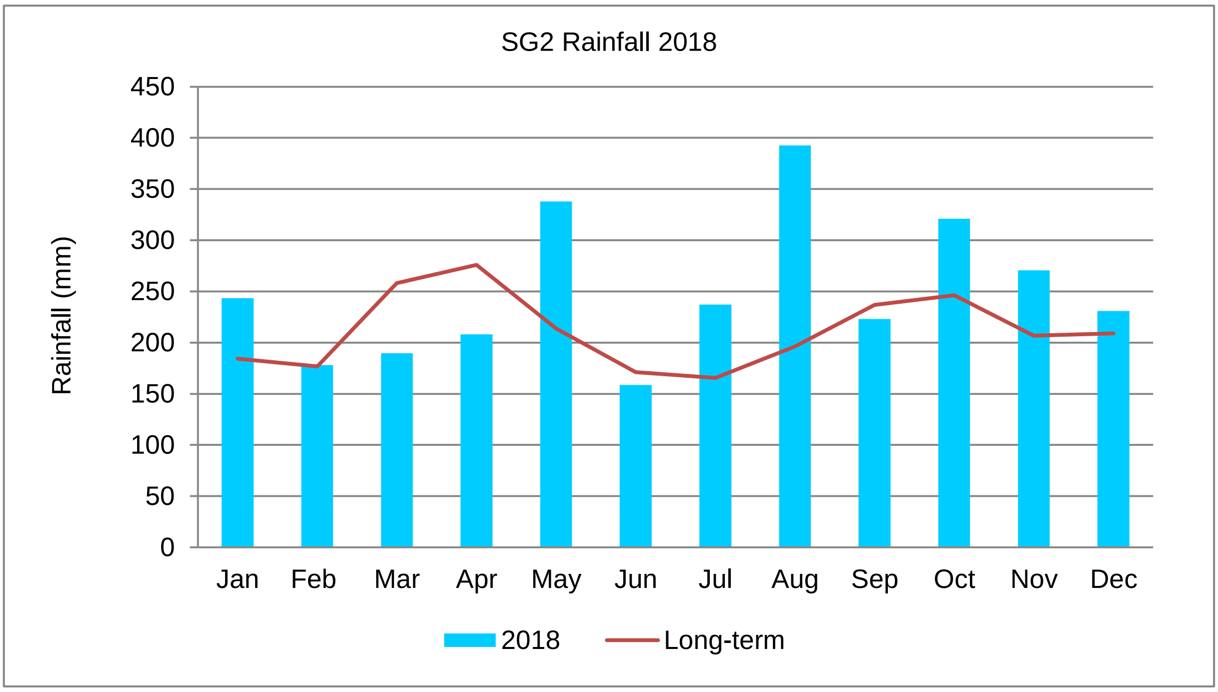


Figure 5-10 Rainfall at SG2 during 2018 compared to long-term monthly means

5.1.3.6 Ok Om

Figure 5-11 shows rainfall at Ok Om during 2018 against long-term monthly means. Data were reconstructed for Jan – Apr by calculating the average ratio of unaffected months against the long term mean and applying that factor to long term mean for the affected months.

The total rainfall recorded was 2,317 mm, compared to a long term mean of 2,228.

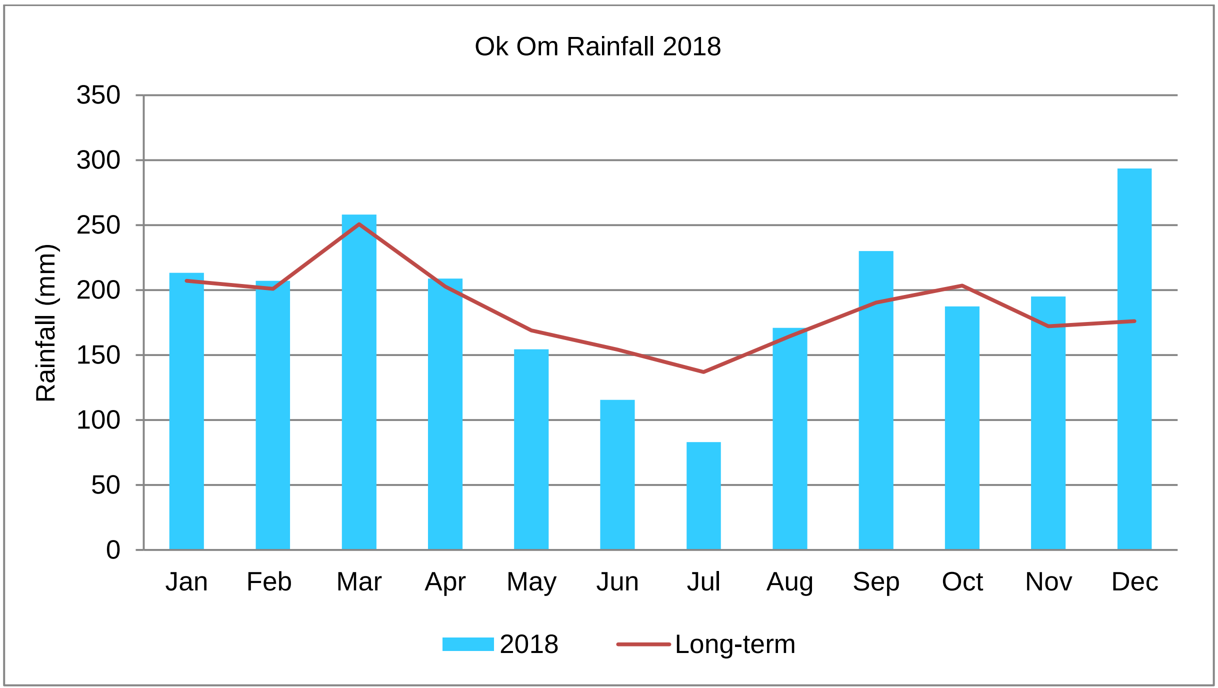


Figure 5-11 Rainfall at Ok Om during 2018 compared to long-term monthly means

5.1.3.7 SG3 (compliance monitoring site)

Figure 5-12 shows rainfall at the SG3 compliance site during 2018 against long-term monthly means. Annual rainfall of 1,605 mm fell on 215 wet days. The long-term mean annual total was 1,760 mm.

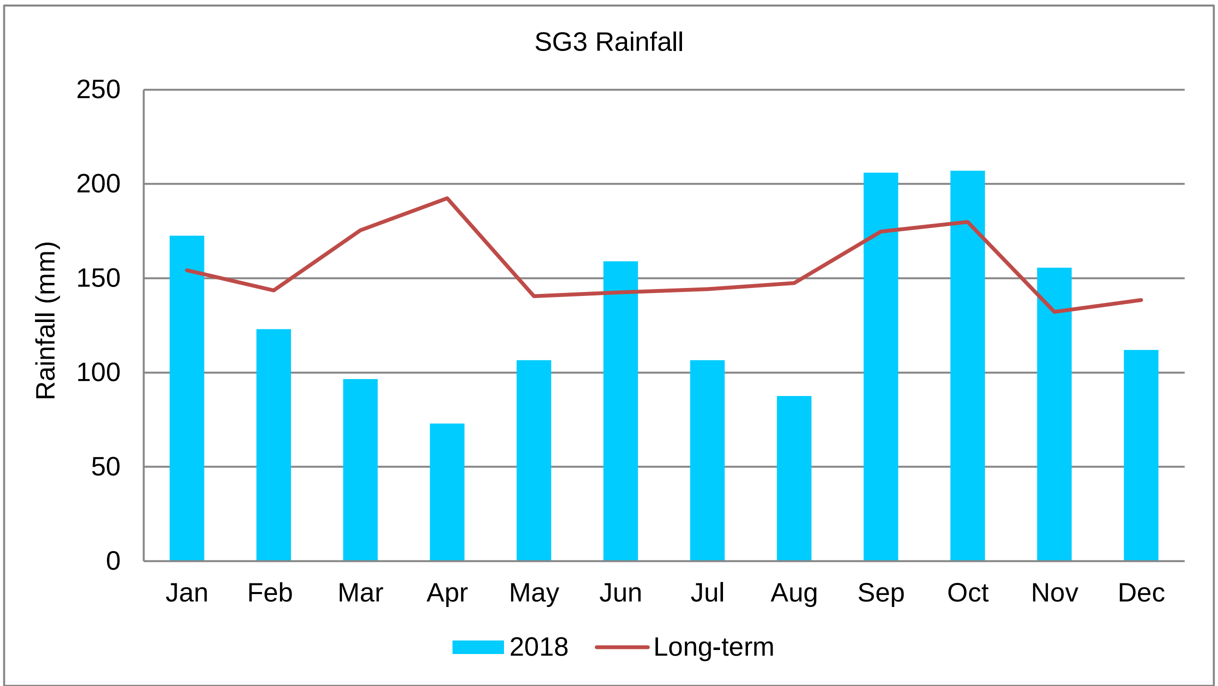


Figure 5-12 Rainfall at SG3 during 2018 compared to long-term monthly means

5.1.3.8 SG4

Figure 5-13 shows rainfall at SG4 in 2018 against long-term monthly means. Annual rainfall of 3,909 mm fell on 251 wet days. The long-term mean annual total is 3,631 mm.

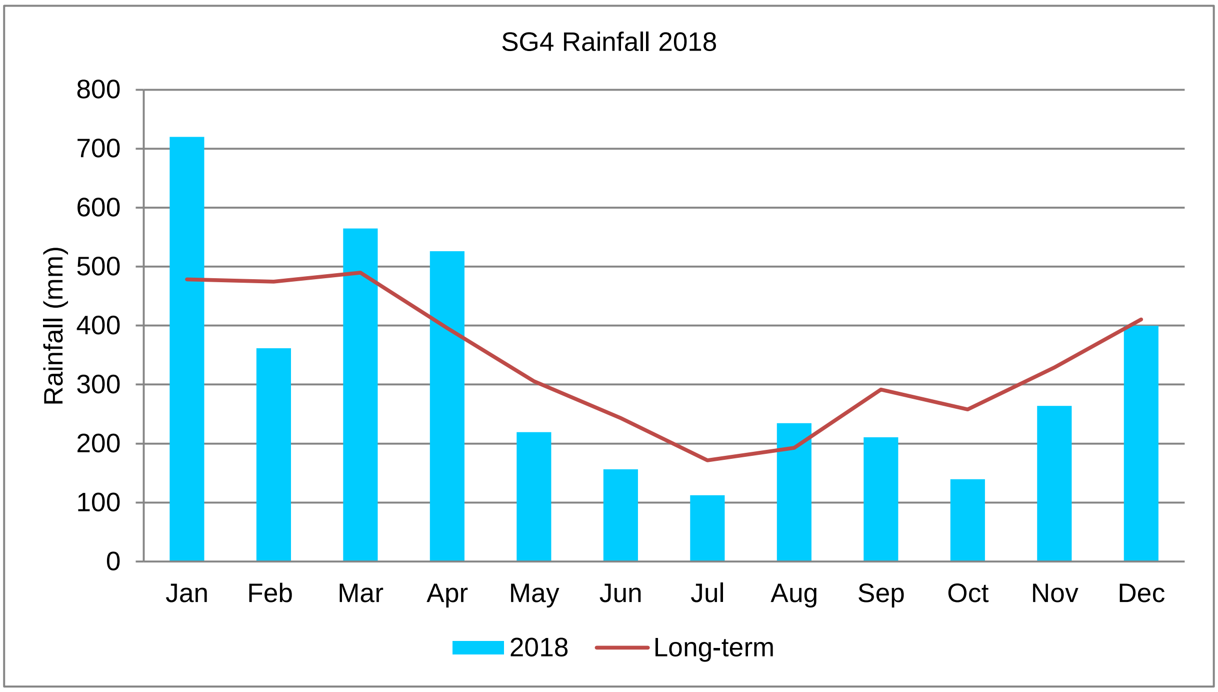


Figure 5-13 Rainfall at SG4 during 2018 compared to long-term monthly means

5.1.3.9 SG5

Figure 5-14 shows rainfall at SG5 during the year against long-term monthly means. Annual rainfall of 2, 826 mm fell on 265 wet days. The long-term mean annual total was 2,360 mm.

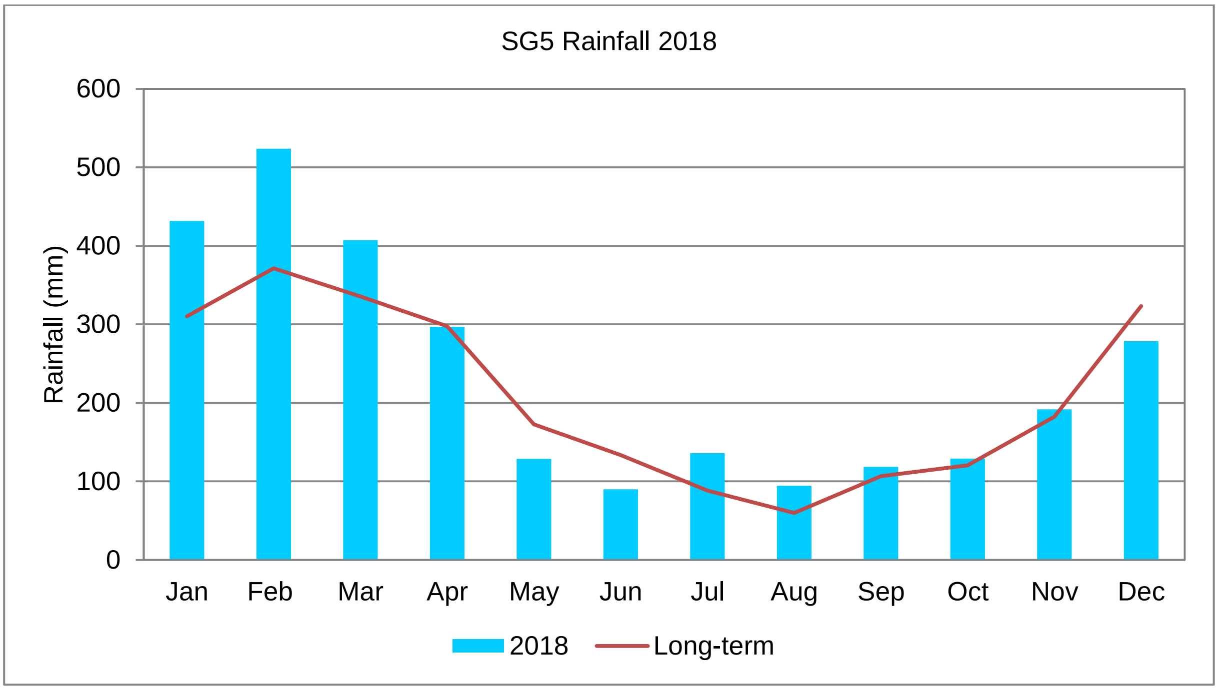


Figure 5-14 Rainfall at SG5 during 2018 compared to long-term monthly means

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 above average in the upper catchment sites of Kogai at SAG Mill and Kogai at the culvert because of the slightly higher than average rainfall recorded around mine site. Actual values could not be calculated for Kogai sagmill and Yunarilama due to stations not being operational throughout the year. About 35% above average flows were recorded in the middle region, at SG2. Flows at SG4 were 22% above average and 2% above average for SG5 at the lower regions.

It should be noted that although100% data recovery was achieved from SG3, 5 months of data form April to August are considered to be of poor quality and not fully representative of actual flows. The sensor was affected by high siltation effects and visits to the site were limited partially due to the earthquake recovery at the mine site. There has been no attempt to re-construct the flow data for SG3, but rather the data have been used as recovered. However, this has had implications on sediment transport estimates and is discussed further in Section 7.2.

A summary of annual river flow data are show in in Table 5-2, total annual river flows at SG2, SG3, SG4 and SG5 from 1999 – 2018 are shown in Figure 5-15.

Table 5-2 Summary of flows in m^3/s for riverine stations in 2018

Station	Days lost 2018	Mean	Min	Long-term Mean
Kogai @ SAG Mill	NR	NR	NR	NR
Kogai @ Culvert	102	2.3	0.1	1.7
Portal @ Yunarilama	NR	NR	NR	NR
Lagaip @ SG2	0	300	143	222
Ok Om	30	189	34.2	141
Strickland @ SG3	0*	534	95.3	759
Strickland @ SG4	0	3,192	984	2,615
Strickland @ SG5	0	3,327	2,135	3,270

NR – No record

*SG3 flow record for 2018 was impacted by poor quality data recovery from April - August

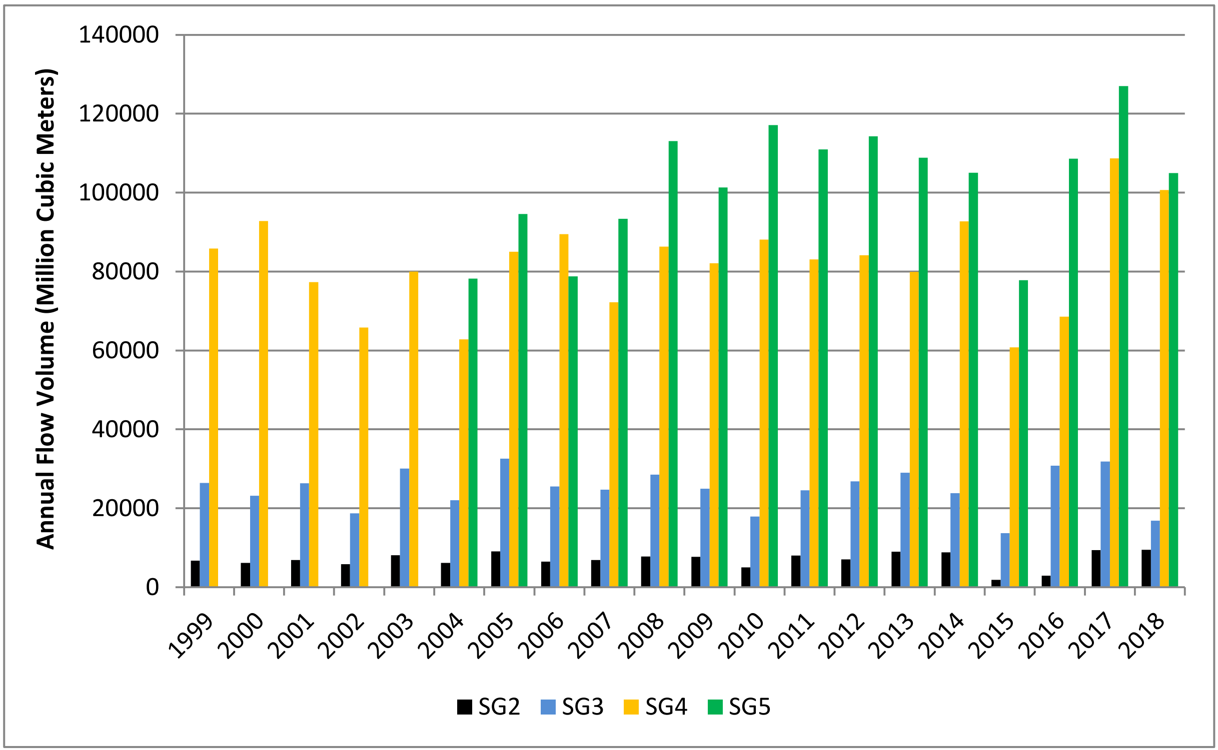


Figure 5-15 Mean annual flow volumes for the main river gauging stations in 2018

5.2.2 SG3 (compliance monitoring site)

Figure 5-16 shows the daily total flows for the year at SG3 while Figure 5-17 shows total monthly flows compared to long-term monthly averages. The recorded data collected between April and August were considered to be of poor or suspect quality due to siltation and instrument malfunctions.

Therefore, the recorded flows between April and August 2018 at SG3 were lower than the anticipated actual flows. This is highlighted by the fact that for these months, the combined flow from SG2 and Ok Om, both upstream of SG3, exceeded the flow recorded at SG3.

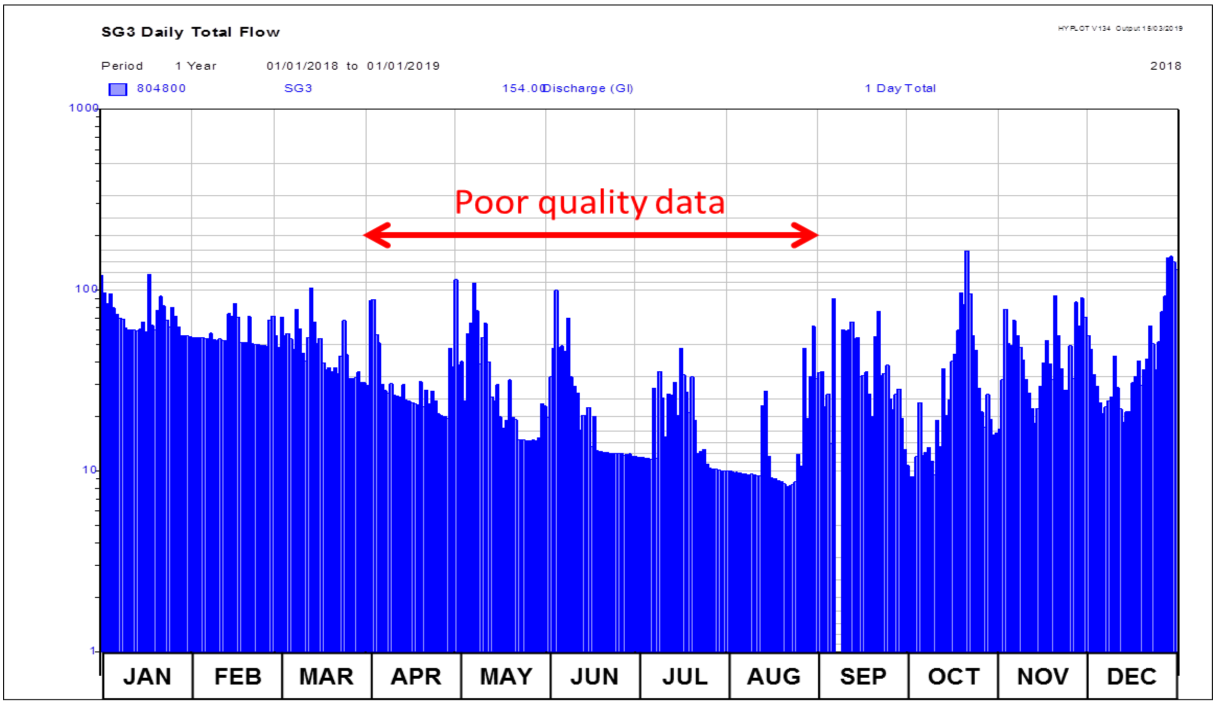
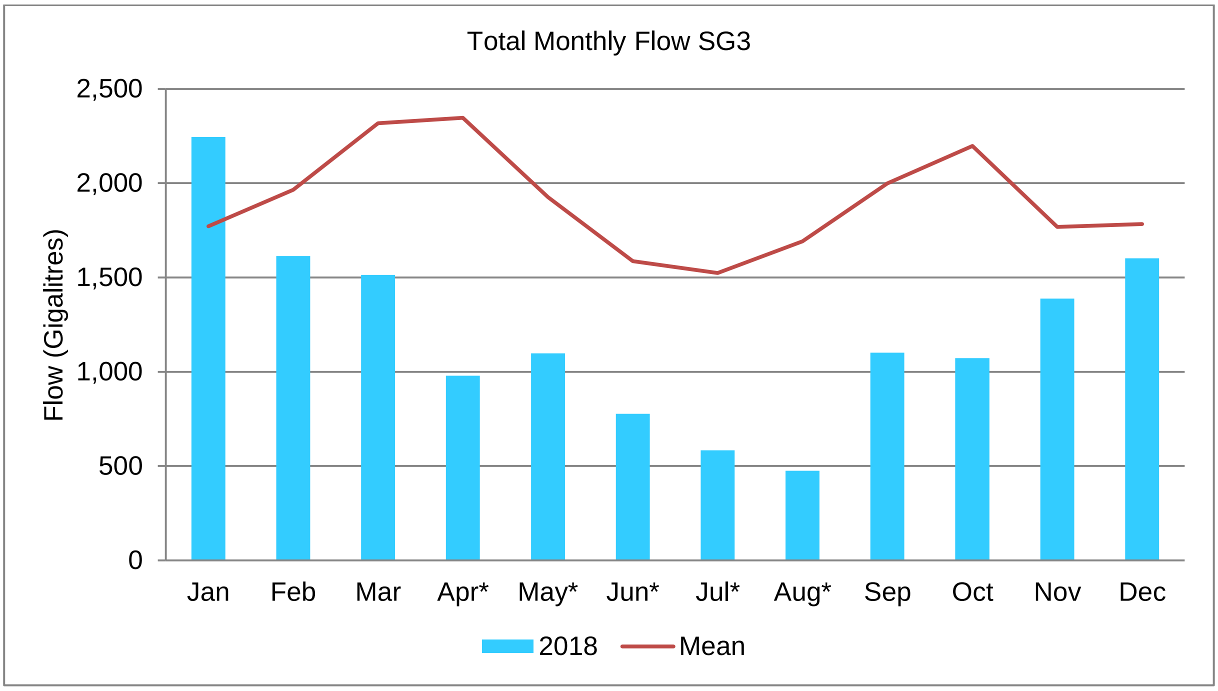


Figure 5-16 Total daily flow (GL) at SG3 for 2018



* Poor quality data not representative of actual flows

Figure 5-17 Total monthly flow (GL) at SG3 during 2018 compared to long-term monthly means

5.3 2018 Earthquake

The magnitude 7.5 earthquake that occurred on the 26th February 2018 in the Hela province resulted in a number of landslides occurring in the surrounding valleys, causing an influx of sediment to the rivers that were directly affected, as well as throughout the river system downstream.

Three of the catchments affected by these landslides were the Baia, Nomad and Rintoul River catchments. The Baia River is one of the PJV lower river reference sites, and all three rivers flow into the Strickland River in the vicinity of Bebelubi and SG4 lower river test sites.

Figure 5-18 shows the location of the epicentre of the earthquake and the locations of the Baia, Nomad and Rintoul Rivers, and the Bebelubi and SG4 test sites on the Strickland River. The Tomu River which hosts the second of the PJV lower river reference sites was not affected.

In the days and weeks following the earthquake PJV received reports from communities in Baia and Nomad regions of high sediment loads, debris and fish kills within the rivers. PJV environment staff visited the sites between 24th and 26th of March to investigate the event. The investigation included visual ground and aerial inspections and sampling and analysis of water and sediment quality.

The results showed that the Baia, Nomad and Rintoul Rivers and the Strickland River at SG4 exhibited elevated concentrations of TSS and total metals in water following the earthquake. Sediment quality was not affected. Longitudinal water quality results of TSS, cadmium, copper and zinc concentrations from Strickland River at SG3 upstream to SG5 downstream are presented in Figure 5-19 to Figure 5-22, results from the Strickland River at SG3 are provided as an upstream reference.

Monitoring data for TSS, cadmium, copper and zinc at Baia are presented in Figure 5-23 to Figure 5-26 and show a spike following the earthquake and then return to pre-earthquake levels. Monitoring showed that the influence of the earthquake on these locations was not prolonged and water quality had returned to pre-earthquake conditions by April.

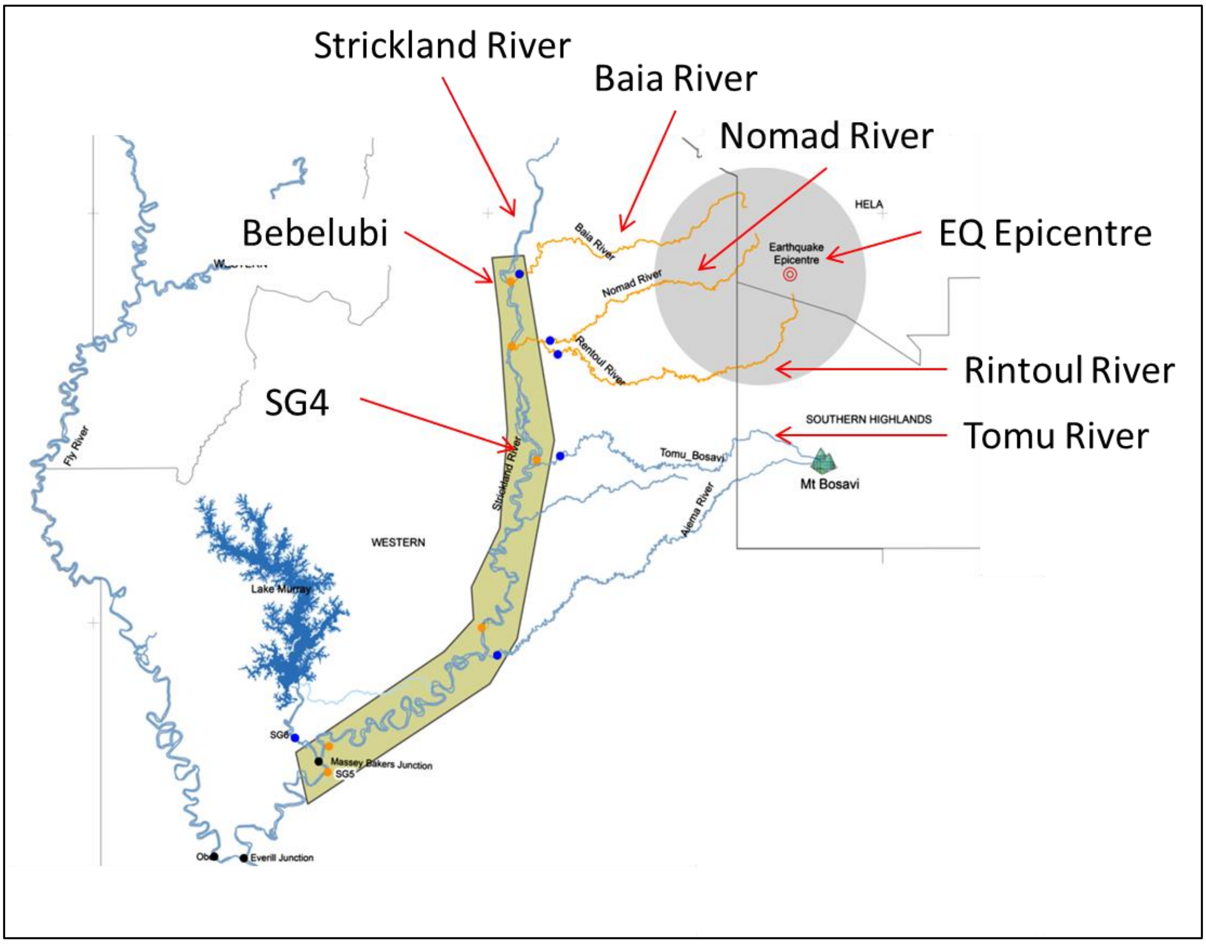


Figure 5-18 Location of the earthquake epicentre relative to lower river reference and test sites

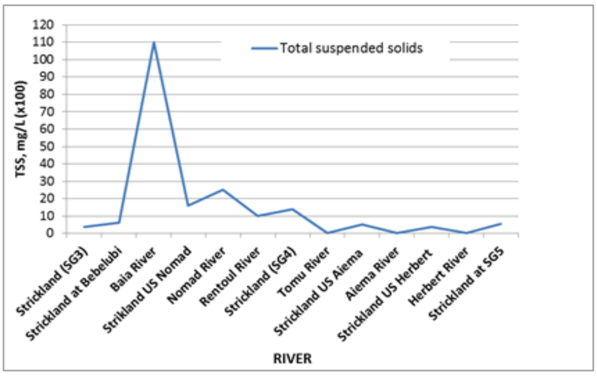


Figure 5-19 TSS concentrations from the post-earthquake investigation on the lower Strickland River

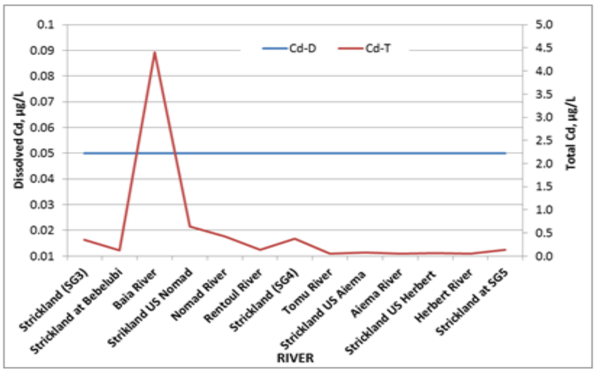


Figure 5-20 Cadmium concentrations from the post-earthquake investigation on the lower Strickland River

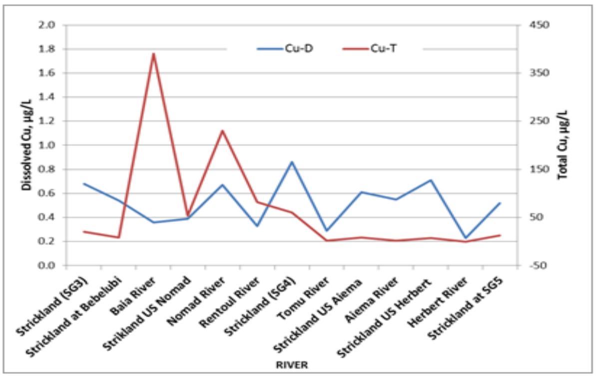


Figure 5-21 Copper concentrations from the post-earthquake investigation on the lower Strickland River

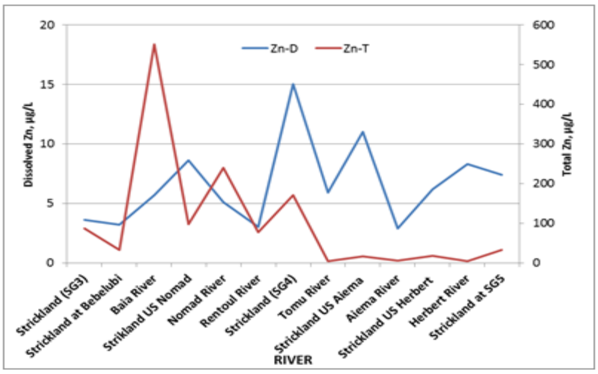


Figure 5-22 Zinc concentrations from the post-earthquake investigation on the lower Strickland River

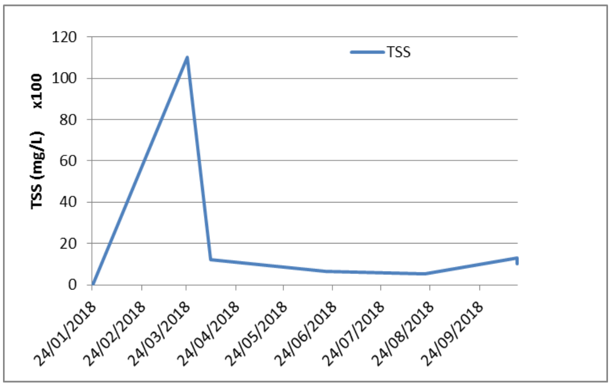


Figure 5-23 Baia 2018 TSS concentrations 2018

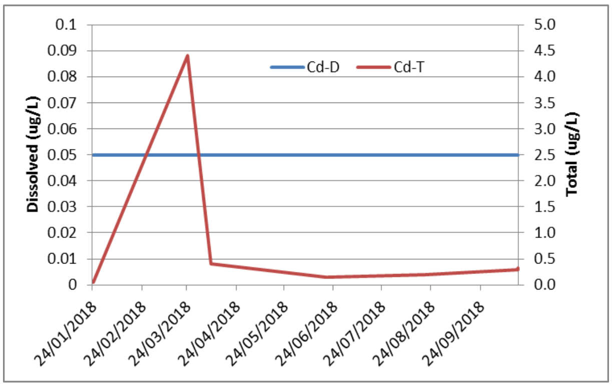


Figure 5-24 Baia 2018 monthly Cadmium concentrations 2018

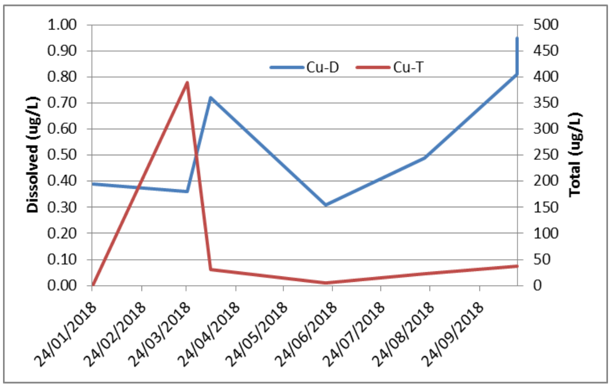


Figure 5-25 Baia 2018 monthly Copper concentrations 2018

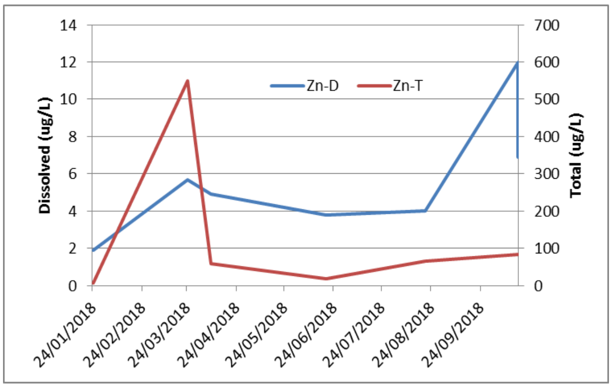


Figure 5-26 Baia 2018 monthly Zinc concentrations 2018

5.4 Background Water Quality and Trigger Values

This section presents the water quality data collected from test sites prior to mining operations commencing (baseline data), from reference sites during the previous 24-months and the guidelines values for 95% species protection from ANZECC/ARMCANZ (2000). In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2018 TV for use in the water quality risk assessment presented in Section 7.4. The sites are grouped into regions; Local Sites, Upper River, Lower River, Lake Murray and Off-River Water Bodies (ORWBs).

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 best represent 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.

5.4.1 Local reference sites

Local sites comprise the small highland creeks within the Porgera River catchment that are not affected by the mining operation. 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 5-3 and median water quality data for 2018 are presented in Table 5-4 and shown in Figure 5-27 to Figure 5-56. The long-term trends from 2009-2018 are shown in Table 5-5 and as median data in Figure 5-27 to Figure 5-56.

Table 5-3 Local reference site monitoring locations

Site Type	Site Name
Local sites	Aipulungu River upstream of lime plant and quarry
	Waile Dam
	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 catchment (Kaiya upstream of Anjolek) and Aipulungu River. Community issues prevented safe access to the Kaiya River upstream of Anjolek erodible dump and this site was not sampled in 2018. 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. Although none of the concentrations exceeded the upper river TV (Table 5-4), elevated concentrations of some total metals were present throughout the record at some sites.

A summary of the trends between 2009 and 2018 is shown in Table 5-5, and details of the statistical analysis for long-term trends are provided in Appendix C. The analysis showed that TSS at Aipulungu US Lime Quarry had increased over time; increased TSS in 2018 is most likely due to disturbance upstream during construction of the Aipulungu weir water intake. Dissolved zinc at each of the sites had also 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 5-57. All other parameters at all sites had either reduced or remained unchanged over the period.

Table 5-4 Local reference site water quality 2018 median values (µg/L except where shown)

Parameter	Aipulungu U/S Lime Plant	Waile Dam	Kaiya Riv U/S Anj Dump	Pongema
pH^	7.7	7.7	NS	8.1
WAD-CN*	0.2	0.2	NS	0.2
Sulfate*	1.0	1.5	NS	2.0
ALK-T**	93	84	NS	136
Hardness**	83	77	NS	135
TSS*	61	8.5	NS	27
Ag-D	0.01	0.01	NS	0.01
Ag-T	0.01	0.01	NS	0.03
As-D	0.2	0.1	NS	0.2
As-T	0.3	0.2	NS	0.3
Cd-D	0.05	0.05	NS	0.05
Cd-T	0.05	0.05	NS	0.05
Cr-D	0.23	0.3	NS	0.2
Cr-T	1.5	0.3	NS	0.5
Cu-D	0.7	0.5	NS	0.4
Cu-T	1.6	0.6	NS	0.8
Fe-D	32	51	NS	17
Fe-T	960	170	NS	350
Hg-D	0.05	0.05	NS	0.05
Hg-T	0.05	0.05	NS	0.05
Ni-D	0.5	0.5	NS	0.5
Ni-T	2.3	0.5	NS	0.6
Pb-D	0.1	0.1	NS	0.1
Pb-T	0.6	0.1	NS	0.7
Se-D	0.2	0.2	NS	0.2
Se-T	0.2	0.2	NS	0.2
Zn-D	7.1	4.2	NS	7.8
Zn-T	5.0	6.5	NS	7.2

	> UpRiv TV

^std units, * mg/L, **mg $CaCO_3$/L, D = Dissolved fraction, T = Total NS – Not sampled

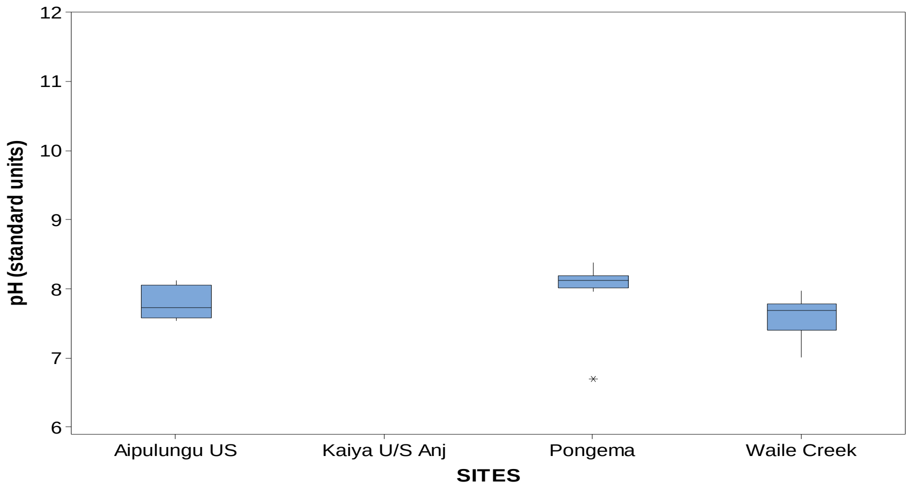


Figure 5-27 pH in local creek runoff 2018

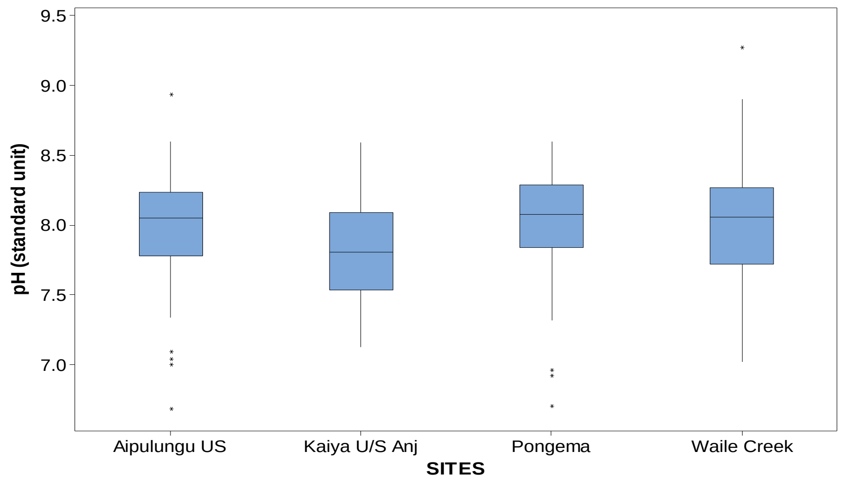


Figure 5-28 pH in local creek runoff 2009-2018

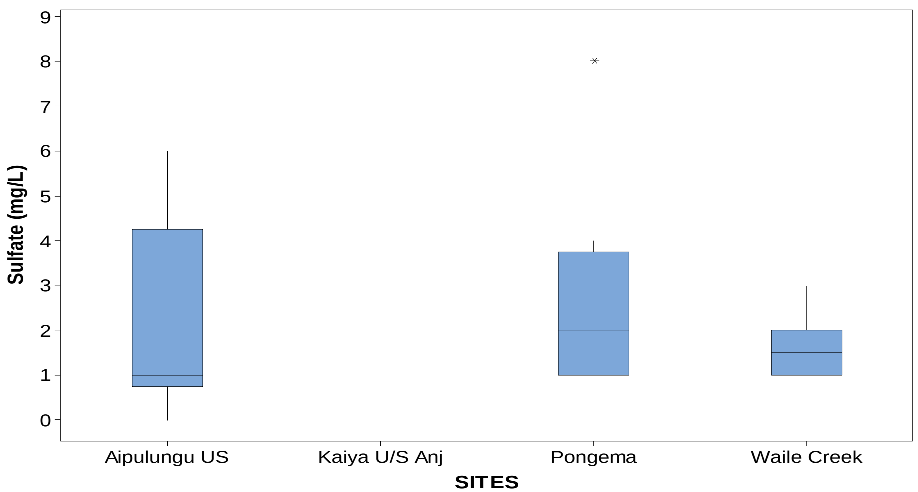


Figure 5-29 Sulfate in local creek runoff 2018

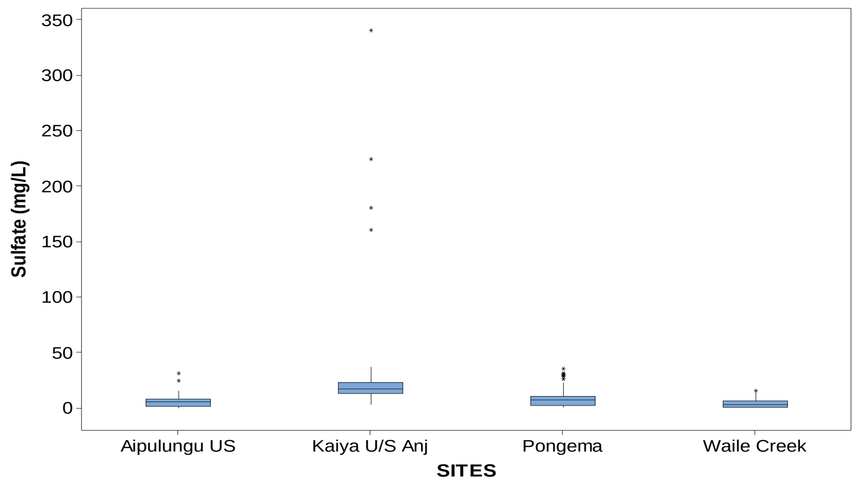


Figure 5-30 Sulfate in local creek runoff 2009-2018

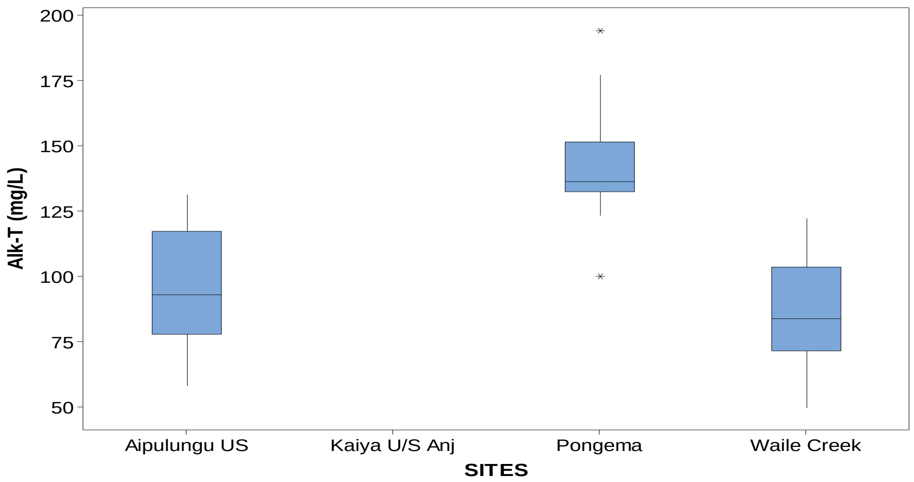


Figure 5-31 Alkalinity in local creek runoff 2018

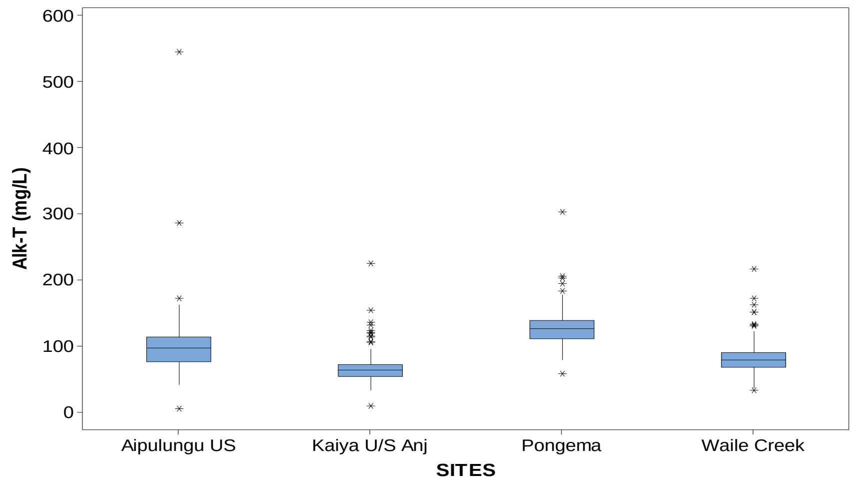


Figure 5-32 Alkalinity in local creek runoff 2009-2018

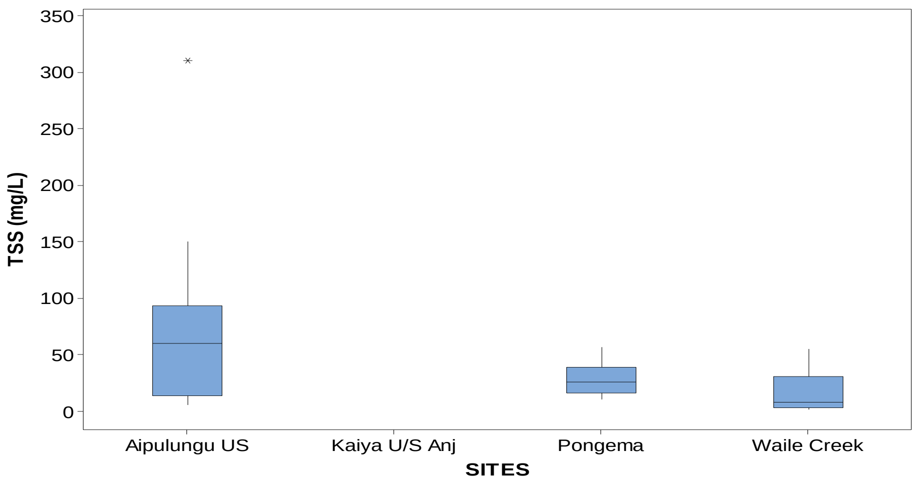


Figure 5-33 TSS in local creek runoff 2018

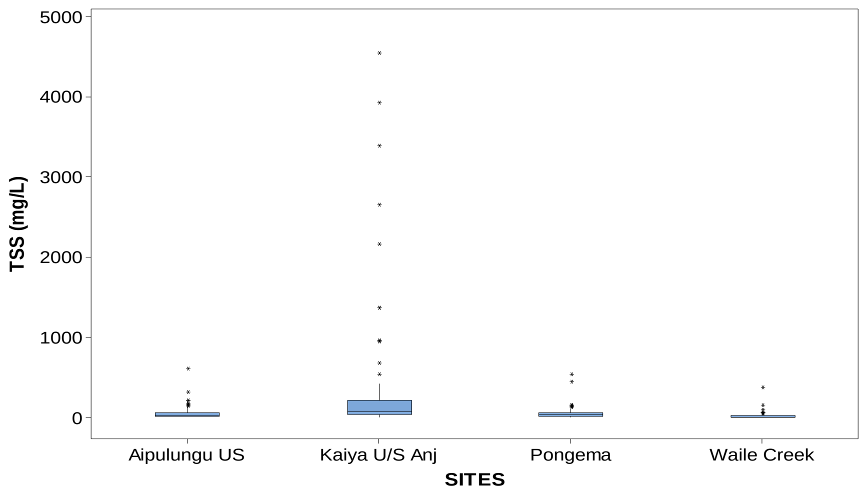


Figure 5-34 TSS in local creek runoff 2009-2018

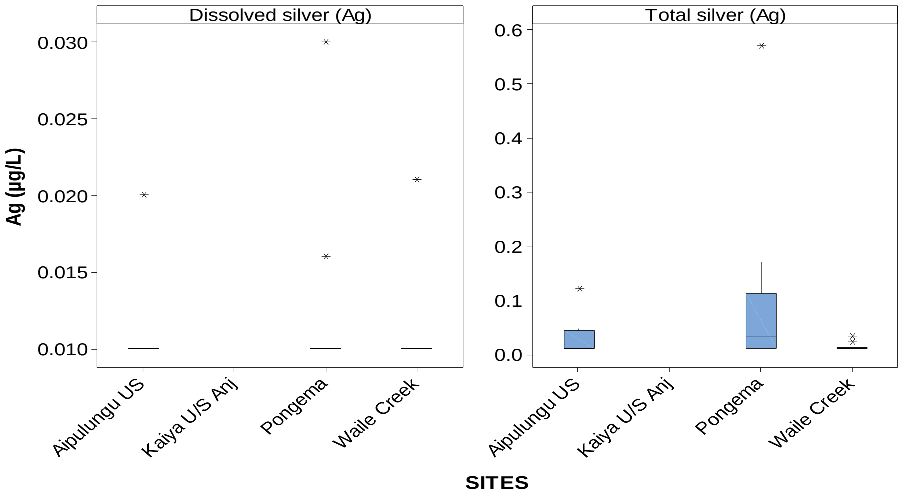


Figure 5-35 Dissolved and total silver in local creek runoff 2018

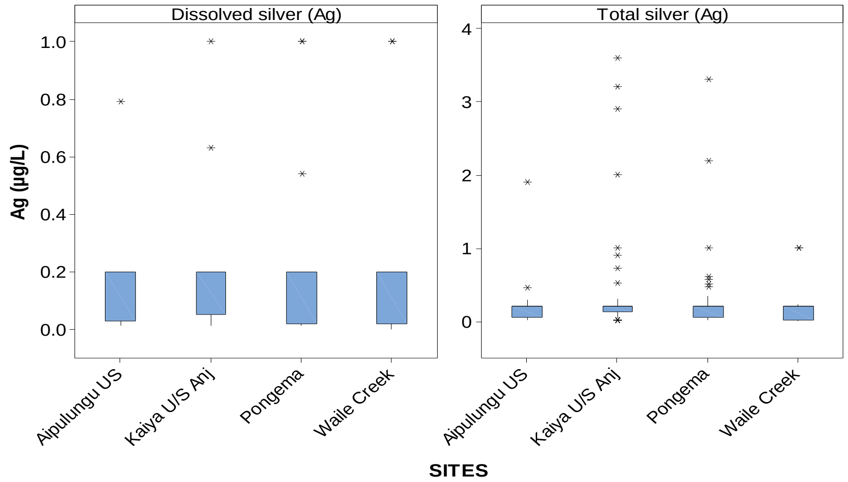


Figure 5-36 Dissolved and total silver in local creek runoff 2009-2018

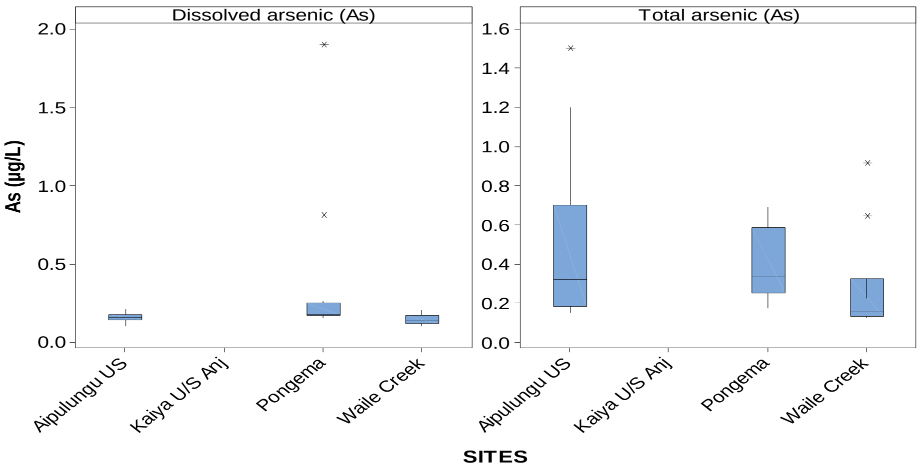


Figure 5-37 Dissolved and total arsenic in local creek runoff 2018

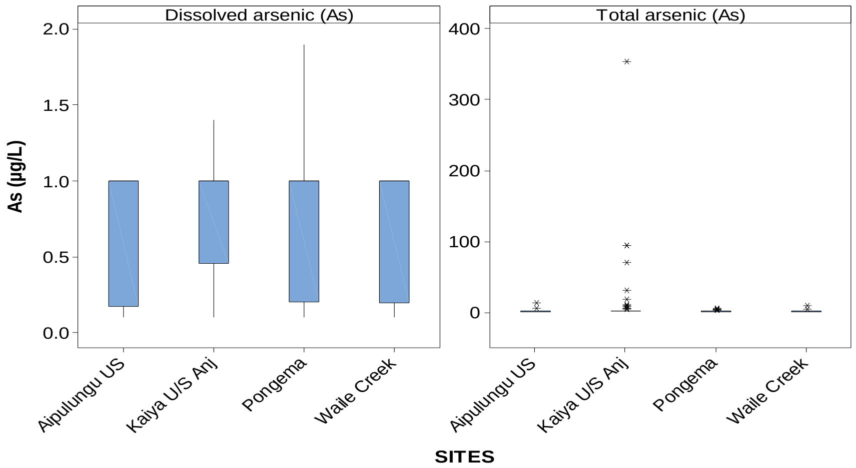


Figure 5-38 Dissolved and total arsenic in local creek runoff 2009-2018

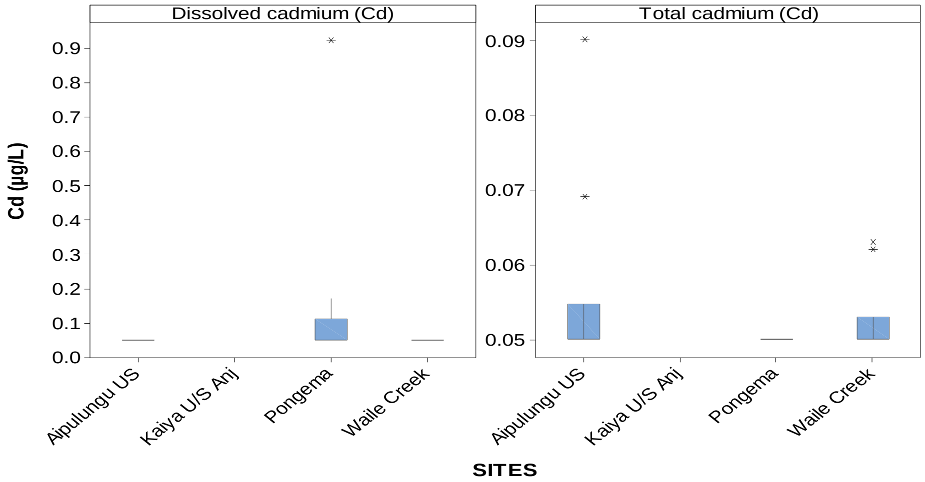


Figure 5-39 Dissolved and total cadmium in local creek runoff 2018

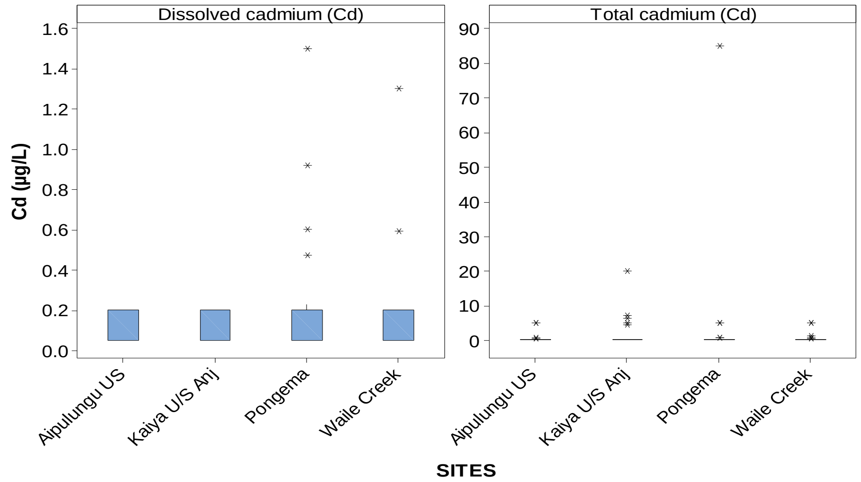


Figure 5-40 Dissolved and total cadmium in local creek runoff 2009-2018

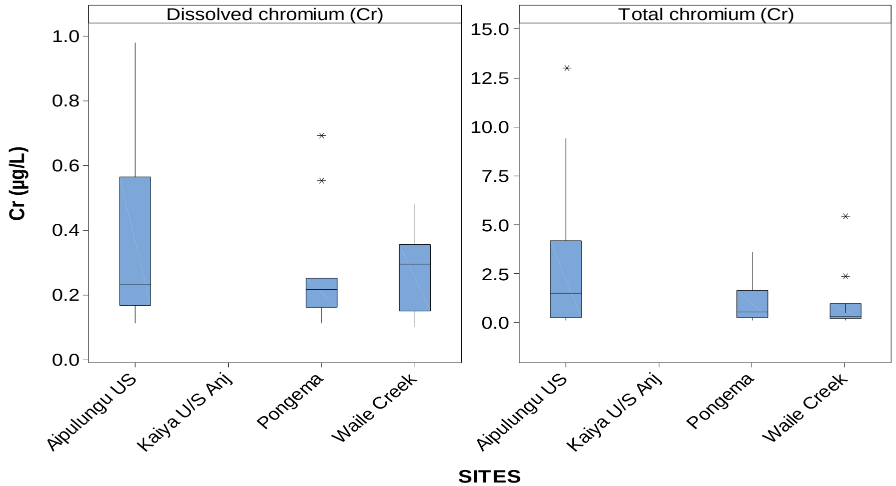


Figure 5-41 Dissolved and total chromium in local creek runoff 2018

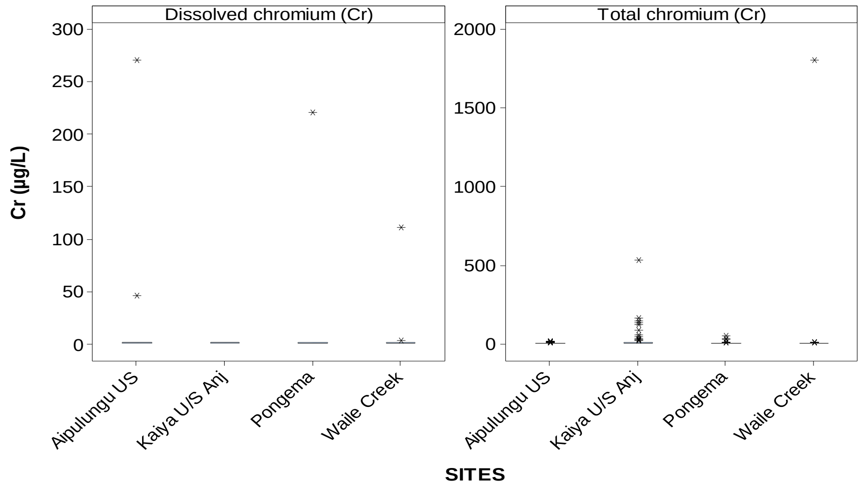


Figure 5-42 Dissolved and total chromium in local creek runoff 2009-2018

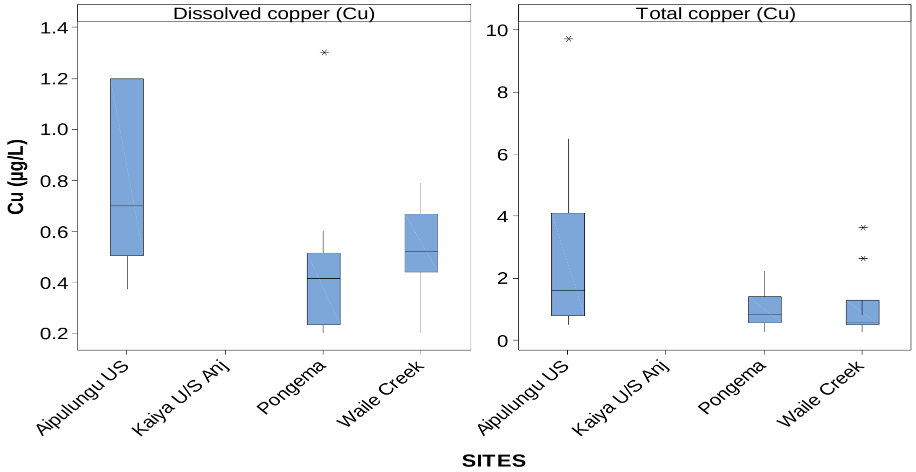


Figure 5-43 Dissolved and total copper in local creek runoff 2018

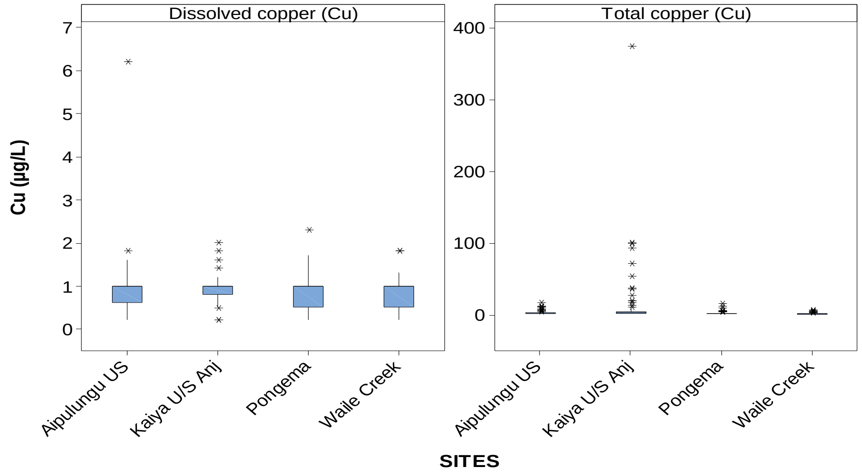


Figure 5-44 Dissolved and total copper in local creek runoff 2009-2018

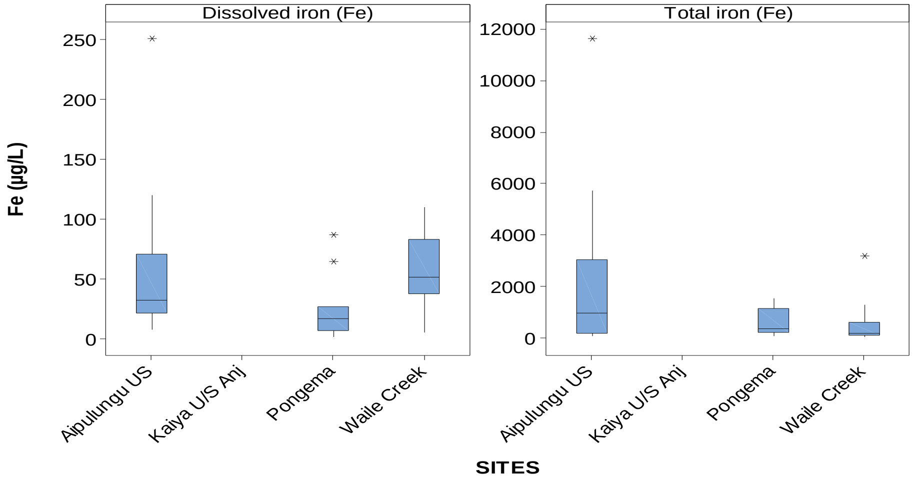


Figure 5-45 Dissolved and total iron in local creek runoff 2018

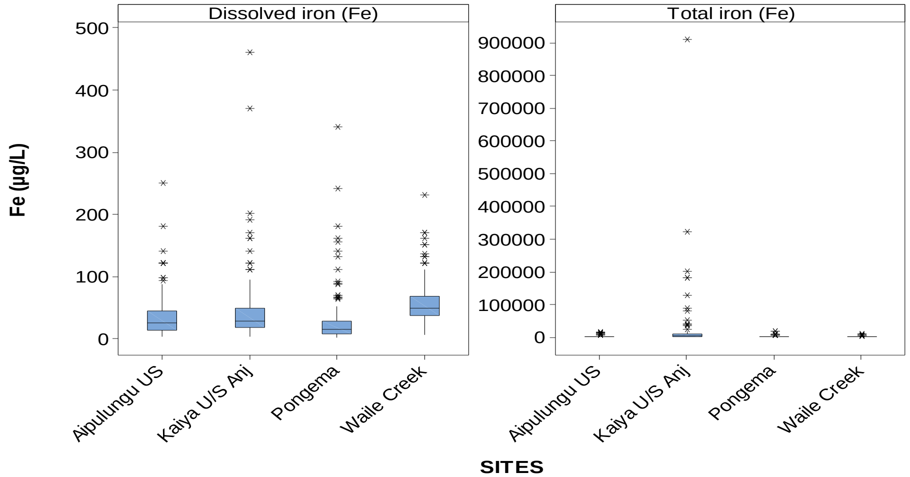


Figure 5-46 Dissolved and total iron in local creek runoff 2009-2018

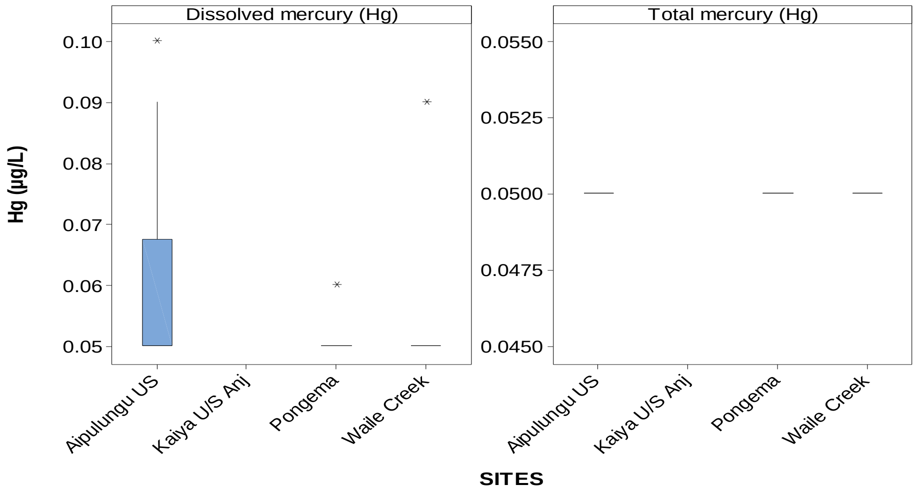


Figure 5-47 Dissolved and total mercury in local creek runoff 2018

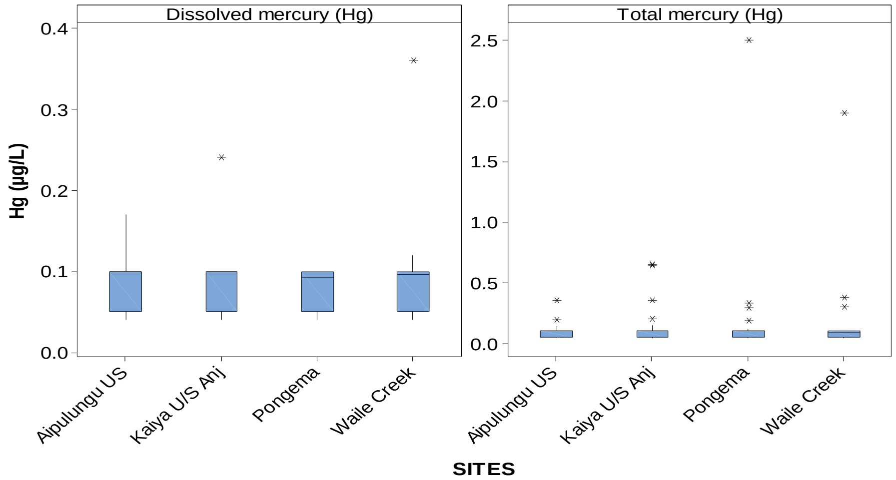


Figure 5-48 Dissolved and total mercury in local creek runoff 2009-2018

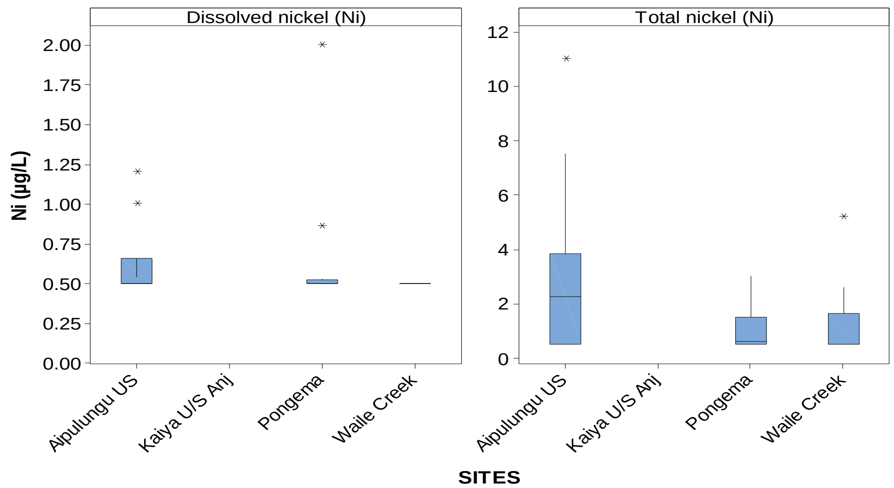


Figure 5-49 Dissolved and total nickel in local creek runoff 2018

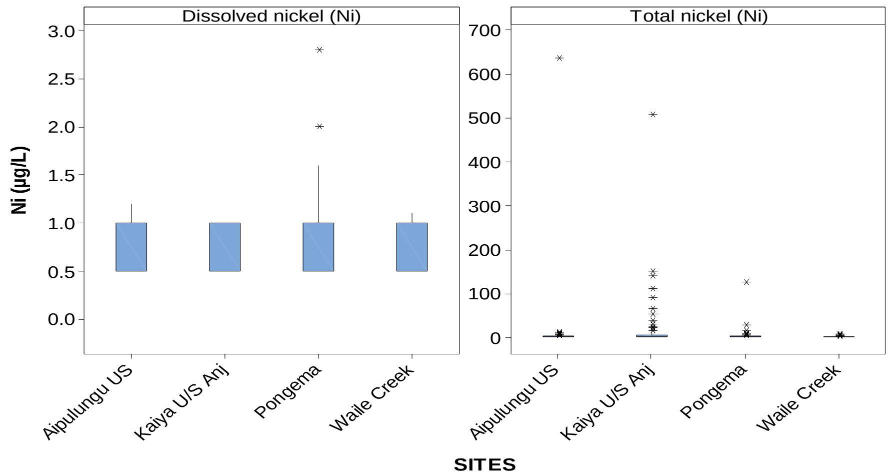


Figure 5-50 Dissolved and total nickel in local creek runoff 2009-2018

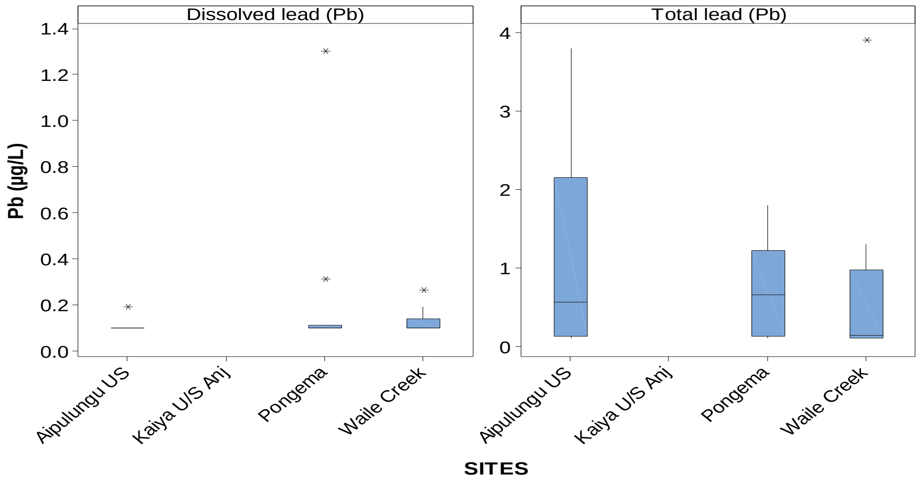


Figure 5-51 Dissolved and total lead in local creek runoff 2018

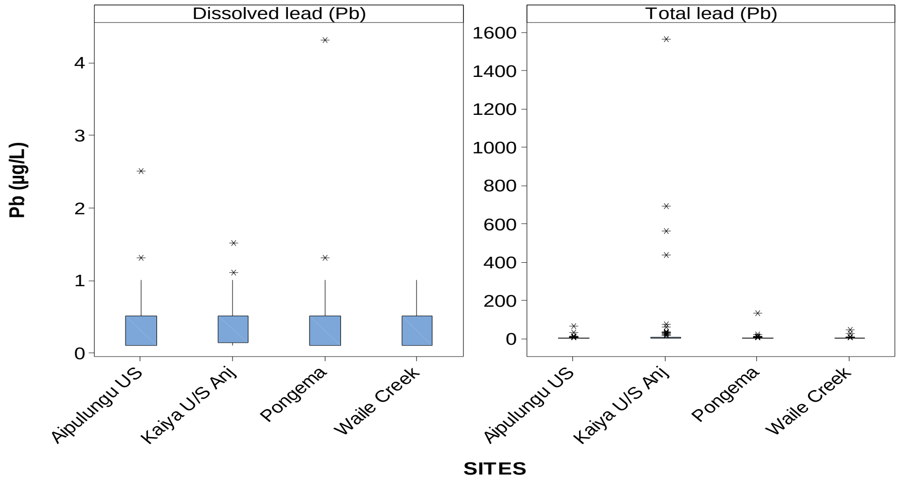


Figure 5-52 Dissolved and total lead in local creek runoff 2009-2018

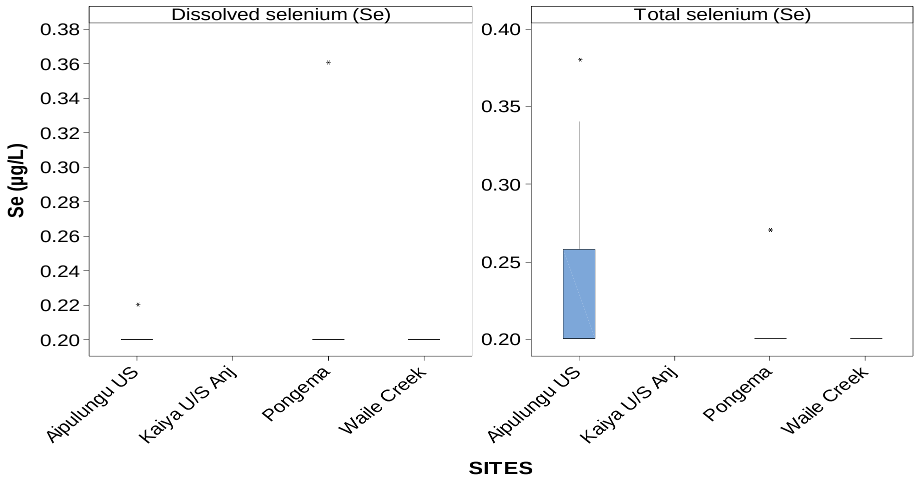


Figure 5-53 Dissolved and total selenium in local creek runoff 2018

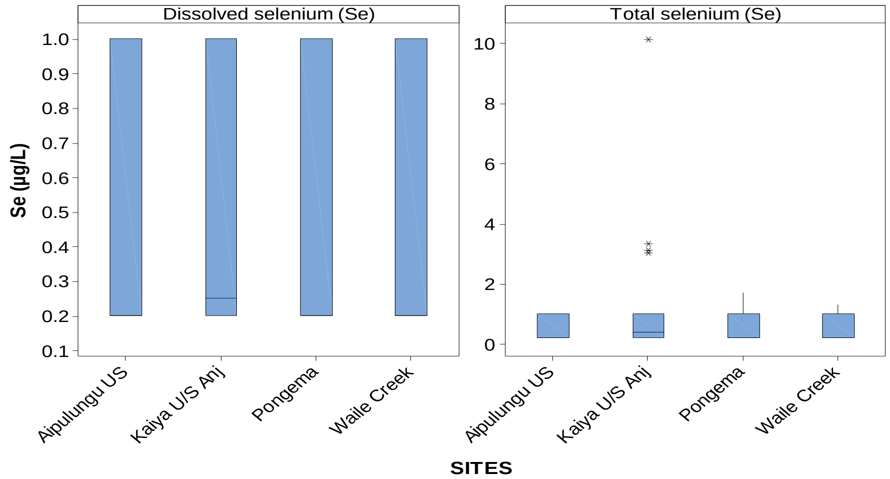


Figure 5-54 Dissolved and total selenium in local creek runoff 2009-2018

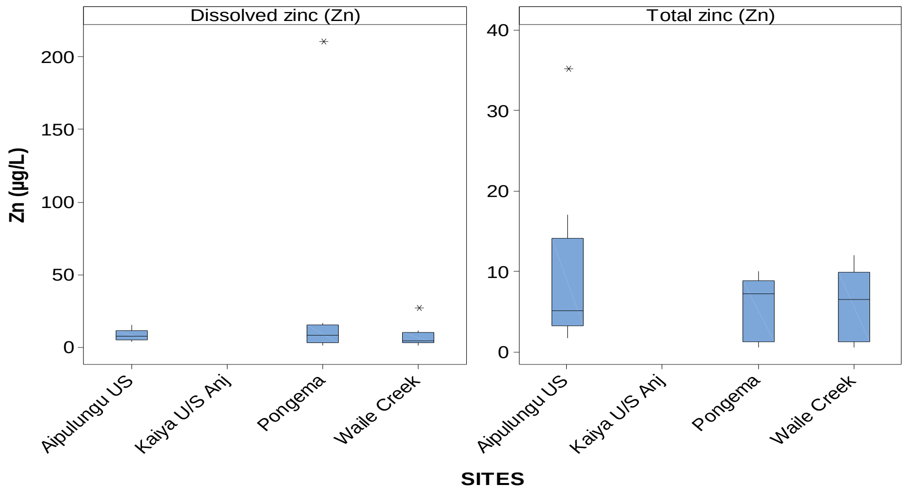


Figure 5-55 Dissolved and total zinc in local creek runoff 2018

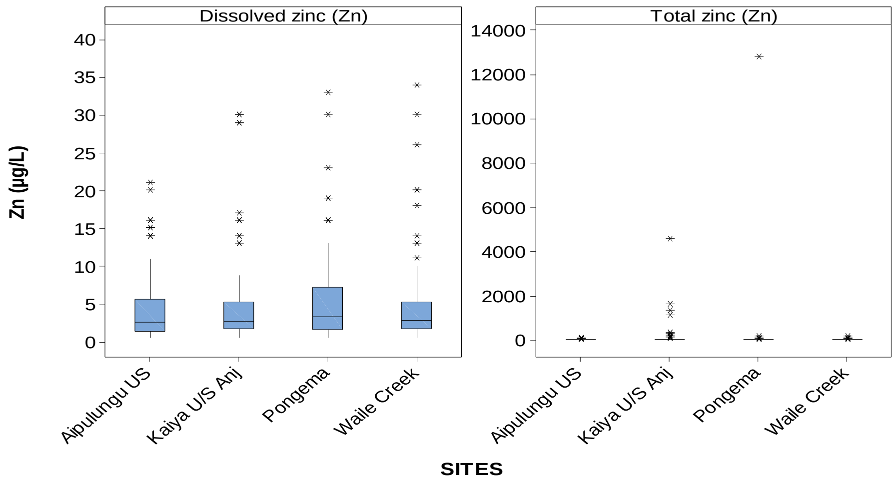


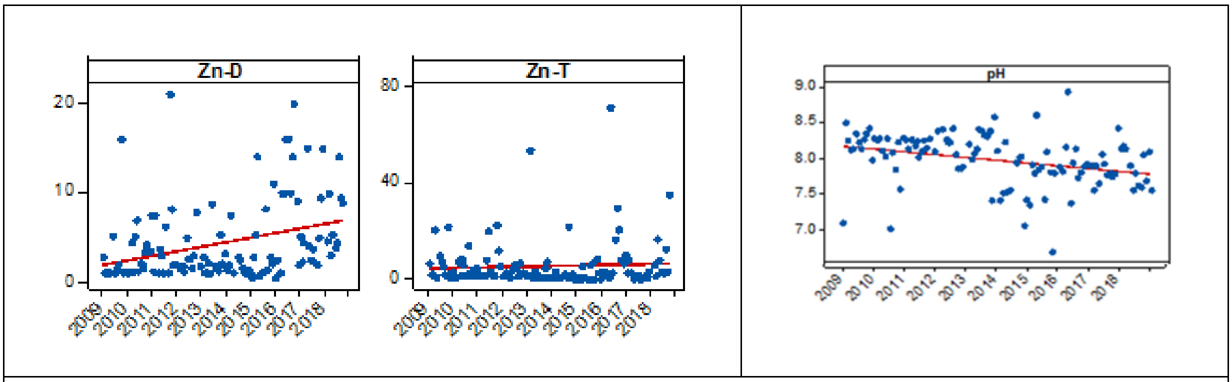
Figure 5-56 Dissolved and total zinc in local creek runoff 2009-2018

Table 5-5 Trends of water quality in local creek runoff reference sites 2009-2018 as tested by Spearman Rank Correlation

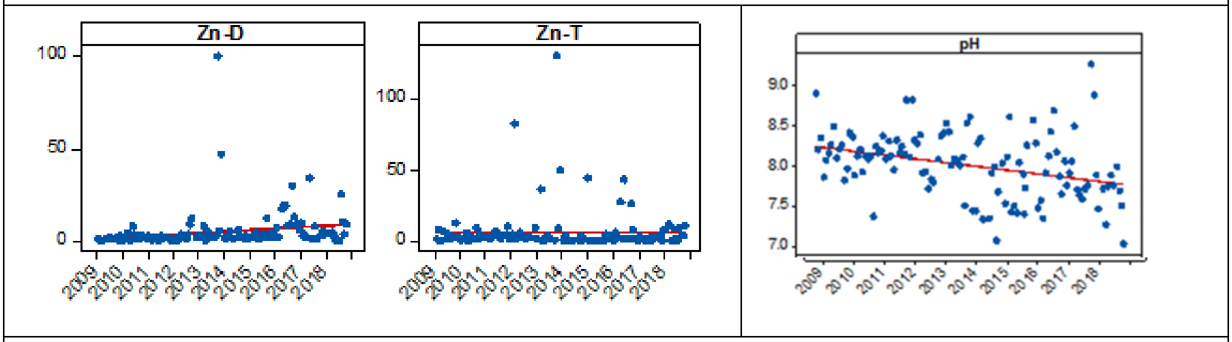
Parameter	Aipulungu U/S Lime Plant	Waile Creek	Kaiya Riv U/S Anj Dump	Pongema
pH^	Green	Green	Green	Green
EC	Green	Green	Green	Green
WAD-CN*	Green	Green	Green	Green
Sulfate*	Green	Green	Green	Green
ALK-T**	Green	Green	Green	Green
TSS*	Orange	Green	Green	Green
Hardness**	Green	Green	Green	Green
Ag-D	Green	Green	Green	Green
Ag-T	Green	Green	Green	Green
As-D	Green	Green	Green	Green
As-T	Green	Green	Green	Green
Cd-D	Green	Green	Green	Green
Cd-T	Green	Green	Green	Green
Cr-D	Green	Green	Green	Green
Cr-T	Green	Green	Green	Green
Cu-D	Green	Green	Green	Green
Cu-T	Green	Green	Green	Green
Fe-D	Green	Green	Green	Green
Fe-T	Green	Green	Green	Green
Hg-D	Green	Green	Green	Green
Hg-T	Green	Green	Green	Green
Ni-D	Green	Green	Green	Green
Ni-T	Green	Green	Green	Green
Pb-D	Green	Green	Green	Green
Pb-T	Green	Green	Green	Green
Se-D	Green	Green	Green	Green
Se-T	Green	Green	Green	Green
Zn-D	Orange	Orange	Orange	Orange
Zn-T	Green	Green	Green	Green

Green	Decreased or no change over time
Orange	Increased over time

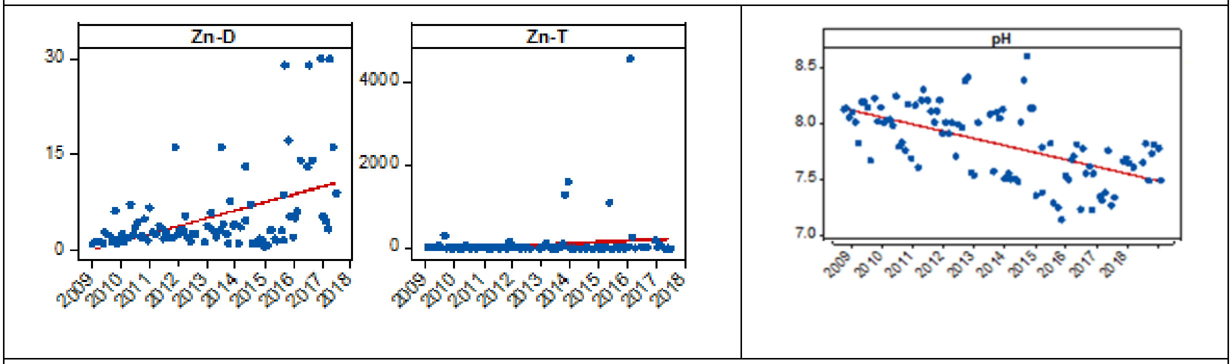
^std units, * mg/L, **mg $CaCO_3$/L, D = Dissolved fraction, T = Total



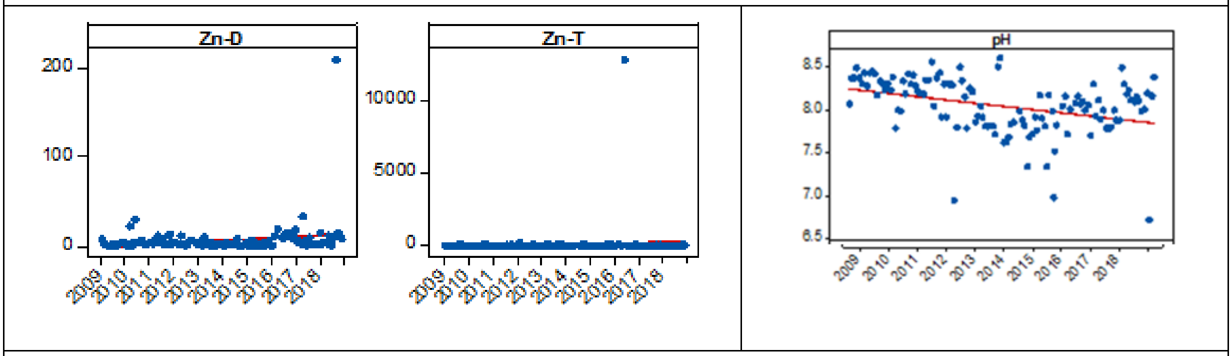
Aipulungu U/S Lime Plant - Dissolved and total zinc and pH 2009 - 2018



Waile Creek - Dissolved and total zinc and pH 2009 - 2018



Kaiya U/S Anj Dump - Dissolved and total zinc and pH 2009 - 2018



Pongema - Dissolved and total zinc and pH 2009 - 2018

Figure 5-57 Trend analysis Local reference sites (scatter plot of all data from 2009 – 2018 with linear trend line)

5.4.2 Upper River

This section presents the water quality data collected from test sites prior to mining operations commencing (baseline data), from reference sites during the previous 24-months and from ANZECC/ARMCANZ (2000) for the upper river region. In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2018 TV for use in the water quality risk assessment presented in Section 7.4. Data summaries and presentation of water quality TVs for the upper river reference sites are presented in Table 5-6.

Reference data are generated by combining the data from each of the upper river reference sites; Upper Lagaip, Pori, Kuru and Ok Om. Reference sites within the upper river region exhibited slightly alkaline pH, elevated EC, occasionally elevated TSS and the presence of arsenic, chromium, copper, iron, nickel, lead and zinc. Analysis of trends between 2009 and 2018 indicate that most parameters remained constant at the reference sites, the exception being dissolved zinc which showed an increasing trend and a concurrent decrease in pH. Trend analysis results are shown in Table 5-7 and graphical representation of dissolved and total zinc and pH data from each site showing increasing and decreasing trends respectively a presented in Figure 5-58.

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 ANZECC/ARMCANZ (2000) GVs for 95% species protection, the highest values for each indicator and therefore the value adopted as the 2018 TV were from the following sources:

- Reference site data: EC
- Baseline data: TSS, dissolved copper, iron, nickel and zinc
- ANZECC/ARMCANZ (2000) GVs: Dissolved silver, arsenic, cadmium, chromium, mercury, lead and selenium.

Table 5-6 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. ANZECC/ARMCANZ (2000) default TV for 95% species protection provided for comparison (µg/L except where indicated)

Parameter	UpRiv Ref 24 month (n=119)			SG1 Baseline (n=15)			SG2 Baseline (n=24)			SG3 Baseline (n=25)			Baseline SG1,SG2 & SG3 (n=64)			ANZECC / ARMCANZ 95%	UpRiv TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%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#	133	196	228	168	180	190	178	185	226	176	188	204	170	185	202	NA	228
Sulfate*	6.0	12	21	10	12	16	18	21	31	28	30	34	15	22	32		
Alk-T*	57	85	108	110	117	122	110	150	263	96	106	124	106	117	169		
TSS*	82	340	1,020	222	401	2,496	258	1,462	4,874	743	1,428	2,663	258	1,188	2,837	NA	2,837
Hardness*	55	79	108	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
Ag-D	0.01	0.01	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05	0.05
Ag-T	0.01	0.035	0.12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		
As-D	0.38	0.51	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	1.2	3.8	13	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	0.095	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	0.19	0.31	0.55	ND	ND	ND	133	133	133	ND	ND	ND	0.5	0.5	0.5	1.0	1.0
Cr-T	3.1	15	43	ND	ND	ND	0.5	0.5	0.5	ND	ND	ND	133	133	133		
Cu-D	0.32	0.49	0.82	1.1	1.2	1.4	0.56	0.9	7.2	1	1.7	4.3	0.98	1.4	4.1	2.5	4.1
Cu-T	2.1	11	36	5.2	15	66	8.8	41	146	7.4	36	68	7	29	82		
Fe-D	10.8	19	45	75	75	75	57	75	75	75	75	75	75	75	75	NA	75
Fe-T*	2.6	16	56	14	17	104	13	40	203	23	64	118	13	44	148		
Hg-D	0.05	0.05	0.054	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	0.073	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	0.54	13	15	15	5.7	9.1	15	11	15.7	23	10	15	21	19***	21
Ni-T	3.3	17	54	16	16	16	20	20	179	10	12	94	12	20	90		
Pb-D	0.10	0.10	0.11	0.30	0.30	0.64	0.26	0.30	0.38	0.3	0.3	1.3	0.3	0.3	1.0	7.5	7.5
Pb-T	1.3	6.2	24	4.36	12	160	6.1	18	139	3.6	23	59	4.4	19	82		
Se-D	0.20	0.20	0.20	ND	ND	ND	0.07	0.07	0.07	ND	ND	ND	0.07	0.07	0.07	11	11
Se-T	0.20	0.28	0.70	ND	ND	ND	0.25	0.25	0.25	ND	ND	ND	0.25	0.25	0.25		
Zn-D	2.2	4.7	9.7	0.18	0.2	0.42	0.28	0.40	0.64	0.8	4.3	25	0.48	1.4	20	14***	20
Zn-T	10	40	142	25	77	374	30	79	623	45	131	249	26	103	376		

^ std units, #µS/cm, *mg/L, **mgCaCO3/L, ***Hardness modified, D – Dissolved fraction, T – Total fraction, NA – Not applicable, ND – Not determined

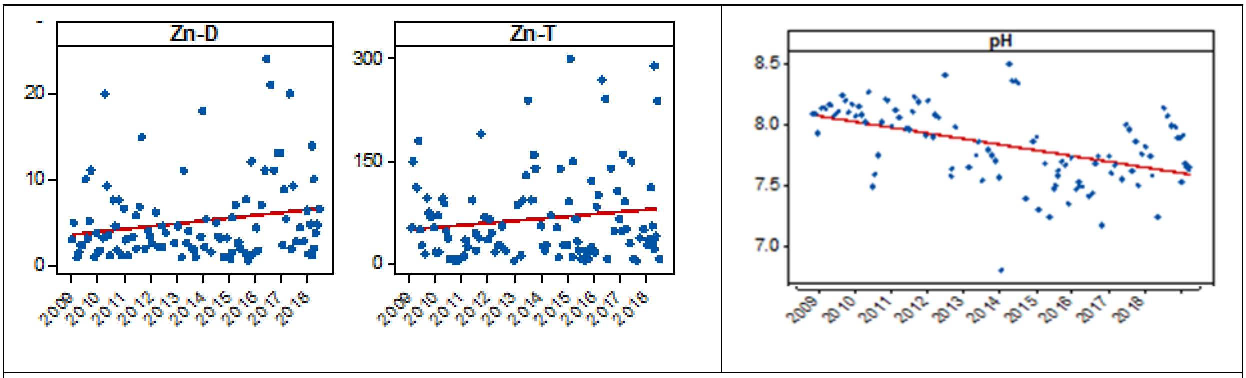
Baseline data were collected from the test sites prior to mine operations commencing

Table 5-7 Trends for water quality at upper river reference sites 2009-2018 as determined by Spearman Rank correlation against time

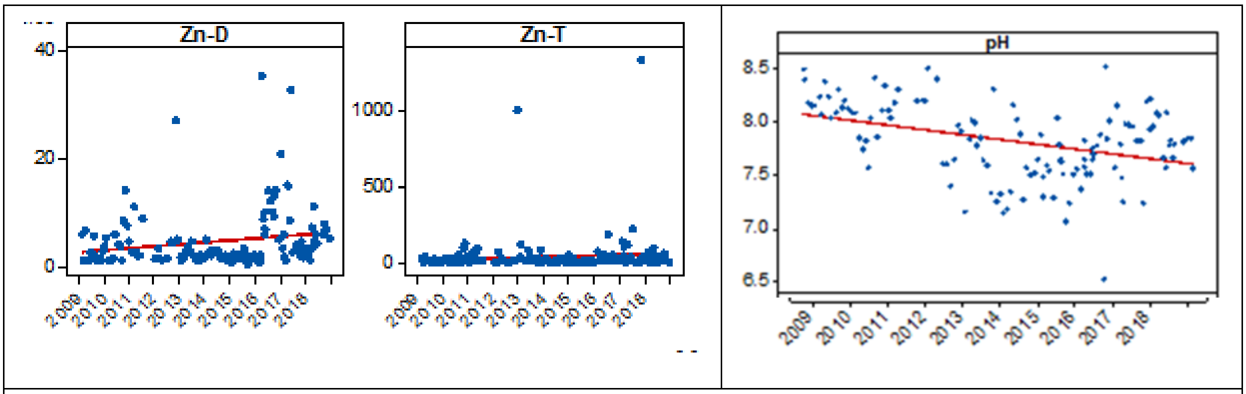
Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2009 – 2018)
Upper River Ref (Trend of all data from 2009 - 2018)	pH	-0.336	<0.001	Reduced over time
	EC	-0.060	0.188	No change over time
	TSS	0.008	0.868	No change over time
	Ag-D*	-0.872	<0.001	Reduced over time
	Ag-T*	-0.638	<0.001	Reduced over time
	As-D*	-0.768	<0.001	Reduced over time
	As-T	0.015	0.734	No change over time
	Cd-D*	-0.836	<0.001	Reduced over time
	Cd-T*	-0.653	<0.001	Reduced over time
	Cr-D*	-0.703	<0.001	Reduced over time
	Cr-T	-0.008	0.867	No change over time
	Cu-D*	-0.645	<0.001	Reduced over time
	Cu-T	-0.018	0.688	No change over time
	Fe-D	0.085	0.059	No change over time
	Fe-T	-0.008	0.862	No change over time
	Hg-D*	-0.705	<0.001	Reduced over time
	Hg-T*	-0.561	<0.001	Reduced over time
	Ni-D*	-0.732	<0.001	Reduced over time
	Ni-T	-0.018	0.683	No change over time
	Pb-D*	-0.768	<0.001	Reduced over time
	Pb-T	-0.002	0.963	No change over time
	Se-D*	-0.737	<0.001	Reduced over time
	Se-T*	-0.393	<0.001	Reduced over time
	Zn-D	0.217	<0.001	Increased over time
	Zn-T	0.030	0.502	No change over time

D - Dissolved fraction, T - Total fraction

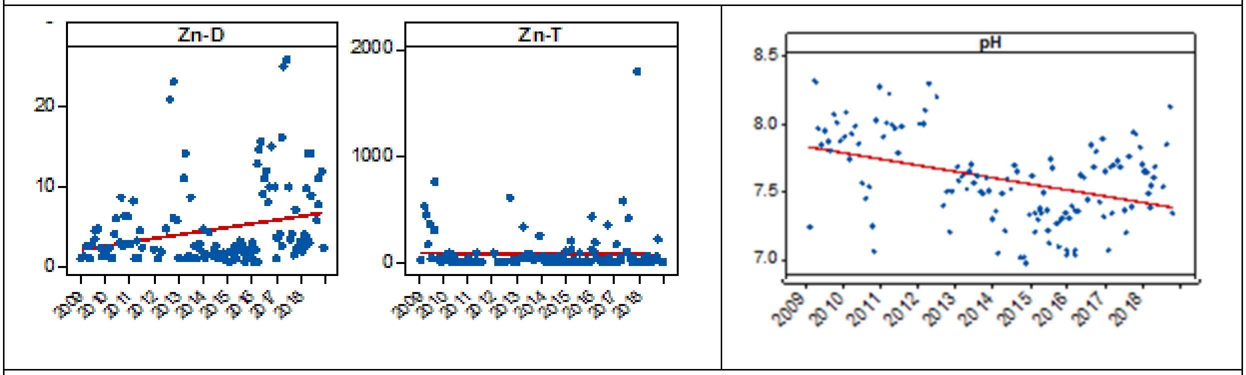
* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore the finding has been corrected to indicate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



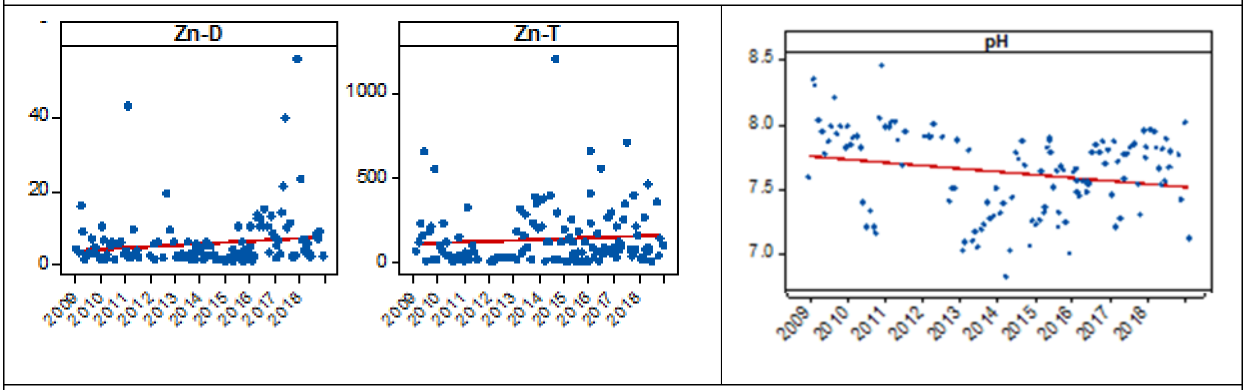
Upper Lagaip Dissolved and total zinc concentrations (µg/L) and pH 2009 - 2018 (Ref site)



Pori Dissolved and total zinc concentrations (µg/L) and pH 2009 - 2018 (Ref site)



Kuru Dissolved and total zinc concentrations (µg/L) and pH 2009 - 2018 (Ref site)



Ok Om Dissolved and total zinc concentrations (µg/L) and pH 2009 - 2018 (Ref site)

Figure 5-58 Trend analysis Upper River reference sites water quality (scatter plot of all data from 2009 – 2018 with linear trend line)

5.4.1 Lower River

This section presents the water quality data collected from test sites prior to mining operations commencing (baseline data), from reference sites during the previous 24-months and from ANZECC/ARMCANZ (2000) for the lower river region. In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2018 TV for use in the water quality risk assessment presented in Section 7.4. Data summaries and presentation of water quality TVs for the lower river are presented Table 5-8.

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 2009 and 2018 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 5-9 and graphical representation of dissolved and total zinc and pH data from each site showing trends is presented in Figure 5-59.

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 ANZECC/ARMCANZ (2000) GVs for 95% species protection, the highest values for each indicator and therefore the value adopted as the 2018 TV were from the following sources:

- Reference site data: EC and dissolved zinc.
- Baseline data: TSS, dissolved iron and nickel.
- ANZECC/ARMCANZ (2000) GVs: Dissolved silver, arsenic, cadmium, chromium, copper, mercury, lead and selenium.

Table 5-8 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. ANZECC/ARMCANZ (2000) 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)			ANZECC / ARMCANZ 95%	LwRiv TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
pH^	7.0	7.5	7.8	7.8	8.0	8.1	6.0-8.0	6.0-8.1
EC#	48	131	172	140	150	170	NA	172
Sulfate*	1.0	2.0	5.6	10	15	18		
ALK-T*	30	61	74	83	93	101		
TSS*	12	66	626	326	638	983	NA	983
Hardness*	20	52	69	ND	ND	ND		
Ag-D	0.01	0.01	0.01	ND	ND	ND	0.05	0.05
Ag-T	0.01	0.01	0.05	ND	ND	ND		
As-D	0.10	0.42	0.76	0.60	0.70	0.80	24	24
As-T	0.19	1.08	8.1	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	0.14	0.26	0.38	0.50	0.50	0.50	1.0	1.0
Cr-T	0.92	2.4	33	18	34	46		
Cu-D	0.31	0.47	0.72	0.50	0.85	1.4	1.4	1.4
Cu-T	1.0	2.5	21	8.0	18	26		
Fe-D	6.2	15	30	0.64	75	75	NA	75
Fe-T*	0.63	2.2	26	17	37	49		
Hg-D	0.05	0.05	0.05	ND	ND	ND	0.60	0.60
Hg-T	0.05	0.05	0.05	0.10	0.10	0.10		
Ni-D	0.50	0.50	0.50	3.6	10	15	11	15
Ni-T	0.95	2.5	30	10	23	24		
Pb-D	0.10	0.10	0.11	0.30	0.50	0.70	3.4	3.4
Pb-T	0.11	0.84	9.3	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	0.28	0.20	0.20	0.50		
Zn-D	3.8	5.1	13	0.50	1.0	2.9	8.0	13
Zn-T	2.6	8.5	64	28	68	94		

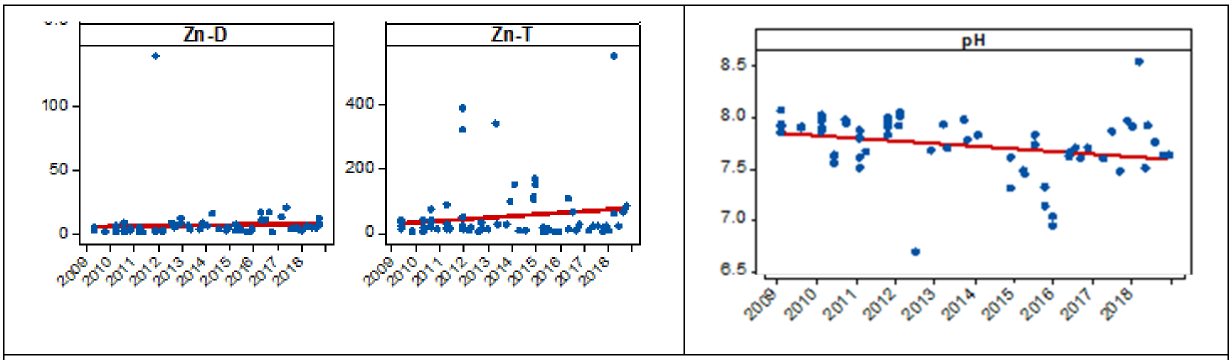
^ std units, #µS/cm, *mg/L, **mgCaCO3/L, ***Hardness modified, D – Dissolved fraction, T – Total fraction, NA – Not applicable, ND – Not determined

Table 5-9 Trends for water quality at lower river reference sites 2009-2018 as determined by Spearman Rank correlation against time

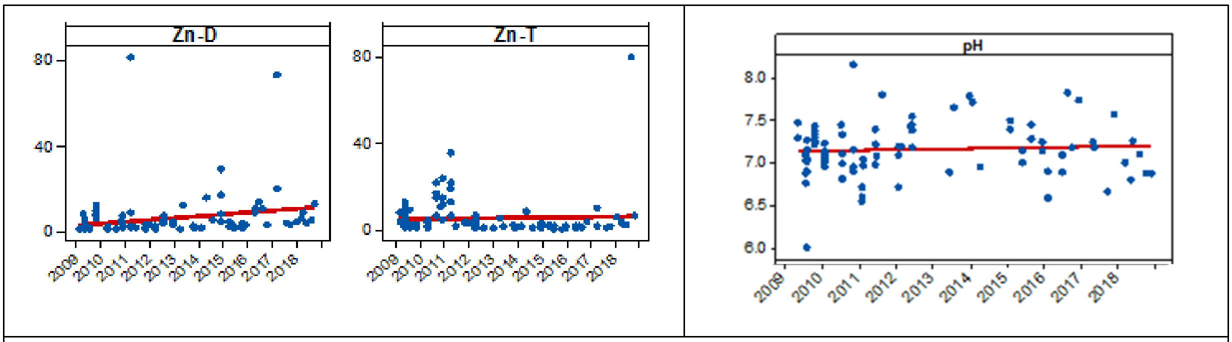
Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2009 – 2018)
Lower River Ref (Trend of all data from 2009 - 2018)	pH	0.083	0.300	No change over time
	EC	0.294	<0.001	Increased over time
	TSS	0.062	0.440	No change over time
	Ag-D*	-0.785	<0.001	Reduced over time
	Ag-T*	-0.543	<0.001	Reduced over time
	As-D*	-0.617	<0.001	Reduced over time
	As-T	-0.115	0.132	No change over time
	Cd-D*	-0.743	<0.001	Reduced over time
	Cd-T*	-0.491	<0.001	Reduced over time
	Cr-D*	-0.710	<0.001	Reduced over time
	Cr-T	0.009	0.907	No change over time
	Cu-D*	-0.590	<0.001	Reduced over time
	Cu-T	-0.039	0.613	No change over time
	Fe-D	-0.286	<0.001	Reduced over time
	Fe-T	-0.010	0.901	No change over time
	Hg-D*	-0.695	<0.001	Reduced over time
	Hg-T*	-0.546	<0.001	Reduced over time
	Ni-D*	-0.650	<0.001	Reduced over time
	Ni-T	-0.007	0.926	No change over time
	Pb-D*	-0.707	<0.001	Reduced over time
	Pb-T	-0.090	0.242	No change over time
	Se-D*	-0.804	<0.001	Reduced over time
	Se-T*	-0.612	<0.001	Reduced over time
	Zn-D	0.377	<0.001	Increased over time
	Zn-T	0.048	0.532	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 2009 - 2018 (Ref site)



Tomu Dissolved and total zinc concentrations (µg/L) and pH 2009 - 2018 (Ref site)

Figure 5-59 Trend analysis Lower River reference sites water quality (scatter plot of all data from 2009 – 2018 with linear trend line)

5.4.2 Lake Murray and ORWBs

This section presents the water quality data collected from test sites prior to mining operations commencing (baseline data), from reference sites during the previous 24-months and from ANZECC/ARMCANZ (2000) for the Lake Murray and ORWB region. In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2018 TV for use in the water quality risk assessment presented in Section 7.4. Data summaries and presentation of water quality TVs for the lower river are presented Table 5-10.

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 2009 and 2018 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 5-11 and graphical representation of dissolved and total zinc and pH data from each site showing increasing trends is presented in Figure 5-60.

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

Upon comparison of reference and baseline data with the ANZECC/ARMCANZ (2000) GVs for 95% species protection, the highest values for each indicator and therefore the value adopted as the 2018 TV were from the following sources. It should be noted that TVs for the ORWBs have been adopted from the lower river TVs, the ORWBs are adjacent to the main river channel and therefore influenced by inflow from the main river, as a result TVs from North Lake Murray were not considered the most appropriate TV for risk assessment purposes for the ORWBs.

- Reference site data: TSS, EC and dissolved zinc.
- Baseline data: Dissolved cadmium and iron
- ANZECC/ARMCANZ (2000) GVs: Dissolved silver, arsenic, chromium, copper, mercury, nickel, lead and selenium.
- Lower TVs: ORWB EC and TSS

Table 5-10 Summarised water quality data for Lake Murray and ORWB river test sites for baseline and reference sites for previous 24 months, presenting 20th%ile , median and 80th%ile of data for each site. ANZECC/ARMCANZ (2000) 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)			ANZECC / ARMCANZ 95%	LMY TV	ORWBs TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile			
pH^	6.6	7.1	7.5	6.3	6.4	6.4	6.3	6.4	6.6	6.3	6.4	6.6	6.0-8.0	6.0-8.0	6.0-8.1
EC#	14.8	16.3	18	15	15	15.5	15	15	15.5	15	15	15.5	NA	18	172
Sulfate	1.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0			
ALK-T*	9.2	12	15	7.7	8.1	8.8	7.9	8.1	8.5	7.8	8.1	8.7			
TSS* #	3.0	4.5	15	6.0	7.0	9.0	4.6	6.0	8.2	5.4	6.5	9.0	NA	15	983
Hardness*	5.0	6.0	7.2	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	0.05	0.05	0.05
Ag-T	0.01	0.01	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND			
As-D	0.12	0.13	0.14	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	24	24	24
As-T	0.13	0.17	0.19	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	0.20
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	0.10	0.11	0.17	0.1	0.1	0.44	0.1	0.1	0.2	0.1	0.1	0.40	1.0	1.0	1.0
Cr-T	0.15	0.24	0.34	0.1	0.1	0.4	0.1	0.25	1.3	0.1	0.15	0.6			
Cu-D	0.27	0.32	0.41	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	1.4	1.4	1.4
Cu-T	0.29	0.40	0.55	0.26	0.4	0.8	0.1	0.3	0.52	0.1	0.3	0.7			
Fe-D	52	75	130	138	255	342	166	230	324	148	250	340	NA	340	75
Fe-T	300	465	796	762	1005	1072	898	945	1024	898	980	1072			
Hg-D	0.05	0.05	0.082	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.60	0.60	0.60
Hg-T	0.05	0.05	0.069	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	15
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	0.10	0.2	0.2	0.7	0.2	0.2	0.62	0.2	0.2	0.7	3.4	3.4	3.4
Pb-T	0.10	0.11	0.24	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	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	2.3	4.0	8.8	0.05	0.05	0.14	0.05	0.5	1.0	0.05	0.08	0.8	8.0	8.8	13
Zn-T	0.82	1.4	4.1	1.2	2	2.7	1.3	2	2.88	1.3	2	2.8			

^ std units, µS/cm, *mg/L, **mgCaCO3/L, ***Hardness modified, D – Dissolved fraction, T – Total fraction, NA – Not applicable, ND – Not determined

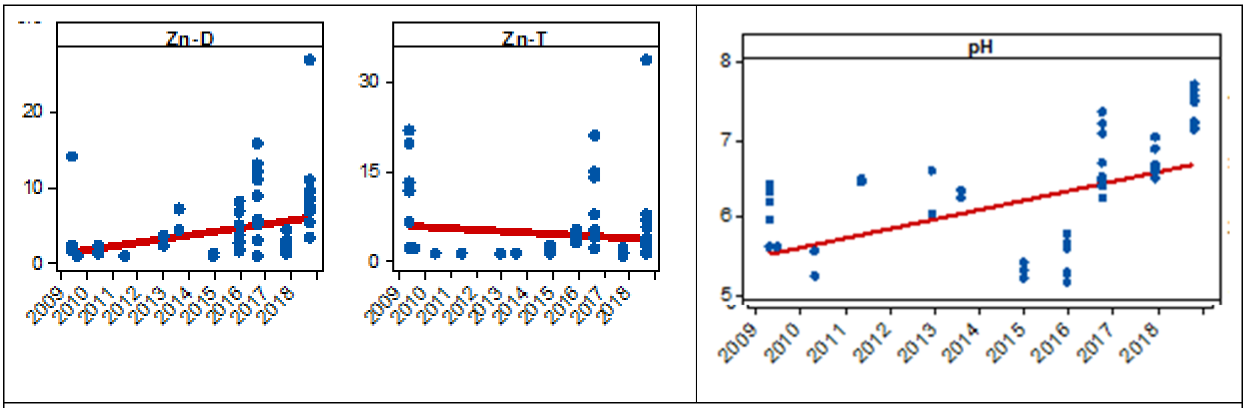
Baseline data were collected from the test sites prior to mine operations commencing

Table 5-11 Trends for water quality in Lake Murray and ORWBs 2009 - 2018 as determined using Spearman Rank Correlation against time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2009 – 2018)
Lake Murray and ORWB Ref (Trend of all data from 2009 - 2018)	pH	0.708	<0.001	Increased over time
	TSS	0.191	0.133	No change over time
	Ag-D*	-0.929	<0.001	Reduced over time
	Ag-T*	-0.919	<0.001	Reduced over time
	As-D*	-0.790	<0.001	Reduced over time
	As-T*	-0.896	<0.001	Reduced over time
	Cd-D*	-0.735	<0.001	Reduced over time
	Cd-T*	-0.779	<0.001	Reduced over time
	Cr-D*	-0.677	<0.001	Reduced over time
	Cr-T*	-0.730	<0.001	Reduced over time
	Cu-D*	-0.786	<0.001	Reduced over time
	Cu-T*	-0.658	<0.001	Reduced over time
	Fe-D	-0.325	0.008	Reduced over time
	Fe-T	-0.352	0.004	Reduced over time
	Hg-D*	-0.527	<0.001	Reduced over time
	Hg-T*	-0.526	<0.001	Reduced over time
	Ni-D*	-0.779	<0.001	Reduced over time
	Ni-T*	-0.663	<0.001	Reduced over time
	Pb-D*	-0.604	<0.001	Reduced over time
	Pb-T*	-0.732	<0.001	Reduced over time
	Se-D	-0.337	0.014	Reduced over time
	Se-T*	-0.744	<0.001	Reduced over time
	Zn-D*	0.459	<0.001	Increased over time
	Zn-T	-0.025	0.845	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 2009 – 2018 (Ref site)

Figure 5-60 Trend analysis Lake Murray and ORWB water quality (scatter plot of all data from 2009 – 2018 with linear trend line)

5.5 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 ANZECC/ARMCANZ (2000) sediment quality guideline values (SQGVs) from Simpson et al (2013). In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2018 TV for use in the sediment quality risk assessment presented in Section 7.4. The sites are grouped into regions; Local Sites, Upper River, Lower River, Lake Murray and Off-River Water Bodies (ORWBs).

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. Total digest concentrations include weakly and strongly bound sediment metals and over estimate the fraction likely to become readily bioavailable and therefore likely overestimates potential toxicity.

5.5.1 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 5-12.

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.

Table 5-12 Local sites sediment quality 2018 (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	0.06	0.08	NS	NS	NS	0.05	0.05	0.06
Ag-TD	0.11	0.13	0.17	NS	NS	NS	0.11	0.18	0.21
As-WAE	1.0	1.1	1.1	NS	NS	NS	1.0	1.2	1.4
As-TD	2.3	2.6	2.7	NS	NS	NS	4.6	5.5	6.4
Cd-WAE	0.11	0.12	0.13	NS	NS	NS	0.11	0.12	0.14
Cd-TD	0.12	0.13	0.15	NS	NS	NS	0.12	0.14	0.24
Cr-WAE	5.3	8.2	12	NS	NS	NS	6.8	11	13
Cr-TD	24	25	26	NS	NS	NS	21	23	25
Cu-WAE	8.7	9.0	9.1	NS	NS	NS	4.0	4.0	4.2
Cu-TD	12	13	13	NS	NS	NS	8.2	8.7	11
Hg-WAE	0.01	0.01	0.01	NS	NS	NS	0.01	0.01	0.01
Hg-TD	0.02	0.03	0.03	NS	NS	NS	0.02	0.03	0.03
Ni-WAE	8.2	12	16	NS	NS	NS	5.7	8.9	10
Ni-TD	20	21	22	NS	NS	NS	15	16	16
Pb-WAE	4.1	4.5	5.0	NS	NS	NS	4.2	5.0	5.9

Parameter	Aipulungu US			Kaiya US			Pongema		
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile
Pb-TD	5.4	6.2	6.7	NS	NS	NS	5.2	10	17
Se-WAE	0.14	0.18	0.22	NS	NS	NS	0.12	0.14	0.16
Se-TD	0.48	0.52	0.56	NS	NS	NS	0.32	0.41	0.45
Zn-WAE	34	48	59	NS	NS	NS	29	39	45
Zn-TD	62	68	77	NS	NS	NS	51	54	76

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

5.5.2 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 SQGVs (Simpson et al (2013)) for the upper river region. In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2018 TV for use in the sediment quality risk assessment presented in Section 7.4. 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 2009 and 2018 show increasing concentrations of WAE arsenic, TD arsenic, WAE chromium, WAE copper, WAE lead, TD lead, WAE nickel, WAE zinc 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 5-14 and graphical representation of WAE arsenic, WAE chromium, WAE copper, WAE lead, WAE nickel and WAE zinc showing increasing trends is presented in Figure 5-61.

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 SQGVs, the highest values for each indicator and therefore the value adopted as the 2018 TV were from the following sources:

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

Table 5-13 Summarised sediment quality data for upper river reference sites for previous 24 months. SQGVs are provided for comparison (mg/kg dry, whole fraction)

Parameter	UpRivs Ref 24 month (n = 101)			UpRivs Baseline (<63µm) (n = 2)			SQGV	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	0.15	ND	ND	ND		
As-WAE	1.5	1.9	2.7	ND	ND	ND	20	20
As-TD	8.8	11	16	6.5	10	14		
Cd-WAE	0.05	0.05	0.06	ND	ND	ND	1.5	1.5
Cd-TD	0.05	0.05	0.09	0.06	0.08	0.10		
Cr-WAE	1.4	2.8	6.8	ND	ND	ND	80	80
Cr-TD	20	30	79	28	31	33		
Cu-WAE	3.8	7.3	12	ND	ND	ND	65	65
Cu-TD	16	32	45	133	175	217		
Hg-WAE	0.01	0.01	0.01	ND	ND	ND	0.15	0.15
Hg-TD	0.04	0.05	0.08	ND	ND	ND		
Ni-WAE	4.0	6.8	19	ND	ND	ND	21	21
Ni-TD	27	39	90	23	29	34		
Pb-WAE	5.6	7.2	9.5	ND	ND	ND	50	50
Pb-TD	12	16	20	13	17	20		
Se-WAE	0.10	0.11	0.16	ND	ND	ND	NA	0.16
Se-TD	0.33	0.42	0.58	0.46	0.50	0.54		
Zn-WAE	11	14	32	ND	ND	ND	200	200
Zn-TD	73	95	110	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

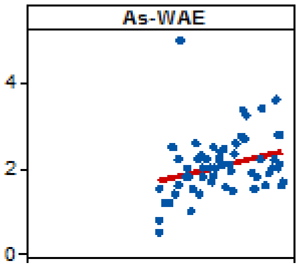
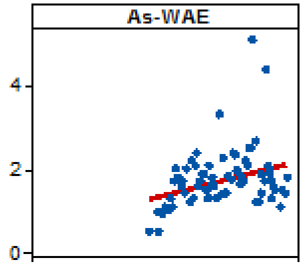
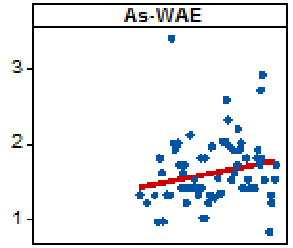
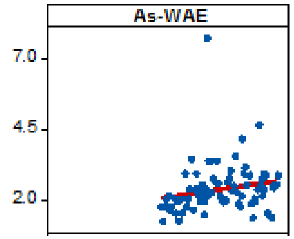
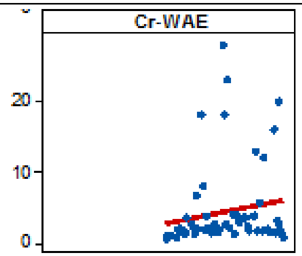
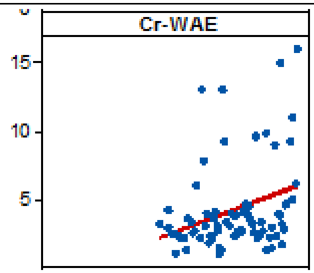
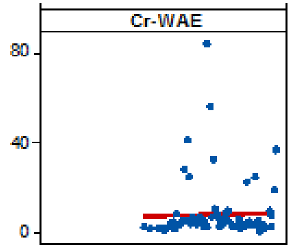
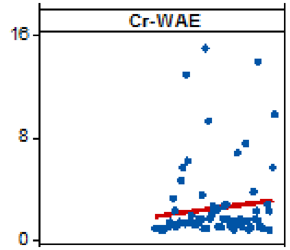
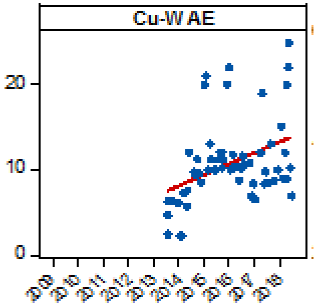
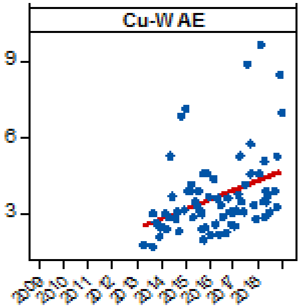
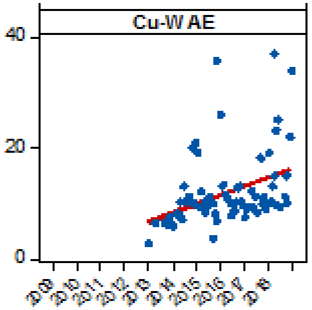
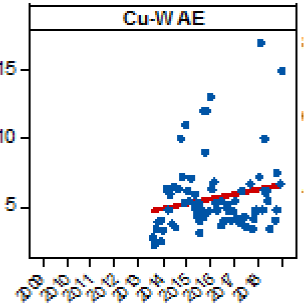
Baseline data were data collected from the test sites prior to mine operations commencing

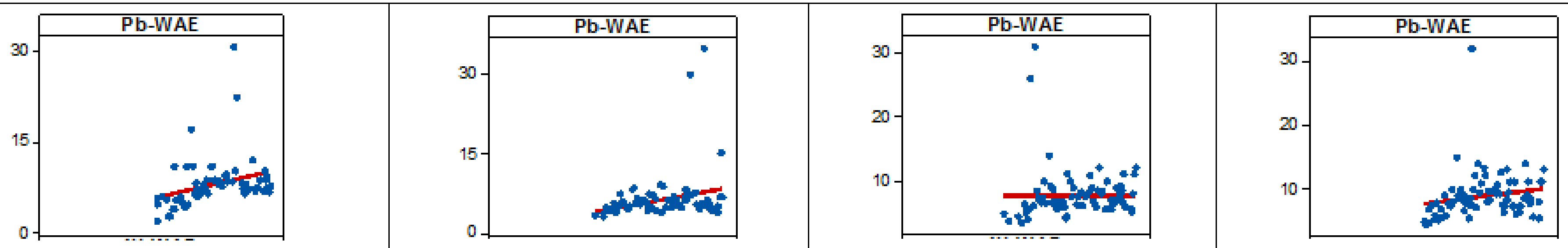
Table 5-14 Trends for sediment quality for upper river reference sites determined by Spearman Rank correlation against time (2009 – 2018)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2009 – 2018)
UpRivs Ref (Trend of all data WAE from 2013–2018 TD from 2009-2018)	Ag-WAE	-0.862	<0.001	Reduced over time
	Ag-TD	-0.747	<0.001	Reduced over time
	As-WAE	0.259	<0.001	Increased over time
	As-TD	0.159	0.001	Increased over time
	Cd-WAE	-0.788	<0.001	Reduced over time
	Cd-TD	-0.741	<0.001	Reduced over time
	Cr-WAE	0.153	0.01	Increased over time
	Cr-TD	0.004	0.936	No change over time
	Cu-WAE	0.207	<0.001	Increased over time
	Cu-TD	0.036	0.442	No change over time
	Pb-WAE	0.311	<0.001	Increased over time
	Pb-TD	0.117	0.012	Increased over time
	Hg-WAE	-0.296	<0.001	Reduced over time
	Hg-TD	-0.701	<0.001	Reduced over time
	Ni-WAE	0.203	0.001	Increased over time
	Ni-TD	-0.018	0.694	No change over time
	Se-WAE	-0.788	<0.001	Reduced over time
	Se-TD	-0.324	<0.001	Reduced over time
	Zn-WAE	0.249	<0.001	Increased over time
	Zn-TD	0.111	0.017	Increased over time

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

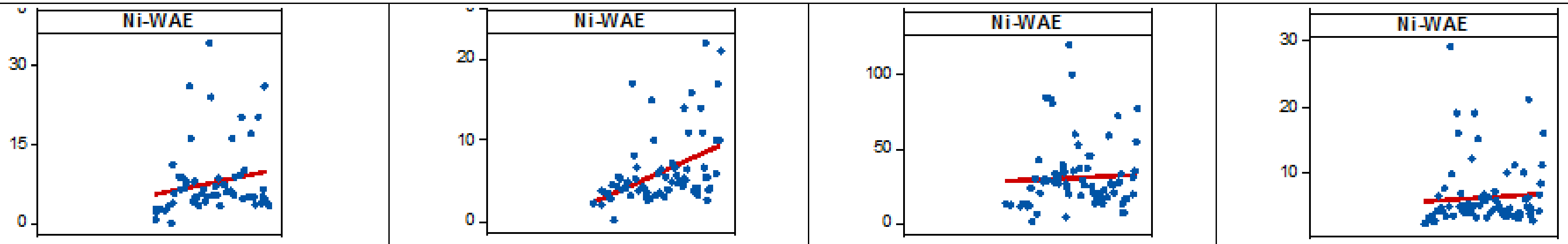
* The trend indicated by Spearman's rho and p of these tests are artefacts of a change (either upwards or downwards) of the analytical limit of reporting throughout the historical record and are not representative of an actual positive or negative trend. Therefore the finding has been corrected to indicate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

 Upper Lagaip	 Pori	 Kuru	 Ok Om
WAE Arsenic concentrations (mg/kg dry whole fraction) – Upper River reference sites 2008 - 2019			
 Upper Lagaip	 Pori	 Kuru	 Ok Om
WAE Chromium concentrations (mg/kg dry whole fraction) – Upper River reference sites 2008 - 2019			
 Upper Lagaip	 Pori	 Kuru	 Ok Om
WAE Copper concentrations (mg/kg dry whole fraction) – Upper River reference sites 2008 - 2019			



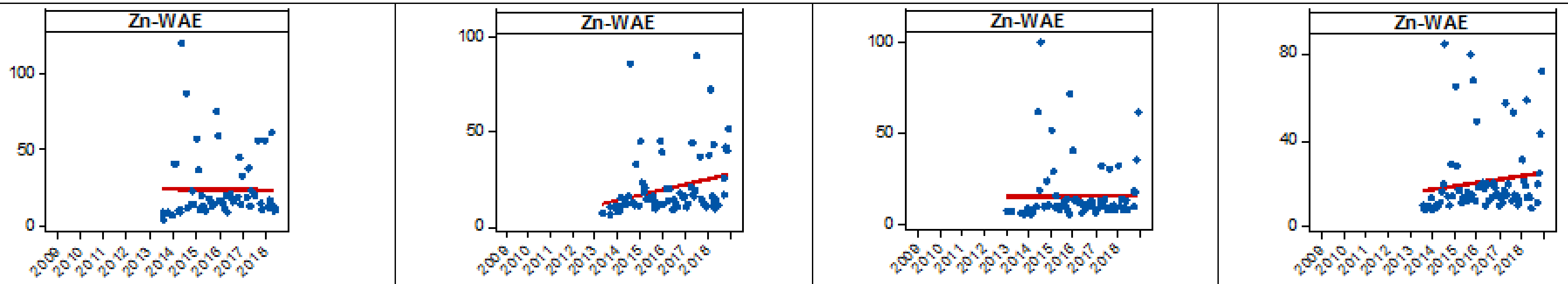
Upper Lagaip | Pori | Kuru | Ok Om

WAE Lead concentrations (mg/kg dry whole fraction) – Upper River reference sites 2008 - 2019



Upper Lagaip | Pori | Kuru | Ok Om

WAE Nickel concentrations (mg/kg dry whole fraction) – Upper River reference sites 2008 - 2019



Upper Lagaip | Pori | Kuru | Ok Om

WAE Zinc concentrations (mg/kg dry whole fraction) – Upper River reference sites 2008 - 2019

Figure 5-61 Trend analysis upper rivers sediment quality showing elements with statistically significant increasing trends (scatter plot of all data from 2009 – 2018 with linear trend line)

5.5.3 Lower 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 ANZECC/ARMCANZ (2000) sediment quality guideline values (SQGVs) 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 2018 TV for use in the sediment quality risk assessment presented in Section 7.4. 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 sediment TVs are presented in Table 5-15.

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 2009 and 2018 show increasing concentrations of TD arsenic and WAE copper. Concentrations of all other metals either reduced or did not change over the time period. Trend analysis results are shown in Table 5-16 and graphical representation of WAE copper showing increasing trends is presented in Figure 5-62.

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 SQGVs, the highest values for each indicator and therefore the value adopted as the 2018 TV were from the following sources:

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

Table 5-15 Summarised sediment quality data for lower river reference sites for previous 24 months. SQGVs are provided for comparison (mg/kg dry whole fraction)

Parameter	LwRiv REF (n=23)			LwRiv Baseline (-63µm)			SQGV	LwRiv 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	0.1	ND	ND	ND		
As-WAE	0.38	0.84	1.3	ND	ND	ND	20	20
As-TD	1.5	2.9	4.1	2.8	10	14		
Cd-WAE	0.05	0.06	0.09	ND	ND	ND	1.5	1.5
Cd-TD	0.05	0.1	0.1	2.4	2.4	2.4		
Cr-WAE	3.3	6.3	7.9	ND	ND	ND	80	80
Cr-TD	30	49	53	12	12	12		
Cu-WAE	3.4	4.8	6.6	ND	ND	ND	65	65
Cu-TD	10.8	16	18	24	24	24		
Hg-WAE	0.01	0.01	0.01	ND	ND	ND	0.15	0.15
Hg-TD	0.01	0.01	0.02	0.3	0.6	0.9		
Ni-WAE	5.2	11	16	ND	ND	ND	21	21
Ni-TD	33	57	66	38	38	38		
Pb-WAE	2.5	3.0	4.1	ND	ND	ND	50	50
Pb-TD	4.5	5.5	6.0	22	22	22		
Se-WAE	0.1	0.1	0.14	ND	ND	ND	NA	0.14

Parameter	LwRiv REF (n=23)			LwRiv Baseline (-63µm)			SQGV	LwRiv TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile		
Se-TD	0.1	0.17	0.23	0.2	0.2	0.2		
Zn-WAE	14	18	28	ND	ND	ND	200	200
Zn-TD	58	84	110	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 5-16 Trends for sediment quality for lower river reference sites determined by Spearman Rank correlation against time (2009 – 2018)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2009 – 2018)
LwRivs Ref (Trend of all data WAE from 2013–2018 TD from 2009-2018)	Ag-WAE*	-0.865	<0.001	Reduced over time
	Ag-TD*	-0.673	<0.001	Reduced over time
	As-WAE	-0.143	0.299	No change over time
	As-TD	0.319	<0.001	Increased over time
	Cd-WAE*	-0.776	<0.001	Reduced over time
	Cd-TD*	-0.579	<0.001	Reduced over time
	Cr-WAE	0.107	0.436	No change over time
	Cr-TD	-0.143	0.084	No change over time
	Cu-WAE	0.305	0.024	Increased over time
	Cu-TD	-0.057	0.489	No change over time
	Hg-WAE*	-0.323	0.016	Reduced over time
	Hg-TD*	-0.784	<0.001	Reduced over time
	Ni-WAE	0.115	0.403	No change over time
	Ni-TD	0.141	0.089	No change over time
	Pb-WAE	-0.192	0.16	No change over time
	Pb-TD	0.077	0.352	No change over time
	Se-WAE*	-0.853	<0.001	Reduced over time
	Se-TD*	-0.654	<0.001	Reduced over time
	Zn-WAE	0.127	0.357	No change over time
	Zn-TD	-0.156	0.059	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.

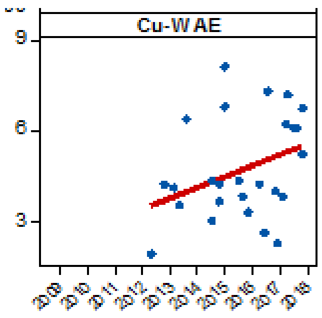
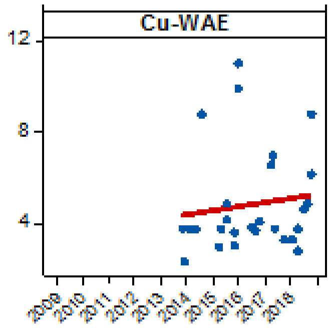
	
Baia WAE Copper concentrations (mg/kg dry whole fraction) (Ref site)	**Tomu WAE Copper concentrations (mg/kg dry whole fraction) (Ref site)**

Figure 5-62 Trend analysis lower river reference sites sediment quality (scatter plot of all data from 2009 – 2018 with linear trend line)

5.5.4 Lake Murray and ORWBs

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 ANZECC/ARMCANZ (2000) sediment quality guideline values (SQGVs) from Simpson et al (2013) for the Lake Murray ORWBs region. In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2018 TV for use in the sediment quality risk assessment presented in Section 7.4. 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 5-17.

Reference data were generated by combining the data from each of the Lake Murray ORWBs reference sites at North Lake Murray. Reference sites within the Lake Murray ORWBs region exhibited detectable concentrations of arsenic, chromium, copper, nickel, lead and zinc. Analysis of trends between 2009 and 2018 show the concentrations of all metals either reduced or did not change over the time period. Trend analysis results are shown in Table 5-18.

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 and ORWB region although at lower concentrations than the upper river region.

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

- Reference site data from Nth Lake Murray for Lake Murray TV: WAE selenium
- Reference site data from lower river reference sites for ORWB TV: WAE selenium
- SQGVs: WAE silver, arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc.

Table 5-17 Summarised sediment quality data for Lake Murray and ORWBs reference sites for previous 24 months, presenting 20th%ile , median and 80th%ile of data for each site. SQGVs are provided for comparison (mg/kg dry whole fraction)

Parameter	Northern Lake Murray (n = 21)			LMY Baseline (-63µm)			SQGV	LMY TV	ORWBs TV
	20th%ile	Median	80th%ile	20th%ile	Median	80th%ile			
Ag-WAE	0.05	0.06	0.12	ND	ND	ND	1.0	1.0	1.0
Ag-TD	0.06	0.10	0.20	ND	ND	ND			
As-WAE	0.85	0.97	1.1	ND	ND	ND	20	20	20
As-TD	2.8	4.8	5.9	2.8	10	14			
Cd-WAE	0.09	0.11	0.12	ND	ND	ND	1.5	1.5	1.5
Cd-TD	0.10	0.13	0.20	2.4	2.4	2.4			
Cr-WAE	5.3	6.0	6.8	ND	ND	ND	80	80	80
Cr-TD	35	40	44	12	12	12			
Cu-WAE	11	12	13	ND	ND	ND	65	65	65
Cu-TD	15	21	23	24	24	24			
Hg-WAE	0.02	0.03	0.03	ND	ND	ND	0.15	0.15	0.15
Hg-TD	0.11	0.14	0.15	0.3	0.6	0.9			
Ni-WAE	7.6	9.0	11	ND	ND	ND	21	21	21
Ni-TD	24	27	34	38	38	38			
Pb-WAE	7.6	8.1	10	ND	ND	ND	50	50	50
Pb-TD	12	14	16	22	22	22			
Se-WAE	0.10	0.20	0.23	ND	ND	ND	NA	0.23	0.14
Se-TD	0.70	0.84	1.0	0.2	0.2	0.2			
Zn-WAE	38	44	47	ND	ND	ND	200	200	200
Zn-TD	92	100	112	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 5-18 Trends for sediment quality Lake Murray and ORWBs reference sites determined by Spearman Rank correlation against time (2013 - 2018)

Sediment Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2013 – 2018)
Lake Murray and ORWB Ref (Trend of all data WAE from 2013 – 2018 TD from 2009 - 2018)	Ag-WAE*	-0.928	<0.001	Reduced over time
	Ag-TD*	-0.927	<0.001	Reduced over time
	As-WAE	0.109	0.470	No change over time
	As-TD	0.099	0.442	No change over time
	Cd-WAE*	-0.900	<0.001	Reduced over time
	Cd-TD*	-0.889	<0.001	Reduced over time
	Cr-WAE	-0.400	0.006	Reduced over time
	Cr-TD	-0.180	0.162	No change over time
	Cu-WAE	-0.319	0.031	Reduced over time
	Cu-TD	-0.136	0.292	No change over time
	Hg-WAE	-0.261	0.080	No change over time
	Hg-TD*	-0.045	0.727	No change over time
	Ni-WAE	-0.074	0.624	No change over time
	Ni-TD*	-0.482	<0.001	Reduced over time
	Pb-WAE	-0.043	0.775	No change over time
	Pb-TD	-0.182	0.156	No change over time
	Se-WAE*	-0.702	<0.001	Reduced over time
	Se-TD	-0.205	0.110	No change over time
	Zn-WAE	-0.121	0.422	No change over time
	Zn-TD*	-0.138	0.285	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.

5.6 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 compared to applicable US EPA guideline values. In accordance with Section 2.3, the data are compared and the highest is then adopted as the 2018 TV for use in the tissue metal risk assessment presented in Section 7.4. The sites are grouped into regions; Local Sites, Upper River, Lower River, Lake Murray.

5.6.1 Upper River

Data summaries of tissue metal TVs for the upper river reference sites are presented in Table 5-19 and Table 5-20.

Reference data were generated from the upper river reference site Ok Om, as this is only upper river reference site where monitoring of fish and prawns is conducted. Indicator species fish flesh at the reference site within the upper river region exhibited detectable concentrations of arsenic, mercury, cadmium, chromium, copper, mercury, selenium and zinc. Prawn abdomen at the upper river reference site exhibited detectable concentrations of arsenic, chromium, copper, selenium and zinc. The results indicate a degree of natural mineralisation at the upper river reference site.

Analysis of trends between 2009 and 2018 indicates that concentrations for metals at the reference site either remained constant or decreased, with the exception of chromium in both fish flesh and prawn abdomen which showed an increasing trend. Trend analysis results are shown in Table 5-21 and Table 5-22, while graphs showing increasing chromium concentrations are shown in Figure 5-63.

Baseline data for fish flesh tissue metal in the upper river region exhibited detectable concentrations of copper, mercury, lead 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 2018 TV were from the following sources:

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

Table 5-19 Tissue metal data for upper river reference sites for previous 24 months (As, Cd, Cr, Cu) (mg/kg 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	0.013	0.020	0.003	0.0064	0.01	0.021	0.18	0.23
	Prawn Ab	24	0.031	0.048	0.003	0.0030	0.02	0.030	5.55	8.38
Wankipe baseline	Fish Flesh	28	0.200	0.200	0.010	0.0200	ND	ND	0.21	0.48
Trigger Value	Fish Flesh	-	-	0.020	-	0.0064	-	0.021	-	0.48
	Prawn Ab	-	-	0.048	-	0.0030	-	0.030	-	8.38

n – number of samples, ND - Not Determined, Ab - Abdomen

Table 5-20 Tissue metal data for upper river reference sites for previous 24 months and applicable US EPA guideline value (Hg, Ni, Pb, Se, Zn) (mg/kg 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	0.044	0.06	0.01	0.01	0.01	0.01	0.24	0.34	5.1	7.04
	Prawn Ab	24	0.010	0.01	0.01	0.01	0.01	0.01	0.45	0.54	13.0	15.40
Wankipe baseline	Fish Flesh	28	0.070	0.08	0.10	0.10	0.70	0.17	0.20	0.20	8.9	10.40
USEPA (2014)	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	-	10.40
	Prawn Ab	-	-	0.01	-	0.01	-	0.01	-	0.54	-	15.40

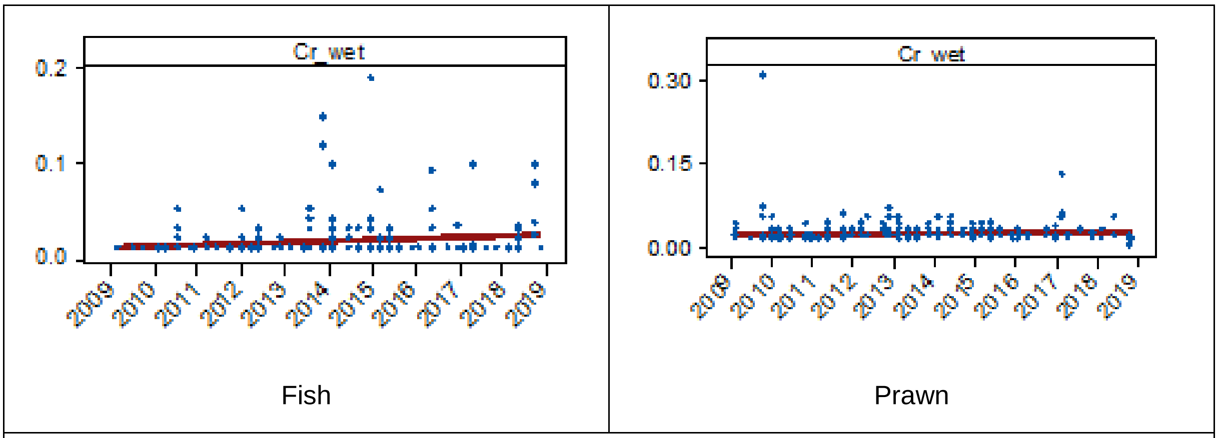
n – number of samples, NA - Not Applicable, dry wt. - dry weight, Ab - Abdomen

Table 5-21 Trends of metals in fish flesh for upper river reference sites 2009 - 2018 determined by Spearman Rank correlation against time

Fish Flesh Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2009–2018)
UpRivs Ref (Trend of all data 2009-2018)	As	-0.049	0.431	No change over time
	Cd	-0.673	<0.001	Reduced over time
	Cr	0.192	0.002	Increased over time
	Cu	-0.120	0.052	No change over time
	Hg	-0.151	0.014	Reduced over time
	Ni	-0.090	0.147	No change over time
	Pb	0.004	0.945	No change over time
	Se	-0.375	<0.001	Reduced over time
	Zn	-0.111	0.073	No change over time

Table 5-22 Trends of metals in prawn abdomen for upper river reference sites 2009 - 2018 determined by Spearman Rank correlation against time

Prawn Abdomen Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend (2009–2018)
UpRivs Ref (Trend of all data 2009-2018)	As	-0.388	<0.001	Reduced over time
	Cd	-0.738	<0.001	Reduced over time
	Cr	0.141	0.019	Increased over time
	Cu	-0.157	0.009	Reduced over time
	Hg*	-	-	No change over time
	Ni	-0.010	0.864	No change over time
	Pb	-0.010	0.863	No change over time
	Se	-0.333	<0.001	Reduced over time
	Zn	-0.228	<0.001	Reduced over time



Chromium concentrations (mg/kg wet wt.) – Upper River reference sites combined 2008 - 2019

Figure 5-63 Trend analysis upper river reference sites tissue metals chromium concentrations (mg/kg wet weight) (scatter plot of all data from 2009 – 2018 with linear trend line)

5.6.2 Lower River

Data summaries and presentation of tissue metal TVs for the lower river sites are presented in Table 5-23 and Table 5-24.

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, mercury, selenium and zinc. The results indicate a degree of natural mineralisation at the lower river reference sites.

Analysis of trends between 2009 and 2018 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 5-25 and Table 5-26, graphical representation of chromium in fish flesh and prawn abdomen data showing increasing trends is presented in Figure 5-64.

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 2018 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, selenium and zinc.
    - Prawn abdomen: NA
- US EPA Guidelines:
    - Fish flesh: selenium
    - Prawn abdomen: NA

Table 5-23 Tissue metal data for lower river reference sites for previous 24 months (As, Cd, Cr, Cu) (mg/kg wet wt.)

Site	Sample	n	As		Cd		Cr		Cu	
			Median	80th%ile	Median	80th%ile	Median	80th%ile	Median	80th%ile
Baia	Fish Flesh	13	0.010	0.010	0.003	0.003	0.01	0.12	0.08	0.12
	Prawn Ab	21	0.067	0.081	0.003	0.003	0.04	0.07	6.40	7.70
Tomu	Fish Flesh	21	0.010	0.010	0.003	0.003	0.01	0.03	0.12	0.14
	Prawn Ab	23	0.053	0.076	0.003	0.009	0.04	0.05	8.50	11.00
Lower River Ref	Fish Flesh		0.010	0.010	0.003	0.003	0.01	0.12	0.12	0.14
	Prawn Ab		0.067	0.081	0.003	0.009	0.04	0.07	8.50	11.00
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	-	0.12	-	0.17
	Prawn Ab	-	-	0.081	-	0.009	-	0.07	-	11.00

n – number of samples, Ab - Abdomen

Table 5-24 Tissue metal data for lower river reference sites for previous 24 months and applicable US EPA guideline value (Hg, Pb, Se, Zn) (mg/kg 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 Flesh	13	0.01	0.02	0.01	0.01	0.01	0.01	0.05	0.057	2.8	3.7
	Prawn Ab	21	0.01	0.01	0.01	0.01	0.01	0.01	0.27	0.32	12.0	14.0
Tomu	Fish Flesh	21	0.05	0.09	0.01	0.01	0.01	0.01	0.11	0.19	2.9	7.5
	Prawn Ab	23	0.01	0.01	0.01	0.01	0.01	0.01	0.24	0.27	12.0	15.0
Lower River Ref	Fish Flesh		0.05	0.09	0.01	0.01	0.01	0.01	0.11	0.19	2.9	7.5
	Prawn Ab		0.01	0.01	0.01	0.01	0.01	0.01	0.27	0.32	12.0	15.0
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	-	0.17	-	0.03	-	2.26	-	7.5
	Prawn Ab	-	-	0.01	-	0.01	-	0.01	-	0.32	-	15.0

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

Table 5-25 Trends of metals in fish flesh at lower river reference site 2009 - 2018 determined by Spearman Rank correlation against time

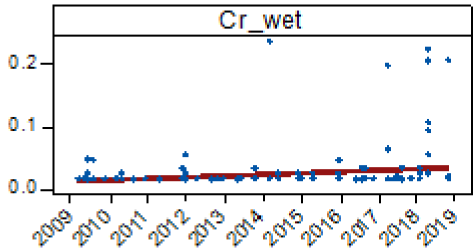
Fish flesh Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (2009–2018)
LwRivs Ref (Trend of all data 2009-2018)	As	-0.181	0.009	Reduced over time
	Cd	-0.816	<0.001	Reduced over time
	Cr	0.191	0.006	Increased over time
	Cu	-0.227	0.001	Reduced over time
	Hg	-0.314	<0.001	Reduced over time
	Ni	-0.224	0.001	Reduced over time
	Pb	-0.005	0.430	No change over time
	Se	-0.466	<0.001	Reduced over time
	Zn	-0.042	0.541	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 5-26 Trends of metals in prawn abdomen at lower river reference sites 2009 - 2018 determined by Spearman Rank correlation against time

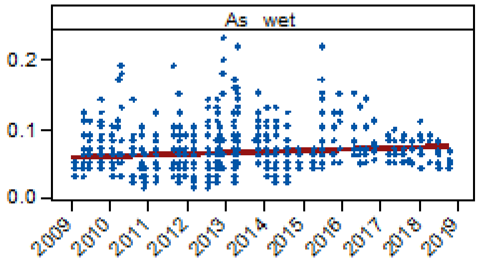
Prawn Abdomen Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (2009–2018)
LwRivs Ref (Trend of all data 2009-2018)	As	0.147	<0.001	Increased over time
	Cd	-0.512	<0.001	Reduced over time
	Cr	0.045	0.247	No change over time
	Cu	0.259	<0.001	Increased over time
	Hg*	-	-	No change over time
	Ni	-0.078	0.045	Reduced over time
	Pb	-0.100	0.010	Reduced over time
	Se	0.104	0.008	Increased over time
	Zn	0.162	<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.



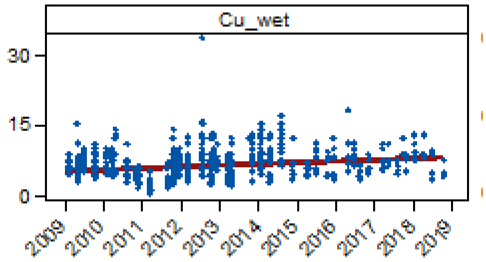
Fish

Chromium concentrations (mg/kg wet wt.) – Lower River reference sites combined 2008 - 2019



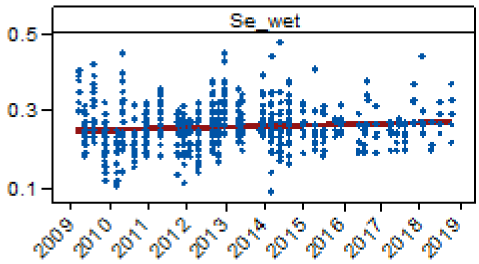
Prawn

Arsenic concentrations (mg/kg wet wt.) – Lower River reference sites combined 2008 - 2019



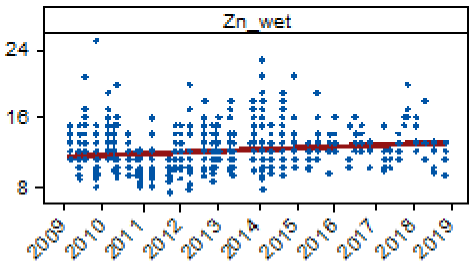
Prawn

Copper concentrations (mg/kg wet wt.) – Lower River reference sites combined 2008 - 2019



Prawn

Selenium concentrations (mg/kg wet wt.) – Lower River reference sites combined 2008 - 2019



Prawn

Zinc concentrations (mg/kg wet wt.) – Lower River reference sites combined 2008 - 2019

Figure 5-64 Trend analysis lower rivers reference site tissue metals concentrations (mg/kg wet weight) (scatter plot of all data from 2009 – 2018 with linear trend line)

5.6.3 Lake Murray

Data summaries and presentation of tissue metal TVs for the Lake Murray and ORWB sites are presented in Table 5-27 and Table 5-28.

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

Analysis of trends between 2009 and 2018 indicated that the concentrations of all metals did not change over the time period. Trend analysis results are shown in Table 5-29.

Baseline data for fish flesh tissue metal in the Lake Murray and ORWB region exhibited detectable concentrations of 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 2018 TV were from the following sources:

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

Table 5-27 Summarised tissue metal data for Lake Murray reference sites for previous 12 months (As, Cd, Cr, Cu), presenting median and 80th%ile of data for each site (mg/kg wet wt.)

Site	Sample	n	As		Cd		Cr		Cu	
			Median	80^{th}%ile	Median	80^{th}%ile	Median	80^{th}%ile	Median	80^{th}%ile
Maka	Fish Flesh	3	0.01	0.01	0.003	0.003	0.01	0.01	0.08	0.10
Miwa baseline	Fish Flesh	7	0.04	0.05	0.002	0.002	0.02	0.03	0.16	0.20
Trigger Value	Fish Flesh	-	-	0.01	-	0.003	-	0.03	-	0.20

n – number of samples

Table 5-28 Summarised tissue metal data for Lake Murray reference sites for previous 12 months and applicable US EPA guideline value (Hg, Ni, Pb, Se, Zn), presenting median and 80th%ile of data for each site (mg/kg wet wt.)

Site	Sample	n	Hg		Ni		Pb		Se		Zn	
			Median	80^{th}%ile	Median	80^{th}%ile	Median	80^{th}%ile	Median	80^{th}%ile	Median	80^{th}%ile
Maka	Fish Flesh	3	0.34	0.49	0.01	0.01	0.01	0.01	0.22	0.24	2.50	2.50
Miwa baseline	Fish Flesh	7	0.11	0.17	0.10	0.19	0.05	0.07	0.13	0.17	2.87	3.12
USEPA (2014)	Fish Flesh	NA	NA	NA	NA	NA	NA	NA	2.26 (11.3 dry wt.)		NA	NA
Trigger Value	Fish Flesh	-	-	0.49	-	0.19	-	0.07	-	2.26	-	3.12

n – number of samples, NA – not applicable

Table 5-29 Trends of metals in fish flesh at Lake Murray and ORWB reference sites 2009-2018 determined by Spearman Rank correlation against time

Fish Flesh Site	Element	Spearman's rho	p-Value (p=0.05)	Trend (2009-2018)
LMY Ref Site (Maka) (Trend of all data 2009-2018)	As	-0.632	0.178	No change over time
	Cd	-1.000	*	No change over time
	Cr	*	*	No change over time
	Cu	-0.735	0.096	No change over time
	Hg	-0.315	0.543	No change over time
	Ni	*	*	No change over time
	Pb	*	*	No change over time
	Se	-0.533	0.276	No change over time
	Zn	-0.630	0.180	No change over time

LOR - Limit of Reporting, ND – No data

5.7 Background Aquatic Biology and Impact Assessment Criteria

Impact assessment trigger values have been developed in accordance with the methodology outlined in Section 2.6.

It should be noted that the impact assessment for Lake Murray cannot be performed for 2018 due a lack of reliable data from 2018 monitoring. Biological sampling in Lake Murray during 2018 was limited with no replication and no repeat sampling, meaning that the data are unable to support a conclusive impact assessment. Therefore, trigger values for Lake Murray have not been presented. Improved sampling methods will be applied in 2019, with the aim of presenting an impact assessment for Lake Murray in the 2019 AER.

5.7.1 Upper River – Indicator Parameters and TVs

A summary of indicator parameters and TVs for the upper river are provided in Table 5-30.

Table 5-30 Trigger values for fish and prawns at Upper River derived from the average of the previous 24 months data from reference Ok Om.

Test Site	Species	TV Source	Indicator	n	Upper River TV	
					Abundance	Biomass (g)
Wasiba & Wankipe	Fish	OK OM REFERENCE	Total fish species	8	20.4	1,383
		OK OM REFERENCE	*N. equinus*	8	12.9	856
	Prawn	OK OM REFERENCE	Total prawn species	8	27.8	123
			M. hanschini	8	12.5	58.0
			M. lorentzi	8	15.1	63.4

5.7.2 Lower River – Indicator Parameters and TVs

A summary of indicator parameters and TVs for the upper river are provided in Table 5-31.

Table 5-31 Trigger value options used for Lower River parameters.

Test Site	Species	Sample	Indicator	n	Lower River Trigger Value		
					Richness	Abundance	Biomass (kg)
Bebelubi	Fish	OPTION A1 BAIA 'BASELINE'	Total fish species	6	3.0	15.0	8.4
		OPTION A2 BAIA REFERENCE	Total fish species	8	3.9	8.6	4.8
Tium-sinawam	Fish	OPTION B1 TOMU 'BASELINE'	Total fish species	19	5.2	24.8	13.5
		OPTION B2 TIUM BASELINE	Total fish species	15	5.0	21.8	15.4
		OPTION B3 TOMU REFERENCE	Total fish species	8	5.8	21.1	17.2

6 COMPLIANCE

This Section provides a summary of the operation's compliance with environmental legal requirements. Table 6-1 is a summary of compliance against the operation's environmental permit conditions. Overall the site achieved compliance with 99% of the permit conditions, non-compliance related to one short duration event each at two of the five sewage treatment plants where TSS concentrations in the discharge exceeded the permit limit. The duration of each event was less than 24 h and TSS in the discharge remained below that of the receiving environment, as a result the environmental risk 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 the SG3 during 2018 and shows that water quality at SG3 complied with the permit criteria during 2018. Water quality data for river monitoring sites upstream of SG3 are also presented and show that water quality complied with the SG3 criteria at all sites between the SG2 and SG3 where monitoring was conducted in 2018. Monitoring was not conducted at SG1 due to security concerns.

Table 6-1 Compliance summary 2018

Permit	% Compliance	Comments
Waste Discharge Permit WD – L3 (121)	99%	Non-compliance related to one short duration event from each of two of the five sewage treatment plants where TSS concentrations in the discharge exceeded the permit limit.
Water Extraction Permit WE – L3 (91)	100%	Compliant with all eight (8) conditions.
TOTAL	**99%**	Target is 100% compliance.

Table 6-2 Median water quality at Upper River Test Sites against SG3 permit criteria 2018 (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	12	7.8	0.01	1.3	0.19	0.4	1.3	0.9	0.1	9.4
Wasiba	14	7.6	0.01	1.3	0.08	0.4	1.1	0.6	0.1	7.1
Wankipe	15	7.8	0.01	1.1	0.05	0.3	1.1	0.7	0.1	5.8
SG3	202	7.7	0.01	1.1	0.05	0.3	1.0	0.6	0.1	6.8
SG3 Permit Criteria		**6.5 – 9.0**	**4.0**	**50**	**1.0**	**10**	**10**	**50**	**3.0**	**50**

(green)	Compliant
(orange)	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 2018, 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 some flow continues to occur downstream of the dam wall when the dam is not overflowing due to leakage from the dam. During 2018, there were 19 occurrences when the dam did not overflow (for one or more days) with the longest period being 11 days.

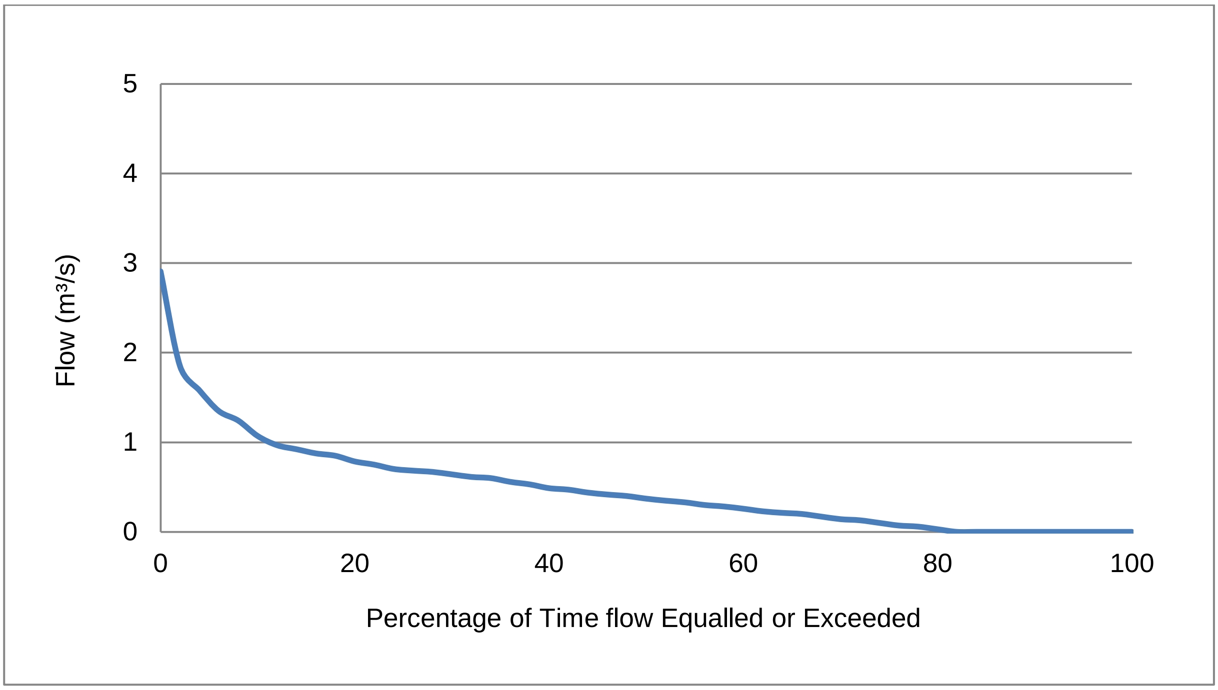


Figure 7-1 Daily flow duration curve (estimated) for Waile Creek Dam overtopping

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 500 m 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.

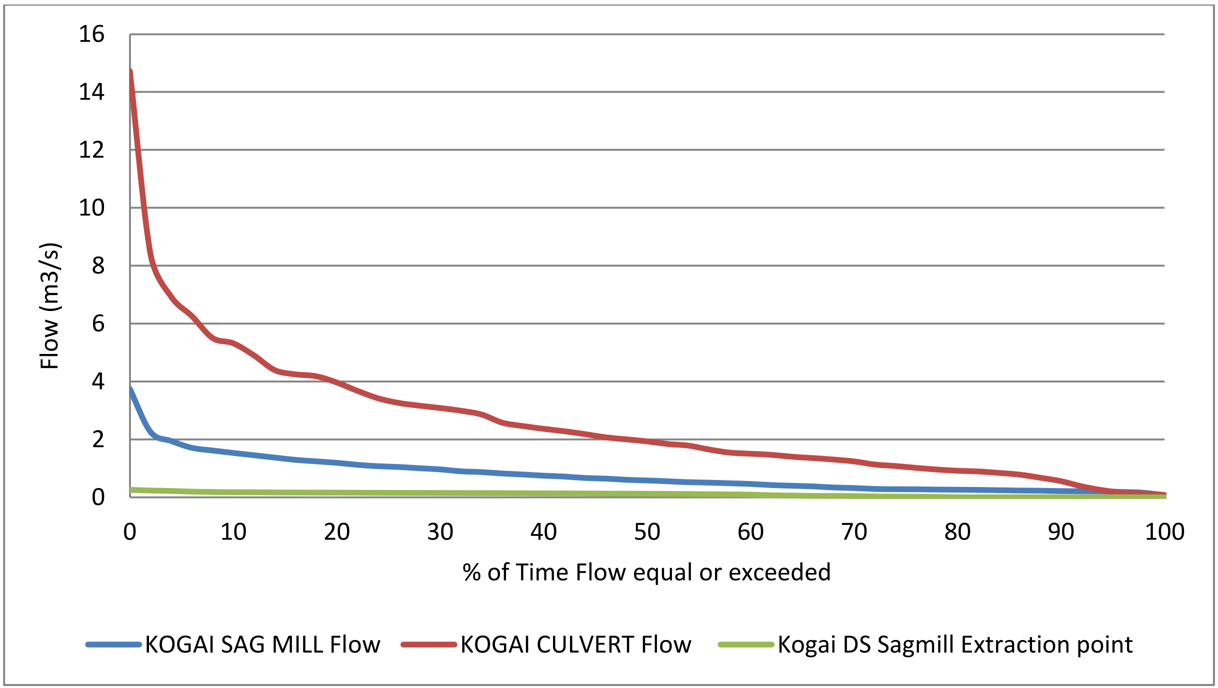


Figure 7-2 Daily flow duration curves for Kogai Creek

7.2 Sediment Transport and Fate of Sediment

Sediments contained in the tailings discharge, as well as those 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 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 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 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 in 2018 are shown in Figure 7-3, 2018 monthly TSS loads are shown in Figure 7-4 and historical annual TSS loads are shown in Figure 7-5. As noted in a previous section, SG3 flow data between about April and August 2018 are known to be of poor quality due to instrumentation problems so there is some uncertainty associated with flow and sediment load summaries reported for those months.

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 2018 was estimated by Gumleaf to be 21.5 Mt, this compares to the long-term median since 1990 of approximately 44 Mt/a, and an annual load in 2017 of 78.9 Mt.

This value of 21.5 Mt is lower than expected and may be an artefact of the poor quality flow data reported for SG3 between April and August 2018. Based on professional judgement, the actual suspended load may be higher, but less than the long-term median of 44 Mt/a.

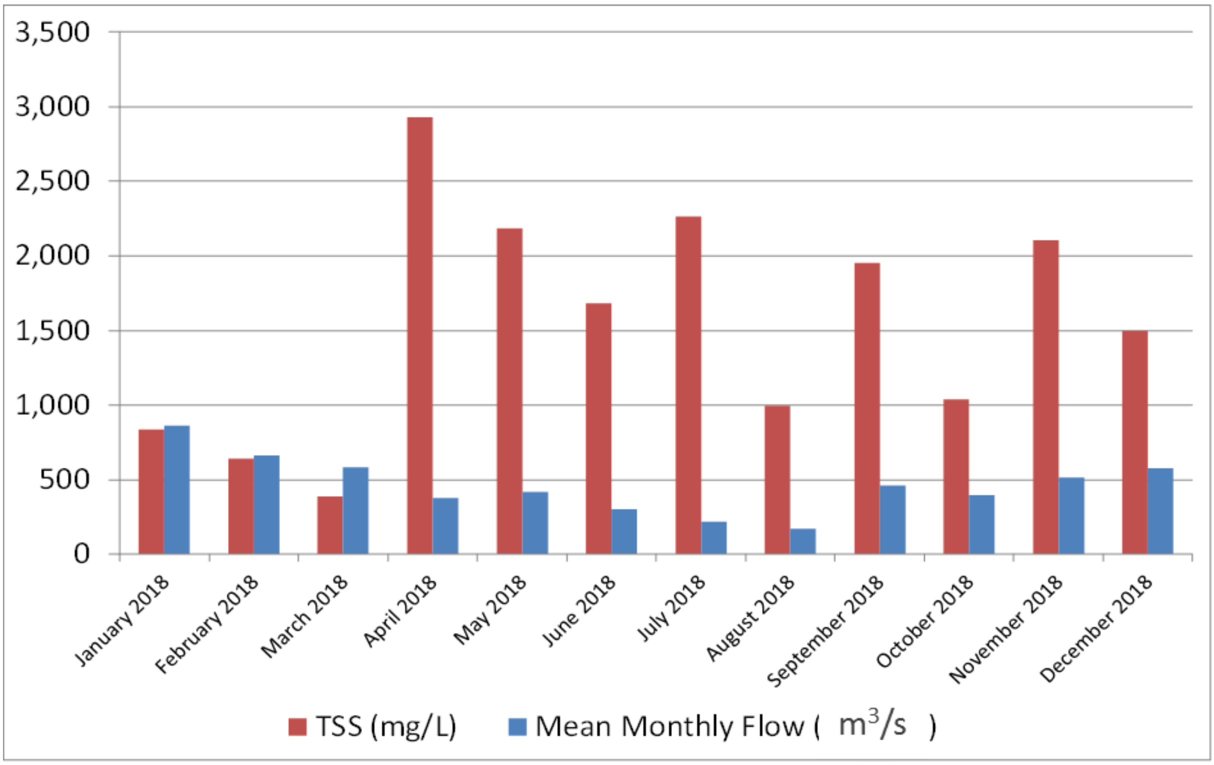


Figure 7-3 Mean monthly TSS and flow at SG3 for 2018

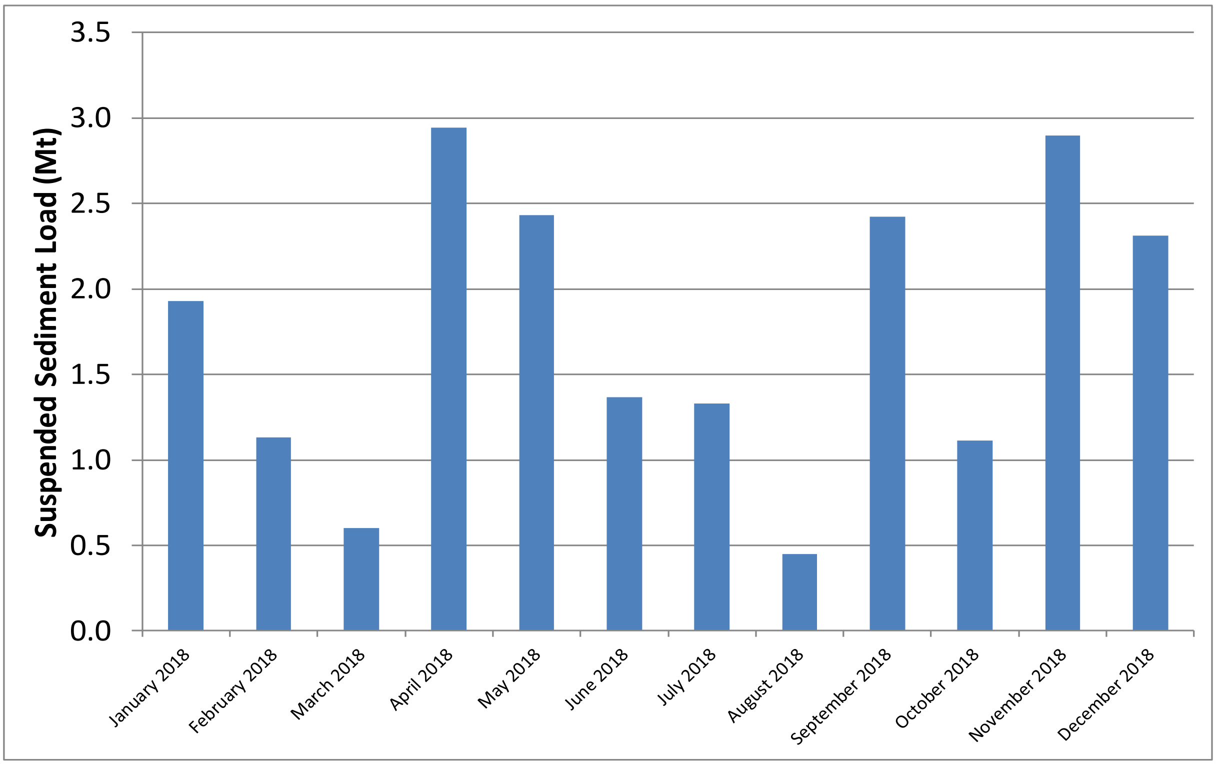


Figure 7-4 Estimated mean monthly suspended sediment loads for SG3 (Mt).

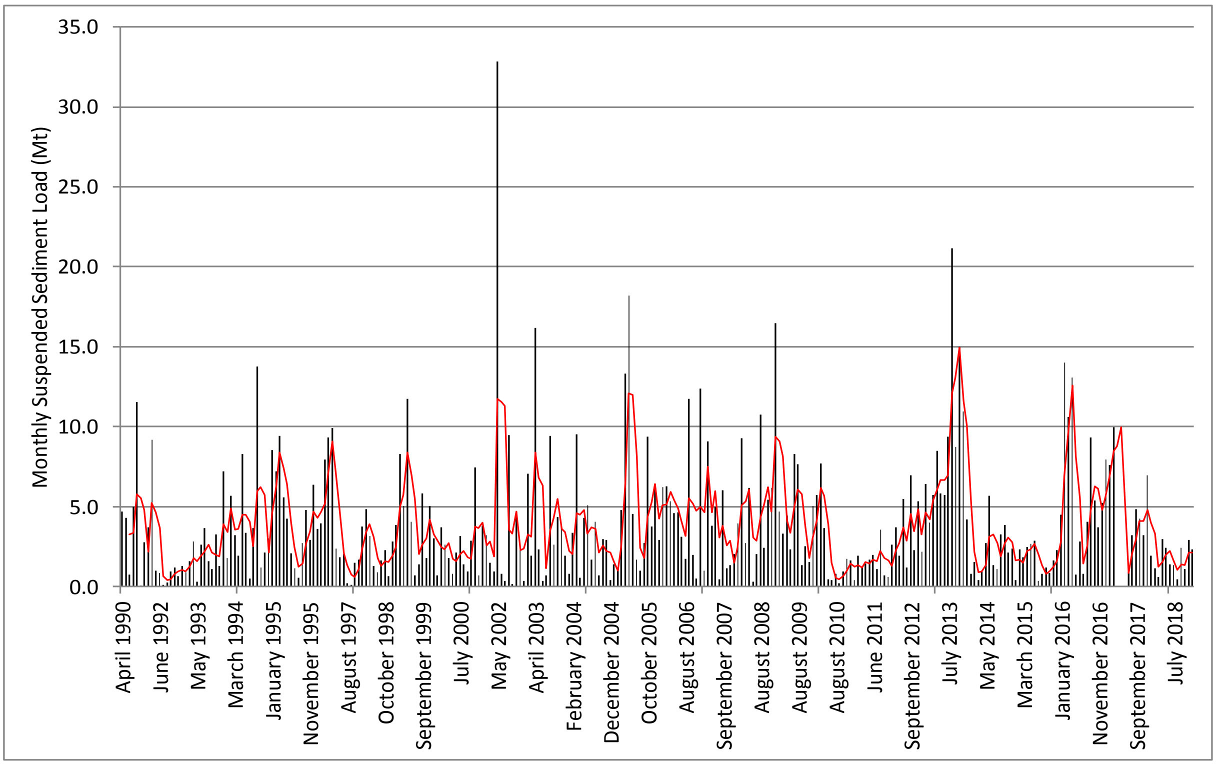
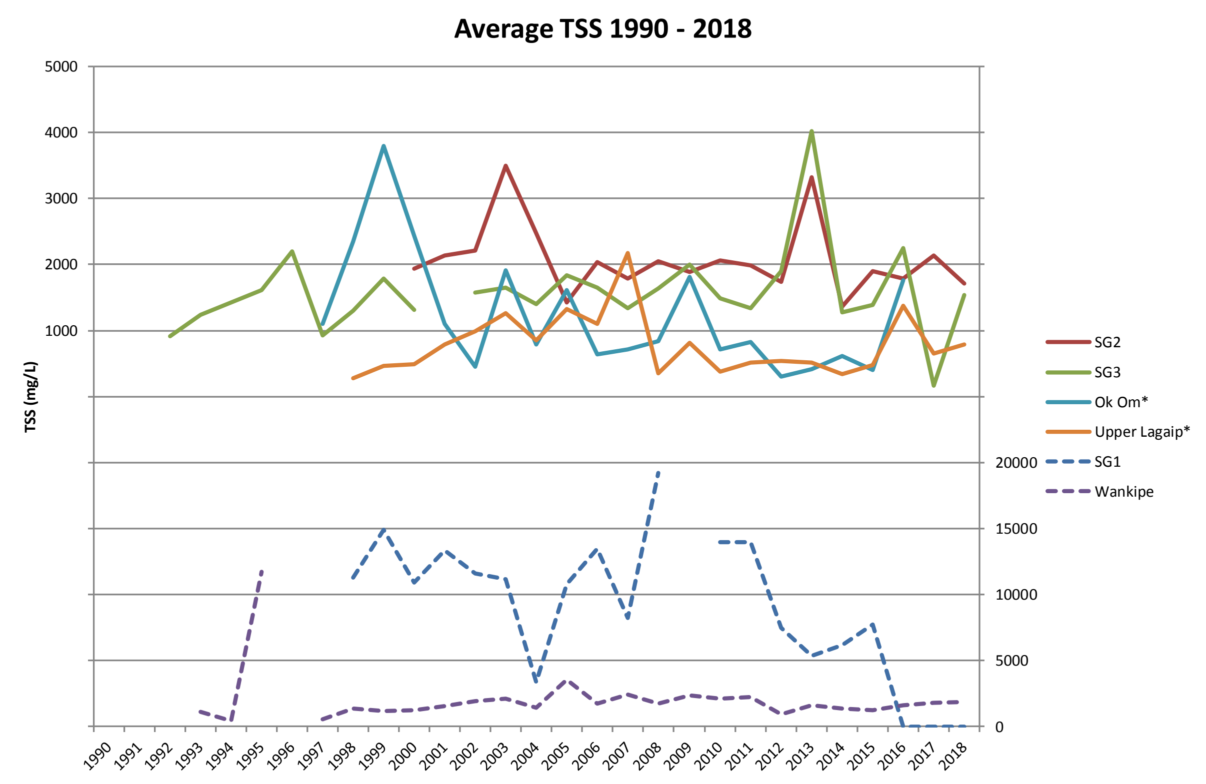


Figure 7-5 Estimated monthly suspended sediment load (black bars) with 3-month moving average at SG3 for full record (red solid line)

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 average TSS concentrations at river monitoring stations upstream of SG3. In 2018, all reference and test sites showed similar TSS concentrations compared to recent historical values.



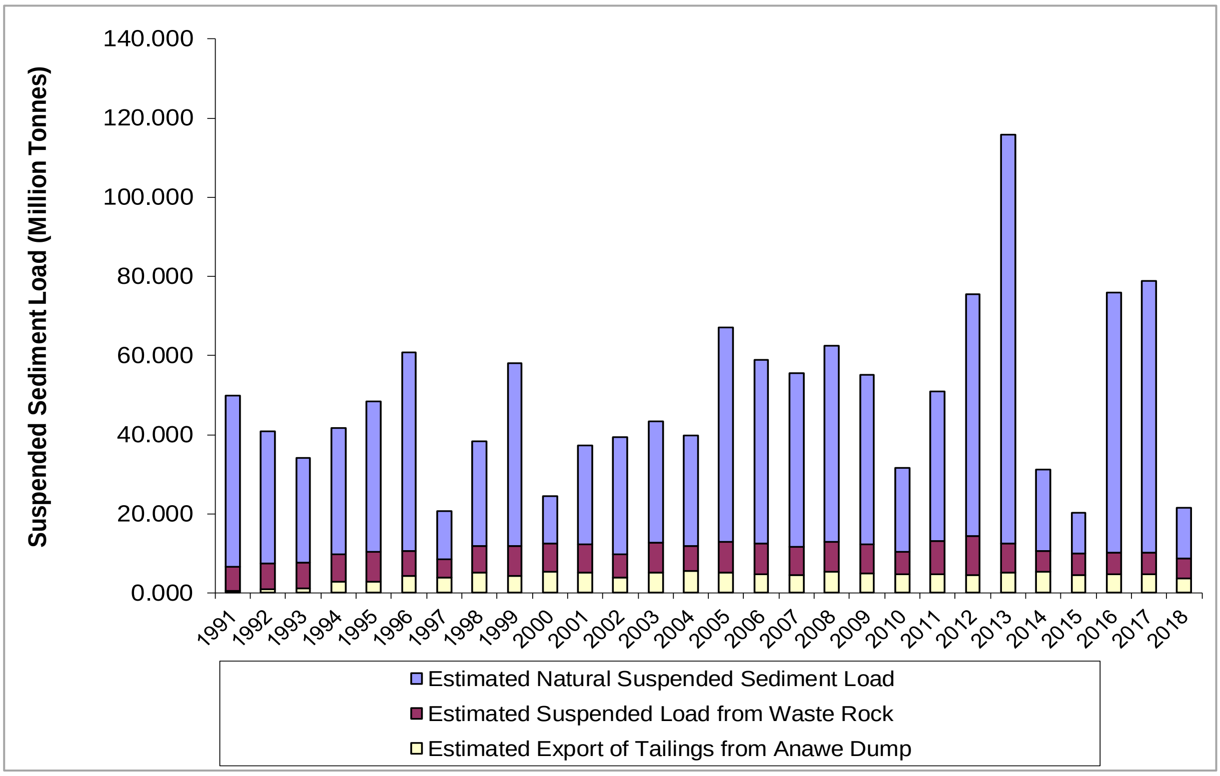
* Reference site, RHS – Right hand side y-axis

Figure 7-6 Historical average TSS 1990-2018

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 2018 were consistent with historical rates. However, the background TSS load (computed from SG3 flow and TSS data) was lower than expected. As previously discussed, this may be an artefact of unreliable flow data being recorded between April and August and the actual natural load therefore is expected to have been higher.

The effect of underestimating the natural load leads to the proportion of the total suspended load that was mine-derived being overestimated. The calculated percentage of total suspended sediment that was mine-derived during 2018 was calculated to be 41%, which compares to a long term median of approximately 23%. 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).



Note – Due to data recovery issues at SG3 during 2018, the actual natural sediment load for 2018 is expected to have been higher than that estimated by the model.

Figure 7-7 Suspended sediment budget at SG3 1991-2018

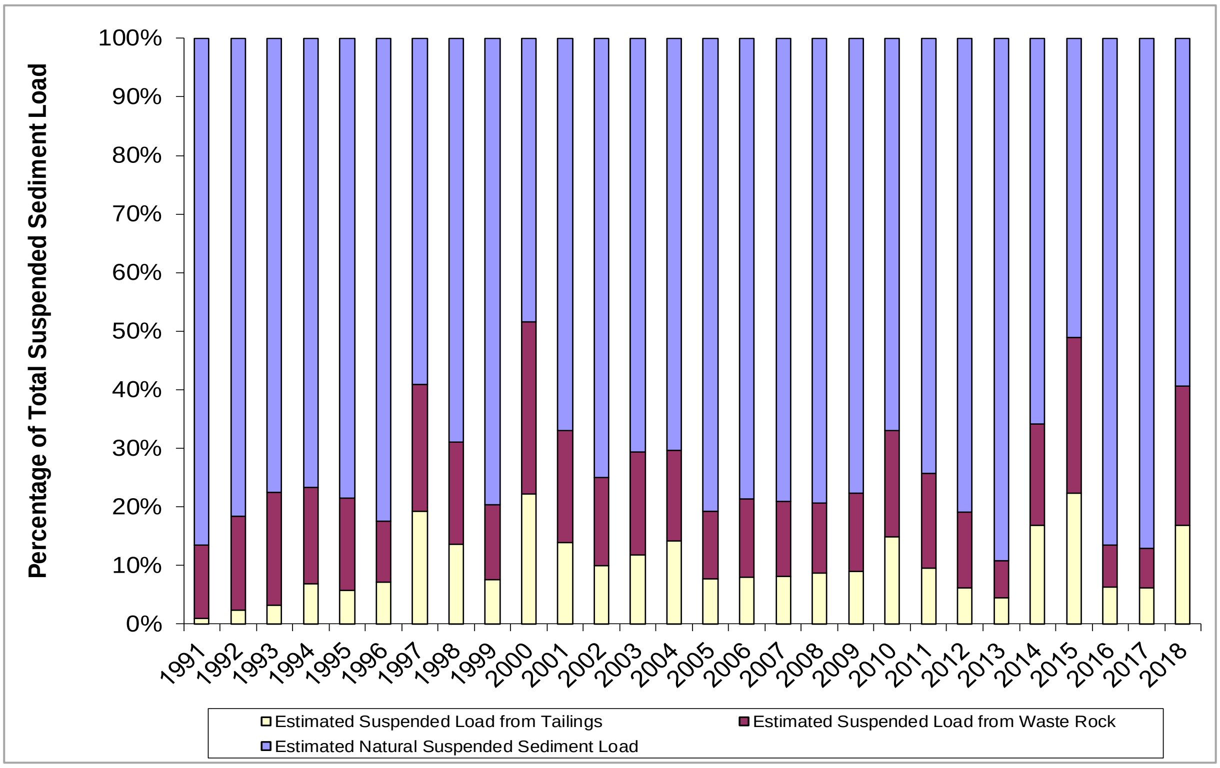


Figure 7-8 Relative contribution of natural and mine-derived suspended sediment at SG3 (%) 1991-2018

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 two 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. The Kaiya cross section was also not surveyed in 2018 due to security concerns but a helicopter flight over the sites confirmed no significant changes. Profiling sites and monitoring history are listed in Table 7-1.

Table 7-1 River profiling sites

Region	Site Name	Duration of monitoring
Porgera Valley	Kaiya River downstream Kogai Creek Confluence	2009 – 2016
	Kaiya River upstream Yuyan Bridge	2009 – 2016
	Kaiya River downstream of Yuyan Bridge	2009 – 2016
Upper Rivers	Lagaip River at SG2	1990 – 2017
Lower Rivers	Strickland River at PF10	2000 – 2017

Observations from previous years indicate that sediment moves along the Kaiya River downstream of the Anjolek erodible dump in an episodic fashion (pulses) showing alternate phases of degradation and aggradation (cut-and-fill) of around 0.5 to 2 m. These phases of cut-and-fill are caused by the interplay of a number of factors, including sediment supply from the dump and river flow rates, which are driven by rainfall patterns. Figure 7-9, Figure 7-10 and Figure 7-11 illustrate the situation within the Kaiya Valley from past surveys. The profiles show that the 2016 bed levels were relatively low compared to levels recorded since 2012.

Figure 7-12 presents a time series of the minimum surveyed point at each cross section within the Kaiya River since between 2009 and up to 2016 and is a useful metric of aggradation or degradation trends. The plots suggest that recently the Kaiya River between the toe of the Anjolek erodible dump and the Porgera River has been variable but steady. The 2016 data indicate that erosion of the bed occurred, with bed levels trending slightly downwards. This is consistent with the interpretation of observations of behaviour of the Anjolek erodible dump which indicates that the landform is eroding and therefore that the river's sediment carrying capacity is not being exceeded.

Helicopter inspections of the Kaiya River valley in 2018 show no evidence of substantial change to the river morphology in 2018 and relative to 2016, although areas of valley wall failure were noted (refer to earlier discussion) and gradual widening in places. Kaiya profiling will resume in the 2019 AER if security concerns abate.

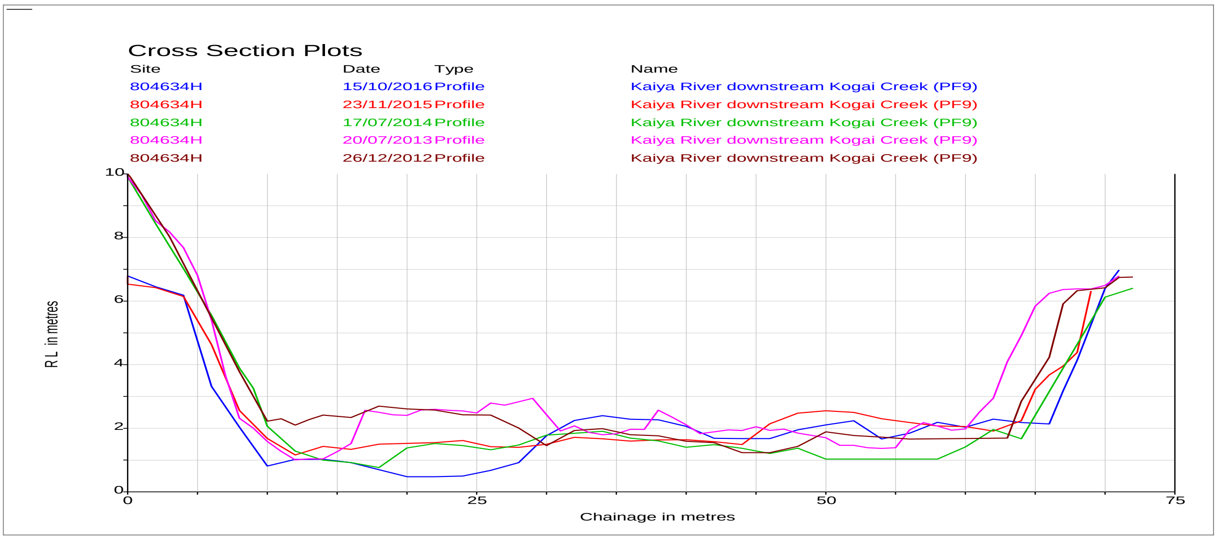


Figure 7-9 Profile comparison (2012-2016) at the Kaiya River downstream of Kogai Creek Confluence

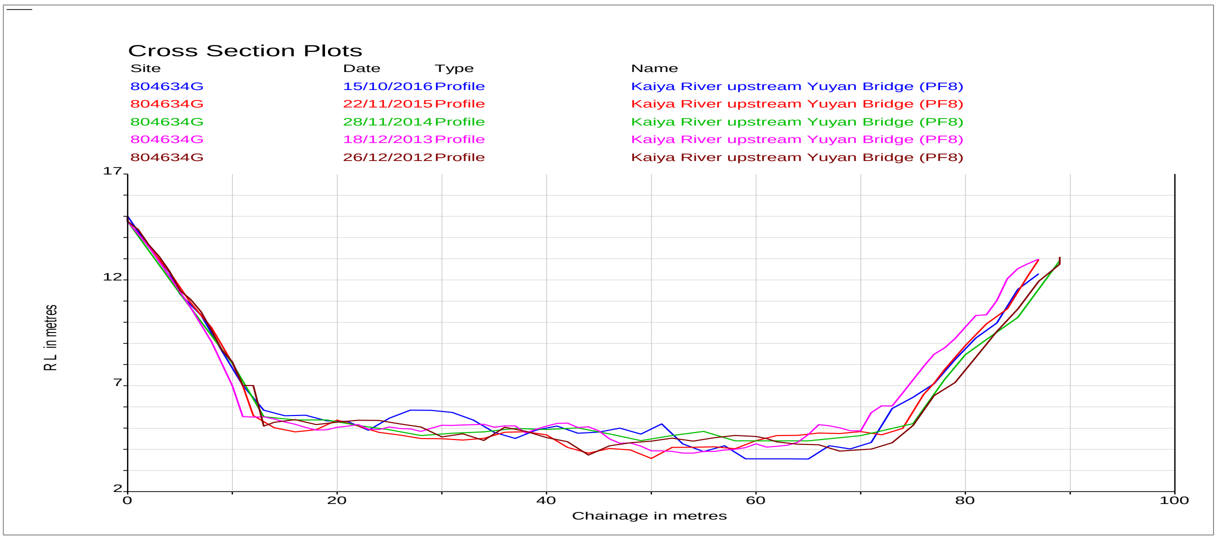


Figure 7-10 Profile comparison (2012- 2016) for the Kaiya River upstream of Yuyan Bridge

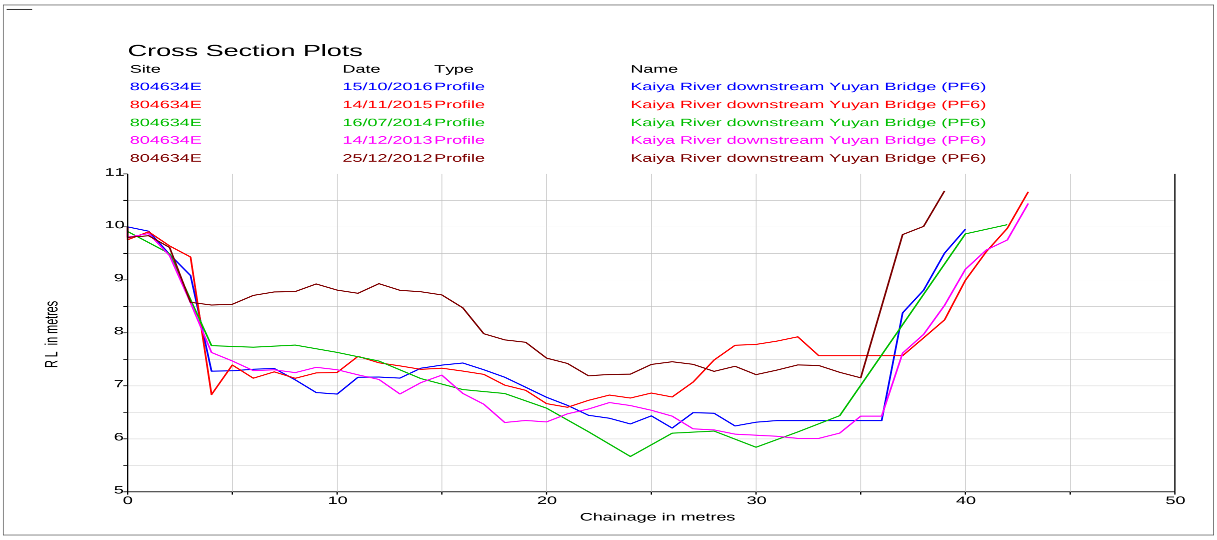


Figure 7-11 Profile comparison (2012-2016) for the Kaiya River downstream of Yuyan Bridge

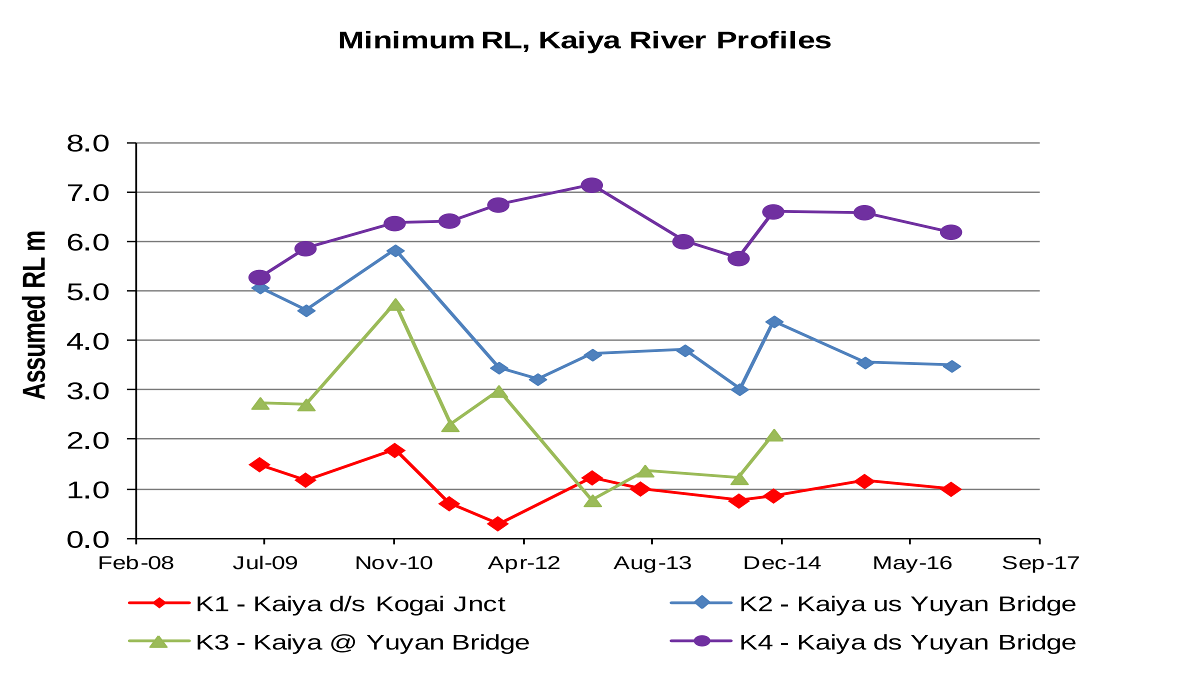


Figure 7-12 Time series of minimum bed elevations along the Kaiya River 2008-2016

As discussed in previous Annual Reports, the bed of the Porgera River at SG1 aggraded 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 7-13 and indicate alternate periods of sediment aggradation and degradation over the years. Aggradation appears to have occurred in 2017, however, in the longer-term there appears to be no long term aggradation or degradation. It was not possible to undertake a survey at SG2 during 2018 due to security concerns at the site.

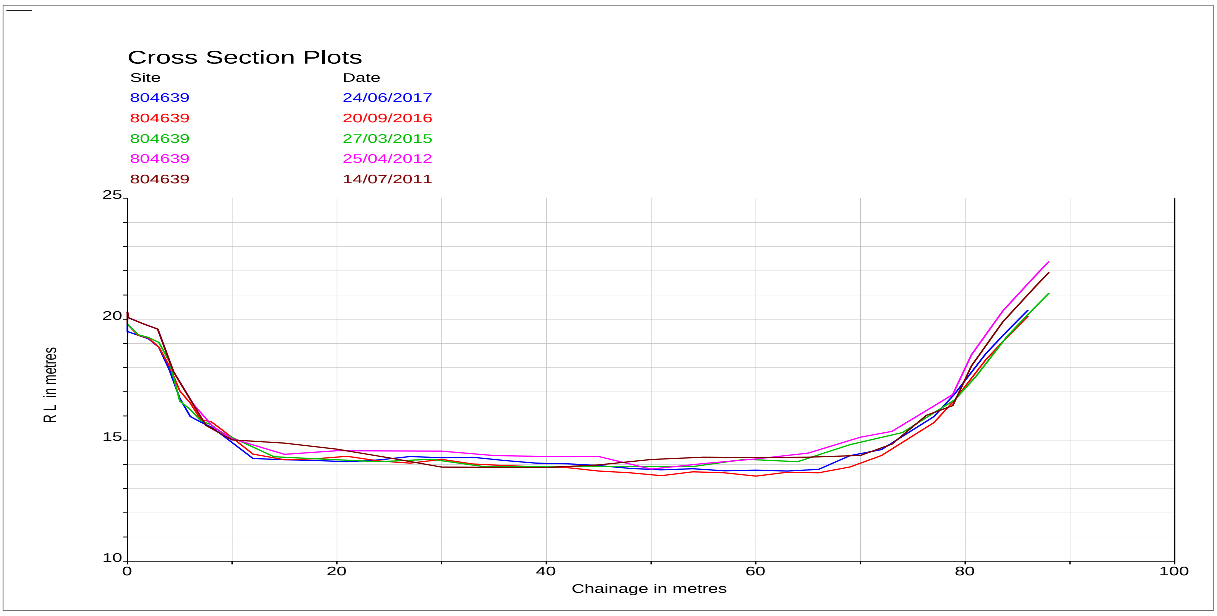


Figure 7-13 Profile comparison (2011-2017) of the Lagaip River at SG2

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.

Figure 7-14 illustrates changes at Profile 10 (PF10), 400 km downstream from the mine (location shown as PF10 in Figure 3-1), located between sites SG4 and SG5). Although generally there is no discernible change or evidence of sediment aggradation at PF10 aside from the variability that is typical of meandering lowland rivers, a notable build up of sediment in the centre of the channel was evident from the 2018 survey results. This is likely to have been formed as a result of increased sediment loads from the Baia, Nomad and Rintoul Rivers following the February earthquake and subsequent landslides within the headwaters of those catchments. The right bank of the channel has been eroded progressively over the last 15 years, resulting in widening of the channel by approximately 30 m, this is attributed to natural meandering processes.

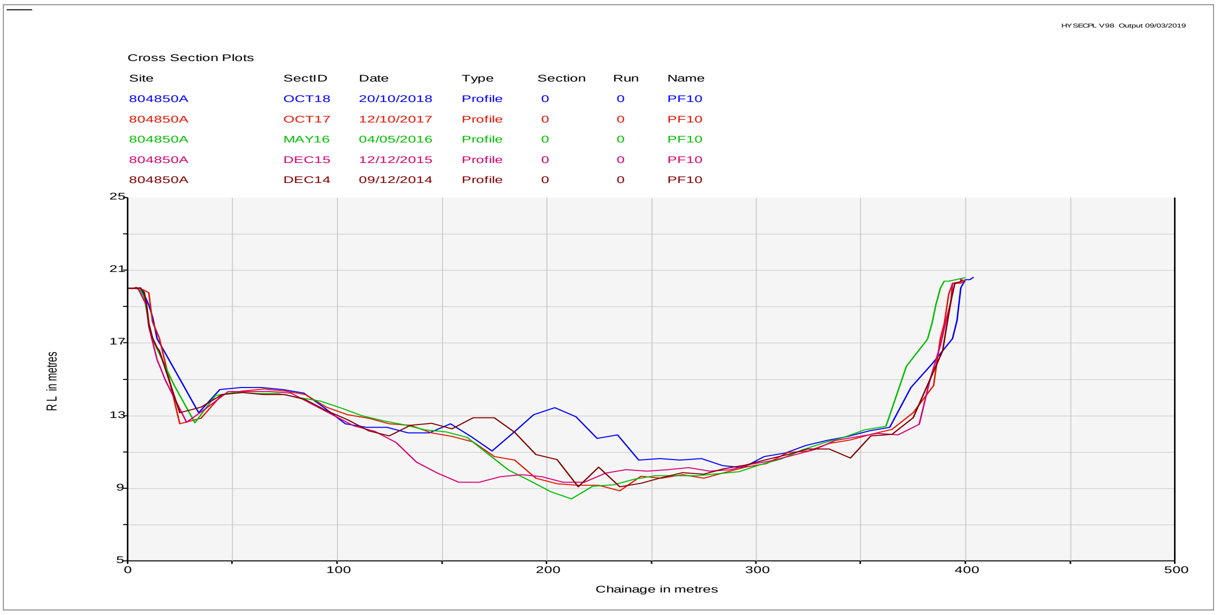


Figure 7-14 Profile comparison (2014-2018) at Profile 10

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, 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 7.4.4.

7.4.1 Water quality

7.4.1.1 Upper and Lower River

The risk assessment for water quality at the upper and lower river involved comparing the 2018 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. It should be noted that in some cases, low sample size (n) results in low statistical power of the Wilcoxon's Rank Test, and therefore can indicate potential risk even when the TSM is lower than the TV. The results of the risk assessment for the upper and lower river are summarised in Table 7-2 and Table 7-3, respectively. Detailed results of the statistical analysis are shown in Appendix D, Tables D-3 to D-10 and figures showing comparisons of the historical data against the TVs are shown in Appendix D, Figures D-1 to D-28.

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 that reflect these processes.

The risk assessment showed that TSS concentrations in 2018 at all upper river test sites were significantly less than the respective TVs and therefore did not pose a risk to aquatic ecosystems. TSS concentrations at Bebelubi and SG4 in the lower river were not significantly different from the TV which indicates potential risk. Both Bebelubi and SG4 experience a large variation in TSS concentrations throughout the year, Bebelubi experienced elevated TSS during the October sampling and TSS at SG4 was elevated in March and April following the February earthquake.

EC at all test sites within the upper and lower rivers, with the exception of SG5, exceeded the relevant TV, indicating potential risk to aquatic ecosystems.

Elevated concentrations of dissolved metals in water 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 ecosystem health and biodiversity.

Risk assessment results indicated that in 2018, dissolved cadmium and chromium concentrations at SG2 in the upper river and dissolved silver at Bebelubi in the lower river were not significantly different from the respective TVs, indicating potential risk. All other dissolved metals concentrations at all sites within the upper and lower rivers, were below their respective TVs and therefore posed a low risk to aquatic ecosystems during 2018.

Table 7-2 Risk assessment – median water quality at upper river test sites in 2018 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	12	7.8	1,300	248	0.01	1.3	0.19[1]	0.4[1]	1.3	10	0.05	0.9	0.1	0.2	9.4
Wasiba	14	7.6	1,950	240	0.01	1.3	0.08	0.4	1.1	13	0.05	0.6	0.1	0.2	7.1
Wankipe	15	7.8	1,200	248	0.01	1.1	0.05	0.3	1.1	11	0.05	0.7	0.1	0.2	5.8
SG3	202	7.7	1,000	242	0.01	1.1	0.05	0.3	1.0	12	0.05	0.6	0.1	0.1	6.8
UpRivs WQ TV		**6.0-8.2**	**2,837**	**228**	**0.05**	**24****	**0.34**	**1.0**	**4.1**	**75**	**0.60**	**21**	**7.5**	**11**	**20**

(Green) Low risk = significantly < TV: all pH, TSS, Ag-D, As-D, Cu-D, Fe-D, Hg-D, Ni-D, Pb-D, Se-D and Zn-D values; Cd-D and Cr-D at Wasiba, Wankipe and SG3.

(Yellow) Potential risk = not significantly different from TV OR significantly > TV: EC at all sites; Cd-D (0.19[1]) and Cr-D (0.4[1]) at SG2.

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

[1] Although TSM falls below 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 is not statistically significantly different from the TV.

Table 7-3 Risk assessment – Median water quality results at lower river test sites in 2018 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	7.6	540[1]	221	0.01[1]	0.9	0.05	0.4	0.8	10	0.05	0.5	0.1	0.2	8.2
SG4	6	7.6	325[1]	196	0.01	0.8	0.05	0.5	0.9	9.4	0.05	0.5	0.1	0.2	7.4
SG5	6	7.8	455	162	0.01	0.8	0.05	0.3	0.7	17	0.05	0.5	0.1	0.2	7.1
LwRivs WQ TV		**6.0-8.1**	**983**	**172**	**0.05**	**24****	**0.20**	**1.0**	**1.4**	**75**	**0.60**	**15**	**3.4**	**11**	**13**

(Green) Low risk = significantly < TV: all pH, As-D, Cd-D, Cr-D, Cu-D, Fe-D, Hg-D, Ni-D, Pb-D, Se-D and Zn-D values; TSS, EC and Ag-D at SG5; Ag-D at SG4.

(Yellow) Potential risk = significantly > TV OR not significantly different from TV: TSS (540[1]), EC and Ag-D (0.01[1]) at Bebelubi; TSS (325[1]) and EC at SG4.

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

[1] Although TSM falls below 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 is not statistically significantly different from the TV.

Trends of water quality in the upper river and the lower river test sites over the period 2009-2018 are summarised in Table 7-4 and Table 7-5. Detailed results are shown in Appendix D, Tables D-10 and D-11, respectively.

Results showed that in the upper river pH and dissolved iron at Wasiba, dissolved zinc at Wankipe and dissolved iron and dissolved zinc at SG3 exhibited a significantly increasing trend over the period.

In the lower river, dissolved zinc at SG4 and TSS and EC at SG5 exhibited a significant increasing trend over the period. Graphical representation of trends at these sites are shown in Figure 7-15.

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 increasing 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 which is not driven by mine inputs. Graphical representation of trends for dissolved zinc at these sites are shown in Figure 7-16.

Details of the statistical analysis are shown in Appendix D, Tables D-3 to D-9, Figures showing comparisons of 2018 data against the TVs are shown in Appendix D, Figures D-1 to D-28 and detailed results of the trend analysis are presented in Table D-10 and D-11.

Table 7-4 Water quality trends at the upper river test sites 2009-2018 (SG1 2009 – 2015)

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
SG1														
SG2														
Wasiba														
Wankipe														
SG3														

	Reduced over time, no change over time or system wide increasing trend
	Increased over time

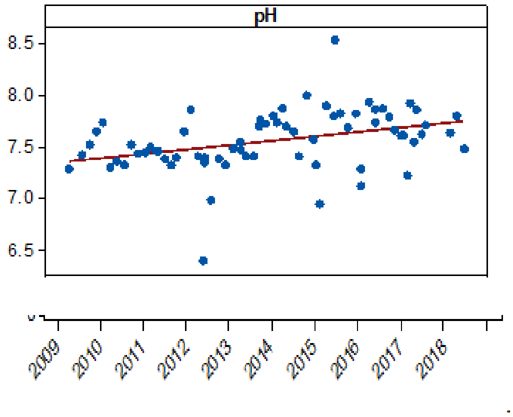
D - Dissolved fraction

Table 7-5 Water quality trends at the lower river reference and test sites 2009- 2018.

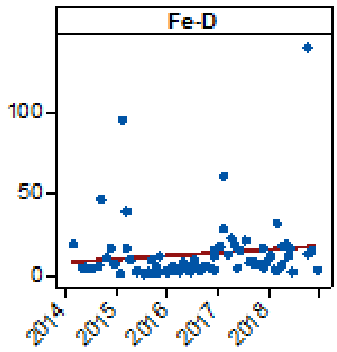
Site	pH	TSS	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Bebelubi														
SG4														
SG5														

	Reduced or no change over time
	Increased over time

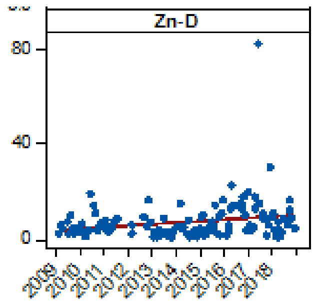
D - Dissolved fraction



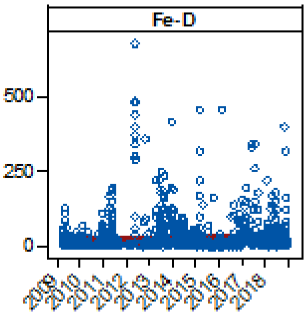
Wasiba pH (Test site)



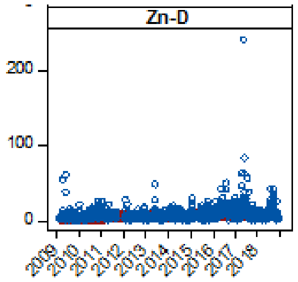
Wasiba Dissolved iron concentrations (µg/L) (Test site)



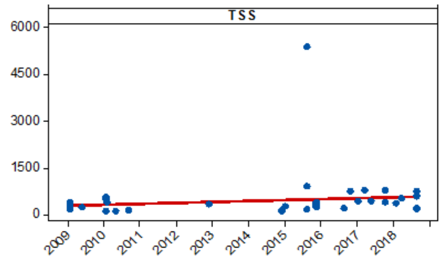
Wankipe Dissolved zinc concentrations (µg/L) (Test site)



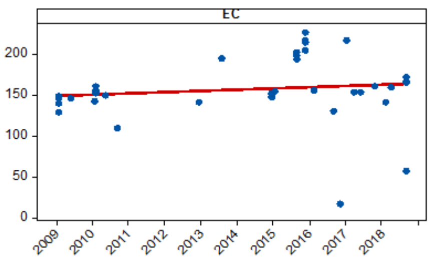
SG3 Dissolved iron concentrations (µg/L) (Test site)



SG3 Dissolved zinc concentrations (µg/L) (Test site)

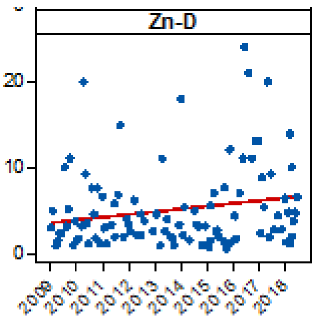


SG5 TSS concentrations (mg/L) (Test site)

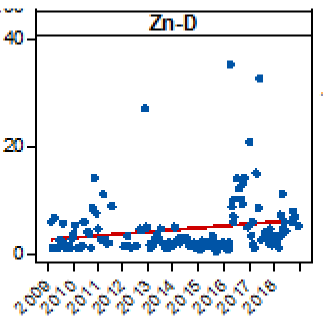


SG5 EC concentrations (mg/L) (Test site)

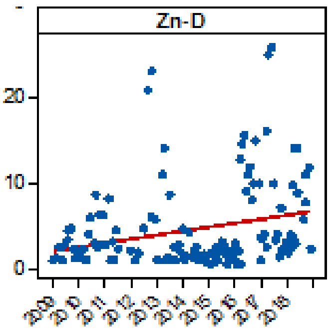
Figure 7-15 Trend analysis upper rivers water quality showing elements with statistically significant increasing trends (scatter plot of all data from 2009 – 2018 with linear trend line)



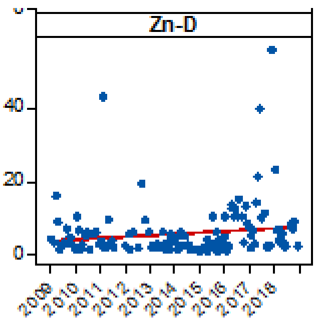
Upper Lagaip - Dissolved zinc (Ref site)



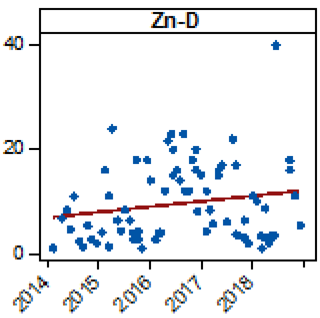
Pori - Dissolved zinc (Ref site)



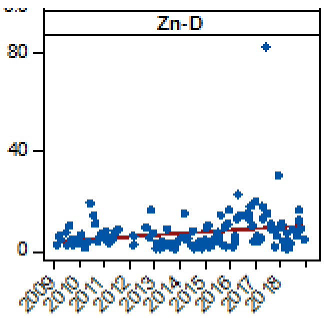
Kuru - Dissolved zinc (Ref site)



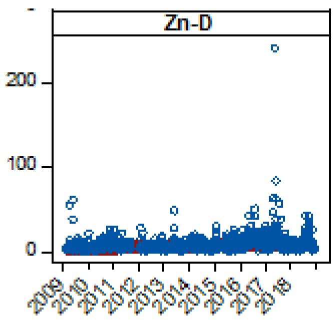
Ok Om - Dissolved zinc (Ref site)



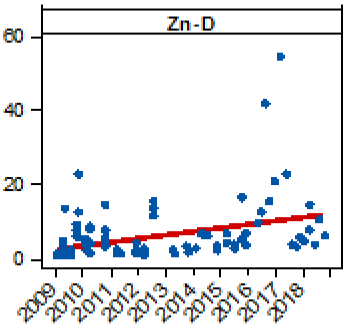
Wasiba - Dissolved zinc (Test site)



Wankipe - Dissolved zinc (Test site)



SG3 - Dissolved zinc (Test site)



SG4 Dissolved zinc concentrations (µg/L) (Test site)

Figure 7-16 Trend analysis upper rivers water quality showing statistically significant increasing trends in dissolved zinc at reference and test sites (scatter plot of all data from 2009 – 2018 with linear trend line)

7.4.1.2 Lake Murray and ORWBs

A summary of the water quality risk assessment results for Lake Murray and the ORWBs is shown in Table 7-6. The results show that EC in Lake Murray at Central Lake, Southern Lake and SG6 exceeded the relevant TV, TSS at Southern Lake and SG6 and dissolved zinc at Central Lake and Southern Lake was not significantly different from the relevant TV, indicating potential risk at these sites. In the ORWBs EC at Kukufionga and Levame and dissolved iron at Avu and Levame exceeded the relevant TV.

Trend analysis results presented in Table 7-7 show a statistically significant increasing trend in pH at all sites, TSS in the Central Lake, Southern Lake and at Kukufionga and Zongamange, EC at Southern Lake and SG6 and dissolved zinc at Central Lake, Southern Lake and Avu. Graphical representation of trends for dissolved zinc at Central Lake, Southern Lake and Avu are shown in Figure 7-17.

Details of the statistical analysis are shown in Appendix D, Tables D-12 to D-18, Figures showing comparisons of 2018 data against the TVs are shown in Appendix D, Figures D-29 to D-58 and detailed results of the trend analysis are presented in Table D-19.

Table 7-6 Risk Assessment – Median water quality results at Lake Murray and ORWB test sites in 2018 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
Central Lake	10	7.5	9.5	21	0.01	0.1	0.05	0.2	0.5	40	0.05	0.5	0.1	0.2	8.4[1]
Southern Lake	10	7.5	14[1]	21	0.01	0.2	0.05	0.3	0.6	27	0.05	0.5	0.2	0.2	5.9[1]
SG6	4	7.4	11[1]	45	0.01	0.5	0.05	0.3	0.5	52	0.05	0.5	0.1	0.2	5.4
LMY WQ TV		**6.0-8.0**	**15**	**18**	**0.05**	**24****	**0.72**	**1.0**	**1.4**	**340**	**0.60**	**11**	**3.4**	**11**	**8.8**
Kuku-fionga	2	7.8	75	273	0.01	1.5	0.05	0.1	0.8	9.8	0.08	0.5	0.1	0.2	4.7
Zonga-mange	2	7.5	225	86	0.01	0.8	0.05	0.1	1.0	20	0.06	0.5	0.1	0.2	8.6
Avu	4	7.1	49	51	0.01	0.9	0.05	0.3	0.9	220	0.05	0.6	0.4	0.2	11
Levame	2	8.2	19	235	0.02	1.2	0.05	0.1	0.8	90	0.05	0.5	0.1	0.2	11
ORWB WQ TV		**6.0-8.1**	**983**	**172**	**0.05**	**24****	**0.20**	**1.0**	**1.4**	**75**	**0.60**	**15**	**3.4**	**11**	**13**

Green	Low risk = significantly < TV
Yellow	Potential risk = significantly > TV or not significantly different from TV

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

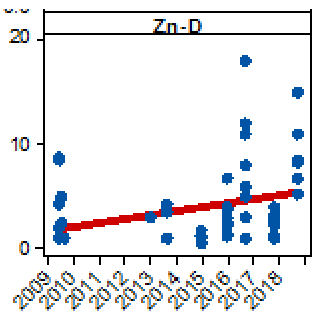
[1] Although TSM falls below the TV, the 2018 dataset contains some values that do exceed the TV, this increases the standard deviation of the dataset and as a result, the TSM is found to be not statistically significantly different from

Table 7-7 Water quality trends at Lake Murray and ORWB reference and test sites 2009-2018

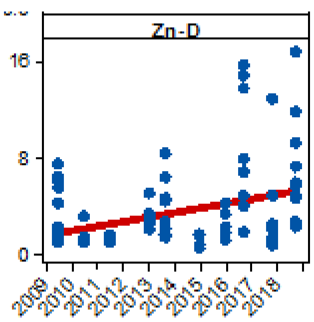
Site	pH	TSS	EC	Ag-D	As-D	Cd-D	Cr-D	Cu-D	Fe-D	Hg-D	Ni-D	Pb-D	Se-D	Zn-D
Central Lake														
Southern Lake														
SG6														
Kuku-fionga														
Zonga-mange														
Avu														
Levame														

	Reduced or no change over time
	Increased over time

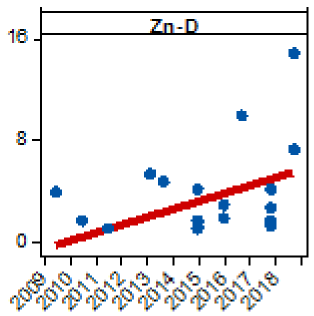
D - Dissolved fraction



Central Lake Dissolved Zinc concentrations (µg/L) (Test site)



Southern Lake Dissolved Zinc concentrations (µg/L) (Test site)



Avu Dissolved Zinc concentrations (µg/L) (Test site)

Figure 7-17 Trend analysis upper rivers water quality showing elements with statistically significant increasing trends (scatter plot of all data from 2009 – 2018 with linear trend line)

7.4.2 Sediment quality

7.4.2.1 Upper and Lower River

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 sediment quality risk assessment for the upper river are presented in Table 7-8 and shows that at SG2 WAE cadmium, WAE selenium and WAE Zn were not significantly different from the respective TVs while WAE lead was significantly greater than the TV. At Wasiba WAE lead and WAE selenium were not significantly different from the TV, at Wankipe WAE nickel was not significantly different from the TV and at SG3 WAE nickel was not significantly different from the TV.

The results of the sediment quality risk assessment in the lower river are presented in Table 7-9 and show WAE selenium at SG4 and SG5 was not significantly different from the TV.

Trend analysis of sediment quality in the upper river showed a statistically significant increasing trend in WAE arsenic, WAE chromium, WAE nickel WAE lead and WAE zinc at SG2 and WAE arsenic, WAE chromium, WAE copper, WAE nickel, WAE lead and WAE zinc at SG3 between 2013 and 2018. In the lower river WAE copper at SG4 showed a significantly increasing trend over the same period. The results of trend analysis for sediment in the upper and lower rivers are shown in Table 7-10 and Table 7-11 respectively. Graphical representation of the trends are shown in Figure 7-18.

Detailed results of the statistical analysis are shown in Appendix E, Tables E-2 to E-8 and figures showing comparisons of the historical data against the TVs are shown in Appendix E, Figures E-1 to E-22, and detailed results of the trend analysis are presented in Appendix E, Table E-9 and E-10.

Table 7-8 Risk Assessment – Median sediment quality results at upper river test sites in 2018 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	0.20	7.8	0.70[1]	12	14	0.01	13	120	0.10[1]	140[1]
Wasiba	14	0.05	3.8	0.40	2.6	8.7	0.01	6.8	33[1]	0.10[1]	55
Wankipe	13	0.05	4.2	0.32	3.6	8.7	0.01	8.0[1]	33	0.10	61
SG3	18	0.05	3.7	0.51	2.8	8.8	0.01	12[1]	25	0.10	70
UpRivs Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.16**	**200**
(green)	Low risk = significantly < TV										
(orange)	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 2018 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 7-9 Risk Assessment – Median sediment quality results at lower river test sites in 2018 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	2.0	0.2	3.5	4.4	0.01	6.2	8.1	0.10	34
SG4	6	0.05	1.4	0.1	3.5	8.7	0.01	6.9	7.8	0.11[1]	26
SG5	6	0.05	3.6	0.3	2.7	12	0.01	6.9	15	0.12[1]	51
LwRivs Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.14**	**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 2018 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 Sediment quality trends at upper river reference and test sites 2013-2018 (mg/kg dry, whole sediment)

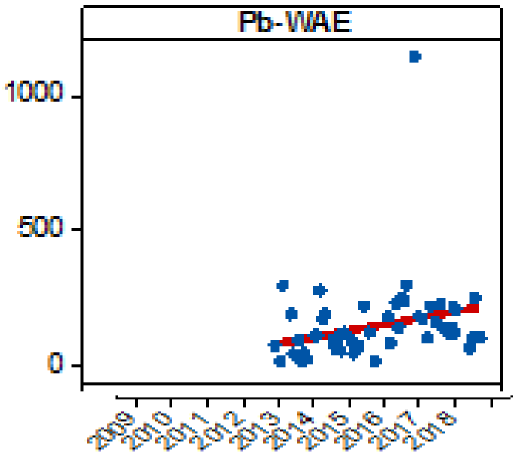
Site	Ag - WAE	As - WAE	Cd - WAE	Cr - WAE	Cu - WAE	Hg - WAE	Ni - WAE	Pb - WAE	Se - WAE	Zn - WAE
SG2										
Wasiba										
Wankipe										
SG3										
	No change or reduced over time									
	Increased over time									

WAE – Weak-Acid-Extractable

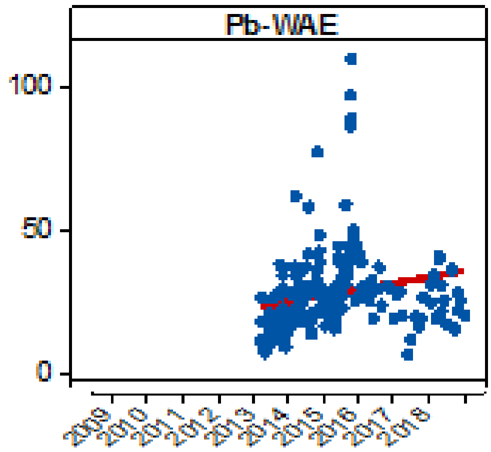
Table 7-11 Comparison of trends of sediment quality at lower river reference and test sites 2013-2018 (mg/kg dry, whole sediment)

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									

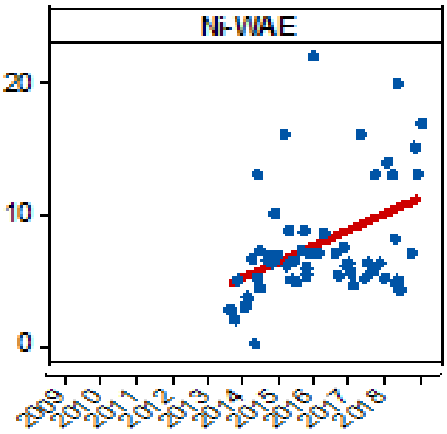
WAE – Weak-Acid-Extractable



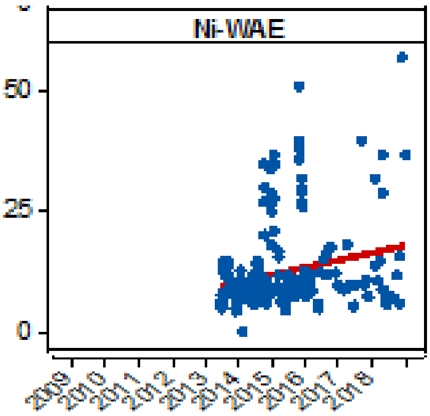
SG2 - WAE lead concentrations (mg/kg dry, whole sediment) (Test site)



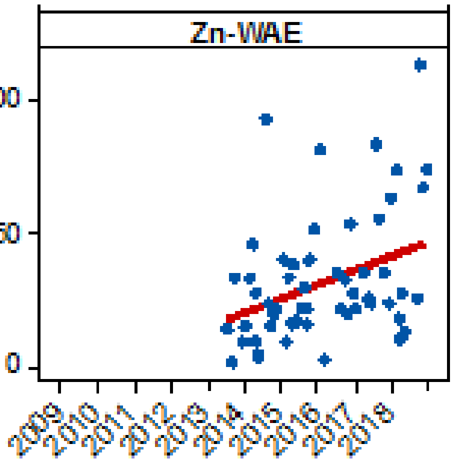
SG3 - WAE lead concentrations (mg/kg dry, whole sediment) (Test site)



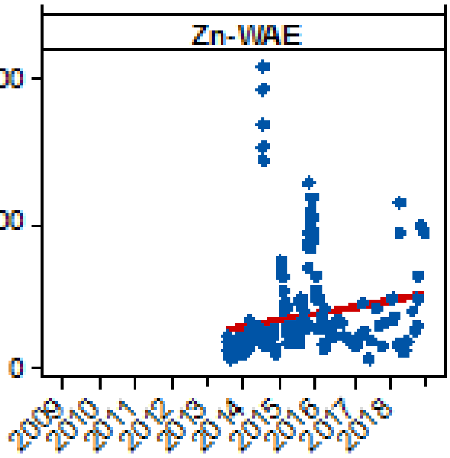
SG2 - WAE nickel concentrations (mg/kg dry, whole sediment) (Test site)



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



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



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

Figure 7-18 Trend analysis upper river test site sediment quality showing statistically significant increasing trends in WAE lead and WAE zinc concentrations (mg/kg dry, whole sediment) (scatter plot of all data from 2009 – 2018 with linear trend line)

7.4.2.2 Lake Murray and ORWBs

The results of the risk assessment for WAE metals concentrations in sediment at Lake Murray and the ORWB test sites are presented in Table 7-12. The risk assessment shows that WAE lead at Avu and Levame and WAE selenium at Zongamange and Levame were not significantly different from the TV, while all other metals at all other sites were below their respective TVs.

A summary of analysis of benthic sediment quality trends analysis, presented in Table 7-13, showed a statistically significant increasing trend of WAE copper at Levame between 2013 and 2018.

Detailed results of the statistical analysis are shown in Appendix E, Tables E-11 to E-17 and figures showing comparisons of the historical data against the TVs are shown in Appendix E, Figures E-23 to E-42. Details of the statistical analysis are shown in Appendix E, Table E-18.

Table 7-12 Risk assessment – median sediment quality results at Lake Murray and ORWB test sites in 2018 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	1.8	0.09	5.4	9.6	0.02	11	11	0.11	46
Southern Lake	10	0.06	1.4	0.1	2.2	17	0.01	5.9	19	0.10	34
SG6	4	0.09	5.2	0.3	3.0	16	0.02	8.0	25	0.15	61
Lake Murray Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.23**	**200**
Kukufionga	2	0.05	2.8	0.4	2.7	11	0.01	6.6	13	0.10	50
Zongamange	2	0.2	5.4	0.3	2.9	15	0.01	6.2	29	0.12[1]	51
Avu	4	0.2	5.4	0.3	2.6	19	0.01	7.6	35[1]	0.12	56
Levame	2	0.2	8.5	0.3	3.8	23	0.01	8.3	49[1]	0.16[1]	61
ORWBs Sed TV		**1.0**	**20**	**1.5**	**80**	**65**	**0.15**	**21**	**50**	**0.14**	**200**

Green	Low risk = significantly < TV
Orange	Potential risk = significantly > TV OR not significantly different from TV

WAE – Weak-Acid-Extractable

[1] Although TSM falls below 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 is found to be not statistically significantly different from the TV.

Table 7-13 Sediment quality trends at Lake Murray and ORWB reference and test sites 2013-2018 (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
L Murray/ORWBs Ref										
Central Lake										
Southern Lake										
SG6										
Kukufionga										
Zongamange										
Avu										
Levame										
	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 River

The results of the tissue metal risk assessment for the upper and lower rivers are shown in Table 7-14 and Table 7-15.

The assessment showed that at Wasiba in the upper river concentrations of arsenic in fish were greater than the TV and copper and nickel in fish flesh were not significantly different from the TVs, while in prawns cadmium and selenium were greater than the TVs and chromium, nickel and lead were not significantly different from the TVs. Results from Wankipe in the upper river showed that arsenic and chromium concentrations in fish flesh were not significantly different from the TVs, while cadmium in prawns was greater than the TV and chromium, nickel and lead were not significantly different from the TVs

In the lower river, the risk assessment showed that at Bebelubi concentrations of copper in fish flesh were not significantly different from the TVs, while arsenic in prawn abdomen was greater than the TV and cadmium in prawn abdomen was not significantly different from the TV. At SG4 selenium in prawn abdomen was greater than the TV while cadmium and nickel in prawn abdomen were not significantly different form the TVs.

A summary of results from trend analysis performed for the upper and lower rivers are presented in Table 7-16 Table 7-17. The results showed that in the upper river concentrations of chromium, lead and selenium in prawn abdomen at Wasiba and nickel in prawn abdomen at Wankipe increased between 2009 and 2018. In the lower river concentrations of copper, selenium and zinc in prawn abdomen at Bebelubi and chromium in fish flesh and copper and selenium in prawn abdomen at SG4 increased over the same period.

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 7-14 Risk assessment – median tissue metal results at upper river test sites in 2018 compared against UpRivs TVs showing which indicators pose low and potential risk (mg/kg wet wt.)

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Wasiba	Fish Flesh	12	0.03	0.004	0.01	0.14[1]	0.06	0.01[1]	0.01	0.42	4.0
	Prawn Ab	12	0.03	0.005	0.02[1]	4.25	0.01	0.01[1]	0.01[1]	0.56	13.0
Wankipe	Fish Flesh	12	0.02[1]	0.003	0.01[1]	0.14	0.04	0.01	0.01	0.30	3.4
	Prawn Ab	12	0.03	0.005	0.02[1]	5.30	0.01	0.01[1]	0.01[1]	0.45	14.0
UpRivs TV	Fish Flesh		0.02	0.0064	0.02	0.48	0.08	0.01	0.17	2.26	10.4
	Prawn Ab		0.048	0.003	0.03	8.38	0.01	0.01	0.01	0.54	15.4
(green)	Low risk = significantly < TV										
(orange)	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 7-15 Risk assessment – median tissue metal results at lower river test sites in 2018 compared against LwRivs TVs showing which indicators pose low and potential risk (mg/kg wet wt.)

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Bebelubi	Fish Flesh	9	0.01	0.003	0.01	0.10[1]	0.05	0.01	0.01	0.15	3.1
	Prawn Ab	11	0.09	0.005[1]	0.03	5.20	0.01	0.01	0.01	0.28	11.0
SG4	Fish Flesh	12	0.01	0.003	0.01	0.09	0.06	0.01[1]	0.01	0.14	3.2
	Prawn Ab	12	0.07	0.006[1]	0.02	8.00	0.01	0.01[1]	0.01	0.34	12.5
LwRivs TV	Fish Flesh		0.07	0.003	0.12	0.17	0.12	0.17	0.03	2.26	7.5
	Prawn Abdo		0.08	0.009	0.07	11.00	0.01	0.01	0.01	0.32	15.0
(green)	Low risk = significantly < TV										
(orange)	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 7-16 Tissue metal trends at upper river ref and test sites 2009 - 2018

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 7-17 Tissue metal trends at lower river ref and test sites 2009–2018

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

7.4.3.2 Lake Murray

The results of the tissue metal risk assessment for Lake Murray are shown in Table 7-18. The assessment shows that all metals were below their respective TVs. It should be noted that Wilcoxon's test was not applied to Lake Murray due to the small sample size, the assessment has been performed based on direct comparison of the TSM and TV. Results of the trend analysis are shown in Table 7-19 and shows that concentrations of all metals either did not change or reduced between 2009 and 2018.

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, Tables F-11.

Table 7-18 Risk assessment – median tissue metal results at Lake Murray test site in 2018 compared against Lake Murray TVs showing which indicators pose low and potential risk (mg/kg wet wt.)

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Miwa	Fish Flesh	1	0.01	0.003	0.01	0.09	0.4	0.01	0.01	0.3	2.5
Lake Murray TV	Fish Flesh		0.01	0.003	0.03	0.20	0.5	0.19	0.07	2.3	3.1
(green)	Low risk = significantly < TV										
(orange)	Potential risk = significantly > TV OR not significantly different from TV										

At Lake Murray, the analysis showed no change in concentration of all metals in fish flesh at Miwa during the period.

Table 7-19 Tissue metal trends at Lake Murray ref and test sites 2009–2018

Site	Sample	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Lake Murray Ref	Fish Flesh	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
Miwa	Fish Flesh	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)	(green)
(green)	No change or reduced over time									
(orange)	Increased over time									

7.4.4 Discussion of physical & chemical toxicant environmental risk assessment

This section presents a discussion and summary of the risk to aquatic ecosystem condition posed by each physical and chemical toxicant within discharges from the operation.

In some cases further investigation and overall assessment of risk posed by each indicator throughout the receiving environment has resulted in a change of the initial risk assessment result from potential risk to low risk. For example, concentrations of dissolved and WAE copper in tailings indicate potential risk. In the receiving environment the initial risk assessment indicates potential risk from copper in fish flesh at Wasiba in the upper river and Bebelubi in the lower river, however in both cases the test site median is not significantly different from the TV, and additionally no other indicators throughout the receiving environment indicate potential risk. Therefore, the overall risk posed by copper is considered low, and the risk ratings for fish flesh at Wasiba and Bebelubi are downgraded from potential risk to low risk.

The final risk assessment results, following further investigation, have been categorised in accordance with the criteria outlined in Table 7-20.

Table 7-22 to Table 7-24 provide a compilation of final risk assessment results for each physical and chemical toxicant in water, benthic sediment, fish tissue and prawn abdomen, for the purposes of comparison throughout the receiving environment and between matrices.

Table 7-20 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 metals 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, the pH was within upper and lower bounds of the respective TVs, indicating low risk to the condition of the receiving environment. An increasing trend for pH at all Lake Murray and ORWB test sites is noted and will continue to be monitored closely in future years.

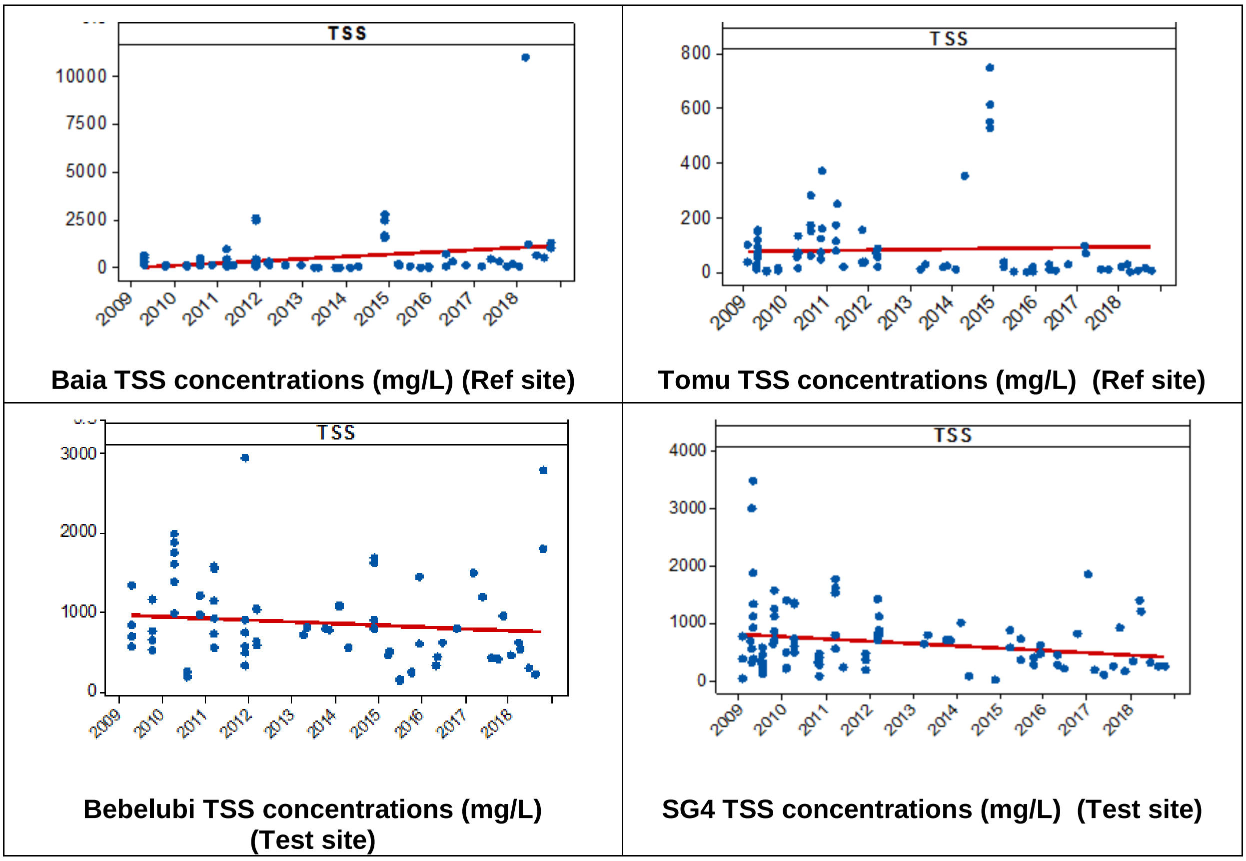
7.4.4.2 Total suspended solids

Tailings and water discharged from Lime Plant, Yakatabari Creek D/S 28 Level and Yunarilama/Yarik at Portal exhibited TSS concentrations that 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, TSS concentrations at Bebelubi and SG4 were not significantly different from the lower river TV, indicating potential risk and warranting further investigation.

Further assessment of the data against the TV showed that there was elevated TSS at reference site Baia, likely caused by the February 2018 earthquake, and this has influenced the results of the risk assessment. The Baia River flows into the Strickland River upstream of Bebelubi and SG4, and therefore increased TSS concentrations in Baia likely also increased TSS concentrations at the Bebelubi and SG4 test sites. The method used to derive the TV is intended to account for potential non-mine related changes, such as the earthquake event. However, the lower river TV is derived from the most recent 24 months data from the Baia and Tomu Rivers and the magnitude of change reflected in the lower river TV for 2018 does not fully account for the increased TSS at the test sites Bebelubi and SG4 caused by natural inputs to the system during the earthquake event. This contributes to the findings that the 2018 test site medians, from these two sites, were not statistically different from the TVs. TSS trends between 2009 and 2018 at the lower river test and reference sites are shown in Figure 7-19. Additionally, it is worth noting that TSS trends at both of the test sites (Bebelubi and SG4) decreased between 2009 and 2018.

Therefore, given the short duration influence of the earthquake and associated elevated TSS concentrations at reference site Baia and downstream on the Strickland River at test sites Bebelubi and SG4 and the long-term decreasing trends of TSS at both sites, the overall risk of TSS at Bebelubi and SG4 in 2018 was considered low.



Baia TSS concentrations (mg/L) (Ref site)

Tomu TSS concentrations (mg/L) (Ref site)

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

SG4 TSS concentrations (mg/L) (Test site)

Figure 7-19 Trend analysis Lower River TSS concentrations (scatter plot of all data from 2009 – 2018 with linear trend line)

In Lake Murray and the ORWBs, TSS concentrations at Southern Lake and SG6 were not significantly different from the TV, indicating potential risk and triggering further investigation. Further assessment of this result showed that unusually low TSS recorded at the Lake Murray reference site in 2017, combined with the method of deriving the TV has contributed to the risk assessment result. Table 7-21 shows summary data from the North Lake Murray reference site for 2017 and 2018 and summary data from the test sites Central Lake, Southern Lake and SG6 for 2018. The 2018 TSS TV for Lake Murray is also provided for comparison, having been calculated from the combined 2017 and 2018 North Lake Murray data set.

The results show that TSS concentrations at North Lake in 2017 were significantly lower than in 2018 and compared to the mean value between 2009 and 2018 of 10mg/L. Therefore when the 2018 TV is calculated using the combined 2017/2018 data, the results is that the TV is reduced, generating a lower TSS TV from that which would be derived from the 2018 data alone.

Furthermore, when the 2018 test site median for Central Lake (9.5 mg/L), Southern Lake (11 mg/L) and SG6 (11 mg/L) are compared to the 2018 reference site data (median = 15 mg/L), it is clear that TSS at the test sites in 2018 was in fact lower than at the reference sites. This indicates a system wide increase in TSS within Lake Murray during 2018 This increase is not fully reflected in the 2018 TSS TV due to the inclusion of the low results from 2017.

In summary, the overall risk posed by TSS at Central and Southern Lake sites in 2018 was considered low.

Table 7-21 Summary data for TSS at Lake Murray reference and test sites (mg/L)

Year	Site Name	N	Mean	StDev	Min	Q1	Median	Q3	Max
2017	Nth Lake	10	3.3	0.95	2	2.8	3	4	5
2018	Nth Lake	10	15	7.6	2	9.5	15	23	24
2018	Central Lake	10	9.9	2.6	7	8	9.5	11	16
2018	Southern Lake	10	14	3.1	9	11	14	17.3	18
2018	SG6	4	12.5	3	11	11	11	15.5	17
2018	LMY Trigger Value	15 (80th%ile from 2017 and 2018 Nth Lake data)							

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; sulphates, calcium, magnesium, sodium and potassium. Sulfides are present in the natural geology of the Porgera deposit, but are concentrated in the tailings, discharge from the competent waste rock dumps (Wendoko Creek downstream of Anawe Nth and Yakatabari Creek downstream of 28 level), and in discharge from the underground mine (Yunarilama/Yarik at Portal), due to oxidation of sulphides in the highly mineralised material.

At all test sites within the receiving environment, with the exception of SG5, Zongamange and Avu, the 2018 median EC was not statistically different from the respective TVs, indicating potential risk to the conditions of the receiving environment.

Further assessment of the data indicated that EC in the upper river test sites was consistently elevated compared to the reference sites, which supports the finding that EC posed a potential risk in the upper river from the mine to SG3. EC data and trends at upper river test and reference site from 2009 – 2018 are presented in Figure 7-20.

In the lower river and Lake Murray and ORWBs, the test site medians for 2018 were not significantly different from the TVs. EC data and trends at the lower river and Lake Murray ORWB test and reference sites from 2009 – 2018 are presented in Figure 7-21. EC at the test and reference sites were comparable throughout the period 2009 – 2018, although increasing trends were observed at Southern Lake, SG6 and Kukufionga. Overall EC was considered to present a low risk in 2018 at the lower river and Lake Murray ORWB sites.

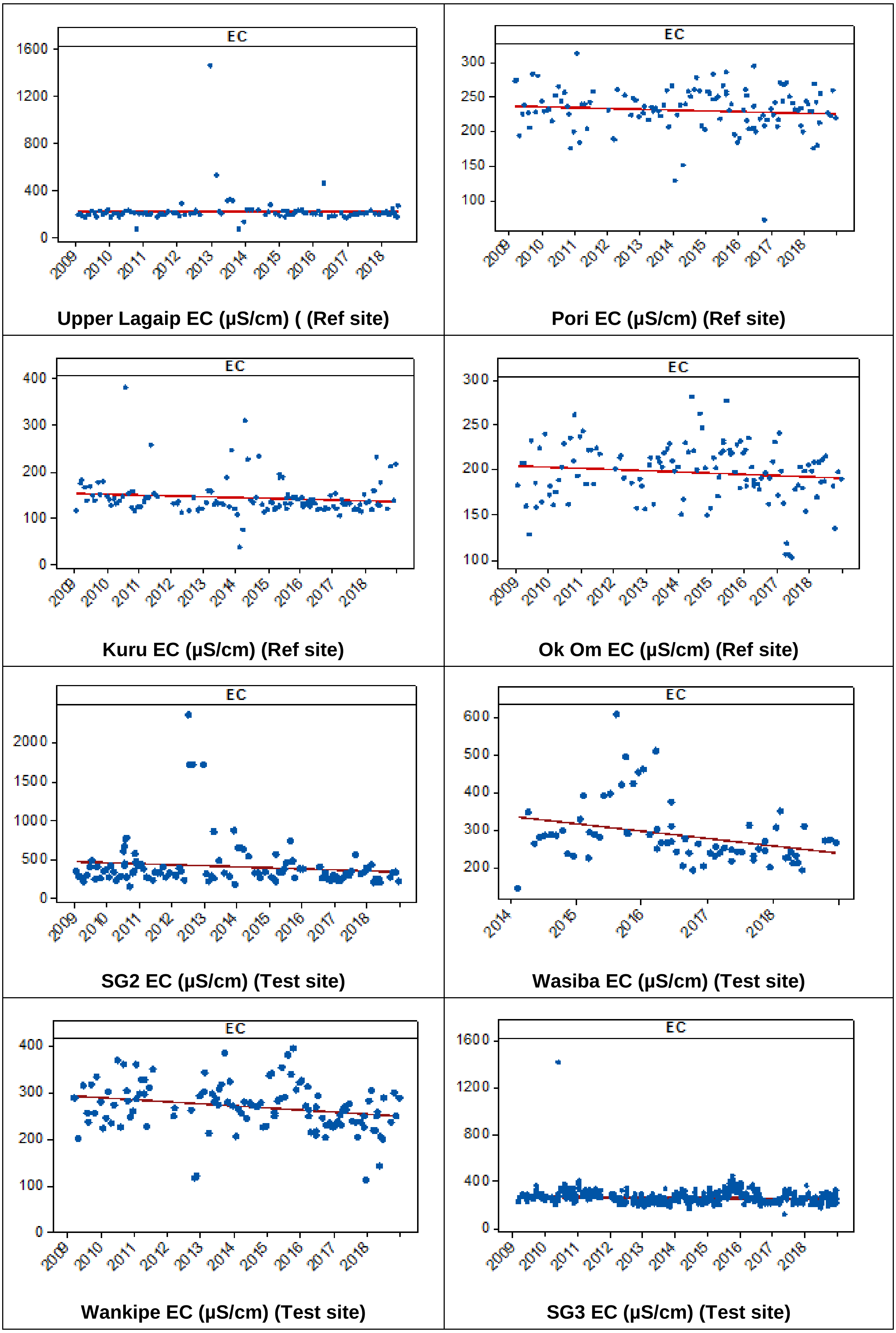
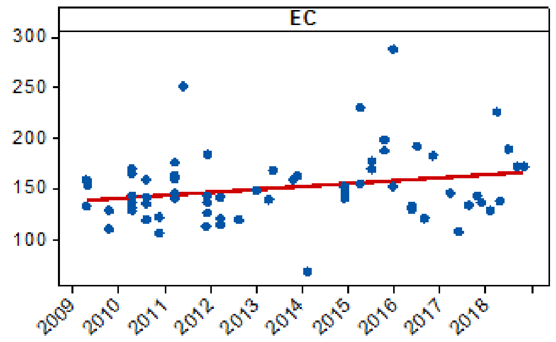
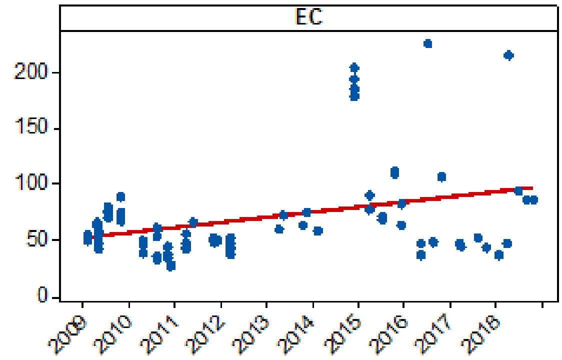


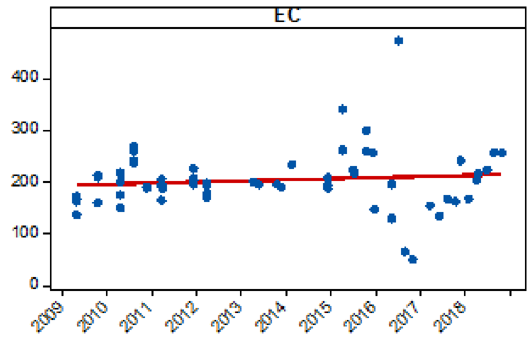
Figure 7-20 EC data and trends at upper river test and reference sites (2009 – 2018) (µS/cm)



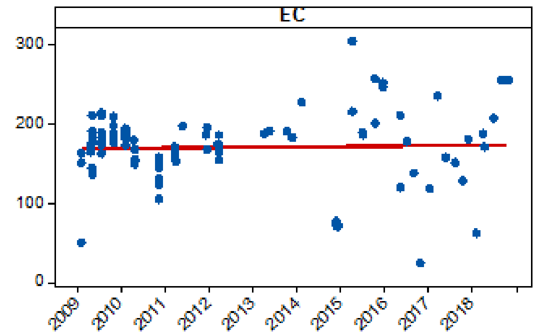
Baia EC (µS/cm) (Ref site)



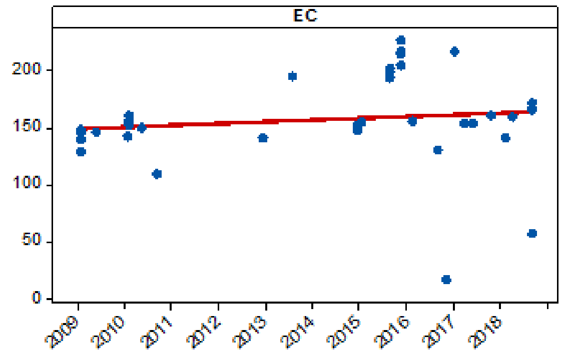
Tomu EC (µS/cm) (Ref site)



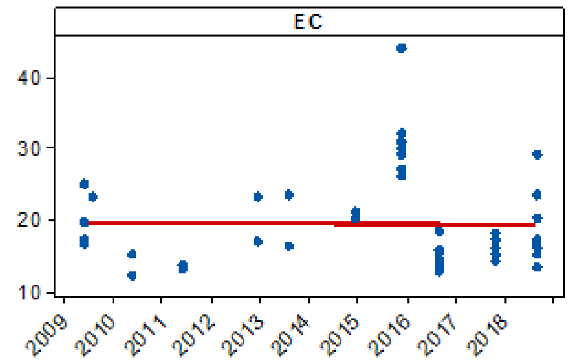
Bebelubi EC (µS/cm) (Test site)



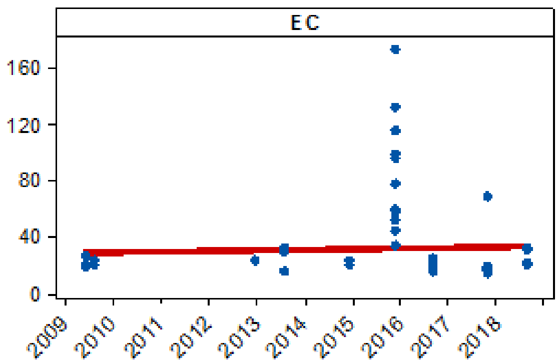
SG4 EC (µS/cm) (Test site)



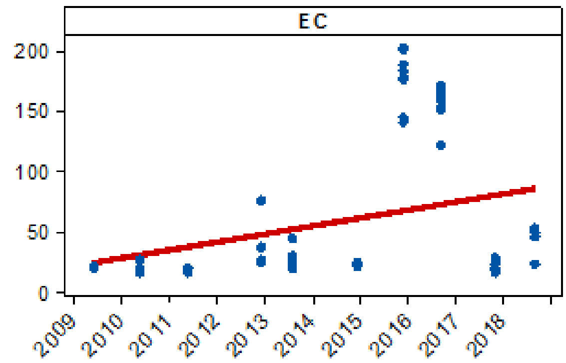
SG5 EC (µS/cm) (Test site)



Nth Lake EC (µS/cm) (Ref site)



Central Lake EC (µS/cm) (Test site)



Sth Lake EC (µS/cm) (Test site)

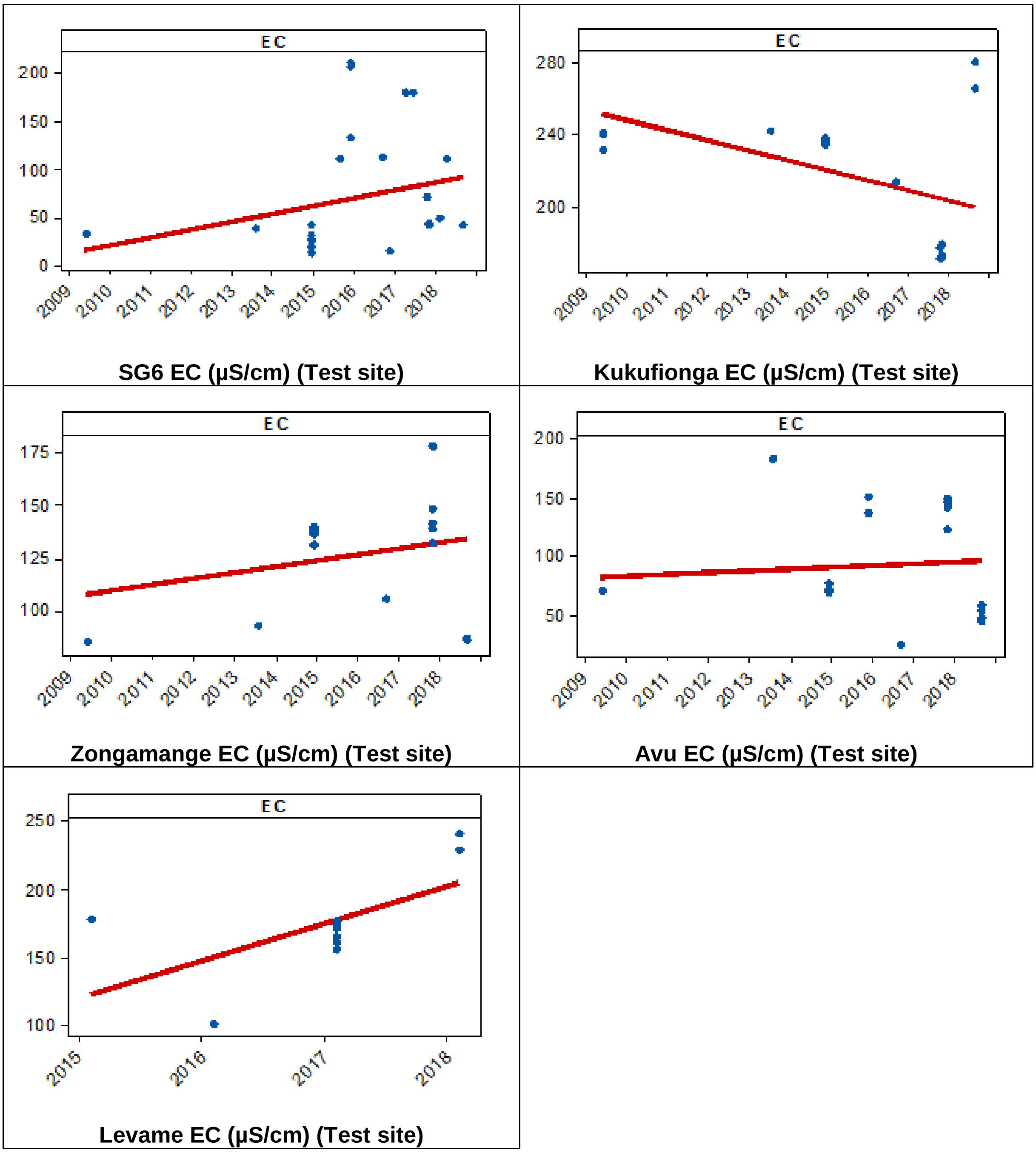


Figure 7-21 EC data and trends at lower river and Lake Murray ORWB test and reference sites (2009 – 2018)

7.4.4.4 Silver (Ag)

Concentrations of dissolved silver in water discharged from the mine in 2018 were lower than the upper river TV, indicating low risk. Throughout the receiving environment median silver concentrations in 2018 indicated low risk, with the exception of Bebelubi in the lower river, where the median silver concentration in 2018 was not significantly different from the TV.

Concentrations of WAE silver in sediment discharged at 28 Level and at Kogai Stable Dump Toe exceeded the upper river TV, indicating potential risk. Within the receiving environment downstream of the Porgera River, 2018 median WAE silver concentrations in benthic sediment indicated low risk.

Overall, the risk posed by silver to the condition of the receiving environment downstream of the Porgera River in 2018 was low.

7.4.4.5 Arsenic (As)

Concentrations of dissolved arsenic in water discharged from the mine posed a low risk to the receiving environment. Throughout the receiving environment, dissolved arsenic concentrations posed a low risk.

WAE arsenic in sediment discharged from the operation in tailings and from 28 level exceed the upper river TV, indicating potential risk. Throughout the receiving environment, WAE arsenic concentrations in sediment posed a low risk, although increasing trends were observed at SG2 and SG3.

Arsenic concentrations in fish flesh at Wasiba and Wankipe and in Prawn abdomen at Bebelubi indicated potential risk, although trends of arsenic in tissue metals at all test sites within the receiving environment either decreased or did not change between 2009 and 2018.

Overall, given the low risk posed by arsenic in water and sediment throughout the receiving environment, combined with trends indicating decrease or no change over time, the overall risk posed by arsenic to the condition of the receiving environment downstream of the Porgera River in 2018 was low.

7.4.4.6 Cadmium (Cd)

Concentrations of dissolved cadmium in water discharged in tailings and from Kogai Culvert, Kogai Stable Dump Toe, Wendoko Creek downstream Anawe Nth and Yunarilama/Yarik at Portal exceeded the upper river TV, indicating potential risk. Dissolved cadmium concentrations in tailings and from Kogai Dump Toe have increased between 2009 and 2018.

In the upper river at SG2, the 2018 median concentration of dissolved cadmium in water was not significantly different from the TV, indicating potential risk.

The 2018 median WAE cadmium concentrations in sediment discharged from the operation in tailings and from 28 Level, Kogai Culvert, Kogai Stable Dump Toe and Yakatabari Creek D/S 28 Level exceeded the upper river TV, indicating potential risk. In the upper river at SG2, the 2018 median concentration of WAE cadmium in sediment was not significantly different from the TV, indicating potential risk.

Cadmium concentrations in prawn abdomen at Wasiba and Wankipe in the upper river exceed the TV, indicating potential risk, although there was a decreasing trend of cadmium in prawn abdomen at these sites between 2009 and 2018. Cadmium concentrations in prawn abdomen at Bebelubi and SG4 in the lower river were not significantly different from the TV, indicating potential risk.

The trends of dissolved cadmium in water, WAE cadmium in sediment and in prawn and fish have either decreased or not changed between 2009 and 2018.

In the upper river, due to elevated cadmium concentrations in water and sediment from some operational sites and the concurrent indication of risk in water and sediment at SG2 and in prawn abdomen at Wasiba and Wankipe, cadmium was found to have posed a potential risk to the condition of the receiving environment in the upper river during 2018.

In the lower river, Lake Murray and ORWBs, potential risk was indicated by cadmium in prawn tissue at Bebelubi and SG4,where the test site medians were not significantly different from the TV. However, given there was no indication of risk in water, sediment or fish tissue at any of the lower river, lake Murray or ORWB test sites, and no evidence of increasing trends in any matrices, the overall risk of cadmium to the condition of the receiving environment in the lower river, Lake Murray and ORWBs in 2018 was considered to be low.

7.4.4.7 Chromium (Cr)

Concentration of dissolved chromium in water discharged from the Lime Plant exceeded the upper river TV and in water from Wendoko Creek downstream Anawe Nth and Yunarilama/Yarik at Portal were not significantly different from the TV, indicating potential risk.

Dissolved chromium concentrations at SG2 indicated potential risk, at all other sites throughout the receiving environment dissolved chromium concentrations in water and WAE chromium concentrations in sediment indicated low risk. Increasing trends in WAE chromium were observed at SG2 and SG3.

In the upper river, chromium in prawn abdomen at Wasiba, and fish flesh and prawn abdomens at Wankipe was not significantly different from the TV, indicating potential risk. Concentrations of chromium in prawn abdomens at Wasiba and fish flesh at SG4 increased between 2009 and 2018.

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 chromium in prawn abdomens at Wasiba and fish flesh and prawn abdomens at Wankipe was not significantly different from the TV, the risk of chromium to the condition of the receiving environment downstream of the Porgera River in 2018 was considered to be low.

7.4.4.8 Copper (Cu)

The concentrations of dissolved copper in water and WAE copper in sediment discharged in tailings in 2018 exceeded the upper river TVs, indicating potential risk.

However, dissolved copper concentrations in water and WAE copper concentrations in sediment throughout the receiving environment indicated low risk.

Copper in fish flesh at Wasiba in the upper river and at Bebelubi in the lower river were not significantly different from the respective TVs, indicating potential risk to aquatic ecosystems, triggering further investigation to determine whether actual impact is occurring.

WAE copper in sediment at SG3, SG4 and Levame, and in prawn abdomen at Bebelubi and SG4 showed an increasing trends. The trends of copper concentrations in all matrices throughout the receiving environment either decreased or did not change between 2009 and 2018.

Overall, given the low concentrations of copper in discharge from the site, the low risk was indicated by concentrations of dissolved copper in water and WAE copper in sediment throughout the receiving environment, and that copper in fish flesh at Wasiba and Bebelubi was not significantly different from the TV, and trends of copper are predominantly not increasing, the risk posed by copper to the condition of the receiving environment downstream of the Porgera River in 2018 was low.

7.4.4.9 Mercury (Hg)

The concentrations of WAE mercury in sediment discharged in tailings exceeded the upper rivers TV, indicating potential risk.

Mercury concentrations in all matrices throughout the receiving environment indicated low risk and the trend of mercury concentrations in all matrices at all test sites throughout the receiving environment either decreased or did not change between 2008 and 2018.

Overall, given the low concentrations of mercury in the discharges, low risk indicated throughout the receiving environment, and trends either decreasing or not changing, the overall risk of mercury to the condition of the receiving environment downstream of the Porgera River in 2018 was low.

7.4.4.10 Nickel (Ni)

Concentrations of dissolved nickel in water and WAE nickel in sediment discharged in tailings in 2018 exceeded the upper rivers TVs, indicating potential risk. The concentration of nickel in tailings showed an increasing trend between 2009 and 2018.

Throughout the receiving environment, the concentration of dissolved nickel in water indicated low risk.

In the upper river at Wankipe and SG3, the concentration of WAE nickel in sediment was not significantly different from the TV, indicating potential risk.

Nickel concentrations in fish flesh and prawn abdomens at Wasiba and in prawn abdomen at Wankipe were not significantly different from the respective TVs, indicating potential risk. An increasing trend of nickel concentrations in prawn abdomens at Wankipe was observed between 2009 and 2018.

In the lower river, WAE nickel concentrations in sediment indicated low risk. Nickel concentrations in fish flesh and prawn abdomen at Bebelubi and in fish flesh at SG4 indicated low risk. Nickel concentrations in prawn abdomen at SG4 were not significantly different from the TV, indicating potential risk.

Trends for WAE nickel in sediment at SG2 and SG3 increased over time, trends for nickel in all other matrices between 2009 and 2018 either decreased or did not change between 2009 and 2018.

Due to the elevated concentrations of nickel in tailings, indications of potential risk in sediment at Wankipe and Wasiba, fish and prawns at Wasiba and prawns at Wankipe, and in the context of increasing trends of nickel in tailings between 2009 and 2018. Nickel posed a potential risk to the condition of the receiving environment in the upper river during 2018.

In the lower rivers, Lake Murray and ORWBs, due to no indication of potential risk in water or sediment and given that the 2018 median concentrations in prawns at SG4 were not significantly different from the TVs, the overall risk of nickel to the condition of the receiving environment in 2018 was considered low.

7.4.4.11 Lead (Pb)

Concentrations of dissolved lead in water discharged from the site and throughout the receiving environment in 2018 were below the respective TVs and therefore posed low risk. Trends of dissolved and total lead concentrations in tailings did not change between 2009 and 2018.

The concentrations of WAE lead in sediment discharged in tailings and from 28 Level, Kogai Culvert, Kogai Stable Dump Toe, Yakatabari Creek downstream of 28 Level and Yunarilama/Yarik at Portal in 2018 exceeded the upper river TV, indicating potential risk.

In the upper river at SG2, WAE lead in sediment exceeded the upper river TV and in the upper river at Wasiba, WAE lead in sediment was not significantly different from the TV, indicating potential risk. In the ORWBs at Avu and Levame, WAE lead in sediment was not significantly different from the TV. Concentrations of WAE lead in sediment at SG2 and SG3 increased between 2008 and 2018, while concentrations at Avu and Levame did not change over the same period.

Lead in prawn abdomens in the upper river at Wasiba and Wankipe was not significantly different from the TV, indicating potential risk. Lead in prawn abdomen at Wasiba in the upper river increased between 2009 and 2018.

Overall, due to elevated lead in discharge from the mine, indication of potential risk from lead in sediment at SG2 and Wasiba, indication of potential risk from lead in prawns at Wasiba and Wankipe, and an increasing trend of lead in prawns at Wasiba. Lead in sediment posed a potential risk to the condition of the receiving environment in the upper river during 2018.

In the lower river, Lake Murray and ORWBs, due to low risk posed by lead in water and sediment, with the exception of sediment at Avu and Levame, low risk posed by lead in fish and prawns, and reducing or no change in trends for lead in all matrices, the overall risk posed by lead to the condition of the environment in the lower river in 2018 was considered low.

7.4.4.12 Selenium (Se)

Concentrations of dissolved selenium in water discharged from the site and throughout the receiving environment in 2018 were below the respective TVs and therefore posed low risk. Trends of dissolved and total selenium concentrations in tailings and at all test sites throughout the receiving environment either decreased or did not change between 2009 and 2018.

The concentrations of WAE selenium in sediment discharged in tailings, Wendoko Creek downstream Anawe Nth and Yunarilama/Yarik at Portal exceeded the upper river TV, and WAE selenium in sediment discharged from 28 Level was not significantly different from the TV, indicating potential risk.

In the upper river at SG2 and Wasiba, in the lower river at SG4 and SG5 and in ORWBs Zongamange and Levame, WAE selenium in sediment was not significantly different from the respective TVs, indicating potential risk. Selenium concentrations in sediment at all test sites throughout the receiving environment either decreased or did not change between 2008 and 2018.

Selenium in prawn abdomens at Wasiba in the upper river, and at SG4 in the lower river exceeded the relevant TVs, indicating potential risk. Selenium concentrations in prawn abdomen at Wasiba in the upper river and Bebelubi and SG4 in the lower river increased between 2009 and 2018. Concentrations in prawns and fish at all other test sites within the receiving environment either decreased or did not change over the period.

Overall, due to elevated selenium in discharges from the mine, indication of potential risk from selenium in sediment at SG2 and Wasiba, indication of potential risk from selenium in prawns at Wasiba, and an increasing trend of selenium in prawns at Wasiba. Selenium in sediment posed a potential risk to the condition of the receiving environment in the upper river during 2018.

In the lower river, Lake Murray and ORWBs, due to low risk posed by selenium in water, and decreasing or no change in trends for selenium in water, sediment, fish and prawns throughout the lower river and Lake Murray ORWB test sites, the risk posed by selenium to the condition of the receiving environment in the lower river during 2018 was low.

7.4.4.13 Zinc (Zn)

Concentrations of dissolved zinc in tailings and in discharge from 28 Level, Kogai Culvert, Kogai Stable Dump Toe, Wendoko Creek downstream Anawe Nth and Yunarilama/Yarik at Portal in 2018 exceeded the upper river TV, indicating potential risk. Trends of dissolved and total zinc in tailings and Kogai Stable Dump Toe increased between 2009 and 2018.

In the receiving environment, the 2018 median dissolved zinc concentrations at Central Lake and Southern Lake were not significantly different from the TV, indicating potential risk. Trends of dissolved zinc in water Wankipe, SG4, SG4, Central Lake, Southern Lake and Avu increased between 2009 and 2018, at all other sites throughout the receiving environment either decreased or did not change over the same period.

The concentrations of WAE zinc in sediment in tailings and discharged from 28 Level, Kogai Culvert, Kogai Stable Dump Toe, Yakatabari Creek downstream 28 Level and Yunarilama/Yarik at Portal exceeded the upper river TV, indicating potential risk.

In the receiving environment, WAE zinc concentrations in sediment at SG2 indicated potential risk. Trends of WAE zinc in sediment at SG2 and SG3 increased between 2009 and 2018, concentrations at all other sites either decreased or did not change over the period.

Zinc concentrations in fish and prawns throughout the receiving environment indicated low risk. Trends of zinc in prawn abdomen at Bebelubi increased between 2009 and 2018, trends of zinc in fish and prawns at all other sites either reduced or did not change over the same period.

Overall, due to low concentrations of zinc in water, sediment, fish and prawns throughout the receiving environment, and overall decreasing or no change in trends between 2009 and 2018, the risk of zinc in the receiving environment downstream of the Porgera River in 2018 was low.

7.4.5 Metals speciation and toxicity

Elevated concentrations of dissolved cadmium 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 upper reaches of the Lagaip River downstream of its confluence with the Porgera River. 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, 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 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, and assessed metal toxicity to sensitive bacteria and algal species using bioassay techniques developed by CSIRO. The study design was based on the environmental monitoring sites of PJV. Water samples were collected in November 2017 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 in 2019 and the results presented in the 2019 AER.

The key findings of the 2017 study 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 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, the only metal concentrations that exceeded ANZECC/ARMCANZ guideline values for 95% species protection were dissolved cadmium, copper and zinc at SG2 and Chelex-labile zinc at SG2.
- 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.
- 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.
- The only samples showing small (10% or lower) but significant algal growth inhibition were form 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.

Table 7-22 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 2018 (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	7.0	120,000	3,028	0.01	0.82	35	0.14	13	0.12	565	0.1	1.6	7,900
	28 Level	7.8	27	682	0.01	7.1	0.06	0.12	0.38	0.05	2.1	0.13	0.2	30
	SDA Toe	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kaiya Riv D/S Anj Dump	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kogai Culvert	8	270	828	0.01	1.3	0.23	0.21	1.2	0.05	1.1	1.2	0.2	31
	Kogai Stable Dump Toe	7.7	101	1,628	0.01	0.76	0.58	0.17	0.45	0.05	2.1	0.53	0.21	155
	Lime Plant	11.2	5,001	491	0.01	0.1	0.05	4.0	0.55	0.05	0.5	0.11	0.2	3.9
	Wendoko Creek D/S Anawe Nth	7.6	2	2,685	0.01	0.87	1.1	0.31[1]	0.35	0.05	1.9	0.15	0.56	350
	Yakatabari Creek D/S 28 Level	7.5	3,350	674	0.01	9.5	0.08	0.44	0.94	0.05	1.6	1	0.21	11
	Yunarilama/Yarik @ Portal	7.5	18,000	2,890	0.03	2.1	0.11	0.36[1]	0.48	0.05	2.3	0.46	0.9	9.6
Upper River	SG1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SG2	7.8	1,300	248	0.01	1.3	0.19[1]	0.4[1]	1.3	0.05	0.9	0.1	0.2	9.4
	Wasiba	7.6	1,950	240	0.01	1.3	0.08	0.4	1.1	0.05	0.6	0.1	0.2	7.1
	Wankipe	7.8	1,200	248	0.01	1.1	0.05	0.3	1.1	0.05	0.7	0.1	0.2	5.8
	SG3	7.7	1,000	242	0.01	1.1	0.05	0.3	1.0	0.05	0.6	0.1	0.2	6.8
Lower River	Bebelubi	7.6	540[1]	221	0.01[1]	0.9	0.05	0.4	0.8	0.05	0.5	0.1	0.2	8.2
	SG4	7.6	325[1]	196	0.01	0.8	0.05	0.5	0.9	0.05	0.5	0.1	0.2	7.4
	SG5	7.8	455	162	0.01	0.8	0.05	0.3	0.7	0.05	0.5	0.1	0.2	7.1
Lake Murray and ORWBs	Central Lake	7.5	9.5	21	0.01	0.1	0.05	0.2	0.5	0.05	0.5	0.1	0.2	8.4[1]
	Southern Lake	7.5	14[1]	21	0.01	0.2	0.05	0.3	0.6	0.05	0.5	0.2	0.2	5.9[1]
	SG6	7.4	11[1]	45	0.01	0.5	0.05	0.3	0.5	0.05	0.5	0.1	0.2	5.4
	Kukufionga	7.8	75	273	0.01	1.5	0.05	0.1	0.8	0.08	0.5	0.1	0.2	4.7
	Zongamange	7.5	225	86	0.01	0.8	0.05	0.1	1.0	0.06	0.5	0.1	0.2	8.6
	Avu	7.1	49	51	0.01	0.9	0.05	0.3	0.9	0.05	0.6	0.4	0.2	11
	Levame	8.2	19	235	0.02	1.2	0.05	0.1	0.8	0.05	0.5	0.1	0.2	11

Legend: 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

Table 7-23 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 2018 (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	0.79	58	6.8	24	79	0.15	22	150	0.22	1,100
	28 Level	4.4	49	1.8	14	25	0.07	17	570	0.16[1]	485
	SDA Toe	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kaiya Riv D/S Anj Dump	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Kogai Culvert	0.78	11	2.4	7.6	11	0.01	8.8	360	0.14	445
	Kogai Stable Dump Toe	1.1	12	2.5	7.4	10	0.01	7.8	475	0.13	405
	Lime Plant	0.05	0.51	0.23	7.8	3.5	0.01	2.9	3.2	0.1	14
	Wendoko Creek D/S Anawe Nth	0.12	2.5	0.53	13	6.1	0.01	11	21	0.19	135
	Yakatabari Creek D/S 28 Level	0.84	15	1.8	11	14	0.01	13	205	0.13	315
	Yunarilama/Yarik @ Portal	0.38	5.3	1.2	11	5.1	0.01	11	170	0.27	235
Upper River	SG1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SG2	0.2	7.8	0.7[1]	12	14	0.01	13	120	0.10[1]	140[1]
	Wasiba	0.05	3.8	0.4	2.6	8.7	0.01	6.8	33[1]	0.10[1]	55
	Wankipe	0.05	4.2	0.3	3.6	8.7	0.01	8.0[1]	33	0.10	61
	SG3	0.05	3.7	0.5	2.8	8.8	0.01	12[1]	25	0.10	70
Lower River	Bebelubi	0.05	2.0	0.2	3.5	4.4	0.01	6.2	8.1	0.10	34
	SG4	0.05	1.4	0.1	3.5	8.7	0.01	6.9	7.8	0.11[1]	26
	SG5	0.05	3.6	0.3	2.7	12	0.01	6.9	15	0.12[1]	51
Lake Murray and ORWBs	Central Lake	0.06	1.8	0.09	5.4	9.6	0.02	11	11	0.11	46
	Southern Lake	0.06	1.4	0.1	2.2	17	0.01	5.9	19	0.10	34
	SG6	0.09	5.2	0.3	3.0	16	0.02	8.0	25	0.15	61
	Kukufionga	0.05	2.8	0.4	2.7	11	0.01	6.6	13	0.10	50
	Zongamange	0.2	5.4	0.3	2.9	15	0.01	6.2	29	0.12[1]	51
	Avu	0.2	5.4	0.3	2.6	19	0.01	7.6	35[1]	0.12	56
	Levame	0.2	8.5	0.3	3.8	23	0.01	8.3	49[1]	0.16[1]	61

(light green)	Low Risk	(dark green)	Initial assessment showed potential risk – downgraded to low risk after further investigation	(orange)	Potential risk

WAE – Weak acid extraction

Table 7-24 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 2018

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	7.6	1,950	240	0.01	1.3	0.08	0.4	1.1	0.05	0.6	0.1	0.2	7.1
		Sed-WAE	mg/kg	-	-	-	0.05	3.8	0.4	2.6	8.7	0.01	6.8	33[1]	0.10[1]	55
		Fish Flesh	mg/kg	-	-	-	-	0.03	0.004	0.01	0.14[1]	0.06	0.01[1]	0.01	0.42	4.0
		Prawn Abdo	mg/kg	-	-	-	-	0.03	0.005	0.02[1]	4.25	0.01	0.01[1]	0.01[1]	0.56	13.0
	Wankipe	Water-D	µg/L	7.8	1,200	248	0.01	1.1	0.05	0.3	1.1	0.05	0.7	0.1	0.2	7.8
		Sed-WAE	mg/kg	-	-	-	0.05	4.2	0.3	3.6	8.7	0.01	8.0[1]	33	0.10	61
		Fish Flesh	mg/kg	-	-	-	-	0.02[1]	0.003	0.01[1]	0.14	0.04	0.01	0.01	0.30	3.4
		Prawn Abdo	mg/kg	-	-	-	-	0.03	0.005	0.02[1]	5.30	0.01	0.01[1]	0.01[1]	0.45	14.0
Lower River	Bebelubi	Water-D	µg/L	7.6	540[1]	221	0.01[1]	0.9	0.05	0.4	0.8	0.05	0.5	0.1	0.2	8.2
		Sed-WAE	mg/kg	-	-	-	0.05	2.0	0.2	3.5	4.4	0.01	6.2	8.1	0.10	34
		Fish Flesh	mg/kg	-	-	-	-	0.010	0.003	0.01	0.10[1]	0.05	0.01	0.01	0.15	3.1
		Prawn Abdo	mg/kg	-	-	-	-	0.090	0.005[1]	0.03	5.20	0.01	0.01	0.01	0.28	11.0
	SG4	Water-D	µg/L	7.6	325[1]	196	0.01	0.8	0.05	0.5	0.9	0.05	0.5	0.1	0.2	7.4
		Sed-WAE	mg/kg	-	-	-	0.05	1.4	0.1	3.5	8.7	0.01	6.9	7.8	0.11[1]	26
		Fish Flesh	mg/kg	-	-	-	-	0.010	0.003	0.01	0.09	0.06	0.01[1]	0.01	0.14	3.2
		Prawn Abdo	mg/kg	-	-	-	-	0.070	0.006[1]	0.02	8.00	0.01	0.01[1]	0.01	0.34	12.5
Lake Murray	Miwa / S. Lake	Water-D	µg/L	7.5	14[1]	21	0.01	0.2	0.05	0.3	0.6	0.05	0.5	0.2	0.2	5.9[1]
		Sed-WAE	mg/kg	-	-	-	0.06	1.4	0.1	2.2	17	0.01	5.9	19	0.1	34
		Fish Flesh	mg/kg	-	-		-	0.01	0.003	0.01	0.09	0.4	0.01	0.01	0.3	2.5

(light green)	Low Risk	(dark green)	Initial assessment showed potential risk – downgraded to low risk after further investigation	(orange)	Potential risk

[1] Although TSM falls below 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 not statistically significantly different from the TV.

7.5 Local Water Supplies

Participatory sampling of local village water supplies was carried out in August 2018 at Special Mining Lease (SML) and Lease for Mining Purposes (LMP) villages (Timorope, Panadaka, Alipis, Mungalep and Kulapi). The purpose of the program is to assess the suitability of water for domestic use. Apalaka village was not sampled due to community issues that prevented the PJV team from sampling, while sampling was not performed at Yarik and Pakien Camp as the tanks were empty.

The samples were analysed for physical, chemical and biological parameters at the SGS laboratory in Port Moresby, PNG and for metals at the National Measurement Institute laboratory in Sydney, Australia. However, it should be noted that the biological analysis performed by SGS did not meet QA & QC criteria, the sites were re-sampled in April 2019 and duplicate analysis performed at SGS and also the PJV environmental lab. The results of the re-test from SGS again failed the QA & QC criteria, therefore the results presented here for biological analysis (faecal and total coliforms) are from 2019 samples analysed at the PJV environmental lab. An alternate external lab will be engaged to replace SGS for future sampling.

The sampling was arranged in consultation with the Porgera Land Owners Association (PLOA), who participated in the sampling of the water supplies. Samples were collected from drinking water sites that were identified by PLOA representatives. Sampling sites and details are listed in Table 7-25 and locations are shown in Figure 7-22.

Table 7-25 Sampling sites for local village water supplies 2018

Village	Site	Name on map	Easting	Northing
Panadaka	Panadaka 1 Bilip Aile Tank	PA_V1H6	9395507	733671
	Panadaka 2 Timothy Kerene Tank	PA_V2H4	9395780	733845
Alipis	Alipis Village Tank 3	AL_T3	9395775	733346
Kulapi	Kulapi V4 H1 tank	KL_V4H1	9394700	732772
Timorope	Iso Kulina Tank	TI_H2	9397580	733221
Mungalep	Catholic Mission	MG_CM	9397184	734407

The water quality test results are presented in Table 7-26 and Table 7-27 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, and therefore non-compliant with, the WHO and PNG drinking water quality guideline lower value at all sites. The volume of water in the tanks at the time of sampling was low and 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. It should be noted that the most recent pH data, collected during the re-sampling in April 2019, are presented here.

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 100 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.

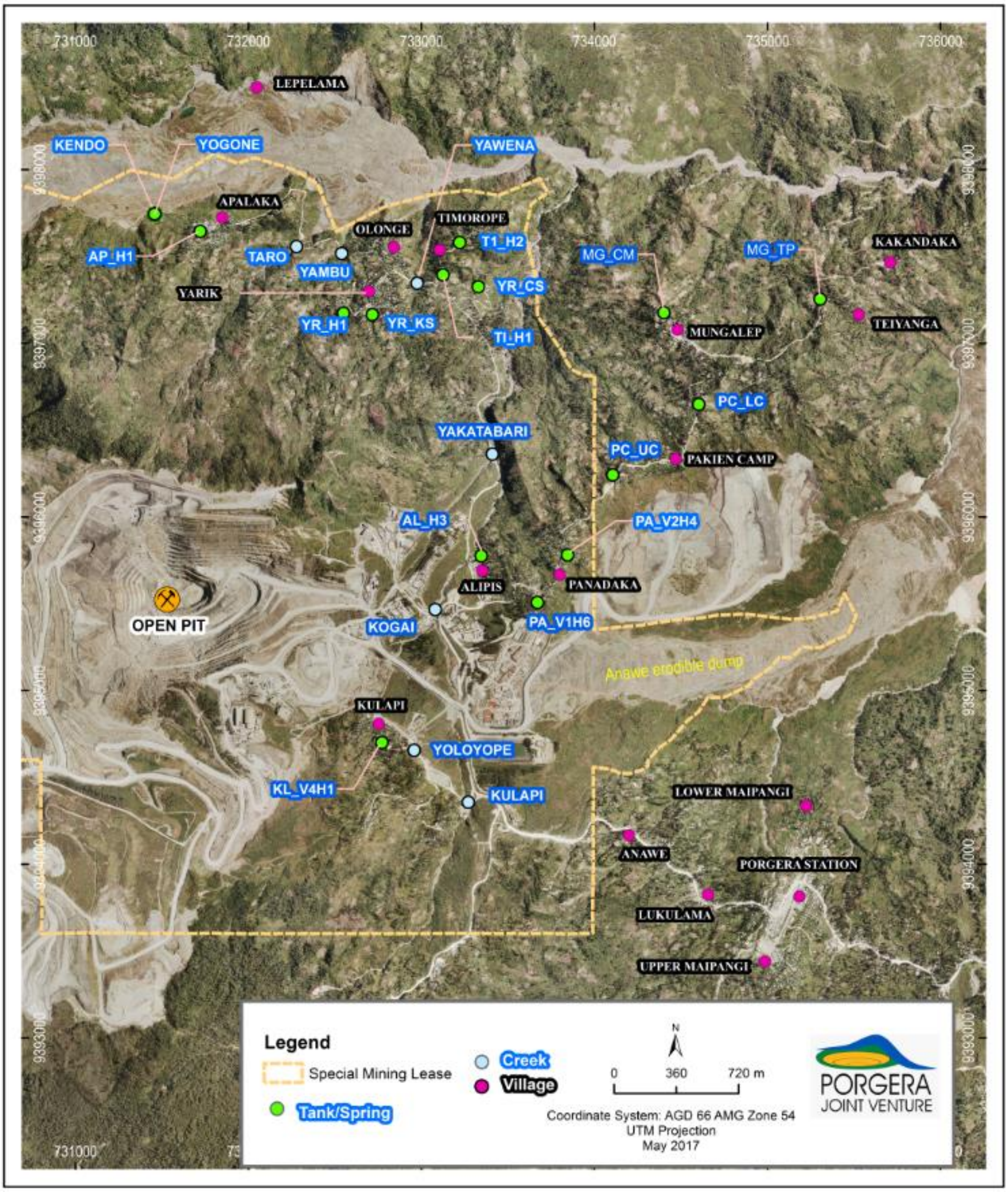


Figure 7-22 Sampling sites for local village water supplies

Table 7-26 Physiochemical and biological water quality 2018* at drinking water sites against Drinking Water Quality Standards

Site / Parameter	**pH***	**Electrical Cond. @ 25°C**	**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
Bilip Aile (Tank)	5.8	6.0	10	2.0	0.3	NR	None	None
Timothy Kerene (Tank)	6.2	11	10	20	0.4	NR	None	None
Alipis Village (Tank 3)	6.4	8.0	10	2.0	0.6	NR	None	None
Kulapi V4 H1 (Tank)	5.9	5.0	10	2.0	0.4	NR	None	None
Iso Kulina (Tank)	6.4	4.0	10	2.0	0.3	NR	None	None
Mungalep Catholic Mission (Tank)	5.8	5.0	10	2.0	0.5	NR	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**

(green)	Compliant
(orange)	Non-compliant

*Results for pH, faecal and total coliforms are from samples collected in April 2019 and analysed at the PJV environment lab

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 7-27 Metal concentrations of drinking water sites against Drinking Water Quality Standards in 2018 (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
Bilip Aile (Tank)	0.1	0.1	0.05	0.05	2.5	2.8	0.3	0.7	0.05	0.05	0.5	0.5	0.2	0.2	220	200
Timothy Kerene (Tank)	0.5	0.5	0.05	0.05	1.0	1.0	0.3	0.4	0.1	0.05	0.5	0.5	0.2	0.2	100	86
Alipis Village (Tank 3)	0.2	0.2	0.05	0.05	1.9	1.7	0.4	0.3	0.1	0.05	0.5	0.5	0.2	0.2	190	180
Kulapi V4 H1 (Tank)	0.1	0.1	0.08	0.1	0.4	0.4	0.3	0.3	0.1	0.05	0.5	0.5	0.2	0.2	260	330
Iso Kulina (Tank)	0.1	0.1	0.05	0.05	2.3	2.7	0.3	0.4	0.1	0.05	0.5	0.5	0.2	0.2	140	140
Mungalep Catholic Mission (Tank)	0.1	0.1	0.05	0.05	0.5	0.7	0.3	0.5	0.1	0.05	0.5	0.5	0.2	0.2	1,300	1,330
PNG (1984)	**7.0**		**2.0**		**1,000**		**10**		**1**		**20**		**10**		**3,000**	
WHO (2017)	**10**		**3.0**		**2,000**		**10**		**6**		**70**		**40**		**NA**	

(green)	Compliant
(orange)	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 and result in contact with water: 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 monitoring sites downstream of the mine in the upper river were compared against the ANZECC/ARMCANZ (2000) recreational water quality guideline values and the WHO Drinking Water Quality Guidelines (2017) in Table 7-28.

The results showed that concentrations of dissolved cadmium, nickel and zinc in undiluted tailings exceeded the guideline values, and therefore indicate 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 and dissolved metal concentrations were below, and therefore compliant with, the respective guideline values and therefore posed a low risk to human health.

Exposure patterns obviously 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 dissolved metals pose a low risk to human health.

Table 7-28 Comparison of 2018 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	7.0	0.01	0.8	35	0.1	13	31	0.12	565	0.1	1.6	7,900
SG1	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SG2	12	7.8	0.01	1.3	0.2	0.4	1.3	10	0.05	0.9	0.1	0.2	9.4
Wasiba	14	7.6	0.01	1.3	0.08	0.4	1.1	13	0.05	0.6	0.1	0.2	7.1
Wankipe	15	7.8	0.01	1.1	0.05	0.3	1.1	11	0.05	0.7	0.1	0.2	7.8
SG3	202	7.7	0.01	1.1	0.05	0.3	1.0	12	0.05	0.6	0.1	0.2	6.8
ANZECC / ARMCANZ 2000 Recreational water quality guideline		**6.5 – 8.5**	**50**	**50**	**5**	**50**	**1,000**	**300**	**1**	**100**	**50**	**10**	**5,000**
WHO Drinking Water Quality Guidelines (2017)		**6.5 – 8.5**	**NA**	**10**	**3**	**NA**	**2,000**	**NA**	**6**	**70**	**10**	**40**	**NA**
(green)	< Guideline = Low risk												
(yellow)	≥ 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 abdomens are compared against relevant food standards in Table 7-29. The results show that all tissue metals at all locations were below the relevant food standard. Although dietary intake of fish and prawns differs greatly between the mountain and lowland sections of the river, the results show that tissue metals in fish flesh and prawn abdomen pose a low risk to human health.

Table 7-29 Risk assessment – median tissue metal results at upper and lower river and Lake Murray test sites in 2018 compared against food standard showing which indicators pose low and potential risk (mg/kg wet wt.)

Site	Sample	n	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Wasiba	Fish Flesh	12	0.03	0.004	0.01	0.14	0.06	0.01	0.01	0.42	4.0
	Prawn Ab	12	0.03	0.005	0.02	4.3	0.01	0.01	0.01	0.56	13
Wankipe	Fish Flesh	12	0.02	0.003	0.01	0.14	0.04	0.01	0.01	0.30	3.4
	Prawn Ab	12	0.03	0.005	0.02	5.3	0.01	0.01	0.01	0.45	14
Bebelubi	Fish Flesh	9	0.01	0.003	0.01	0.10	0.05	0.01	0.01	0.15	3.1
	Prawn Ab	11	0.09	0.005	0.03	5.2	0.01	0.01	0.01	0.28	11
Tium-sinawam	Fish Flesh	12	0.01	0.003	0.01	0.09	0.06	0.01	0.01	0.14	3.2
	Prawn Ab	12	0.07	0.006	0.02	8.0	0.01	0.01	0.01	0.34	12.5
Miwa	Fish flesh	1	0.01	0.003	0.01	0.09	0.37	0.01	0.01	0.31	2.5
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 (ANZFA 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 2017. 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 2017 against the standards is presented in Table 7-30. The results show that particulate matter in emissions from the Lime Kiln No 2 and oxides of nitrogen (NO_x) in emissions from the Anawe Diesel Generator exceeded the respective targets.

Table 7-30 Point source emission metal concentrations (mg/Nm^3)

Source	PM	NO_X	As	Cd	Pb	Ni	Hg	SO_3
Anawe Diesel Generator	20	2,690	0.0064	0.0093	0.155	0.126	0.00076	1.3
Assay Laboratory	2.3	NA	0.0049	0.0018	0.780	0.0046	0.00020	NA
Anawe Autoclaves	36	2.1	0.049	0.0062	0.049	0.088	0.038	82
Carbon Regeneration Kiln	81	24	0.012	0.019	0.017	0.146	0.217	NA
Gold Room Retort	4.3	2.1	0.0079	0.00042	0.022	0.0098	0.034	1.0
Lime Kiln No 2	1,110	51	0.017	0.041	0.943	0.028	0.00068	NA
Primary Crusher	11	NA	0.0039	0.0012	0.042	0.0098	0.00012	NA
Hides Gas Turbine	2.6	281	0.0064	0.0056	0.052	0.014	0.010	1.4
789 Haul Truck 93	19	NA	0.011	0.0020	0.018	0.027	0.00087	1.4
777 Haul Truck 22	36	NA	0.013	0.0023	0.022	0.032	0.001	0.31
Criterion	**500**	**1,000**	**10**	**3**	**10**	**20**	**3**	**200**

(green)	Compliant
(orange)	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 2018 mean value for biological indicators at each test site against their respective TVs using 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 trends for each indicator at both the test and reference site are investigated. Where significant downward or negative trends are observed at the test sites and not at the reference sites, it 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 have been gathered using a standardised hook and line fishing method.

8.1.1.1 Comparison against fish impact assessment TVs

Results from the comparison of 2018 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 sites Wasiba and Wankipe showed that the 2018 test site mean for all indicators were not significantly different from their respective TVs, indicating no impact on fish in the upper rivers during 2018.

Table 8-1 Results from one-sample t-tests testing for significant differences between average values for Wasiba and Wankipe for 2018, and TVs derived from the previous 24 months for reference Ok Om. Significant ($p < 0.05$) results are highlighted. NS = not significantly different.

Test Site	Indicator Parameter	2018 Test Mean	TV SOURCE	TV	t-Test			Level of Impact
					df	t-stat	*p*	
WASIBA	Total Species Abundance	25	OK OM REFERENCE	20	3	0.77	0.495	NS. No adverse Impact
	Total Biomass (g)	1,476		1,383	3	0.34	0.754	NS. No adverse Impact
	N. equinus Abundance	10		13	3	-1.28	0.292	NS. No adverse Impact
	N. equinus Biomass	812		856	3	-0.13	0.902	NS. No adverse Impact

Test Site	Indicator Parameter	2018 Test Mean	TV SOURCE	TV	t-Test			Level of Impact
					df	t-stat	*p*	
WANKIPE	Total Species Abundance	32	OK OM REFERENCE	20	3	1.69	0.190	NS. No adverse Impact
	Total Biomass (g)	2,314		1,383	3	2.20	0.115	NS. No adverse Impact
	N. equinus Abundance	24		13	3	3.18	0.050	NS. No adverse Impact
	N. equinus Biomass	1,995		856	3	2.53	0.085	NS. No adverse Impact

8.1.1.2 Trends for fish impact indicators

The results of Spearman 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 and the dominant species *N. equinus* are shown in Figure 8-1 and Figure 8-2. Note that the catch from consecutive days is shown in the plots but only the first day's catch was used for impact assessment.

The analysis showed no significant increasing or decreasing trends for any of the indicators at any sites, indicating no significant change in any of the indicators over the period. There appeared to be a downward trend in *N. equinus* abundance and biomass at Wasiba, though this trend was not statistically significant.

Table 8-2 Fish upper river - Spearman correlation coefficients (rho), linear regression coefficients (R) and associated significance values (*p*) for species richness, abundance and biomass (g) parameters from hook and line catch for 2015 - 2018 (ns = not significant).

Site		Parameter	Spearman Corr.			Linear Regress.		Trend
			n	Rho	*p*	R	*p*	
TEST	WASIBA 2015-2018	Total Species Abundance	28	0.186	0.342	0.030	0.374	ns
		Total Biomass (g)	28	-0.039	0.844	0.005	0.710	ns
		N. equinus abundance	28	-0.296	0.126	0.133	0.056	ns
		N. equinus biomass (g)	28	-0.255	0.191	0.117	0.075	ns
	WANKIPE 2015-2018	Total Species Abundance	29	0.299	0.115	0.095	0.104	ns
		Total Biomass (g)	29	0.015	0.938	0.003	0.772	ns
		N. equinus abundance	29	0.096	0.621	0.003	0.778	ns
		N. equinus biomass (g)	29	0.021	0.913	0.004	0.746	ns
REF	OK OM 2015-2018	Total Species Abundance	26	0.005	0.979	0.0005	0.912	ns
		Total Biomass (g)	26	-0.081	0.694	0.023	0.456	ns
		N. equinus abundance	26	-0.036	0.862	0.002	0.814	ns
		N. equinus biomass	26	-0.120	0.559	0.034	0.369	ns

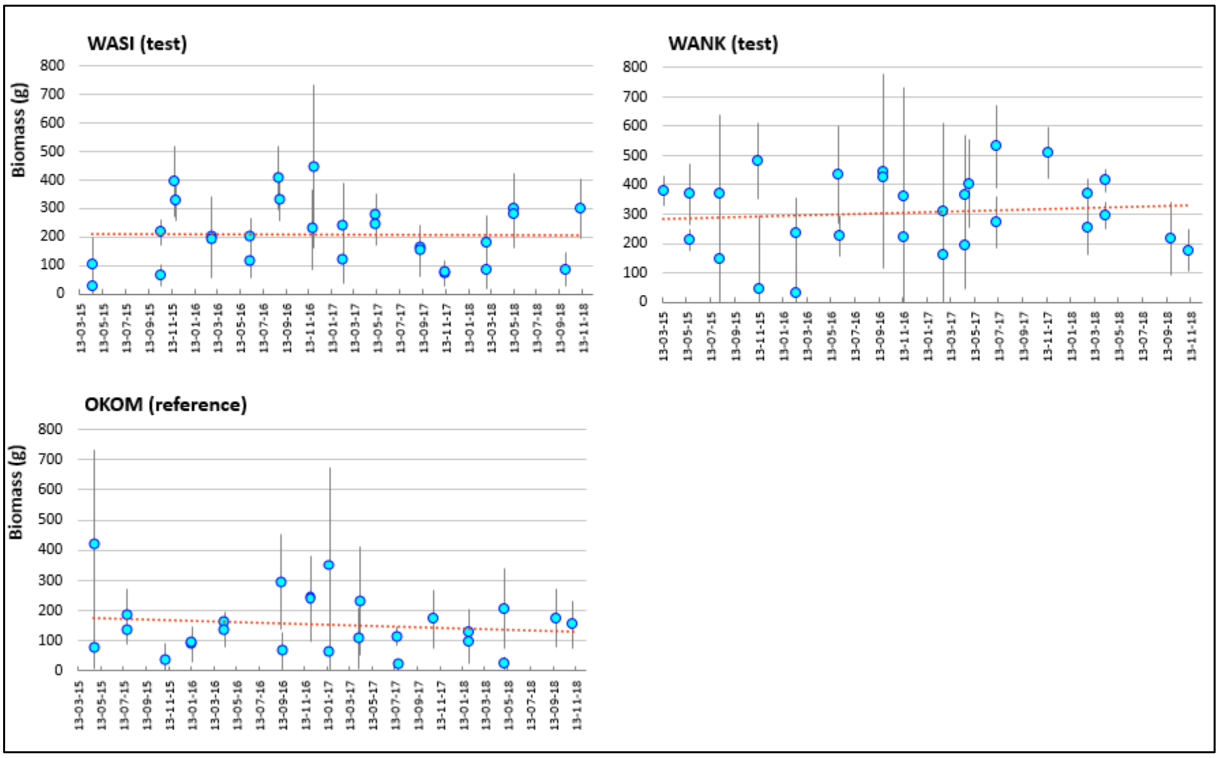


Figure 8-1 Time series plots of average (± 95%CIs) fish biomass (g) from all replicate hook and line catch on each occasion at each site. Linear trend lines are shown in red.

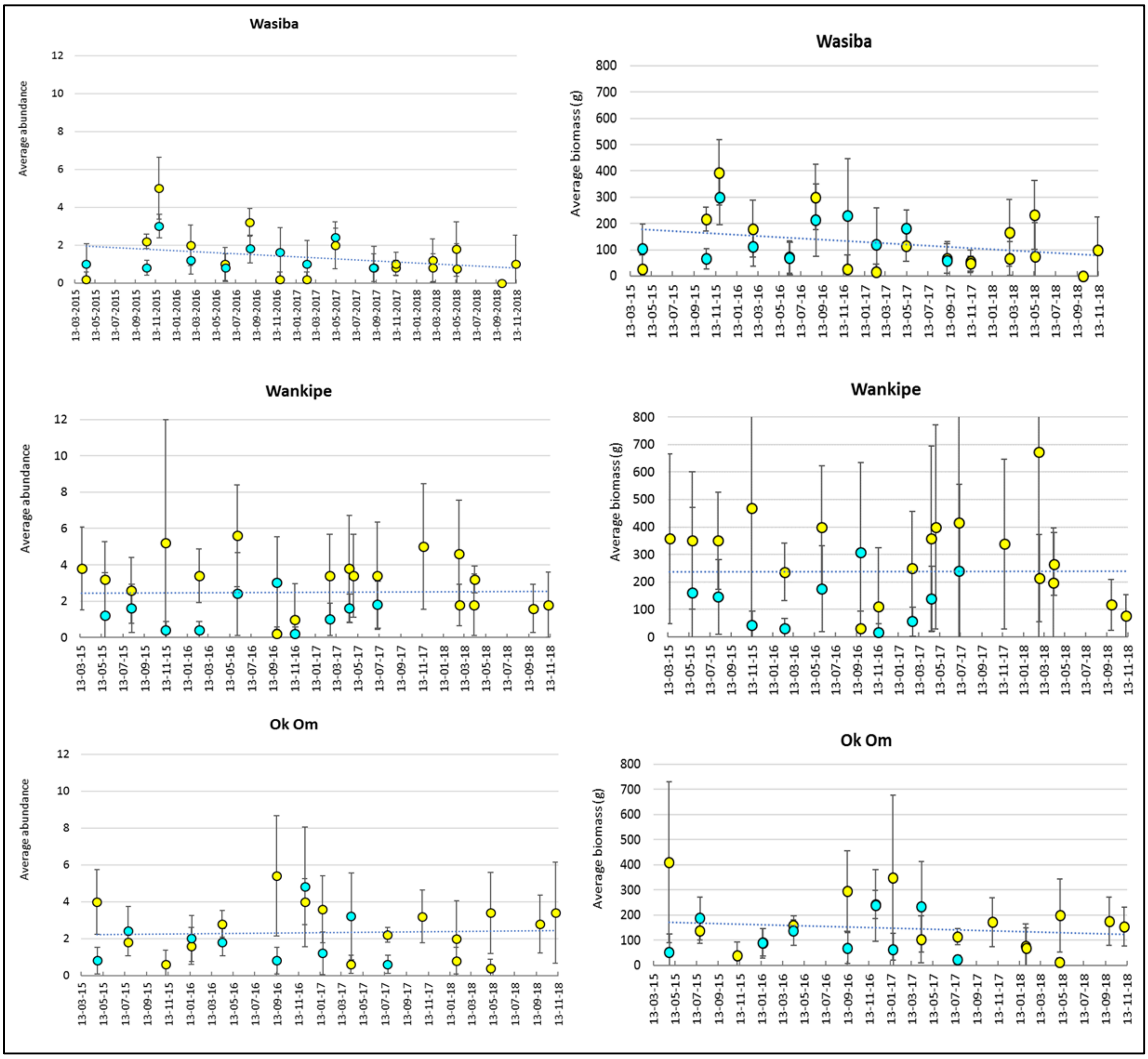


Figure 8-2 Time series plots of average abundance and biomass (g) of *Neosilurus equinus* from hook and line catch for each sampling occasion at each site during 2015 - 2018. Note that data from consecutive days sampling are shown in the plots, yellow dots are first day sampling and blue dots are second day sampling. Only data from the first day sampling (yellow) was used for impact assessment.

8.1.2 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 prawn species *M. handschini*, biomass of *M. handschini*, abundance of *M. lorentzi and* biomass of *M. lorentzi*. Data have been gathered using a standardised electro-seining method.

8.1.2.1 Comparisons against prawn impact TVs

Results from the comparison of 2018 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 2018 test site mean for all indicator parameters were not significantly different from their respective TVs, indicating no impact on prawns in the upper rivers during 2018.

Table 8-3 Results from one-sample t-tests testing for significant differences between average values for Wasiba and Wankipe for 2018, and TVs derived from the average of the relevant previous 24 months for reference Ok Om. Significant ($p < 0.05$) results are highlighted. NS = not significantly different.

Test Site	Indicator Parameter	2018 Test Mean	TV SOURCE	TV	t-Test			Level of Impact
					df	t-stat	*p*	
WASIBA	Total Prawn Abundance	49.3	OK OM REFERENCE	27.8	3	2.51	0.087	NS. No adverse Impact
	Total Prawn Biomass	161.3		122.3	3	1.45	0.244	NS. No adverse Impact
	M. handschini Abundance	20.3		12.5	3	2.36	0.099	NS. No adverse Impact
	M. handschini Biomass	88.8		58.0	3	2.56	0.083	NS. No adverse Impact
	M. lorentzi Abundance	29		15.1	3	2.14	0.122	NS. No adverse Impact
	M. lorentzi Biomass	72.6		63.4	3	0.36	0.741	NS. No adverse Impact
WANKIPE	Total Prawn Abundance	43.8	OK OM REFERENCE	27.8	3	2.01	0.138	NS. No adverse Impact
	Total Prawn Biomass	134.5		122.3	3	0.44	0.690	NS. No adverse Impact
	M. handschini Abundance	19.3		12.5	3	2.01	0.137	NS. No adverse Impact
	M. handschini Biomass	77.0		58.0	3	0.89	0.438	NS. No adverse Impact
	M. lorentzi Abundance	24.5		15.1	3	1.4	0.255	NS. No adverse Impact
	M. lorentzi Biomass	57.5		63.4	3	-0.25	0.820	NS. No adverse Impact

8.1.2.2 Trends for prawn impact indicators

The results of Spearman 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 analysis showed a significantly decreasing trend in biomass of prawn species *M. lorentzi* at test site Wasiba between 2015 and 2018, all other indicators at upper river test and reference sites showed no significant change over the same period. It should be noted that the impact assessment presented in Section 8.2.1.1 showed no impact to *M. lorentzi* biomass in 2018, 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 overtime in total prawn abundance and biomass (g) and in abundance and biomass of the dominant prawn species. Analyses were performed using average of replicate gill net sets averaged within each occasion in each year, 2015 - 2018 (ns = not significant).

Site		Parameter	Spearman Corr.			Linear Regress.		Trend
			n	**Rho**	***p***	**R**	***p***	
TEST	**WASIBA** 2015-2018	Prawn Abundance	25	-0.253	0.213	0.09	0.140	ns
		Prawn Biomass	25	-0.306	0.128	0.06	0.220	ns
		M. handschini abundance	25	0.189	0.356	0.001	0.864	ns
		M. handschini biomass	25	0.223	0.273	0.03	0.419	ns
		M. lorentzi abundance	25	-0.358	0.072	0.13	0.073	ns
		M. lorentzi biomass	25	-0.503	0.009	0.13	0.069	sig, -ve
TEST	**WANKIPE** 2015-2018	Prawn Abundance	24	0.184	0.379	0.04	0.312	ns
		Prawn Biomass	24	-0.036	0.866	0.0003	0.936	ns
		M. handschini abundance	24	0.358	0.079	0.14	0.062	ns
		M. handschini biomass	24	0.325	0.114	0.10	0.129	ns
		M. lorentzi abundance	24	0.052	0.804	0.0003	0.932	ns
		M. lorentzi biomass	24	-0.166	0.427	0.04	0.319	ns
REF	**OK OM** 2015-2018	Prawn Abundance	25	-0.219	0.283	0.04	0.340	ns
		Prawn Biomass	25	-0.174	0.397	0.03	0.395	ns
		M. handschini abundance	25	-0.133	0.516	0.02	0.539	ns
		M. handschini biomass	25	-0.177	0.387	0.02	0.441	ns
		M. lorentzi abundance	25	-0.208	0.307	0.03	0.424	ns
		M. lorentzi biomass	25	-0.121	0.558	0.02	0.486	ns

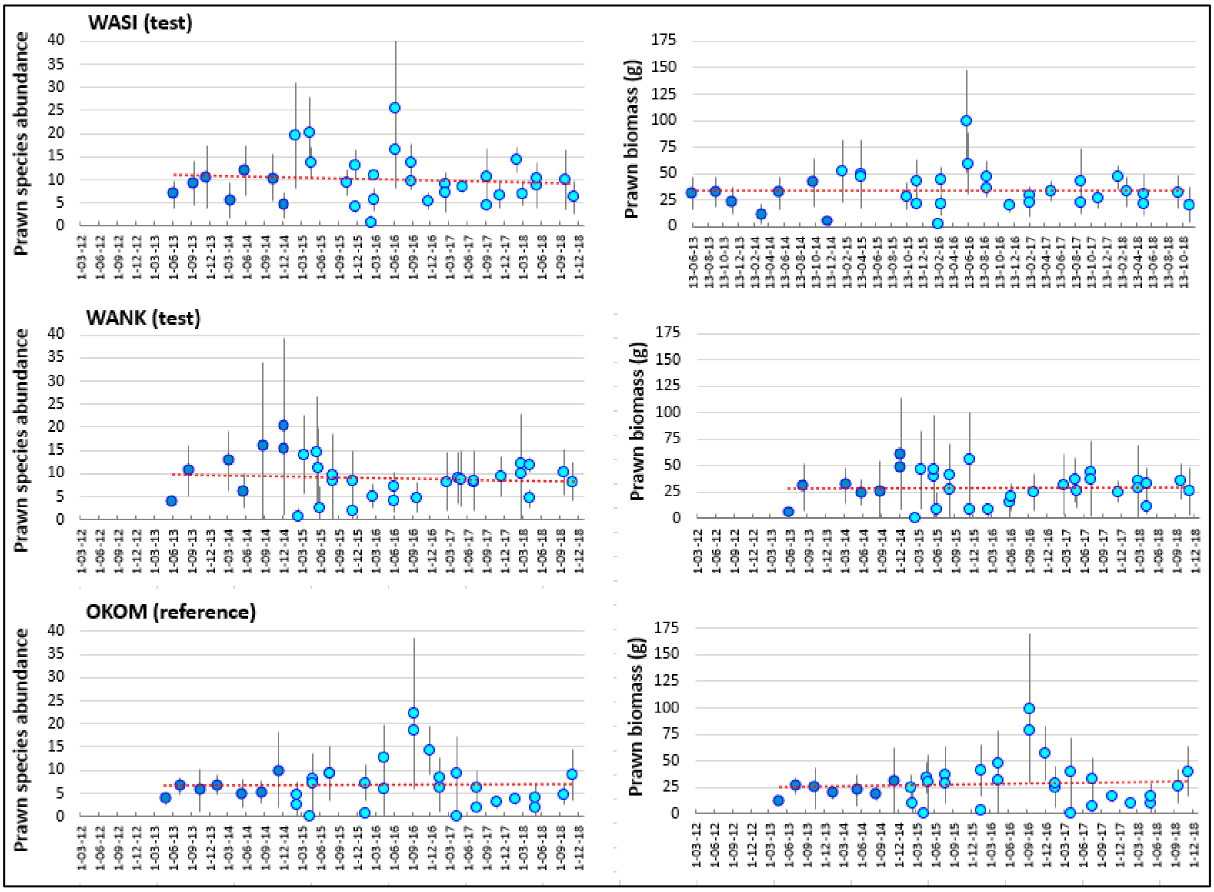


Figure 8-3 Time series plots of abundance and biomass (g) for combined prawn species from electro-seining catch at test sites Wasiba and Wankipe, and reference site Ok Om. Average values (± 95%CIs) are shown for replicate samples, and linear trend lines for average values shown in red. Darker blue symbols indicated non-standard field sampling not included in temporal analyses (*i.e.* pre-2015 sampling).

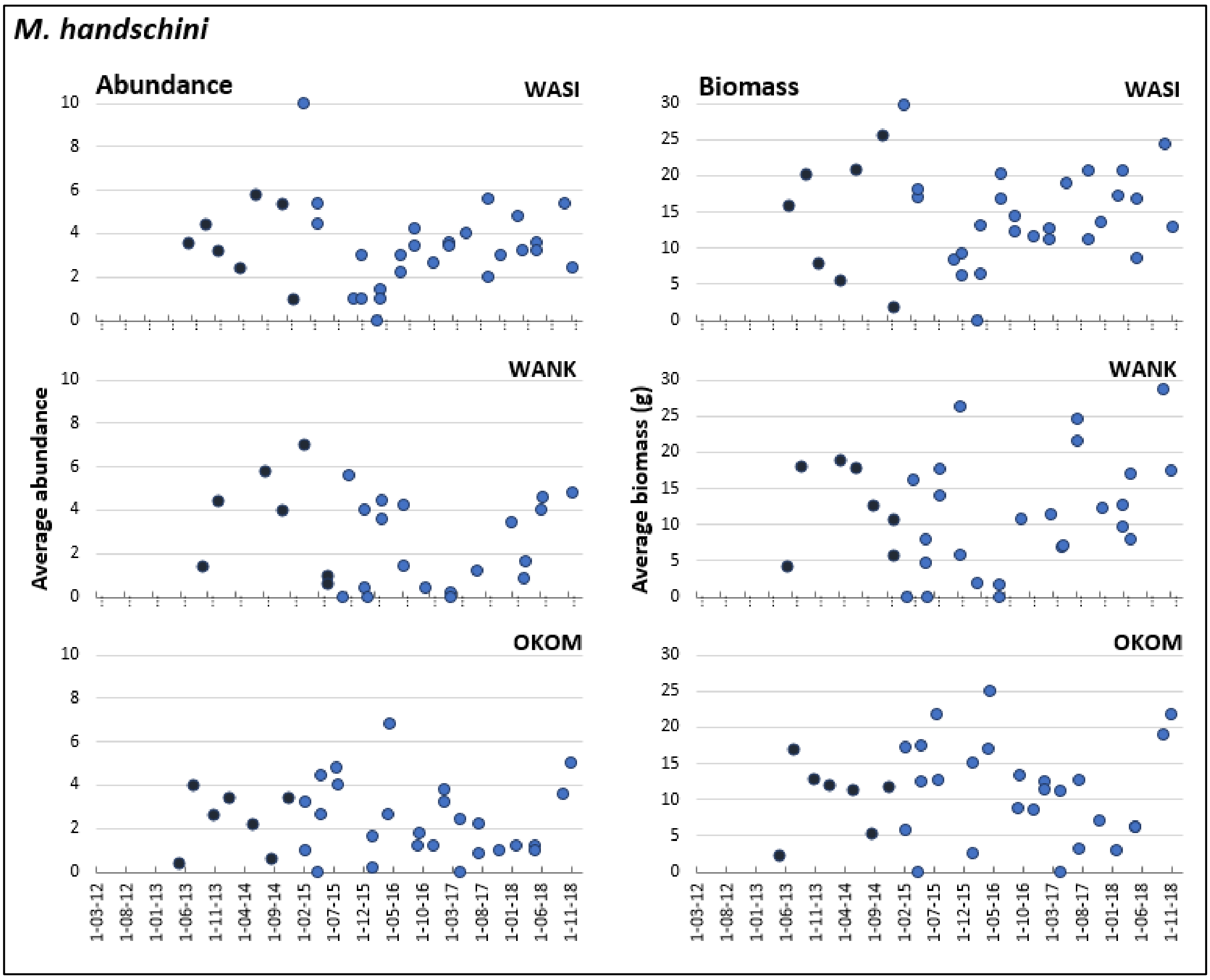


Figure 8-4 Time series plots of average abundance and biomass (g) of *Macrobrachium handschini* in electro-seining catch for each sampling occasion. Darker symbols indicate non-standard field sampling not included in temporal analyses (*i.e.* pre-2015 sampling).

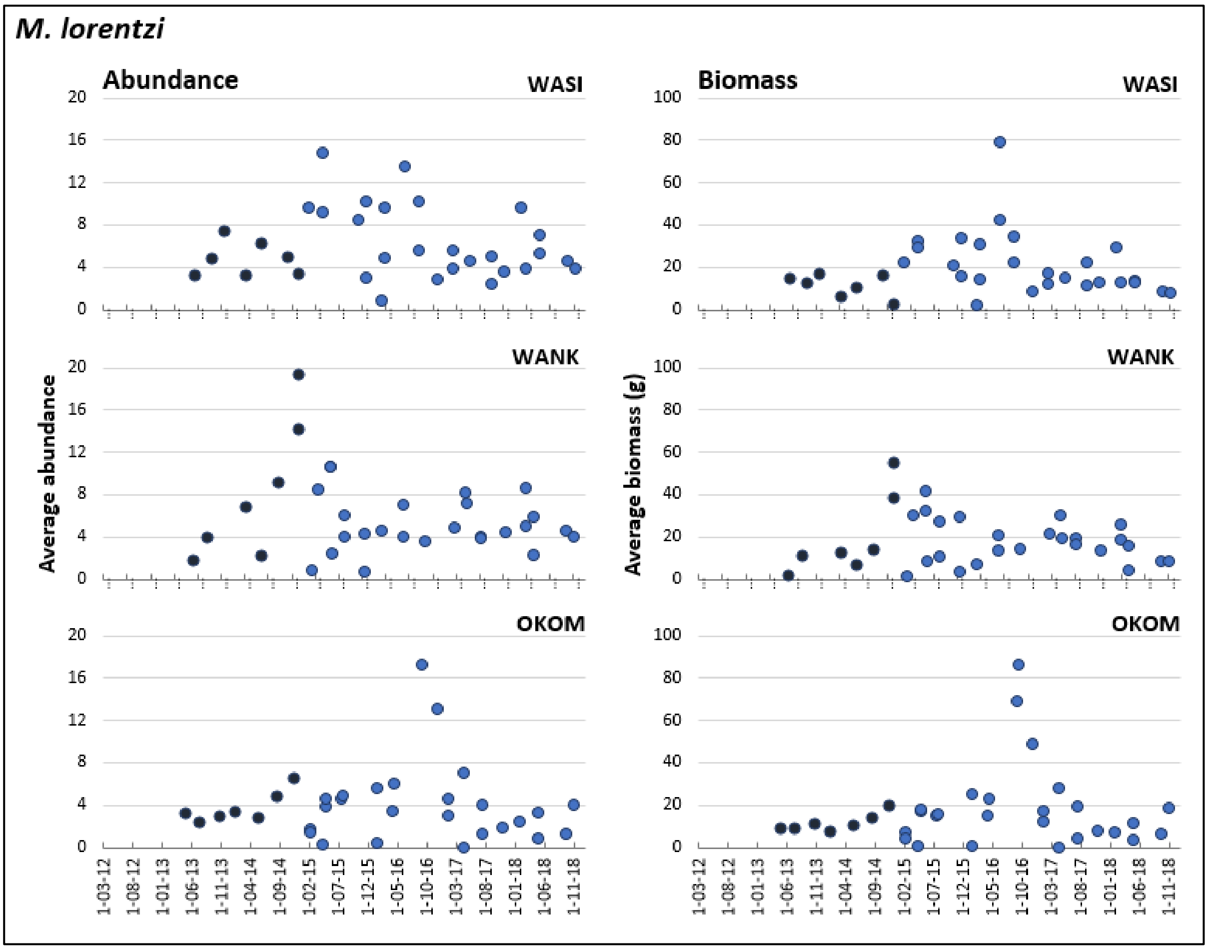


Figure 8-5 Time series plots of average abundance and biomass (g) of *Macrobrachium lorentzi* in electro-seining catch for each sampling occasion. Darker symbols indicate non-standard field sampling not included in temporal analyses (*i.e.* pre-2015 sampling).

8.2 Lower Rivers

8.2.1 Fish

The impact assessment for fish in the lower river is based on the following indicators: species richness of all fish catch, total abundance and total biomass. Data have been gathered using a standardised gill net fishing method.

8.2.1.1 Comparison against fish impact TVs

Results from the comparison of 2018 test site means for fish impact indicators in the upper 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 2018 test site means for all indicators were not significantly different to or significantly greater than their respective TVs, indicating no impact on fish at Bebelubi during 2018.

At Tiumsinawam, all indicators were not significantly different from their respective TVs, except for species richness against TV option 3. TV option 3 was derived from the most recent 24-months data from the reference site Tomu. The result indicates therefore that mean species richness at test site Tiumsinawam in 2018 was significantly less than the mean species richness at the adjacent reference site Tomu across 2017 and 2018. It should be noted that when compared against TV option 1, Tomu baseline TV calculated as the average species richness at Tomu between 1999 and 2004, and TV option 2, Tiumsinawam baseline TV calculated at the average species richness at Tiumsinawam between 1989 and 1998, the mean species richness at Tiumsinawam in 2018 was not significantly different. Given that two out of three assessments for species richness returned a result of no impact, and all other indicators also indicated no impact, on a weight of evidence approach, overall it is concluded that there are no impacts on fish at Tiumsinawam.

Table 8-5 Results from one-sample t-tests testing for significant ($p < 0.05$) differences between average values for Tiumsinawam and Bebelubi for 2018, using TV option 1, TV option 2, and current PJV approach. TVs for option 1 were derived from average values, or 20%ile for biomass, of baseline data for reference Tomu (1999 – 2004). TVs for option 2 were derived from average values for baseline data for Tiumsinawam (1989 – 1998). NS = not significantly different.

Test Site	Indicator Parameter	Year	Test Average	TV	TV	t-Test			Level of Impact
						df	t-stat	*p*	
BEBE	Species Richness	2018	7.0	OPTION A1 BAIA 'BASELINE'	3.0	3	6.93	0.006	Signif > TV. No Impact
	Abundance	2018	13.8		15.0	3	-0.66	0.555	NS. No adverse Impact
	Biomass (kg)	2018	6.7		8.4	3	-1.05	0.370	NS. No adverse Impact
	Species Richness	2018	7.0	OPTION A2 BAIA REFERENCE	3.9	3	5.37	0.013	Signif > TV. No adverse Impact
	Abundance	2018	13.8		8.6	3	2.73	0.072	NS. No adverse Impact
	Biomass (kg)	2018	6.7		4.8	3	1.20	0.317	NS. No adverse Impact

Test Site	Indicator Parameter	Year	Test Average	TV	TV	t-Test			Level of Impact
						df	t-stat	*p*	
TIUM	Species Richness	2018	3.5	OPTION B1 TOMU 'BASELINE'	5.2	3	-2.63	0.078	NS. No adverse Impact
	Abundance	2018	16.3		24.8	3	-0.85	0.458	NS. No adverse Impact
	Biomass (kg)	2018	10.2		13.5	3	-0.53	0.634	NS. No adverse Impact
	Species Richness	2018	3.5	OPTION B2 TIUM 'BASELINE'	5.0	3	-2.32	0.103	NS. No adverse Impact
	Abundance	2018	16.3		21.8	3	-0.55	0.619	NS. No adverse Impact
	Biomass (kg)	2018	10.2		15.4	3	-0.82	0.465	NS. No adverse Impact
	Species richness	2018	3.5	OPTION B3 TOMU REFERENCE	5.8	3	-3.56	0.038	Signif. < TV. Adverse Impact
	Abundance	2018	16.3		21.1	3	-0.49	0.656	NS. No adverse Impact
	Biomass (kg)	2018	10.2		17.2	3	-1.12	0.345	NS. No adverse Impact

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 no change over time for any indicators at test site Bebelubi. At test site Tiumsinawam, statistically significant weak negative trends were observed in species richness, abundance and biomass.

The fact that declines in richness, abundance and biomass were only recorded at Tiumsinawam and not at Bebelubi, which is upstream of Tiumsinawam, suggests the cause may be non-mine related. If the declines were entirely mine-related, then a similar, if not stronger mine-response would be expected at Bebelubi, closer to the mine. However, this was not the case. 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 7.4) 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 at Tiumsinawam (and Baia) 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 2017) 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 2017).

Table 8-6 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, with replicate net set # 1 within occasions in each year (ns = not significant).

Site		Parameter		Spearman Corr.		Linear Regress.		Trend
			n	**Rho**	***p***	**R**	***p***	
TEST	**BEBE** 2006-2018	Species Richness	50	0.098	0.497	0.004	0.653	ns
		Abundance	50	-0.044	0.764	0.029	0.241	ns
		Biomass	50	-0.103	0.478	0.051	0.115	ns
	TIUM 1989-2018	Species Richness	108	-0.227	0.018	0.035	0.052	Signif, negative, weak
		Abundance	108	-0.230	0.007	0.048	0.023	Signif, negative, weak
		Biomass	108	-0.400	<0.001	0.080	0.003	Signif, negative, weak
REF	**BAIA** 2006-2018	Species Richness	45	-0.117	0.445	0.004	0.695	ns
		Abundance	45	-0.223	0.141	0.077	0.064	ns
		Biomass	45	-0.334	0.025	0.12	0.020	Signif, negative, weak
	TOMU 1996-2018	Species Richness	95	-0.114	0.272	0.012	0.287	ns
		Abundance	95	-0.068	0.512	0.030	0.095	ns
		Biomass	95	-0.140	0.175	0.090	0.003	ns

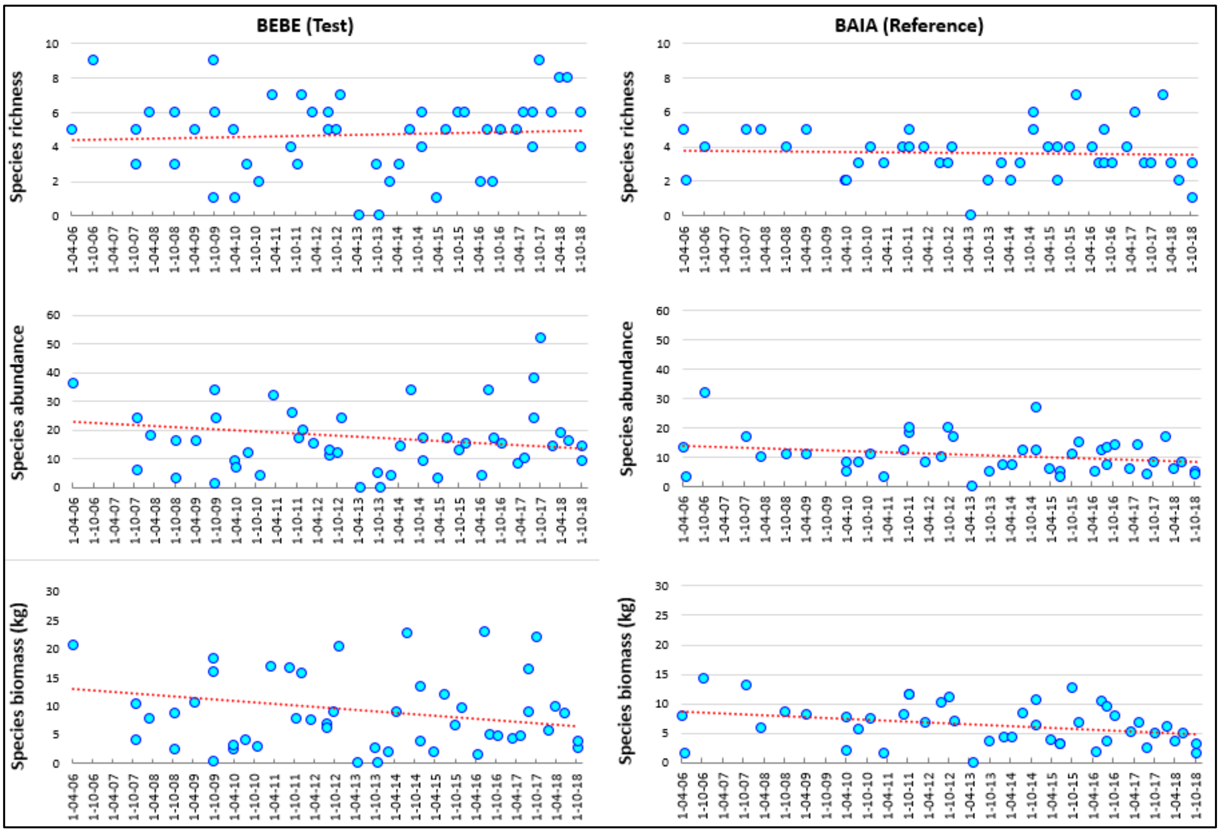


Figure 8-6 Time series plots of species richness, abundance and biomass (kg) from replicate net set #1 gill net catch at paired monitoring sites Bebelubi and Baia. Linear trend lines are shown in red.

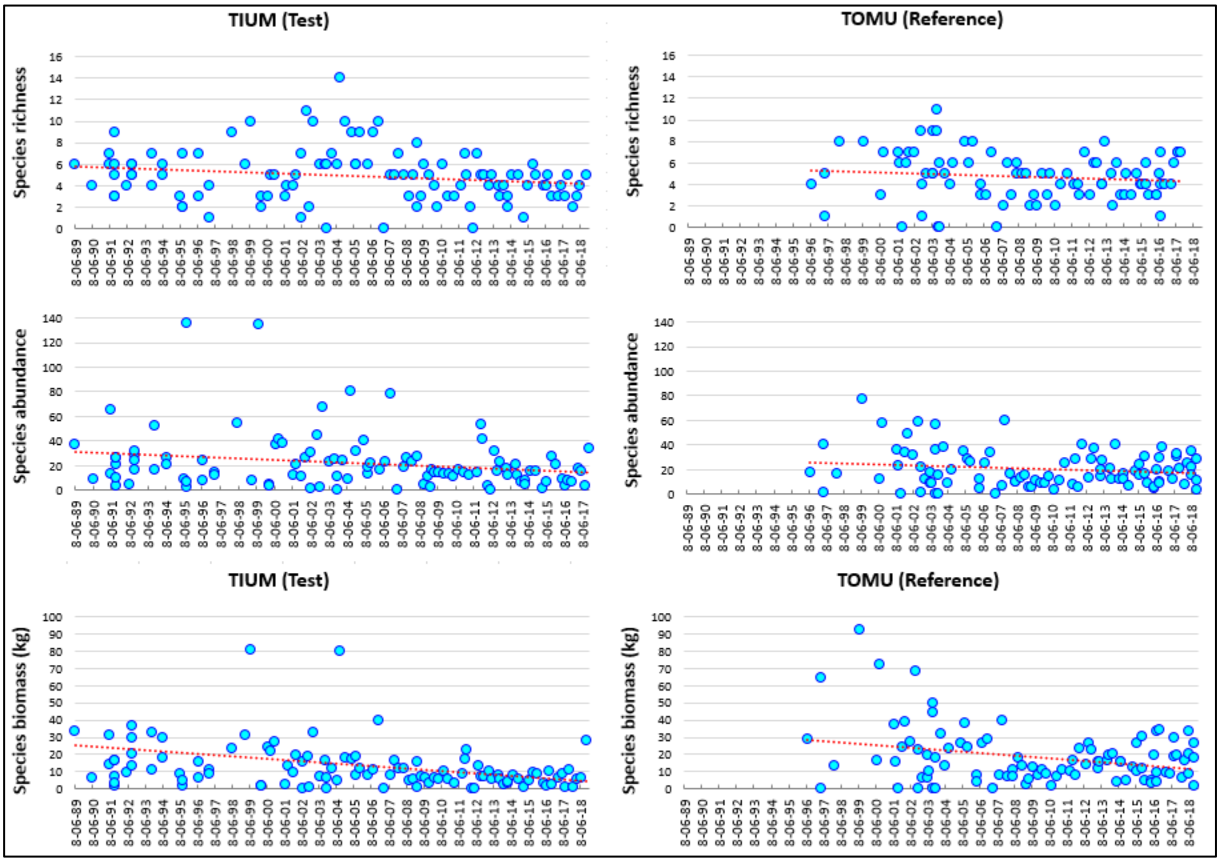


Figure 8-7 Time series plots of species richness, abundance and biomass (kg) from replicate net set #1 gill net catch at paired monitoring sites Tiumsinawam and Tomu. Linear trend lines for average values shown in red.

8.3 Lake Murray

The impact assessment for Lake Murray could not be performed for 2018 due a lack of reliable data. Biological sampling in Lake Murray during 2018 was limited with no replication and no repeat sampling, meaning that the data are unable to support a conclusive impact assessment. Improved sampling methods will be applied in 2019, with the aim of presenting an impact assessment for Lake Murray in the 2019 AER.

In lieu of an impact assessment, available data from the Lake Murray sites were used to assess temporal trends for biological indicators: fish species richness; fish abundance and fish biomass.

8.3.1 Fish

8.3.1.1 Trends for fish impact indicators

Trend analysis is restricted by limited sampling in Lake Murray in recent years, resulting in a discontinuous time series. Standardised sampling will be re-instated in 2019 with replicate sampling at each site on two occasions per year. This will provide more continuous data in coming years, allowing more robust interpretation of temporal changes.

The results of Spearman correlation and linear regression analyses provided in Table 8-7, time series plots for each site are shown in Figure 8-8 to Figure 8-10. Time series plots for reference site Maka indicated a significant downward trend in species richness, and an apparent downward trend in abundance and biomass, though this was not statistically significant. Trends in indicators at test sites Miwa and Pangoa did not change over time.

Table 8-7 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, with replicate gill net set # 1 within each occasion in each year (ns = not significant).

Site		Parameter	*n*	Spearman Corr.		Linear Regress.		Trend
				Rho	*p*	R	*p*	
TEST	**MIWA** 1989-2008, 2011-2012, 2018	Species Richness	78	0.20	0.080	0.048	0.055	ns
		Abundance	78	0.079	0.493	0.000	0.964	ns
		Biomass	78	-0.005	0.964	0.006	0.495	ns
TEST	**PANG** 1992-2008, 2018	Species Richness	66	0.026	0.834	0.0001	0.929	ns
		Abundance	66	0.076	0.543	0.001	0.788	ns
		Biomass	66	0.056	0.655	0.000	0.961	ns
REF	**MAKA** 1993, 1997-2009, 2018	Species Richness	41	-0.364	0.019	0.12	0.025	Signif, negative, weak
		Abundance	41	-0.251	0.114	0.035	0.245	ns
		Biomass	41	-0.159	0.322	0.022	0.358	ns

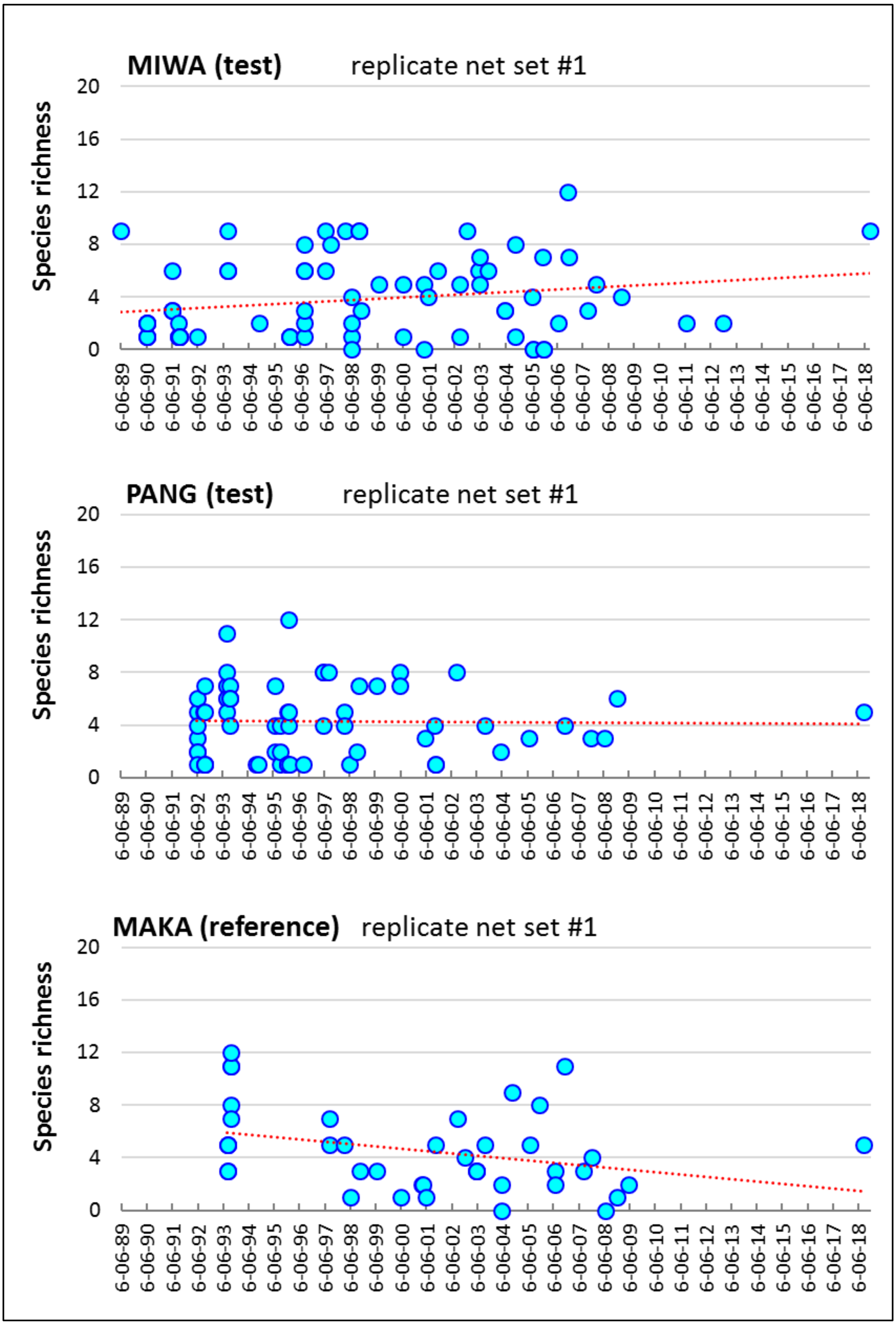


Figure 8-8 Time series plots of average species richness from replicate gill net set #1 only. Data are for Lake Murray test sites Miwa and Pangoa, and reference site Maka. Linear trend lines are shown in red.

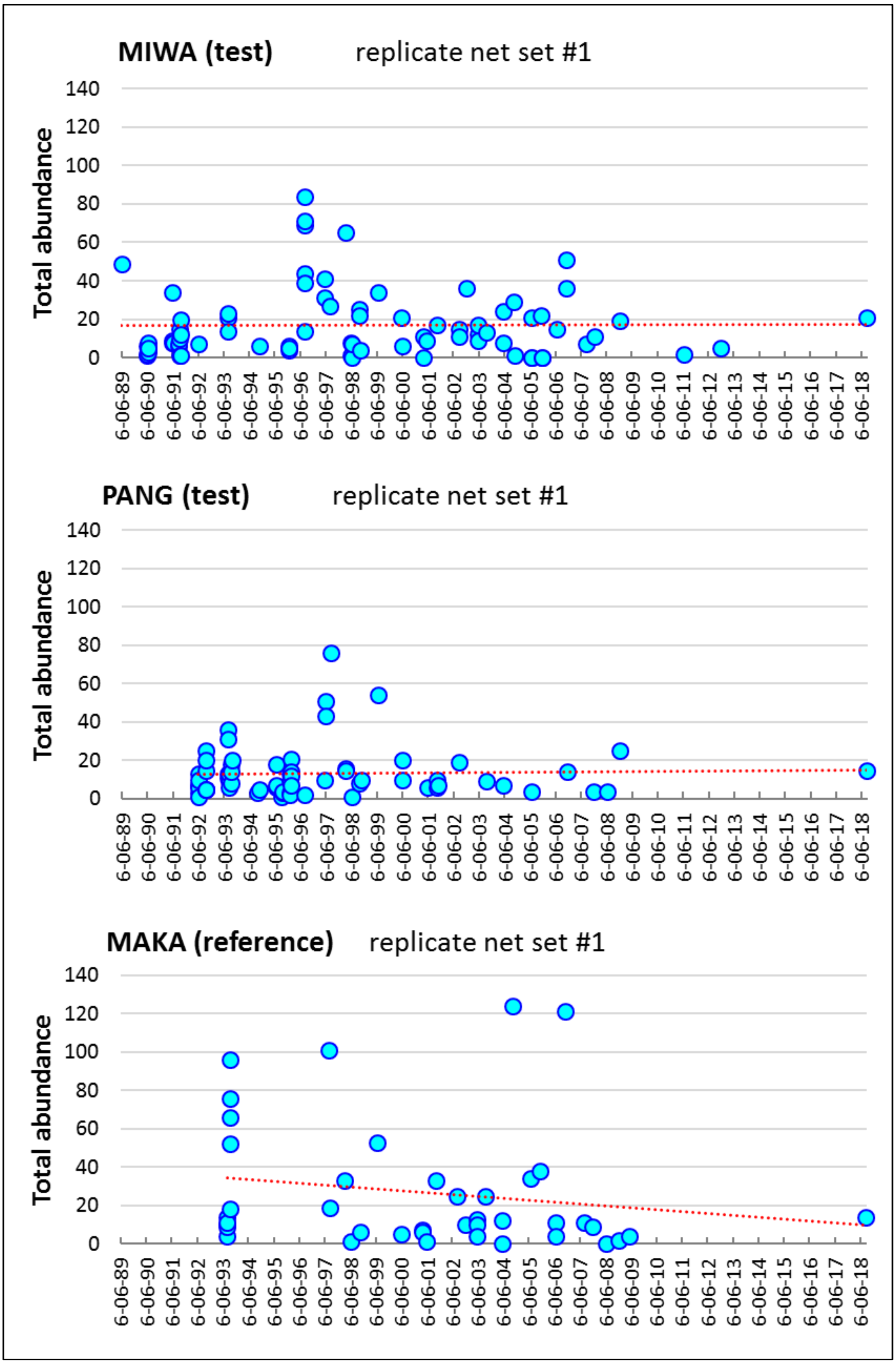


Figure 8-9 Time series plots of average species abundance from replicate gill net set #1 only. Data are for Lake Murray test sites Miwa and Pangoa, and reference site Maka. Linear trend lines are shown in red.

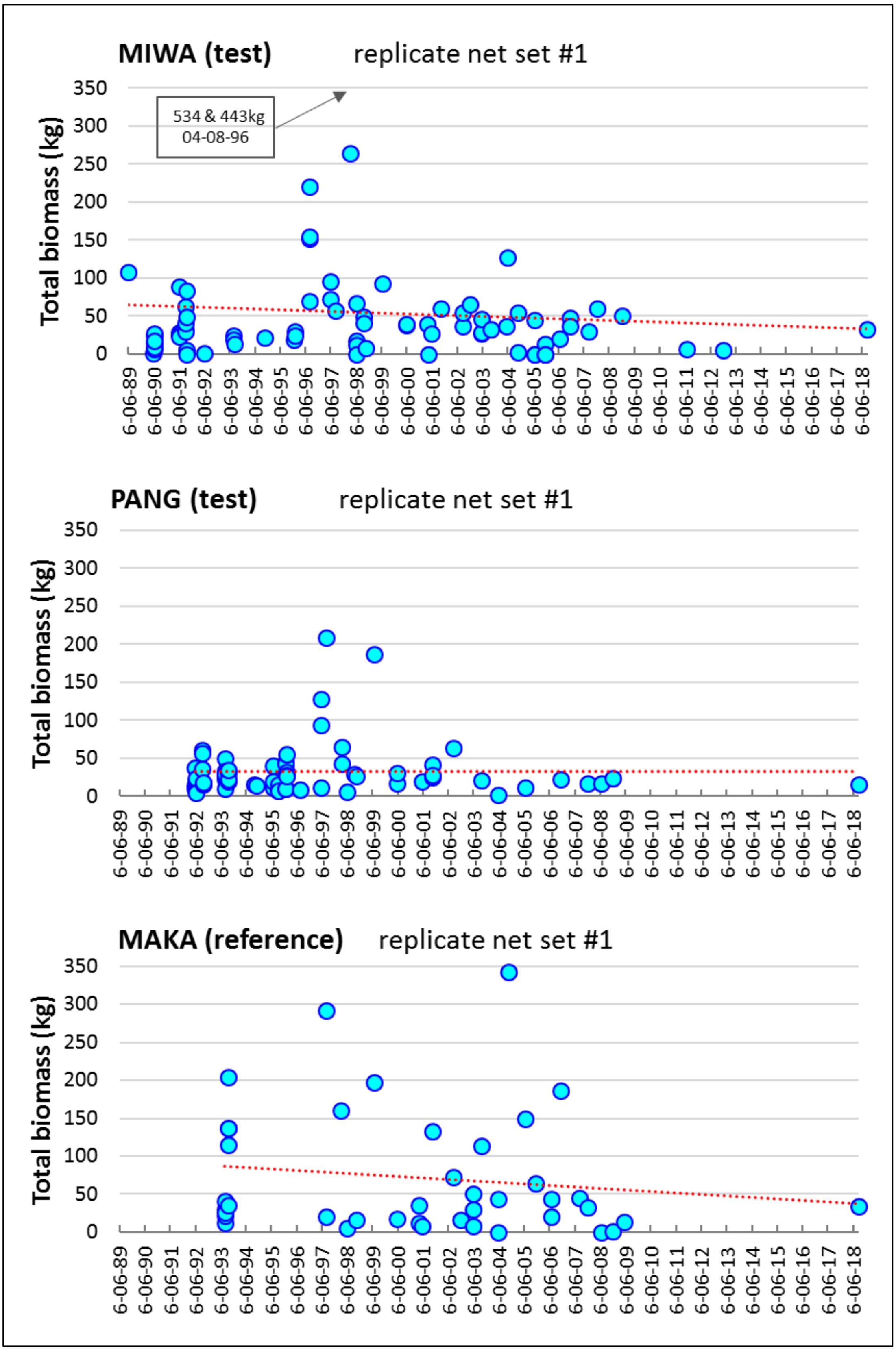


Figure 8-10 Time series plots of average biomass (kg) from replicate gill net set #1 only. Data are for Lake Murray test sites Miwa and Pangoa, and reference site Maka. Linear trend lines are shown in red. Testing the Performance of the Impact Assessment TVs.

9 DISCUSSION, CONCLUSIONS AND OVERALL PERFORMANCE

PJV is a large-scale open cut and underground gold mine operating in the PNG Highlands since 1990. The environmental aspects of the operation are managed through the implementation of the PJV EMS. The objectives of the EMS are to consistently and effectively achieve compliance with legal obligations, mitigate risk and continually improve performance.

The PJV environmental monitoring program provides data and information upon which the operation can assess the effectiveness of the EMS for achieving compliance, risk mitigation and continual improvement of environmental performance. The monitoring program has continually evolved over the years, benefiting from improvements to scientific knowledge, sampling and data analysis techniques and environmental management practices. The 2018 Annual Environment Report continues this tradition by incorporating historical and newly acquired data, information and knowledge within the AER framework.

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 comparison 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 trends. Where possible, the comparison is supported by statistical analysis to provide added confidence in the results.

The site achieved compliance with an average of 99% of the conditions of the environmental permits. Non-compliance was related to short-duration events where TSS concentrations exceeded the permit limit in discharge from two of the five sewage treatment plants. PJV complied with all other water extraction and waste discharge permit conditions, including water quality at the compliance point at SG3 on the Strickland River, which was compliant with all permit requirements throughout 2018.

Background environmental conditions in 2018 were characterised by 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 in the receiving aquatic ecosystem is 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, which provide moderate dilution of mine inputs.

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 that are not influenced by the PJV mine within the upper and lower rivers and northern Lake Murray.

Similar to waters, 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 not influenced by the PJV mine within the upper and lower rivers and northern Lake Murray.

Baseline and reference tissue metal concentrations reflected low baseline and reference concentrations in water and sediment, whereby baseline and reference fish tissue and prawn abdomens in the upper and lower rivers exhibit detectable concentrations of some metals.

Environmental risk assessment was performed by developing trigger values (TVs) for physical and chemical parameters in water, benthic sediment, metals in fish and prawn tissues and air emissions using baseline, reference and guideline values. TVs act as a benchmark for assessing the risk posed by concentrations of physical and chemical parameters in discharges from the mine and at test sites within the receiving environment. Where the concentration of the physical or chemical parameter at a discharge or a test site is greater than or equal to the TV, it indicates a potential risk to aquatic ecosystems and triggers further investigation to determine whether impact is actually occurring. It should be noted that the 2018 assessment applies to sites downstream of SG1 on the Porgera River, monitoring was not conducted at SG1 during 2018 due to security concerns, therefore the assessment could not be performed at this location.

The results of the risk assessment show that near average rainfall and subsequently moderate natural river flows during 2018, had an average moderating influence of river flows and natural sediment loads on the operations environmental aspects within the receiving aquatic ecosystem.

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, Aipulungu Creek, FT07 and Kogai Creeks downstream of the extraction points.

Inputs from the mine in 2018 were slightly lower than recent years. This was due to the earthquake event that affected production for the first half of the year. Near average rainfall and subsequently moderate natural river flows in the receiving environment resulted in less dilution of mine inputs by water and natural sediment.

In the upper river section of the receiving environment, from the mine to SG3 on the Strickland River, the risk assessment indicated a potential risk to aquatic ecosystems due to elevated EC in water, cadmium in benthic sediment and prawns, nickel in sediment fish and prawns, lead in sediment and prawns and selenium in sediment and prawns. The risk is associated with elevated EC in tailings and contact runoff from the mine site, elevated dissolved cadmium and nickel in tailings, elevated WAE cadmium, nickel, lead and selenium in sediment discharged in tailings, and elevated WAE lead and selenium in mine contact runoff from the competent waste rock dumps, Yakatabari Creek downstream of 28 Level, which drains the open pit mine, and Yunarilama/Yarik at Portal which drain the underground mine.

In the lower river, Lake Murray and ORWBs the concentrations of indicators were largely below the respective TVs, indicating that overall the risk to aquatic ecosystems from mine activities was low.

Metal speciation of waters sampled in 2017 (Angel et al, 2018) showed that although dissolved metals in mine-site waters occurred in bioavailable forms, in the river system significant components of dissolved cadmium, copper and nickel were not present in bioavailable forms. However, lead and selenium were predominantly present in bioavailable forms at SG2 and Wasiba, which was reflected in elevated lead and selenium tissue metal concentrations in prawn abdomens at the upper river sites. Bioassay toxicity testing identified metal-related inhibition of bacterial respiration only at SG2 and Wasiba. There was a small but significant algal growth inhibition at Upper Lagaip, Baia, and Ok Om. These results were very unusual as all of these sites are reference sites, which do not receive mine-related inputs. The dissolved and labile metal concentrations at these sites were well below the concentrations expected to cause algal toxicity.

Overall, the risk assessment based on PJV's monitoring program showed that in 2018, as a result of uniform inputs from the mine, consistent application of environmental controls for detoxifying and neutralising tailings discharges, and dilution of mine inputs by moderate natural river flows and sediment loads, the risk from dissolved metals to aquatic ecosystems downstream of Wankipe was low. This conclusion is in agreement with the separate line of enquiry for dissolved metals provided by the metal speciation and bioassay toxicity testing study by CSIRO.

The elevated concentrations of some metals in biota, but concurrently low concentrations of bioavailable metals in water and sediment, indicate possible exposure to and uptake of mine-derived metals by a pathway other than direct exposure to dissolved metals in water and WAE metals in benthic sediments. Alternate metals uptake pathways are hypothesised to involve ingestion of particulate metals and metals adsorbed or bound to organic matter. Particulate metals occur as fine grain-size particles of mine-derived tailings and sediment that are transported in suspension by the river system and become mixed with benthic sediments when deposited during low river flow and in back-waters. The particulate matter is likely ingested incidentally during feeding by aquatic fauna and particulate-bound metals then may be mobilised and pass into dissolved phase by digestion in the acidic gut of the animal. Alternatively, mine-derived metals may become adsorbed or bound to organic matter, which is a known food source for detritivores and so is ingested by aquatic fauna during feeding and similarly mobilised in the gut of the animal during digestion. In reality, both mechanisms may be occurring, and change spatially and possibly temporally along the system. A separate study is proposed to investigate the metals exposure and uptake pathway from particulate metals and organic matter.

In addition to risks posed to the aquatic ecosystems, the operation's environmental aspects also have the potential to cause risk to human health through exposure to physical and chemical stressors and toxicants. The risk assessment focused on exposure through consumption of water from known drinking water sources within the villages on the SML and LMPs, through contact and incidental consumption of water within the receiving environment where people are known to enter the water for gold panning, fishing or recreational purposes, and through the consumption of fish and prawns downstream within the receiving environment.

Risk assessment showed that the discharges from the mine do not pose a risk to drinking water used by villages within the SML and LMPs. Risk is posed to people who have dermal contact with undiluted tailings when illegally panning for gold on the mine lease and are exposed to elevated concentrations of dissolved cadmium, nickel and zinc. Metals concentrations in fish and prawns at Wasiba and Wankipe in the upper river, and Bebelubi and SG4 in the lower river pose low risk to human health if consumed.

Additionally, localised risks to air quality were posed by elevated concentrations of oxides of nitrogen in emissions from the stand-by Anawe Generator and elevated particulate matter in emissions from the lime kilns.

The impact assessment is performed to determine whether environment risks are translating into detectable environmental impacts. The impact assessment is based on the comparison of aquatic ecosystem health indicators at test sites against TVs derived from reference site data and supported by an analysis of the trends of those same indicators over time.

The results of the impact assessment showed that in the upper river at test sites Wasiba and Wankipe, there were no impacts to fish or prawns during 2018. All indicators from the test sites were not significantly different from the respective TVs. The trend analysis showed a significantly decreasing trend in *M. lorentzi* biomass at Wasiba between 2015 and 2018, and while this does not indicate impact it does provide an indication that impact may be detected in future years if the trend continues. The trends of all other indicators at upper river test sites did not change between 2015 and 2018, the period for which standardised sampling has been applied. These results show that no significant aquatic ecosystem impact has occurred within the upper river during 2018 and that, with the exception of *M. lorentzi* biomass at Wasiba, the condition of the river was not changing over time.

In the lower river, the results showed that, with the exception of species richness at Tiumsinawam when compared against TV option 3, all indicators at test sites Bebelubi and Tiumsinawam were significantly greater than or not significantly different from the respective TVs. Trends for all indicators at test site Bebelubi did not change between 2006 and 2018, however, all indicators at Tiumsinawam showed a declining trend between 1989 and 2018. Further investigation concluded that the changes observed over time at Tiumsinawam were driven by non-mine related factors, primarily increased fishing pressure due to population growth in nearby villages. Therefore, due to the indication of no impact for all indicators at Bebelubi and the majority of indicators at Tiumsinawam in 2018, increasing or no change in trends for all indicators over time at Bebelubi, the absence of mine-related environmental risk indicated by water quality, sediment quality and tissue metal analysis within the lower river, and the presence of non-mine related pressure on fish populations as a result of population growth in nearby villages, it is concluded that there were no significant aquatic ecosystem impacts within the lower river in 2018.

A lack of standardised sampling in Lake Murray during 2018 did not allow for impact assessment to be performed for 2018. Trend analysis has been performed on the available data and shows no change in all indicators at Lake Murray test sites Miwa and Pangoa.

Overall, the impact assessment has shown that there was no significant mine-related aquatic ecosystem impact within the upper and lower river during 2018, and no mine-related change to indicators in the upper river, lower river and Lake Murray over time, with the exception of *M. lorentzi* biomass at Wasiba in the upper river.

The environmental performance of the operation in 2018 remained consistent with recent years. The site achieved a high level of compliance with legal obligations and the scope and magnitude of environmental aspects were comparable with recent years. Elevated EC, cadmium, nickel, lead and selenium in tailings and contact runoff from the competent waste rock dumps, open pit mine and underground mine pose a potential risk to aquatic ecosystems. This potential risk was also observed within the upper river system from the mine to SG3, where elevated EC, cadmium, nickel, lead and selenium in sediment, fish and prawns were observed. These potential risks occured within the permitted and compensated mixing zone which extends from the mine to SG3 on the Strickland River. Downstream of SG3 in the lower river, Lake Murray and ORWBs, there was low risk to aquatic ecosystems. Overall, the condition of the receiving aquatic ecosystem remains consistent with predictions made prior to operations commencing in 1990.

The risk to human health is low throughout the receiving environment, with the exception of those individuals exposed to undiluted tailings when entering the mining lease illegally to pan for gold at the discharge point.

10 RECOMMENDATIONS

Recommendations are proposed 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 2017 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 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 Strickland River 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. Apply improved standardised fishing methods at Lake Murray.
5. Investigate the ions that contribute to elevated EC values.

Reduce Environmental Risk and Impact and Improve Performance

6. Continue to investigate options for reducing the concentrations of bioavailable metals and mass loads of metals in mine discharges.
7. 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.
8. Investigate the apparent trend of increasing pH and metals concentrations from non-mine related sources in the lower river system (e.g. zinc at concentrations slightly above the analytical LOR).

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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 22 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 2018 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 2018 as shown in Table A-2 indicated good performance for all of QA & QC samples across the all parameters.

Table A-2 2018 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	100	96	92	100	100	100	96	100	79	NA	96	100
CRM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	100	100
Field Duplicate	92	100	92	88	100	96	100	79	100	88	100	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 2018 shown in Table A-3 indicated good performance of all samples for all parameters.

Table A-3 2018 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	97	94	92	93	92	94	92	94	97	93
NMI Duplicate	100	100	100	100	100	91	100	100	100	100
NMI Matrix Spike	100	100	100	100	100	100	100	91	100	100
NMI Blank	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NMI LCS	92	83	100	92	100	100	100	100	100	100

WAE = Weak-Acid Extractable

In addition to the routine QA & QC samples, PJV also participated in eight proficiency test rounds in 2018 run by Proficiency Testing Australia. The inter-laboratory testing programs provide 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 26% of the PTA results 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 2018

Date	Analyte	Units	Lab result	MU	Median	NORM IQR	CV (%)	n	z-score
Jan-18	Alkalinity	mg/L	88.5	NA	87.1	3.7	4.2	42	0.4
	Chloride	mg/L	84.8	NA	80.8	1.2	1.5	40	1.77
	Conductivity	µS/cm	496	NA	509	10.2	2.0	49	-1.25
	Sulfate	mg/L	23	NA	29	1.9	6.6	37	-3.11
	Total Solids	mg/L	376	NA	378	31.4	8.3	28	-0.06
Apr-18	Biochemical Oxygen Demand	mg/L	45.9	NA	47	7.4	15.8	25	-0.15
	Biochemical Oxygen Demand	mg/L	21.9	NA	33.2	4.5	13.6	25	-2.5
May-18	Weak Acid Dissociable Cyanide	mg/L	0.417	NA	0.25	0.03	13.4	14	4.88
	Weak Acid Dissociable Cyanide	mg/L	4.87	NA	3.5	0.5	14.7	14	3.01
Jun-18	Sulfate	mg/L	21	NA	23.4	0.9	4	32	-2.59
	Sulfate	mg/L	18	NA	21.65	1.2	5.6	32	-3.03
	Conductivity	µS/cm	255	NA	255	10.7	4.2	54	0
	Conductivity	µS/cm	188	NA	179	7.7	4.3	54	1.16
	pH - potable	SU	8.2	NA	8.66	0.3	3.7	57	-1.44
	pH - potable	SU	8.13	NA	8.51	0.4	5.1	57	-0.87
	pH - standard	SU	7.8	NA	7.76	0.04	0.5	58	1.08
	Turbidity standard	NTU	0.9	NA	2.02	0.2	11.2	40	-4.95
	Colour standard	Pt/Co	10	NA	13	1.5	11.4	27	-2.02

Date	Analyte	Units	Lab result	MU	Median	NORM IQR	CV (%)	n	z-score
Jul-18	Chloride	mg/L	223	NA	210	5.5	2.6	31	2.34
	Chloride	mg/L	92.4	NA	78.94	6.5	8.2	31	2.09
Aug-18	Total Solids	mg/L	284	NA	349	18.5	5.3	28	-3.51
	Total Solids	mg/L	169	NA	241	22.7	9.4	28	-3.18
	Total Suspended Solids	mg/L	33	NA	44.2	4.0	9.1	44	-2.8
	Total Suspended Solids	mg/L	71	NA	85.8	5.9	6.9	45	-2.5
Oct-18	Alkalinity	mg/L	46.3	NA	46.3	2.5	5.4	32	0
	Chloride	mg/L	42.6	NA	65.3	2.6	4	37	2.81
	Conductivity	mg/L	446	NA	431.5	12.9	3	38	1.12
	Sulphate	mg/L	29.8	NA	37.2	2.4	6.4	33	-3.12
	Totals Solids	mg/L	243	NA	291	14.8	5.1	25	-3.24
Nov-18	Sulphate - Potable	mg/L	36	NA	34.6	1.7	4.9	47	0.82
	Sulphate - Potable	mg/L	40	NA	37.15	1.7	4.5	46	1.71
	Conductivity -Potable	µS/cm	269	NA	272.5	6.5	2.4	36	-0.54
	Conductivity - Potable	µS/cm	216	NA	217.5	8.2	3.7	36	-0.18
	pH -Potable	SU	7.17	NA	7.9	0.0	0.43	39	-1.72
	pH -Potable	SU	7.33	NA	8.3	0.0	0.46	39	-2.02
	pH -Standard	SU	7.84	NA	7.77	0.04	0.6	39	1.57
	Turbidity -Standard	NTU	0.98	NA	2.005	0.2	11.2	28	-4.57
	Color -Standard	Pt/Co	12	NA	11	1.3	11.5	20	0.79
(green)	Within acceptable range of results								
(orange)	Outlier – value lies outside acceptable range of results.								

MU - Measurement Uncertainty, NORM IQR - Normalized Interquartile Range, CV - Coefficient of Variation, Z - score - statistical measurement of a score's relationship to the mean.

Tissue Metals

The QA & QC samples for tissue metal, their purpose, collection frequency and performance criteria are shown in Table A-5. It should be noted that the acceptance criteria applied to field duplicate samples of ±44% aligns with the criteria applied by NMI to the internal lab samples, and when combined with the acceptance criteria applied to the field blanks, is considered acceptable for supporting a robust QA program.

Table A-5 QA & QC samples – tissue metals

QA&QC Sample	Purpose	Sample rate	Acceptance Criteria
Field reference sample (Fish flesh of known concentration)	Test for contamination during field work, sample preparation and transport. Test for accuracy of laboratory analytical method.	1 blank per sample batch (as per sampling monitoring schedule)	±44% of known concentration.
Field duplicate	Test repeatability of laboratory analytical method.	1 duplicate for every 8 samples (minimum 1 per batch)	±44% of primary sample
NMI blank	Test for contamination during sample analysis. Test for accuracy of laboratory analytical method.	1 blank per sample batch	≤LOR for each analyte
NMI duplicate	Test repeatability of laboratory analytical method.	Minimum 1 blank per sample batch	±44% of primary sample
NMI lab control sample	Test influence of sample preparation and analysis on recovery.	Minimum 1 blank per sample batch	75 – 120% recovery
NMI matrix spike	Test influence of sample preparation and analysis on recovery.	Minimum 1 blank per sample batch	75 – 120% recovery

The results of QA & QC samples from tissue metal sampling in 2018 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 chromium and copper in the field duplicate sample. The exact cause of the poor results is not known, however, 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 2017 Tissue metal QA & QC sample results

	% Within Acceptable Criteria									
	n	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**
Field Duplicate	33	97	97	73	88	91	94	97	97	97
Field Reference Sample	33	100	100	94	97	97	100	100	100	100
NMI Blank	8	100	100	100	100	100	100	100	100	100
NMI Duplicate	13	100	100	100	100	100	100	100	100	100
NMI Lab Control Sample	4	100	100	100	100	100	100	100	100	100
NMI Matrix Spike	13	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 2019.

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.

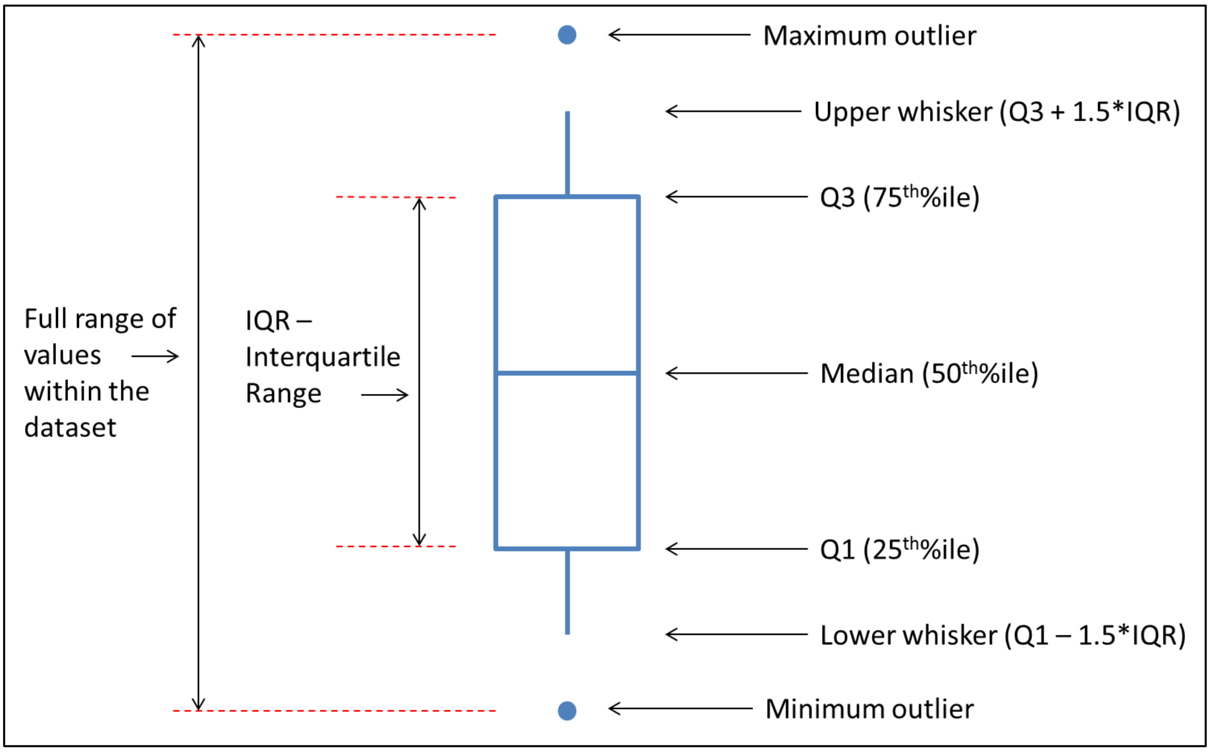


Figure B-1 Box Plot Explained

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 Wilcoxons 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 therefroe 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 Wilcoxons 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 bewteen 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 particulart 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.

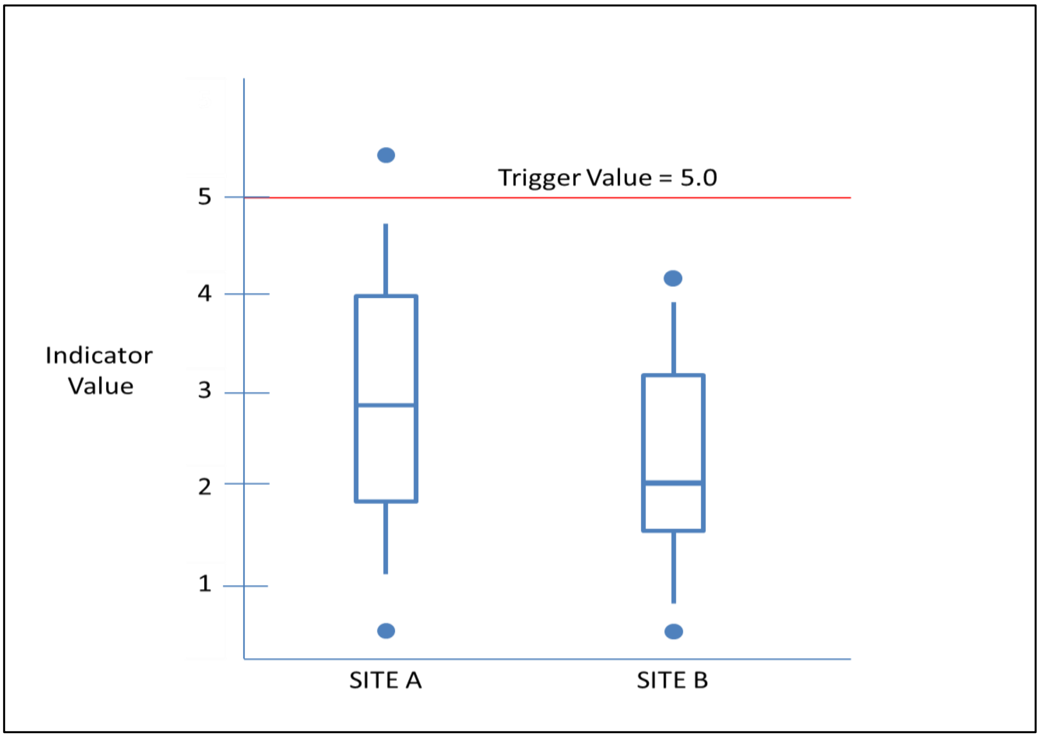


Figure B-1 Comparing box plots between sites and against trigger values

APPENDIX C. BOX PLOTS AND TRENDS OF MINE AREA RUNOFF WATER QUALITY 2009–2018 CHEMISTRY

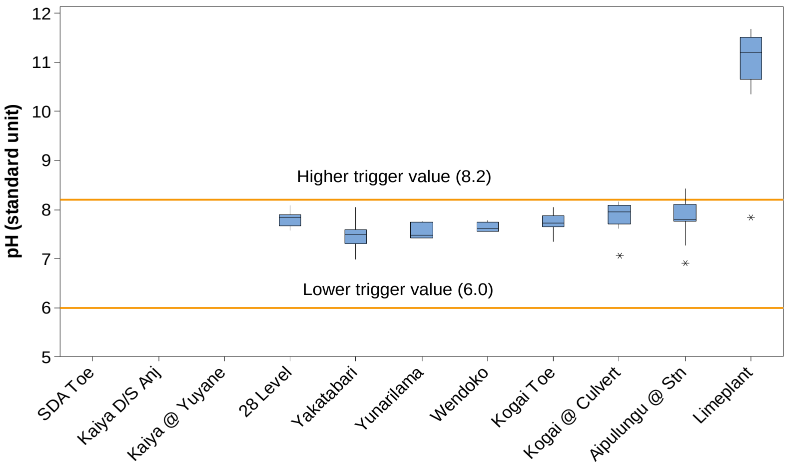


Figure C-1 pH in mine contact runoff 2018

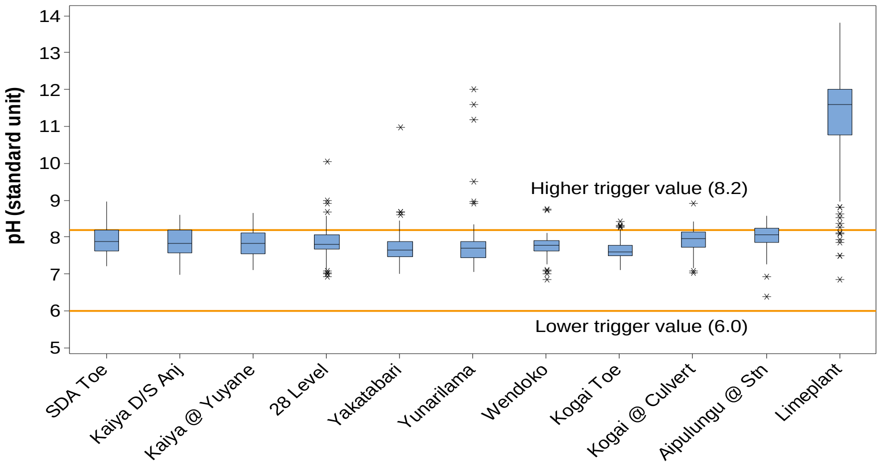


Figure C-2 pH in mine contact runoff 2009-2018

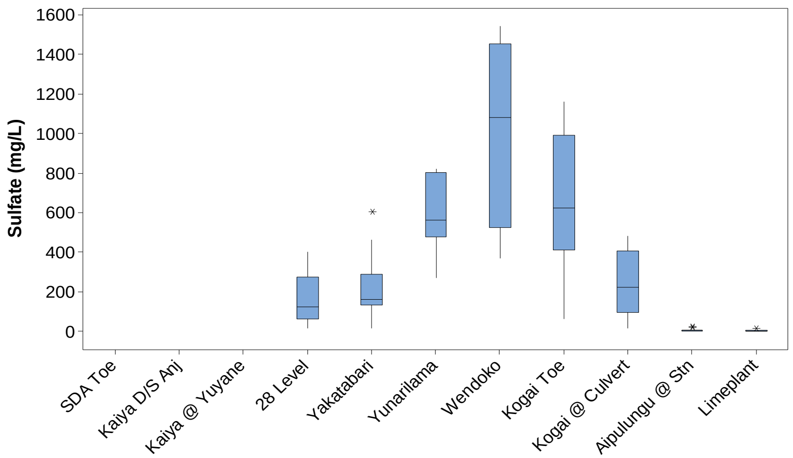


Figure C-3 Sulfate in mine contact runoff 2018

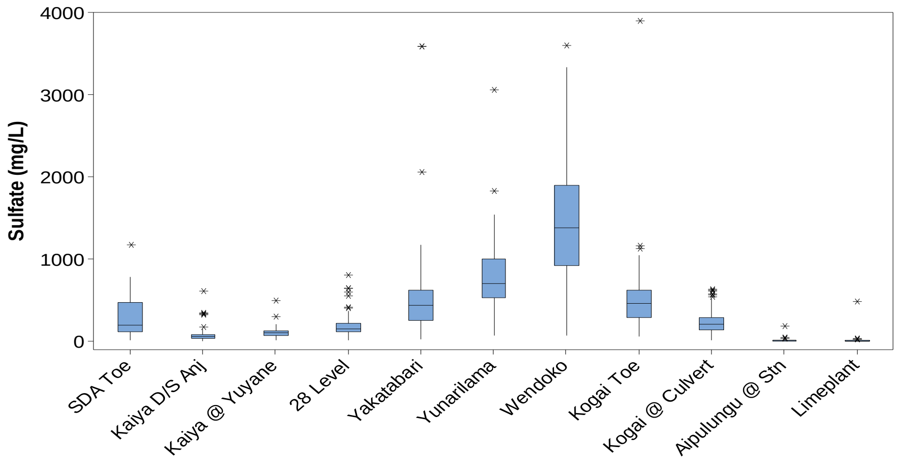


Figure C-4 Sulfate in mine contact runoff 2009-2018

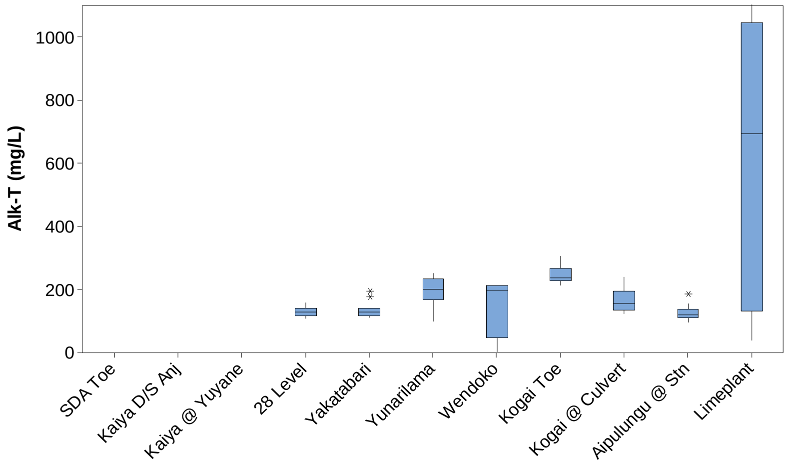


Figure C-5 Alkalinity of contact runoff 2018

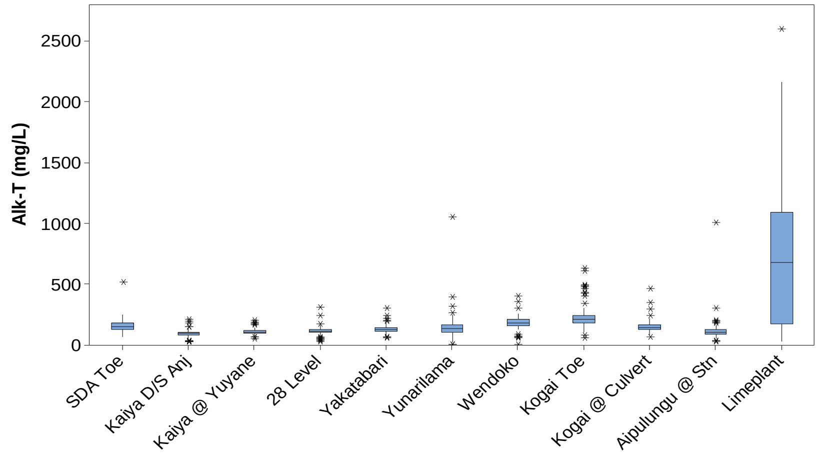


Figure C-6 Alkalinity of contact runoff 2009-2018

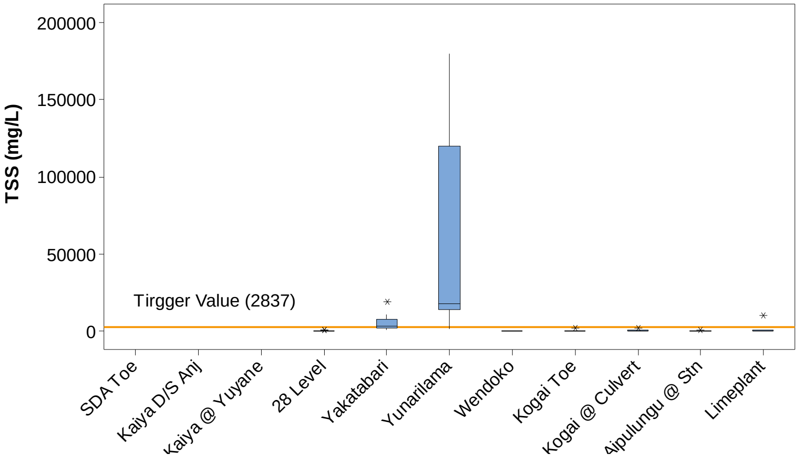


Figure C-7 TSS in contact runoff 2018

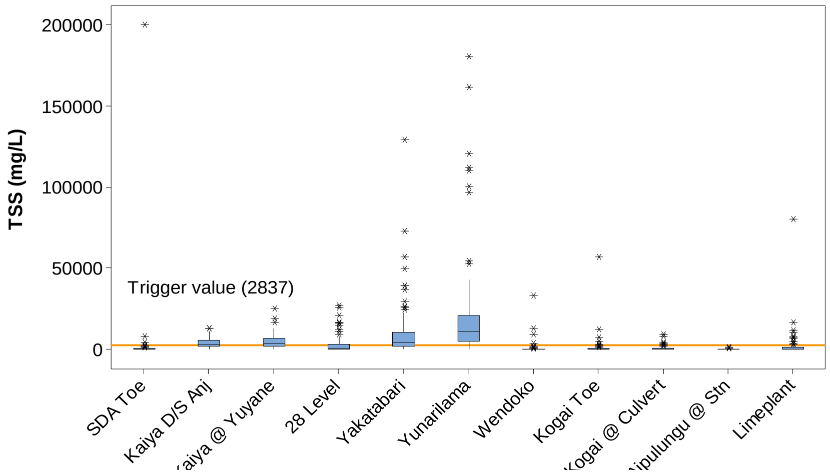


Figure C-8 TSS in contact runoff 2009-2018

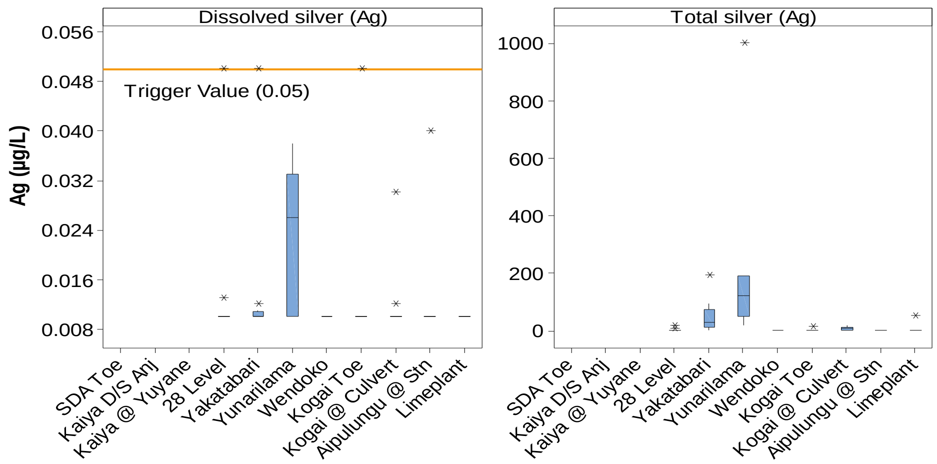


Figure C-9 Dissolved and total silver in contact runoff 2018

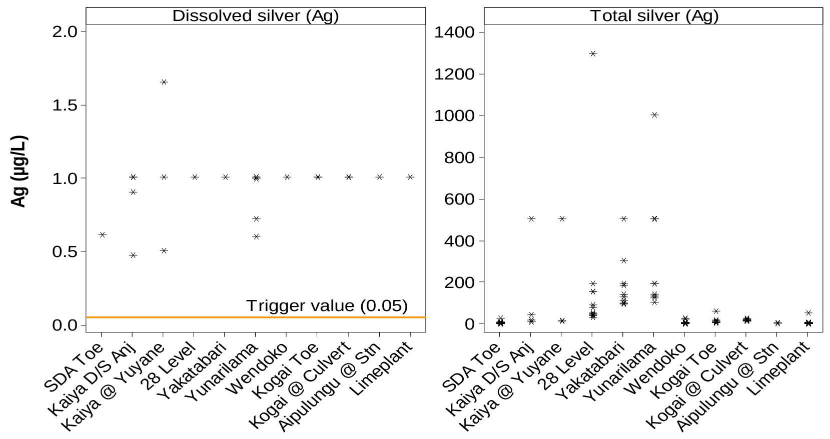


Figure C-10 Dissolved and total silver in contact runoff 2009-2018

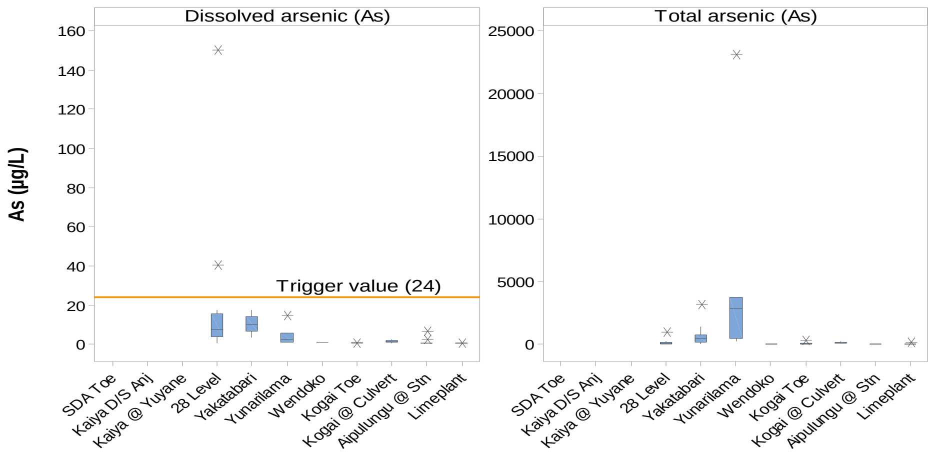


Figure C-11 Dissolved and total arsenic in contact runoff 2018

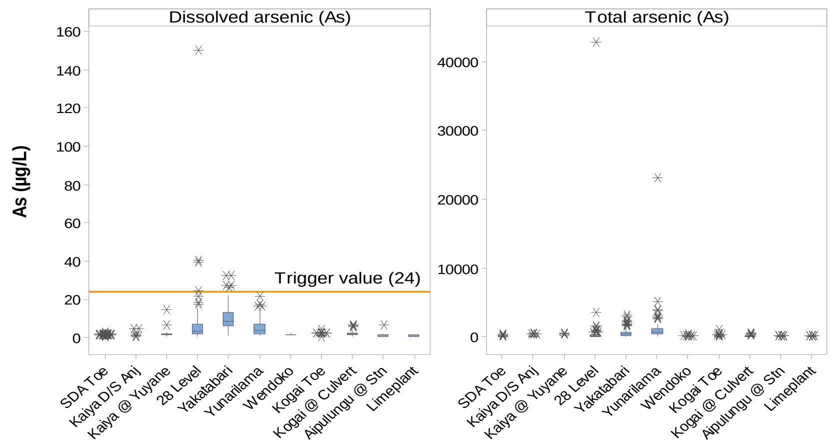


Figure C-12 Dissolved and total arsenic in contact runoff 2009-2018

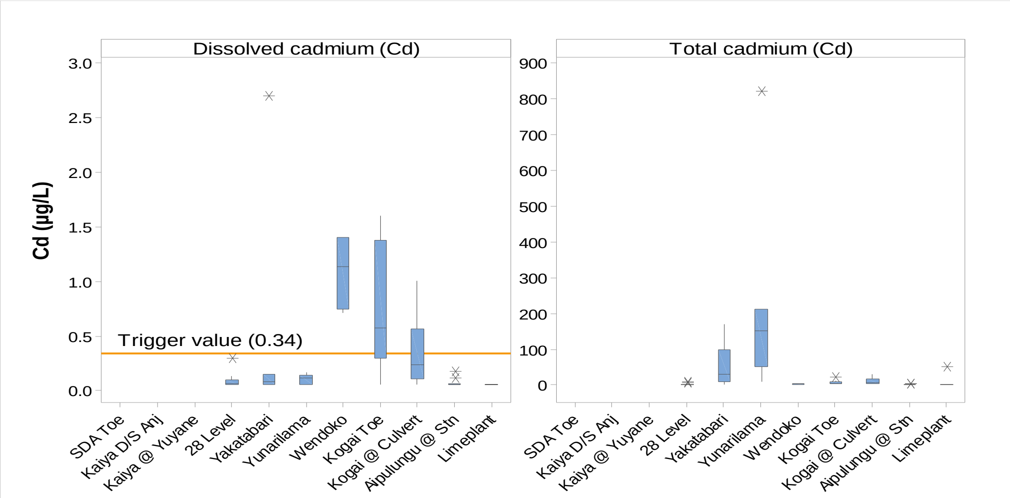


Figure C-13 Dissolved and total cadmium in contact runoff 2018

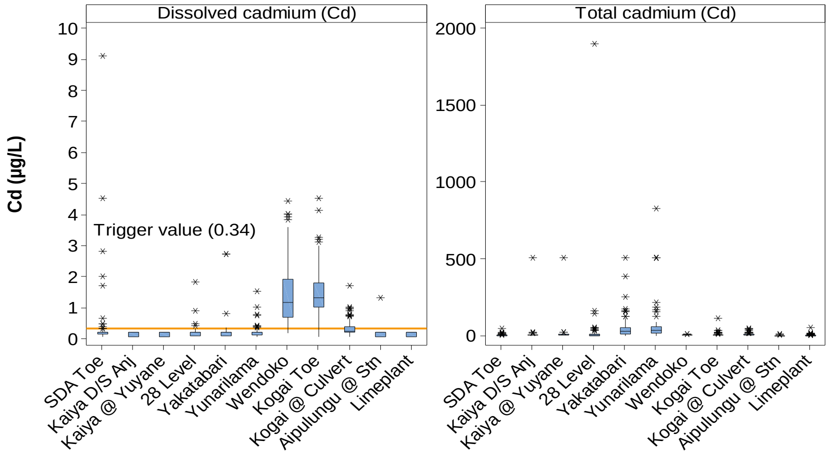


Figure C-14 Dissolved and total cadmium contact runoff 2009-2018

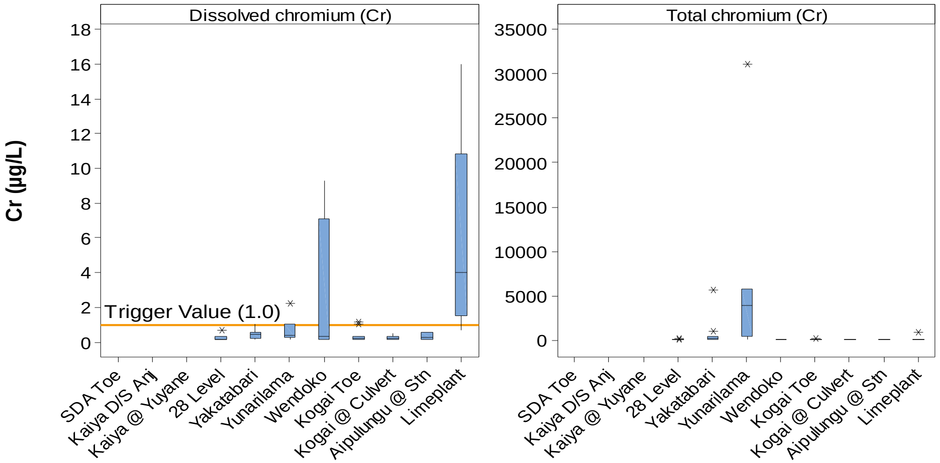


Figure C-15 Dissolved and total chromium in contact runoff 2018

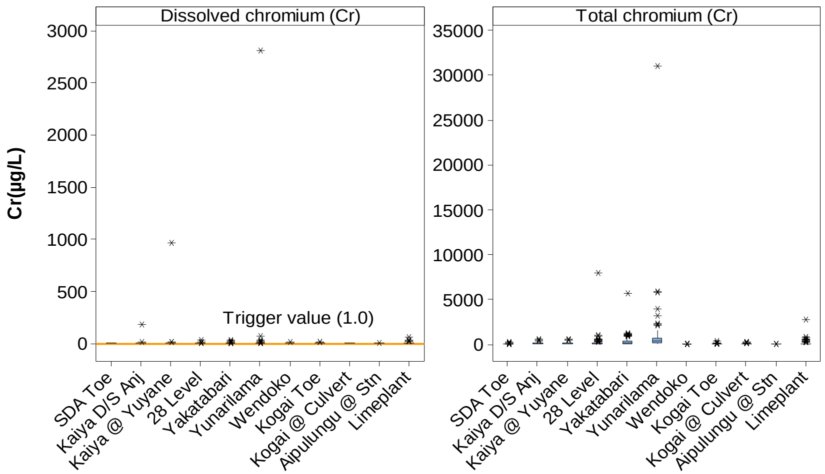


Figure C-16 Dissolved and total chromium in contact runoff 2009-2018

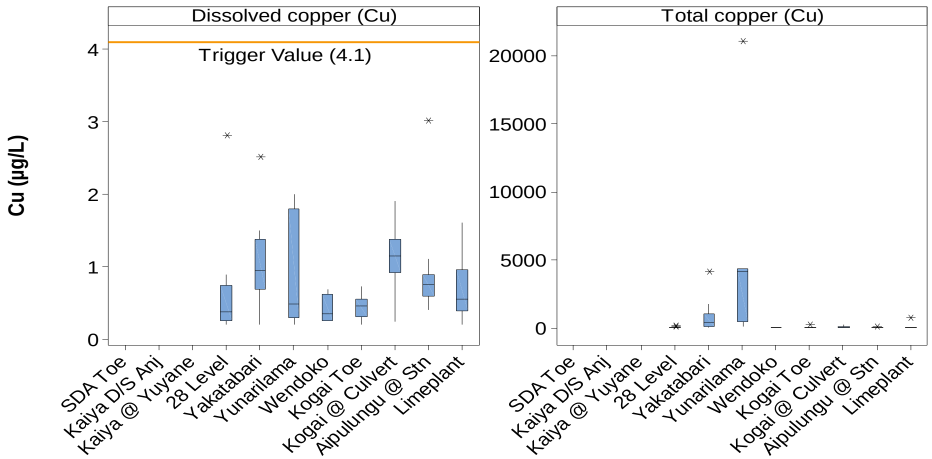


Figure C-17 Dissolved and total copper in contact runoff 2018

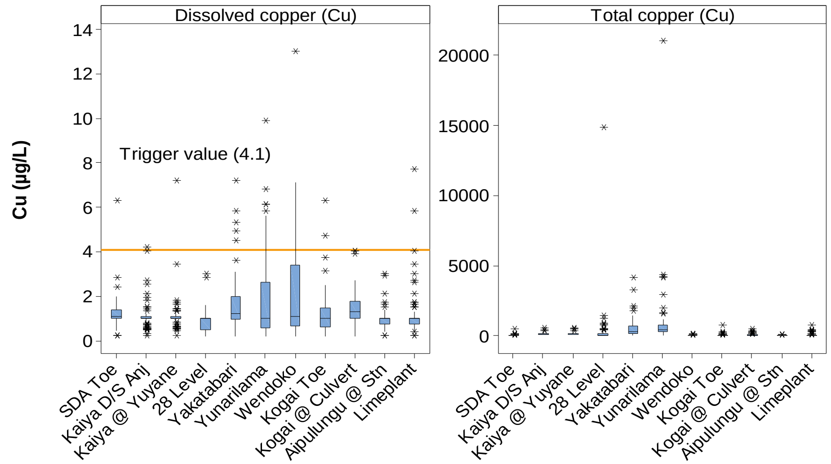


Figure C-18 Dissolved and total copper contact runoff 2009-2018

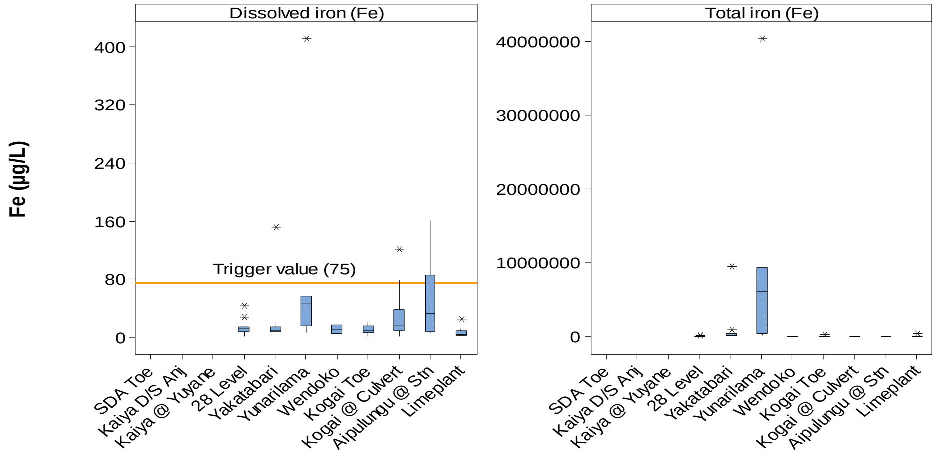


Figure C-19 Dissolved and total iron in contact runoff 2018

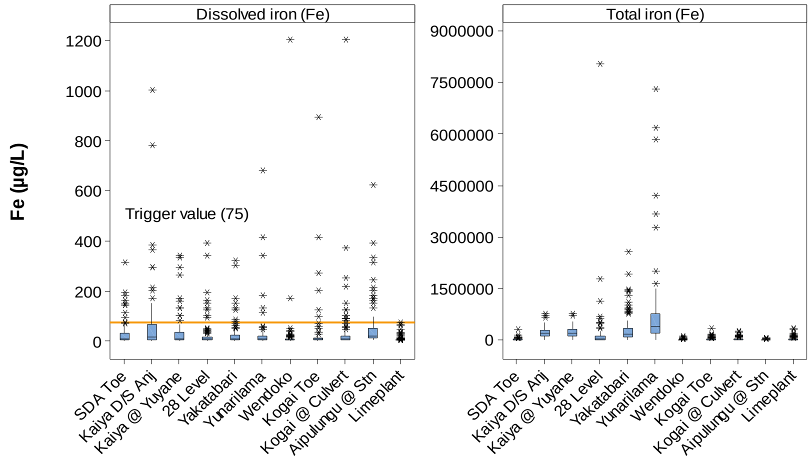


Figure C-20 Dissolved and total iron in contact runoff 2009-2018

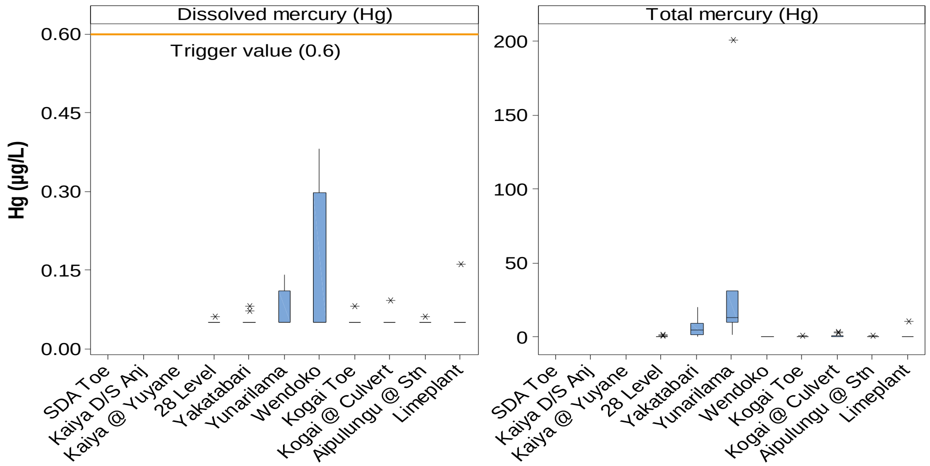


Figure C-21 Dissolved and total mercury in contact runoff 2018

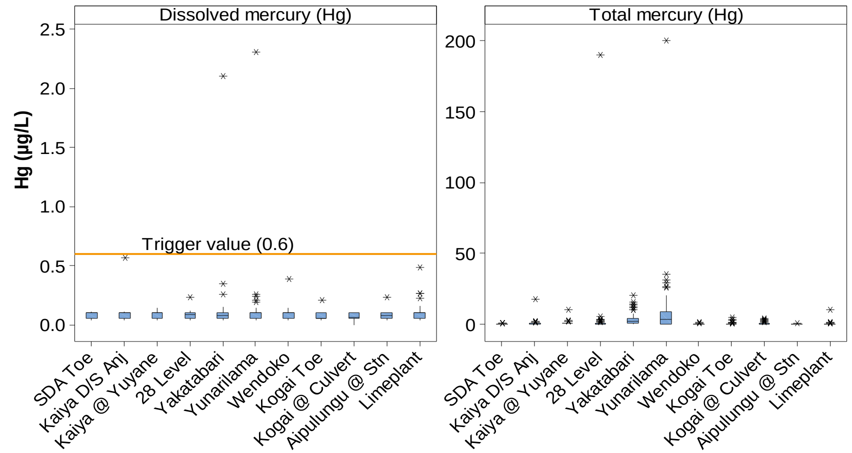


Figure C-22 Dissolved and total mercury in contact runoff 2009-2018

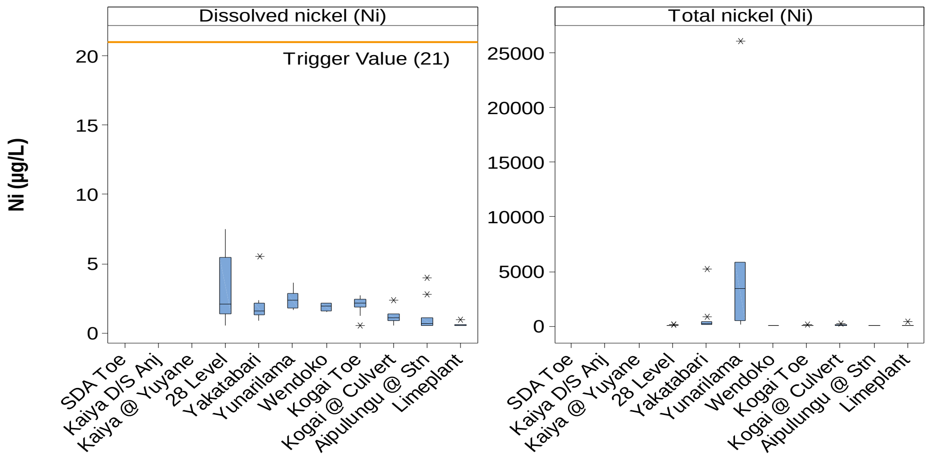


Figure C-23 Dissolved and total nickel in contact runoff 2018

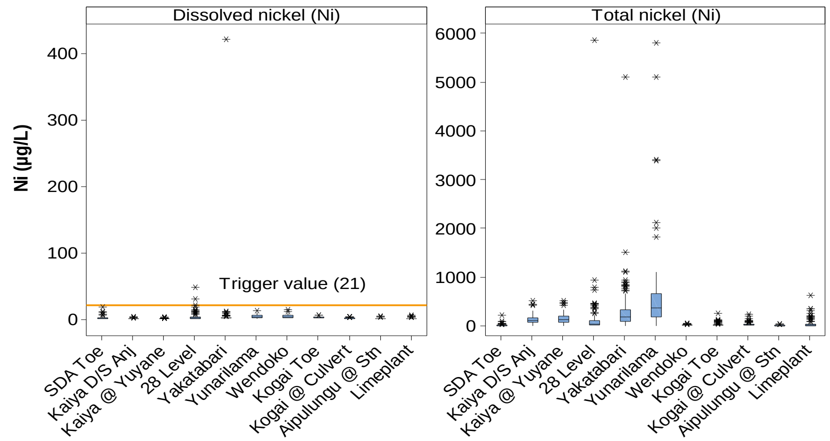


Figure C-23 Dissolved and total nickel in contact runoff 2009-2018

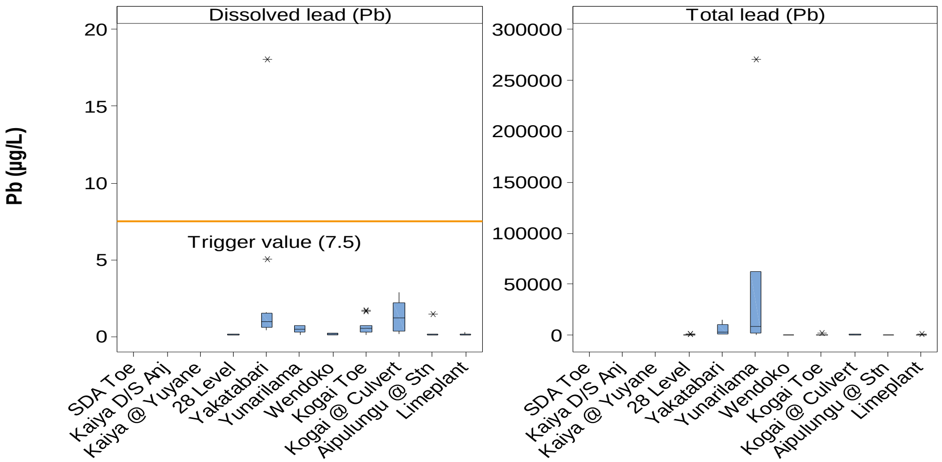


Figure C-24 Dissolved and total lead in contact runoff 2018

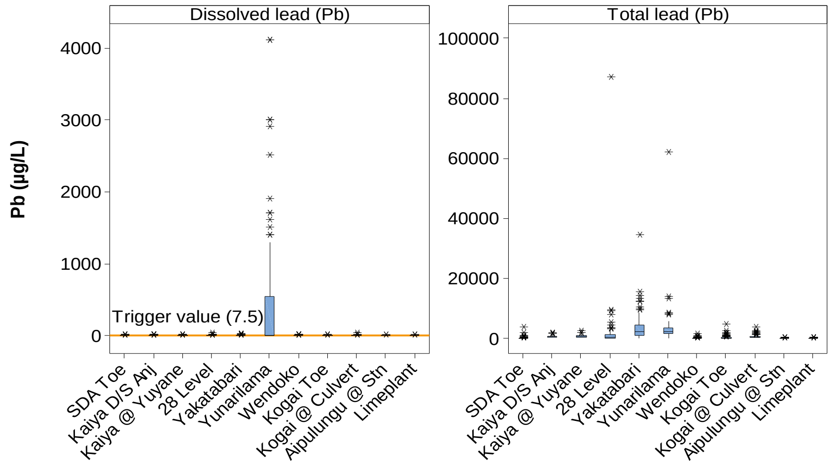


Figure C-25 Dissolved and total lead contact runoff 2009-2018

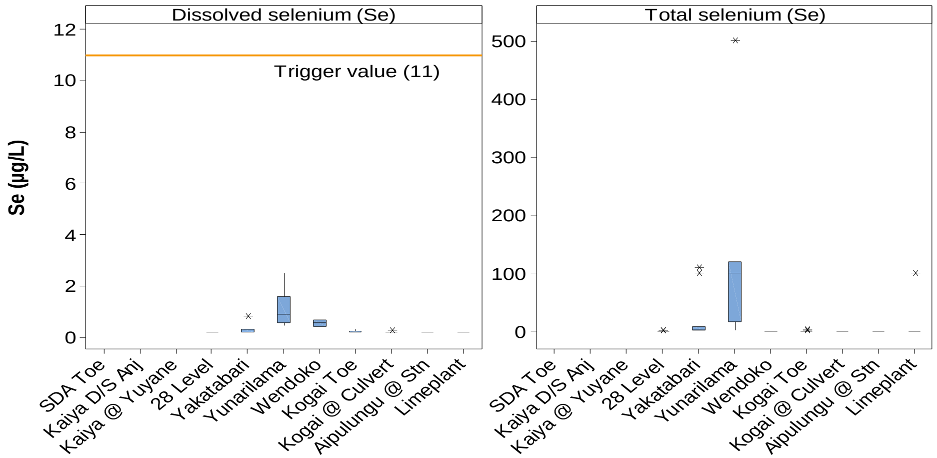


Figure C-25 Dissolved and total selenium in contact runoff 2018

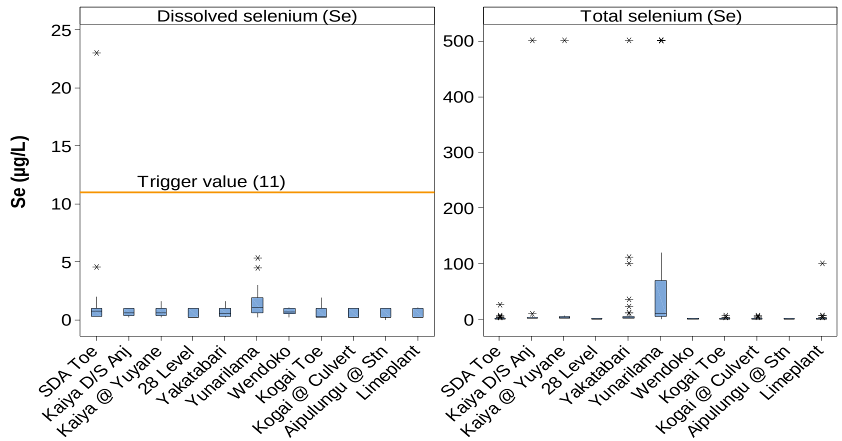


Figure C-26 Dissolved and total selenium in contact runoff 2009-2018

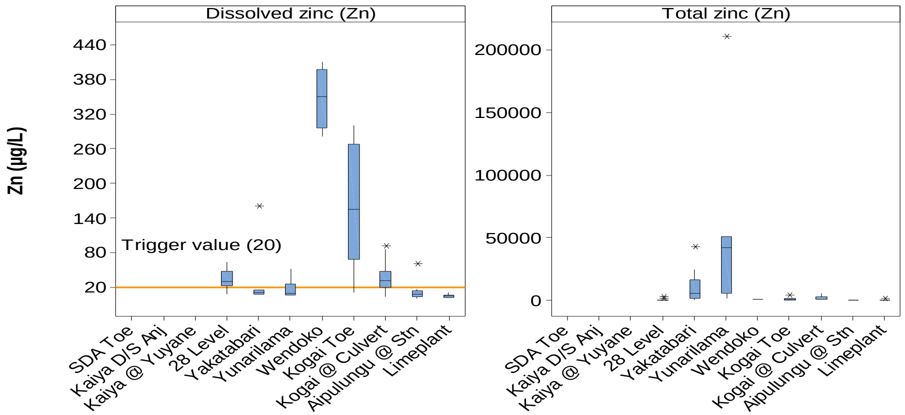


Figure C-27 Dissolved and total zinc in contact runoff 2018

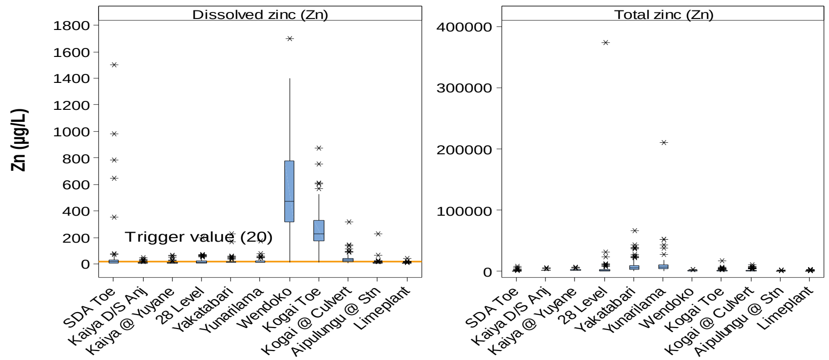


Figure C-28 Dissolved and total zinc in contact runoff 2009-2018

Table C-1 SDA Toe 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.503	<0.001	Reduced over time
EC	-0.022	0.845	No change over time
SO4-D	-0.252	0.015	Reduced over time
Alk-T	0.046	0.658	No change over time
TSS	0.482	<0.001	Increased over time
Ag-D	-0.755	<0.001	Reduced over time
Ag-T	0.101	0.339	No change over time
As-D	-0.195	0.059	No change over time
As-T	0.350	0.001	Increased over time
Cd-D	-0.366	<0.001	Reduced over time
Cd-T	0.158	0.126	No change over time
Cr-D	-0.741	<0.001	Reduced over time
Cr-T	0.434	<0.001	Increased over time
Cu-D	-0.553	<0.001	Reduced over time
Cu-T	0.306	0.003	Increased over time
Fe-D	0.258	0.012	Increased over time
Fe-T	0.400	<0.001	Increased over time
Hg-D	-0.817	<0.001	Reduced over time
Hg-T	-0.521	<0.001	Reduced over time
Ni-D	-0.220	0.032	Reduced over time
Ni-T	0.312	0.002	Increased over time
Pb-D	0.071	0.493	No change over time
Pb-T	0.294	0.004	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	0.309	No change over time
Zn-T	0.169	0.099	No change over time

Table C-2 Kaiya D/S Anjolek 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.625	<0.001	Reduced over time
EC	0.274	0.008	Increased over time
SO4-D	-0.305	0.003	Reduced over time
Alk-T	0.401	<0.001	Increased over time
TSS	0.109	0.301	No change over time
Ag-D	-0.596	<0.001	Reduced over time
Ag-T	0.198	0.061	No change over time
As-D	-0.035	0.736	No change over time
As-T	0.197	0.058	No change over time
Cd-D	-0.795	<0.001	Reduced over time
Cd-T	0.181	0.083	No change over time
Cr-D	-0.782	<0.001	Reduced over time
Cr-T	0.182	0.081	No change over time
Cu-D	-0.425	<0.001	Reduced over time
Cu-T	0.049	0.638	No change over time
Fe-D	-0.152	0.146	No change over time
Fe-T	0.096	0.36	No change over time
Hg-D	-0.728	<0.001	Reduced over time
Hg-T	0.092	0.379	No change over time
Ni-D	-0.623	<0.001	Reduced over time
Ni-T	0.134	0.2	No change over time
Pb-D	-0.642	<0.001	Reduced over time
Pb-T	0.110	0.292	No change over time
Se-D	-0.585	<0.001	Reduced over time
Se-T	0.333	0.022	Increased over time
Zn-D	0.238	0.022	Increased over time
Zn-T	0.133	0.205	No change over time

Table C-3 Kaiya at Yuyan 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.606	<0.001	Reduced over time
EC	-0.110	0.294	No change over time
SO4-D	-0.520	<0.001	Reduced over time
Alk-T	0.017	0.87	No change over time
TSS	-0.015	0.887	No change over time
Ag-D	-0.538	<0.001	Reduced over time
Ag-T	0.238	0.024	Increased over time
As-D	-0.367	<0.001	Reduced over time
As-T	0.122	0.243	No change over time
Cd-D	-0.791	<0.001	Reduced over time
Cd-T	0.074	0.48	No change over time
Cr-D	-0.764	<0.001	Reduced over time
Cr-T	0.076	0.469	No change over time
Cu-D	-0.332	0.001	Reduced over time
Cu-T	-0.051	0.626	No change over time
Fe-D	0.044	0.676	No change over time
Fe-T	0.036	0.734	No change over time
Hg-D	-0.661	<0.001	Reduced over time
Hg-T	-0.118	0.26	No change over time
Ni-D	-0.386	<0.001	Reduced over time
Ni-T	0.051	0.629	No change over time
Pb-D	-0.405	<0.001	Reduced over time
Pb-T	-0.007	0.948	No change over time
Se-D	-0.581	<0.001	Reduced over time
Se-T	0.224	0.13	No change over time
Zn-D	0.285	0.006	Increased over time
Zn-T	0.035	0.736	No change over time

Table C-4 28 Level 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.373	<0.001	Reduced over time
EC	0.335	0.001	Increased over time
SO4-D	-0.049	0.608	No change over time
Alk-T	0.136	0.149	No change over time
TSS	-0.726	<0.001	Reduced over time
Ag-D	-0.866	<0.001	Reduced over time
Ag-T	-0.647	<0.001	Reduced over time
As-D	-0.259	0.005	Reduced over time
As-T	-0.437	<0.001	Reduced over time
Cd-D	-0.596	<0.001	Reduced over time
Cd-T	-0.570	<0.001	Reduced over time
Cr-D	-0.784	<0.001	Reduced over time
Cr-T	-0.617	<0.001	Reduced over time
Cu-D	-0.681	<0.001	Reduced over time
Cu-T	-0.569	<0.001	Reduced over time
Fe-D	0.044	0.641	No change over time
Fe-T	-0.587	<0.001	Reduced over time
Hg-D	-0.709	<0.001	Reduced over time
Hg-T	-0.610	<0.001	Reduced over time
Ni-D	0.530	<0.001	Increased over time
Ni-T	-0.534	<0.001	Reduced over time
Pb-D	-0.658	<0.001	Reduced over time
Pb-T	-0.606	<0.001	Reduced over time
Se-D	-0.762	<0.001	Reduced over time
Se-T	-0.585	<0.001	Reduced over time
Zn-D	0.629	<0.001	Increased over time
Zn-T	-0.506	<0.001	Reduced over time

Table C-5 Yakatabari 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.491	<0.001	Reduced over time
EC	-0.300	0.002	Reduced over time
SO4-D	-0.468	<0.001	Reduced over time
Alk-T	-0.112	0.236	No change over time
TSS	-0.149	0.114	No change over time
Ag-D	-0.860	<0.001	Reduced over time
Ag-T	0.177	0.062	No change over time
As-D	0.038	0.684	No change over time
As-T	0.054	0.566	No change over time
Cd-D	-0.663	<0.001	Reduced over time
Cd-T	0.183	0.05	Increased over time
Cr-D	-0.558	<0.001	Reduced over time
Cr-T	-0.012	0.895	No change over time
Cu-D	-0.542	<0.001	Reduced over time
Cu-T	0.124	0.187	No change over time
Fe-D	0.077	0.411	No change over time
Fe-T	-0.068	0.475	No change over time
Hg-D	-0.763	<0.001	Reduced over time
Hg-T	0.235	0.011	Increased over time
Ni-D	-0.124	0.186	No change over time
Ni-T	-0.010	0.912	No change over time
Pb-D	-0.030	0.748	No change over time
Pb-T	0.149	0.112	No change over time
Se-D	-0.645	<0.001	Reduced over time
Se-T	0.407	0.001	Increased over time
Zn-D	0.220	0.018	Increased over time
Zn-T	0.096	0.309	No change over time

Table C-6 Yunarilama 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.512	<0.001	Reduced over time
EC	-0.338	0.001	Reduced over time
SO4-D	-0.500	<0.001	Reduced over time
Alk-T	0.587	<0.001	Increased over time
TSS	0.141	0.184	No change over time
Ag-D	-0.769	<0.001	Reduced over time
Ag-T	0.216	0.044	Increased over time
As-D	-0.578	<0.001	Reduced over time
As-T	0.012	0.914	No change over time
Cd-D	-0.417	<0.001	Reduced over time
Cd-T	0.078	0.463	No change over time
Cr-D	-0.747	<0.001	Reduced over time
Cr-T	0.223	0.035	Increased over time
Cu-D	-0.691	<0.001	Reduced over time
Cu-T	0.103	0.333	No change over time
Fe-D	0.294	0.005	Increased over time
Fe-T	0.167	0.117	No change over time
Hg-D	-0.468	<0.001	Reduced over time
Hg-T	0.054	0.611	No change over time
Ni-D	-0.148	0.164	No change over time
Ni-T	0.240	0.023	Increased over time
Pb-D	-0.797	<0.001	Reduced over time
Pb-T	0.005	0.966	No change over time
Se-D	0.063	0.679	No change over time
Se-T	0.056	0.711	No change over time
Zn-D	0.325	0.002	Increased over time
Zn-T	-0.008	0.943	No change over time

Table C-7 Wendoko 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.293	0.003	Reduced over time
EC	-0.186	0.08	No change over time
SO4-D	-0.342	0.001	Reduced over time
Alk-T	-0.301	0.002	Reduced over time
TSS	-0.074	0.457	No change over time
Ag-D	-0.821	<0.001	Reduced over time
Ag-T	-0.417	<0.001	Reduced over time
As-D	-0.678	<0.001	Reduced over time
As-T	0.091	0.365	No change over time
Cd-D	-0.354	<0.001	Reduced over time
Cd-T	-0.444	<0.001	Reduced over time
Cr-D	-0.764	<0.001	Reduced over time
Cr-T	-0.123	0.218	No change over time
Cu-D	-0.743	<0.001	Reduced over time
Cu-T	-0.428	<0.001	Reduced over time
Fe-D	0.266	0.007	Increased over time
Fe-T	0.127	0.205	No change over time
Hg-D	-0.738	<0.001	Reduced over time
Hg-T	-0.697	<0.001	Reduced over time
Ni-D	-0.725	<0.001	Reduced over time
Ni-T	-0.494	<0.001	Reduced over time
Pb-D	-0.411	<0.001	Reduced over time
Pb-T	0.077	0.44	No change over time
Se-D	-0.619	<0.001	Reduced over time
Se-T	-0.578	<0.001	Reduced over time
Zn-D	-0.524	<0.001	Reduced over time
Zn-T	-0.499	<0.001	Reduced over time

Table C-8 Kogai Toe 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	0.328	0.001	Increased over time
EC	0.695	<0.001	Increased over time
SO4-D	0.529	<0.001	Increased over time
Alk-T	0.423	<0.001	Increased over time
TSS	0.198	0.039	Increased over time
Ag-D	-0.859	<0.001	Reduced over time
Ag-T	0.042	0.666	No change over time
As-D	-0.450	<0.001	Reduced over time
As-T	0.224	0.019	Increased over time
Cd-D	0.231	0.016	Increased over time
Cd-T	0.471	<0.001	Increased over time
Cr-D	-0.679	<0.001	Reduced over time
Cr-T	0.173	0.072	No change over time
Cu-D	-0.702	<0.001	Reduced over time
Cu-T	0.195	0.043	Increased over time
Fe-D	0.109	0.259	No change over time
Fe-T	0.177	0.067	No change over time
Hg-D	-0.803	<0.001	Reduced over time
Hg-T	-0.277	0.004	Reduced over time
Ni-D	0.427	<0.001	Increased over time
Ni-T	0.294	0.002	Increased over time
Pb-D	0.151	0.118	No change over time
Pb-T	0.243	0.011	Increased over time
Se-D	-0.469	<0.001	Reduced over time
Se-T	-0.311	0.01	Reduced over time
Zn-D	0.220	0.022	Increased over time
Zn-T	0.429	<0.001	Increased over time

Table C-9 Kogai at Culvert 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.375	<0.001	Reduced over time
EC	-0.173	0.063	No change over time
SO4-D	-0.380	<0.001	Reduced over time
Alk-T	-0.049	0.6	No change over time
TSS	0.167	0.072	No change over time
Ag-D	-0.862	<0.001	Reduced over time
Ag-T	0.262	0.005	Increased over time
As-D	-0.599	<0.001	Reduced over time
As-T	-0.019	0.841	No change over time
Cd-D	-0.469	<0.001	Reduced over time
Cd-T	0.059	0.527	No change over time
Cr-D	-0.822	<0.001	Reduced over time
Cr-T	0.181	0.05	Increased over time
Cu-D	-0.282	0.002	Reduced over time
Cu-T	0.114	0.221	No change over time
Fe-D	0.248	0.007	Increased over time
Fe-T	0.185	0.047	Increased over time
Hg-D	-0.825	<0.001	Reduced over time
Hg-T	0.251	0.006	Increased over time
Ni-D	-0.396	<0.001	Reduced over time
Ni-T	0.197	0.033	Increased over time
Pb-D	-0.153	0.102	No change over time
Pb-T	0.078	0.402	No change over time
Se-D	-0.708	<0.001	Reduced over time
Se-T	-0.310	0.009	Reduced over time
Zn-D	-0.411	<0.001	Reduced over time
Zn-T	0.052	0.578	No change over time

Table C-10 Aipulungu at Station 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.557	<0.001	Reduced over time
EC	-0.080	0.424	No change over time
SO4-D	-0.591	<0.001	Reduced over time
Alk-T	0.116	0.218	No change over time
TSS	0.255	0.006	Increased over time
Ag-D	-0.869	<0.001	Reduced over time
Ag-T	-0.781	<0.001	Reduced over time
As-D	-0.685	<0.001	Reduced over time
As-T	0.028	0.769	No change over time
Cd-D	-0.818	<0.001	Reduced over time
Cd-T	-0.723	<0.001	Reduced over time
Cr-D	-0.813	<0.001	Reduced over time
Cr-T	0.243	0.009	Increased over time
Cu-D	-0.559	<0.001	Reduced over time
Cu-T	0.200	0.032	Increased over time
Fe-D	0.059	0.531	No change over time
Fe-T	0.233	0.012	Increased over time
Hg-D	-0.796	<0.001	Reduced over time
Hg-T	-0.807	<0.001	Reduced over time
Ni-D	-0.621	<0.001	Reduced over time
Ni-T	0.227	0.014	Increased over time
Pb-D	-0.718	<0.001	Reduced over time
Pb-T	0.165	0.076	No change over time
Se-D	-0.602	<0.001	Reduced over time
Se-T	-0.402	0.001	Reduced over time
Zn-D	0.188	0.045	Increased over time
Zn-T	0.306	0.001	Increased over time

Table C-11 Lime plant 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.372	<0.001	Reduced over time
EC	-0.319	0.001	Reduced over time
SO4-D	-0.495	<0.001	Reduced over time
Alk-T	-0.211	0.026	Reduced over time
TSS	0.433	<0.001	Increased over time
Ag-D	-0.860	<0.001	Reduced over time
Ag-T	-0.333	<0.001	Reduced over time
As-D	-0.833	<0.001	Reduced over time
As-T	0.108	0.256	No change over time
Cd-D	-0.847	<0.001	Reduced over time
Cd-T	0.015	0.873	No change over time
Cr-D	0.017	0.86	No change over time
Cr-T	0.358	<0.001	Increased over time
Cu-D	-0.399	<0.001	Reduced over time
Cu-T	0.438	<0.001	Increased over time
Fe-D	-0.123	0.195	No change over time
Fe-T	0.419	<0.001	Increased over time
Hg-D	-0.607	<0.001	Reduced over time
Hg-T	-0.442	<0.001	Reduced over time
Ni-D	-0.725	<0.001	Reduced over time
Ni-T	0.373	<0.001	Increased over time
Pb-D	-0.643	<0.001	Reduced over time
Pb-T	0.429	<0.001	Increased over time
Se-D	-0.742	<0.001	Reduced over time
Se-T	-0.442	<0.001	Reduced over time
Zn-D	0.147	0.125	No change over time
Zn-T	0.448	<0.001	Increased over time

Table C-12 Aipulungu U/S Lime plant 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.453	<0.001	Reduced over time
EC	-0.067	0.482	No change over time
SO4-D	-0.687	<0.001	Reduced over time
Alk-T	0.162	0.086	No change over time
TSS	0.261	0.005	Increased over time
Ag-D	-0.850	<0.001	Reduced over time
Ag-T	-0.792	<0.001	Reduced over time
As-D	-0.812	<0.001	Reduced over time
As-T	-0.646	<0.001	Reduced over time
Cd-D	-0.847	<0.001	Reduced over time
Cd-T	-0.774	<0.001	Reduced over time
Cr-D	-0.799	<0.001	Reduced over time
Cr-T	-0.267	0.004	Reduced over time
Cu-D	-0.588	<0.001	Reduced over time
Cu-T	-0.186	0.046	Reduced over time
Fe-D	0.043	0.65	No change over time
Fe-T	-0.133	0.158	No change over time
Hg-D	-0.727	<0.001	Reduced over time
Hg-T	-0.794	<0.001	Reduced over time
Ni-D	-0.753	<0.001	Reduced over time
Ni-T	-0.181	0.053	No change over time
Pb-D	-0.795	<0.001	Reduced over time
Pb-T	-0.295	0.001	Reduced over time
Se-D	-0.753	<0.001	Reduced over time
Se-T	-0.665	<0.001	Reduced over time
Zn-D	0.388	<0.001	Increased over time
Zn-T	-0.062	0.512	No change over time

Table C-13 Waile Creek 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.399	<0.001	Reduced over time
EC	-0.065	0.487	No change over time
SO4-D	-0.733	<0.001	Reduced over time
Alk-T	-0.164	0.078	No change over time
TSS	0.069	0.46	No change over time
Ag-D	-0.830	<0.001	Reduced over time
Ag-T	-0.816	<0.001	Reduced over time
As-D	-0.824	<0.001	Reduced over time
As-T	-0.810	<0.001	Reduced over time
Cd-D	-0.822	<0.001	Reduced over time
Cd-T	-0.774	<0.001	Reduced over time
Cr-D	-0.825	<0.001	Reduced over time
Cr-T	-0.597	<0.001	Reduced over time
Cu-D	-0.740	<0.001	Reduced over time
Cu-T	-0.456	<0.001	Reduced over time
Fe-D	0.092	0.325	No change over time
Fe-T	-0.252	0.007	Reduced over time
Hg-D	-0.772	<0.001	Reduced over time
Hg-T	-0.801	<0.001	Reduced over time
Ni-D	-0.835	<0.001	Reduced over time
Ni-T	-0.452	<0.001	Reduced over time
Pb-D	-0.720	<0.001	Reduced over time
Pb-T	-0.499	<0.001	Reduced over time
Se-D	-0.789	<0.001	Reduced over time
Se-T	-0.740	<0.001	Reduced over time
Zn-D	0.467	<0.001	Increased over time
Zn-T	-0.088	0.355	No change over time

Table C-14 Kaiya U/S Anjolek 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.612	<0.001	Reduced over time
EC	0.130	0.246	No change over time
SO4-D	-0.344	0.001	Reduced over time
Alk-T	0.108	0.301	No change over time
TSS	-0.154	0.139	No change over time
Ag-D	-0.715	<0.001	Reduced over time
Ag-T	-0.585	<0.001	Reduced over time
As-D	-0.670	<0.001	Reduced over time
As-T	-0.245	0.017	Reduced over time
Cd-D	-0.787	<0.001	Reduced over time
Cd-T	-0.626	<0.001	Reduced over time
Cr-D	-0.858	<0.001	Reduced over time
Cr-T	-0.108	0.3	No change over time
Cu-D	-0.625	<0.001	Reduced over time
Cu-T	-0.124	0.232	No change over time
Fe-D	-0.054	0.607	No change over time
Fe-T	-0.108	0.302	No change over time
Hg-D	-0.772	<0.001	Reduced over time
Hg-T	-0.650	<0.001	Reduced over time
Ni-D	-0.784	<0.001	Reduced over time
Ni-T	-0.102	0.33	No change over time
Pb-D	-0.608	<0.001	Reduced over time
Pb-T	-0.209	0.043	Reduced over time
Se-D	-0.729	<0.001	Reduced over time
Se-T	-0.669	<0.001	Reduced over time
Zn-D	0.432	<0.001	Increased over time
Zn-T	-0.072	0.493	No change over time

Table C-15 Pongema 2009 - 2018 (trend of all data)

Parameter	Spearman's rho	P-Value (P=0.05)	Trend
pH	-0.419	<0.001	Reduced over time
EC	-0.045	0.625	No change over time
SO4-D	-0.649	<0.001	Reduced over time
Alk-T	0.062	0.505	No change over time
TSS	0.170	0.065	No change over time
Ag-D	-0.850	<0.001	Reduced over time
Ag-T	-0.661	<0.001	Reduced over time
As-D	-0.760	<0.001	Reduced over time
As-T	-0.674	<0.001	Reduced over time
Cd-D	-0.737	<0.001	Reduced over time
Cd-T	-0.769	<0.001	Reduced over time
Cr-D	-0.813	<0.001	Reduced over time
Cr-T	-0.216	0.018	Reduced over time
Cu-D	-0.691	<0.001	Reduced over time
Cu-T	-0.243	0.008	Reduced over time
Fe-D	0.093	0.315	No change over time
Fe-T	-0.113	0.224	No change over time
Hg-D	-0.831	<0.001	Reduced over time
Hg-T	-0.764	<0.001	Reduced over time
Ni-D	-0.778	<0.001	Reduced over time
Ni-T	-0.284	0.002	Reduced over time
Pb-D	-0.717	<0.001	Reduced over time
Pb-T	-0.190	0.039	Reduced over time
Se-D	-0.749	<0.001	Reduced over time
Se-T	-0.710	<0.001	Reduced over time
Zn-D	0.203	0.027	Increased over time
Zn-T	-0.107	0.245	No change over time

Table C-16 28 Level 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	7.8	LowerTV<TSM<UpperTV	Step 1/2	6.0-8.2	0.001/ 0.001	LOW
EC	12	12	706	TSM < TV	Step 1	250	0.999	POTENTIAL
TSS	12	12	60	TSM < TV	Step 1	2,837	0.001	LOW
Ag-D	12	11	0.01	TSM < TV	Step 1	0.05	0.002	LOW
As-D	12	12	8.4	TSM < TV	Step 1	24	0.046	LOW
Cd-D	12	12	0.07	TSM < TV	Step 1	0.34	0.001	LOW
Cr-D	12	12	0.2	TSM < TV	Step 1	1.0	0.001	LOW
Cu-D	12	12	0.4	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	11	TSM < TV	Step 1	75	0.001	LOW
Hg-D	12	12	0.05	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	3.0	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.14	TSM < TV	Step 1	7.5	0.001	LOW
Se-D	12	12	0.2	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	32	TSM ≥ TV	Step 2	20	0.990	POTENTIAL

Table C-17 Anjolek SDA 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	LowerTV<TSM<UpperTV	Step 1/2	6.0-8.2	NR	NR
EC	0	0	NR	TSM < TV	Step 1	250	NR	NR
TSS	0	0	NR	TSM < TV	Step 1	2837	NR	NR
Ag-D	0	0	NR	TSM < TV	Step 1	0.05	NR	NR
As-D	0	0	NR	TSM < TV	Step 1	24	NR	NR
Cd-D	0	0	NR	TSM ≥ TV	Step 2	0.34	NR	NR
Cr-D	0	0	NR	TSM < TV	Step 1	1.0	NR	NR
Cu-D	0	0	NR	TSM < TV	Step 1	4.1	NR	NR
Fe-D	0	0	NR	TSM < TV	Step 1	75	NR	NR
Hg-D	0	0	NR	TSM < TV	Step 1	0.6	NR	NR
Ni-D	0	0	NR	TSM < TV	Step 1	21	NR	NR
Pb-D	0	0	NR	TSM < TV	Step 1	7.5	NR	NR
Se-D	0	0	NR	TSM < TV	Step 1	11	NR	NR
Zn-D	0	0	NR	TSM < TV	Step 1	20	NR	NR

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

Table C-18 Kaiya at Yuyan Bridge 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	LowerTV<TSM<UpperTV	Step 1/2	6.0-8.2	NR	NR
EC	0	0	NR	TSM < TV	Step 1	250	NR	NR
TSS	0	0	NR	TSM < TV	Step 1	2837	NR	NR
Ag-D	0	0	NR	TSM < TV	Step 1	0.05	NR	NR
As-D	0	0	NR	TSM < TV	Step 1	24	NR	NR
Cd-D	0	0	NR	TSM ≥ TV	Step 2	0.34	NR	NR
Cr-D	0	0	NR	TSM < TV	Step 1	1.0	NR	NR
Cu-D	0	0	NR	TSM < TV	Step 1	4.1	NR	NR
Fe-D	0	0	NR	TSM < TV	Step 1	75	NR	NR
Hg-D	0	0	NR	TSM < TV	Step 1	0.6	NR	NR
Ni-D	0	0	NR	TSM < TV	Step 1	21	NR	NR
Pb-D	0	0	NR	TSM < TV	Step 1	7.5	NR	NR
Se-D	0	0	NR	TSM < TV	Step 1	11	NR	NR
Zn-D	0	0	NR	TSM < TV	Step 1	20	NR	NR

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

Table C-19 Kaiya River downstream Anjolek erodible dump 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	LowerTV<TSM<UpperTV	Step 1/2	6.0-8.2	NR	NR
EC	0	0	NR	TSM < TV	Step 1	250	NR	NR
TSS	0	0	NR	TSM < TV	Step 1	2837	NR	NR
Ag-D	0	0	NR	TSM < TV	Step 1	0.05	NR	NR
As-D	0	0	NR	TSM < TV	Step 1	24	NR	NR
Cd-D	0	0	NR	TSM ≥ TV	Step 2	0.34	NR	NR
Cr-D	0	0	NR	TSM < TV	Step 1	1.0	NR	NR
Cu-D	0	0	NR	TSM < TV	Step 1	4.1	NR	NR
Fe-D	0	0	NR	TSM < TV	Step 1	75	NR	NR
Hg-D	0	0	NR	TSM < TV	Step 1	0.6	NR	NR
Ni-D	0	0	NR	TSM < TV	Step 1	21	NR	NR
Pb-D	0	0	NR	TSM < TV	Step 1	7.5	NR	NR
Se-D	0	0	NR	TSM < TV	Step 1	11	NR	NR
Zn-D	0	0	NR	TSM < TV	Step 1	20	NR	NR

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

Table C-20 Kogai Culvert 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	12	12	7.9	LowerTV<TSM<UpperTV	Step 1/2	6.0-8.2	0.001 / 0.001	LOW
EC	12	11	828	TSM ≥ TV	Step 2	250	0.999	POTENTIAL
TSS	12	12	405	TSM < TV	Step 1	2837	0.001	LOW
Ag-D	12	12	0.01	TSM < TV	Step 1	0.05	0.001	LOW
As-D	12	12	1.2	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.3	TSM < TV	Step 1	0.34	0.333	POTENTIAL
Cr-D	12	12	0.2	TSM < TV	Step 1	1.0	0.001	LOW
Cu-D	12	12	1.2	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	20	TSM < TV	Step 1	75	0.003	LOW
Hg-D	12	12	0.05	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	1.1	TSM < TV	Step 1	21	0..001	LOW
Pb-D	12	12	1.3	TSM < TV	Step 1	7.5	0.001	LOW
Se-D	12	12	0.2	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	32	TSM ≥ TV	Step 2	20	0.967	POTENTIAL

Table C-21 Kogai Stable dump toe area 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	12	12	7.7	LowerTV<TSM<UpperTV	Step 1	6.0-8.2	0.001 / 0.001	LOW
EC	12	12	1678	TSM ≥ TV	Step 2	250	0.999	POTENTIAL
TSS	12	12	213	TSM < TV	Step 1	2837	0.001	LOW
Ag-D	12	11	0.01	TSM < TV	Step 1	0.05	0.002	LOW
As-D	12	12	0.77	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.8	TSM ≥ TV	Step 2	0.34	0.973	POTENTIAL
Cr-D	12	12	0.2	TSM < TV	Step 1	1.0	0.002	LOW
Cu-D	12	12	0.5	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	9.6	TSM < TV	Step 1	75	0.001	LOW
Hg-D	12	12	0.05	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	2.1	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.5	TSM < TV	Step 1	7.5	0.001	LOW
Se-D	12	12	0.2	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	160	TSM ≥ TV	Step 2	20	0.998	POTENTIAL

Table C-22 Lime Plant discharge 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	9	9	11	TSM ≥ TV	Step 3	6.0-8.2	0.005 / 0.995	POTENTIAL
EC	9	9	732	TSM ≥ TV	Step 2	250	0.938	POTENTIAL
TSS	9	9	500	TSM < TV	Step 1	2837	0.062	POTENTIAL
Ag-D	9	9	0.01	TSM < TV	Step 1	0.05	0.005	LOW
As-D	9	9	0.1	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	6.3	TSM ≥ TV	Step 2	1.0	0.995	POTENTIAL
Cu-D	9	9	0.6	TSM < TV	Step 1	4.1	0.005	LOW
Fe-D	9	9	4.9	TSM < TV	Step 1	75	0.005	LOW
Hg-D	9	9	0.05	TSM < TV	Step 1	0.6	0.005	LOW
Ni-D	9	9	0.5	TSM < TV	Step 1	21	0.005	LOW
Pb-D	9	9	0.1	TSM < TV	Step 1	7.5	0.005	LOW
Se-D	9	9	0.2	TSM < TV	Step 1	11	0.005	LOW
Zn-D	9	9	3.8	TSM < TV	Step 1	20	0.005	LOW

Table C-23 Wendoko Creek D/S Anawe Nth 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	4	4	7.6	LowerTV<TSM<UpperTV	Step 1	6.0-8.2	0.05	LOW
EC	4	4	2685	TSM ≥ TV	Step 2	250	0.978	POTENTIAL
TSS	4	4	2.0	TSM < TV	Step 1	2837	0.05	LOW
Ag-D	4	4	0.01	TSM < TV	Step 1	0.05	0.05	LOW
As-D	4	4	0.9	TSM < TV	Step 1	24	0.05	LOW
Cd-D	4	4	1.1	TSM ≥ TV	Step 2	0.34	0.978	POTENTIAL
Cr-D	4	4	0.3	TSM < TV	Step 1	1.0	0.428	POTENTIAL
Cu-D	4	4	0.4	TSM < TV	Step 1	4.1	0.05	LOW
Fe-D	4	4	10	TSM < TV	Step 1	75	0.05	LOW
Hg-D	4	4	0.05	TSM < TV	Step 1	0.6	0.05	LOW
Ni-D	4	4	1.9	TSM < TV	Step 1	21	0.05	LOW
Pb-D	4	4	1.6	TSM < TV	Step 1	7.5	0.05	LOW
Se-D	4	4	0.6	TSM < TV	Step 1	11	0.05	LOW
Zn-D	4	4	348	TSM ≥ TV	Step 2	20	0.978	POTENTIAL

*Small sample size (N<10) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians; Risk assessment is based on direct comparison.

Table C-24 Yakatabari Creek D/S 28 level 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	LowerTV<TSM<UpperTV	Step 1	6.0-8.2	0.001 / 0.001	LOW
EC	12	12	709	TSM ≥ TV	Step 2	250	0.999	POTENTIAL
TSS	12	12	4453	TSM ≥ TV	Step 2	2837	0.888	POTENTIAL
Ag-D	12	11	0.01	TSM < TV	Step 1	0.05	0.002	LOW
As-D	12	12	9.7	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.09	TSM < TV	Step 1	0.34	0.019	LOW
Cr-D	12	11	0.4	TSM < TV	Step 1	1.0	0.002	LOW
Cu-D	12	12	1.0	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	10	TSM < TV	Step 1	75	0.019	LOW
Hg-D	12	12	0.05	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	1.6	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	1.0	TSM < TV	Step 1	7.5	0.019	LOW
Se-D	12	12	0.2	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	12	12	TSM < TV	Step 1	20	0.019	LOW

Table C-25 Yunarilama at Portal 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	7	7	7.6	LowerTV<TSM<UpperTV	Step 1	6.0-8.2	0.011 / 0.011	LOW
EC	7	7	2900	TSM ≥ TV	Step 2	250	0.993	POTENTIAL
TSS	7	7	63500	TSM ≥ TV	Step 2	2837	0.989	POTENTIAL
Ag-D	7	7	0.02	TSM < TV	Step 1	0.05	0.011	LOW
As-D	7	7	2.5	TSM < TV	Step 1	24	0.011	LOW
Cd-D	7	7	0.1	TSM < TV	Step 1	0.34	0.011	LOW
Cr-D	7	7	0.5	TSM < TV	Step 1	1.0	0.136	POTENTIAL
Cu-D	7	7	1.0	TSM < TV	Step 1	4.1	0.011	LOW
Fe-D	7	7	40	TSM < TV	Step 1	75	0.136	POTENTIAL
Hg-D	7	7	0.05	TSM < TV	Step 1	0.6	0.011	LOW
Ni-D	7	7	2.3	TSM < TV	Step 1	21	0.011	LOW
Pb-D	7	7	0.5	TSM < TV	Step 1	7.5	0.011	LOW
Se-D	7	7	0.9	TSM < TV	Step 1	11	0.011	LOW
Zn-D	7	7	14	TSM < TV	Step 1	20	0.223	POTENTIAL

*Small sample size (N<10) therefore Wilcoxon (signed rank) does not have sufficient power to detect significance difference between medians; Risk assessment is based on direct comparison.

Table C-26 Tailings slurry 2018 median against upper river TV (µg/L for metals, std pH units for pH 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	6.7	Lower TV < TSM < Higher TV	Step 1 / 2	6.0-8.2	<0.001 / <0.001	LOW
EC	48	48	3028	TSM > TV	Step 2	250	1.0	POTENTIAL
TSS	48	48	120000	TSM > TV	Step 2	2837	1.0	POTENTIAL
Ag-D	48	48	0.01	TSM < TV	Step 1	0.05	0.017	LOW
As-D	48	47	0.8	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	48	48	35	TSM > TV	Step 2	0.34	1.0	POTENTIAL
Cr-D	48	48	0.1	TSM < TV	Step 1	1.0	<0.001	LOW
Cu-D	48	48	13	TSM > TV	Step 2	4.1	1.0	POTENTIAL
Fe-D	48	48	31	TSM < TV	Step 1	75	0.537	POTENTIAL
Hg-D	48	48	0.1	TSM < TV	Step 1	0.60	<0.001	LOW
Ni-D	48	48	565	TSM > TV	Step 2	21	1.0	POTENTIAL
Pb-D	48	48	0.1	TSM < TV	Step 1	7.5	<0.001	LOW
Se-D	48	48	1.6	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	48	48	7900	TSM > TV	Step 2	20	1.0	POTENTIAL

Table C-28 Tailings solids 2018 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	0.8	TSM < TV	Step 1	1.0	0.746	LOW
As- WAE	48	47	58	TSM > TV	Step 2	20	1.0	POTENTIAL
Cd- WAE	48	48	6.8	TSM > TV	Step 2	1.5	1.0	POTENTIAL
Cr- WAE	48	48	24	TSM < TV	Step 1	80	<0.001	LOW
Cu- WAE	48	47	79	TSM > TV	Step 2	65	0.992	POTENTIAL
Hg- WAE	48	46	0.2	TSM > TV	Step 2	0.15	0.746	POTENTIAL
Ni- WAE	48	44	22	TSM > TV	Step 2	21	0.621	POTENTIAL
Pb- WAE	48	48	150	TSM > TV	Step 2	50	1.0	POTENTIAL
Se- WAE	48	48	0.2	TSM > TV	Step 2	0.16	1.0	POTENTIAL
Zn- WAE	48	47	1100	TSM > TV	Step 2	200	1.0	POTENTIAL

APPENDIX D. WATER QUALITY – RISK AND PERFORMANCE ASSESSMENT – DETAILS OF STATISTICAL ANALYSIS AND BOX PLOTS - CHEMISTRY

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					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				POTENTIAL

TSM = Test Site Median

ND = No determination

Table D-3 Water quality upper river test sites - SG2 2018 median (µg/L for metals, std pH units for pH 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	12	12	7.8	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.2	0.001/0.001	LOW
EC	12	12	248	TSM > TV	Step 1	228	0.946	POTENTIAL
TSS	12	12	1300	TSM < TV	Step 1	2837	0.008	LOW
Ag-D	12	11	0.01	TSM < TV	Step 1	0.05	0.002	LOW
As-D	12	12	1.3	TSM < TV	Step 1	24	0.001	LOW
Cd-D	12	12	0.19	TSM < TV	Step 1	0.34	0.068	POTENTIAL
Cr-D	12	12	0.35	TSM < TV	Step 1	1.0	0.063	POTENTIAL
Cu-D	12	12	1.3	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	12	12	10	TSM < TV	Step 1	75	0.001	LOW
Hg-D	12	12	0.05	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	12	12	0.9	TSM < TV	Step 1	21	0.001	LOW
Pb-D	12	12	0.1	TSM < TV	Step 1	7.5	0.001	LOW
Se-D	12	12	0.2	TSM < TV	Step 1	11	0.001	LOW
Zn-D	12	11	9.4	TSM < TV	Step 1	20	0.006	LOW

Table D-4 Water quality upper river test sites - Wasiba 2018 median (µg/L for metals, std pH units for pH 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	14	14	7.6	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.2	<0.001 / <0.001	LOW
EC	14	13	240	TSM > TV	Step 2	228	0.960	POTENTIAL
TSS	14	14	1950	TSM < TV	Step 1	2837	0.009	LOW
Ag-D	14	14	0.01	TSM < TV	Step 1	0.05	0.009	LOW
As-D	14	14	1.3	TSM < TV	Step 1	24	0.001	LOW
Cd-D	14	14	0.08	TSM < TV	Step 1	0.34	0.009	LOW
Cr-D	14	14	0.38	TSM < TV	Step 1	1.0	0.001	LOW
Cu-D	14	14	1.1	TSM < TV	Step 1	4.1	0.001	LOW
Fe-D	14	14	13	TSM < TV	Step 1	75	0.003	LOW
Hg-D	14	14	0.05	TSM < TV	Step 1	0.6	0.001	LOW
Ni-D	14	14	0.64	TSM < TV	Step 1	21	0.001	LOW
Pb-D	14	14	0.1	TSM < TV	Step 1	7.5	0.001	LOW
Se-D	14	14	0.2	TSM < TV	Step 1	11	0.001	LOW
Zn-D	14	14	7.1	TSM < TV	Step 1	20	0.009	LOW

Table D-5 Water quality upper river test sites - Wankipe 2018 median (µg/L for metals, std pH units for pH 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	15	15	7.8	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.2	0.006/<0.001	LOW
EC	15	15	248	TSM > TV	Step 2	228	0.761	POTENTIAL
TSS	15	15	1200	TSM < TV	Step 1	2837	0.017	LOW
Ag-D	15	15	0.01	TSM < TV	Step 1	0.05	0.006	LOW
As-D	15	15	1.1	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	15	15	0.05	TSM < TV	Step 1	0.34	<0.001	LOW
Cr-D	15	15	0.32	TSM < TV	Step 1	1.0	0.007	LOW
Cu-D	15	15	1.1	TSM < TV	Step 1	4.1	<0.001	LOW
Fe-D	15	15	11	TSM < TV	Step 1	75	0.008	LOW
Hg-D	15	15	0.05	TSM < TV	Step 1	0.6	<0.001	LOW
Ni-D	15	15	0.71	TSM < TV	Step 1	21	0.006	LOW
Pb-D	15	15	0.1	TSM < TV	Step 1	7.5	<0.001	LOW
Se-D	15	15	0.2	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	15	14	7.8	TSM < TV	Step 1	20	<0.001	LOW

Table D-6 Water quality upper river test sites - SG3 2018 median (µg/L for metals, std pH units for pH 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	202	202	7.7	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.2	<0.001	LOW
EC	202	202	242	TSM > TV	Step 2	228	1.000	POTENTIAL
TSS	202	202	1000	TSM < TV	Step 1	2837	<0.001	LOW
Ag-D	202	202	0.01	TSM < TV	Step 1	0.05	<0.001	LOW
As-D	202	202	1.1	TSM < TV	Step 1	24	<0.001	LOW
Cd-D	202	202	0.05	TSM < TV	Step 1	0.34	<0.001	LOW
Cr-D	202	202	0.3	TSM < TV	Step 1	1.0	<0.001	LOW
Cu-D	202	202	1.0	TSM < TV	Step 1	4.1	<0.001	LOW
Fe-D	202	202	12	TSM < TV	Step 1	75	<0.001	LOW
Hg-D	202	202	0.05	TSM < TV	Step 1	0.6	<0.001	LOW
Ni-D	202	202	0.62	TSM < TV	Step 1	21	<0.001	LOW
Pb-D	202	202	0.1	TSM < TV	Step 1	7.5	<0.001	LOW
Se-D	202	202	0.2	TSM < TV	Step 1	11	<0.001	LOW
Zn-D	202	202	6.8	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 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	7.6	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	0.011	LOW
EC	7	7	221	TSM > TV	Step 2	172	0.989	POTENTIAL
TSS	7	7	540	TSM < TV	Step 1	983	0.466	POTENTIAL
Ag-D	7	7	0.01	TSM < TV	Step 1	0.05	0.136	POTENTIAL
As-D	7	7	0.87	TSM < TV	Step 1	24	0.011	LOW
Cd-D	7	7	0.050	TSM < TV	Step 1	0.20	0.017	LOW
Cr-D	7	7	0.43	TSM < TV	Step 1	1.0	0.017	LOW
Cu-D	7	7	0.84	TSM < TV	Step 1	1.4	0.011	LOW
Fe-D	7	7	10	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	0.5	TSM < TV	Step 1	15	0.011	LOW
Pb-D	7	7	0.1	TSM < TV	Step 1	3.4	0.011	LOW
Se-D	7	7	0.2	TSM < TV	Step 1	11	0.011	LOW
Zn-D	7	7	8.2	TSM > TV	Step 1	13	0.026	LOW

Table D-8 Water quality lower river test sites - SG4 2018 median (µg/L for metals, std pH units for pH 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	6	6	7.6	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	0.018	LOW
EC	6	6	196	TSM > TV	Step 2	172	0.799	POTENTIAL
TSS	6	6	325	TSM < TV	Step 1	983	0.071	POTENTIAL
Ag-D	6	6	0.01	TSM < TV	Step 1	0.05	0.018	LOW
As-D	6	6	0.83	TSM < TV	Step 1	24	0.018	LOW
Cd-D	6	6	0.05	TSM < TV	Step 1	0.20	0.018	LOW
Cr-D	6	6	0.48	TSM < TV	Step 1	1.0	0.018	LOW
Cu-D	6	6	0.93	TSM <TV	Step 1	1.4	0.018	LOW
Fe-D	6	6	9.4	TSM < TV	Step 1	75	0.018	LOW
Hg-D	6	6	0.05	TSM < TV	Step 1	0.60	0.018	LOW
Ni-D	6	6	0.5	TSM < TV	Step 1	15	0.018	LOW
Pb-D	6	6	0.1	TSM < TV	Step 1	3.4	0.018	LOW
Se-D	6	6	0.2	TSM < TV	Step 1	11	0.018	LOW
Zn-D	6	6	7.4	TSM <TV	Step 1	13	0.037	LOW

Table D-9 Water quality lower river test sites - SG5 2018 median (µg/L for metals, std pH units for pH 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	6	6	7.8	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.1	0.018	LOW
EC	6	6	162	TSM < TV	Step 1	172	0.018	LOW
TSS	6	6	455	TSM < TV	Step 1	983	0.018	LOW
Ag-D	6	6	0.01	TSM < TV	Step 1	0.05	0.018	LOW
As-D	6	6	0.82	TSM < TV	Step 1	24	0.018	LOW
Cd-D	6	6	0.05	TSM < TV	Step 1	0.20	0.018	LOW
Cr-D	6	6	0.33	TSM < TV	Step 1	1.0	0.018	LOW
Cu-D	6	6	0.67	TSM <TV	Step 1	1.4	0.018	LOW
Fe-D	6	6	17	TSM < TV	Step 1	75	0.018	LOW
Hg-D	6	6	0.05	TSM < TV	Step 1	0.60	0.018	LOW
Ni-D	6	6	0.5	TSM < TV	Step 1	15	0.018	LOW
Pb-D	6	6	0.1	TSM < TV	Step 1	3.4	0.018	LOW
Se-D	6	6	0.2	TSM < TV	Step 1	11	0.018	LOW
Zn-D	6	6	7.1	TSM <TV	Step 1	13	0.018	LOW

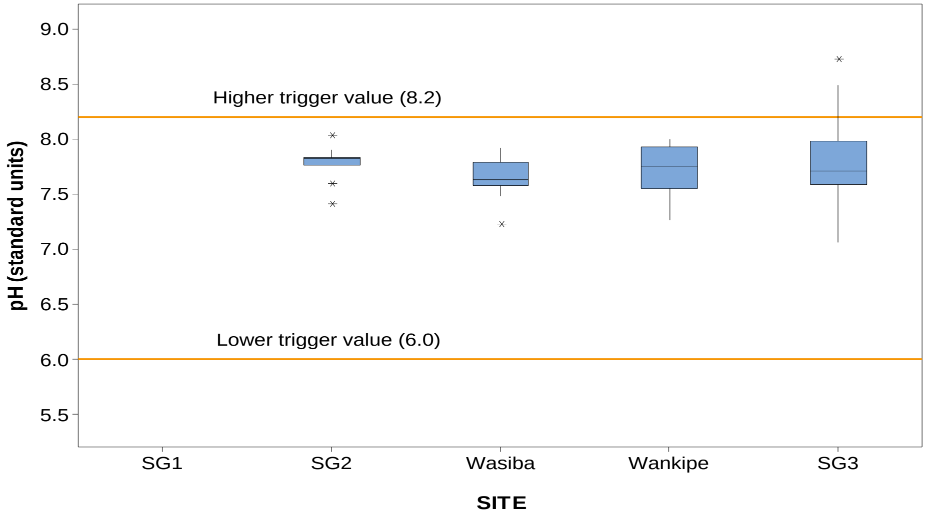


Figure D-1 pH in water upper river test sites 2018

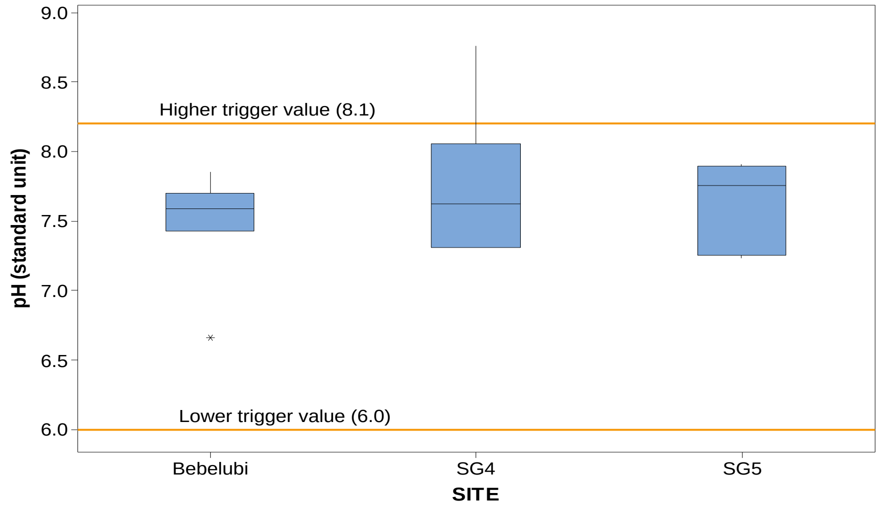


Figure D-2 pH in water at lower river test sites 2018

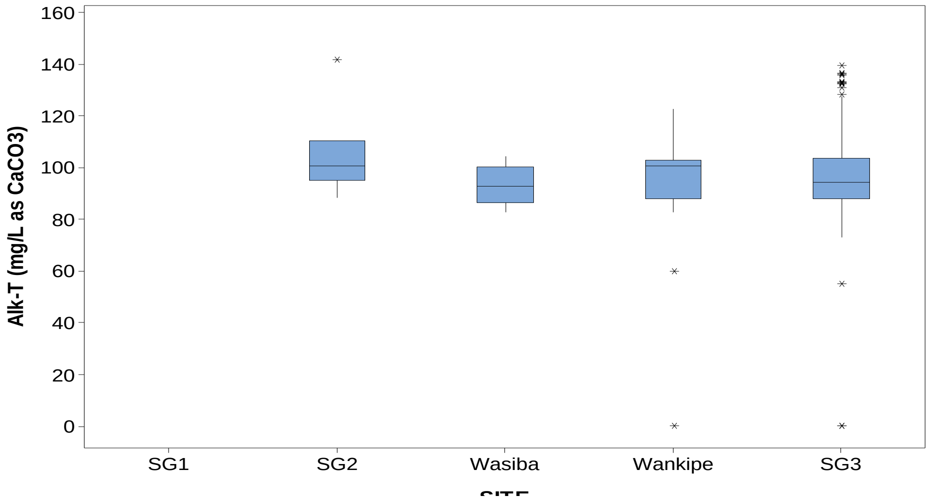


Figure D-3 Alkalinity in water upper river test sites 2018

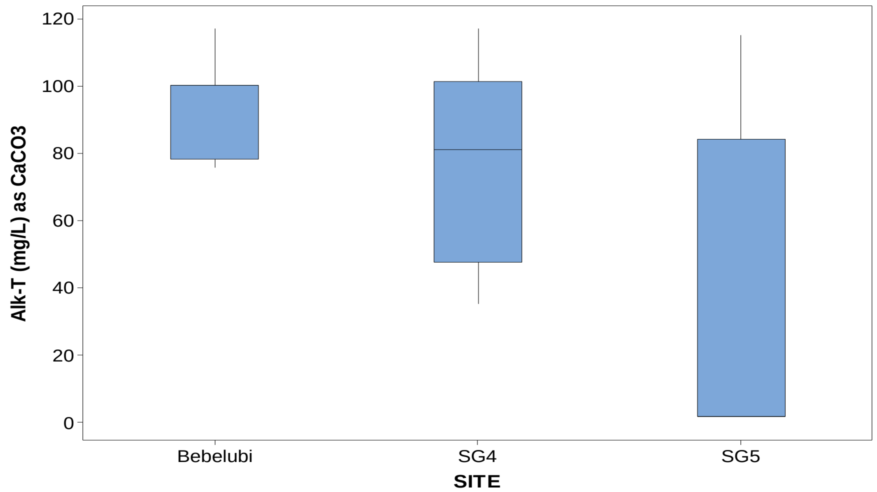


Figure D-4 Alkalinity in water lower river test sites 2018

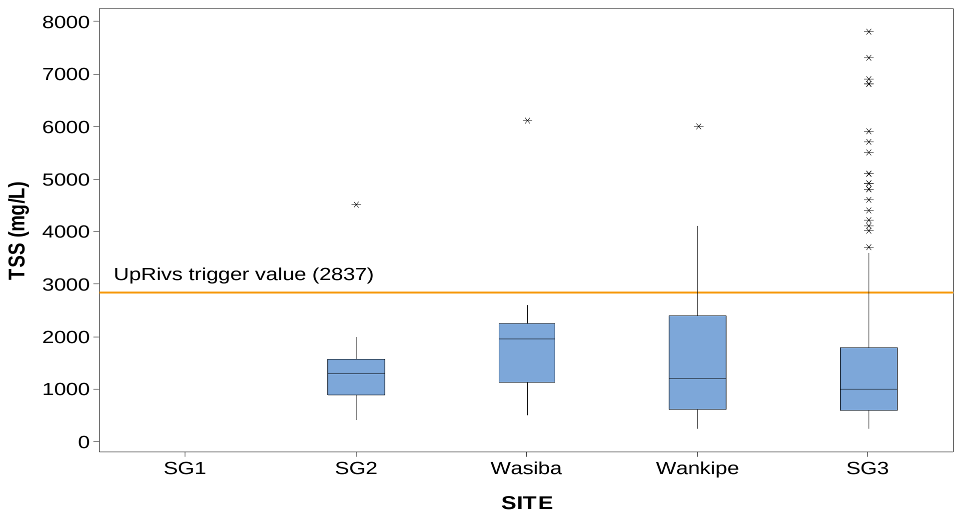


Figure D-5 TSS in water upper river test sites 2018

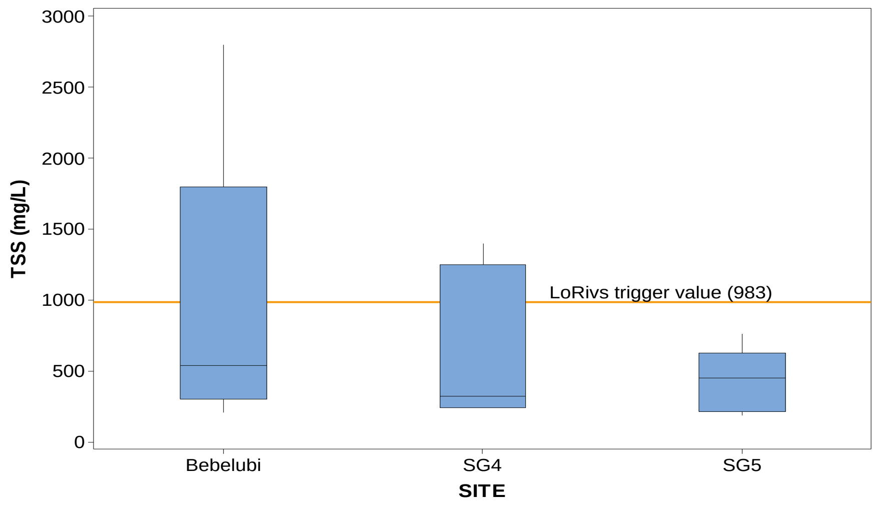


Figure D-6 TSS in water lower river test sites 2018

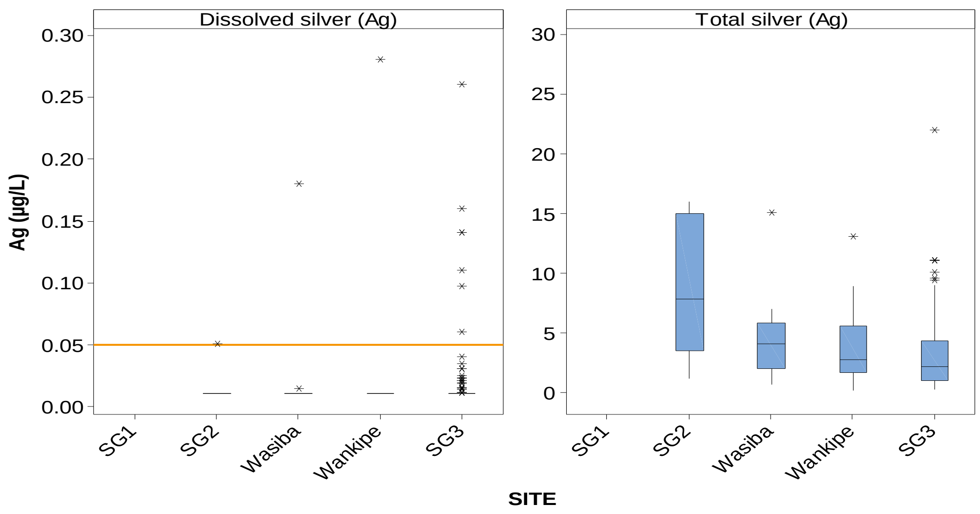


Figure D-7 Silver in water upper river test sites 2018

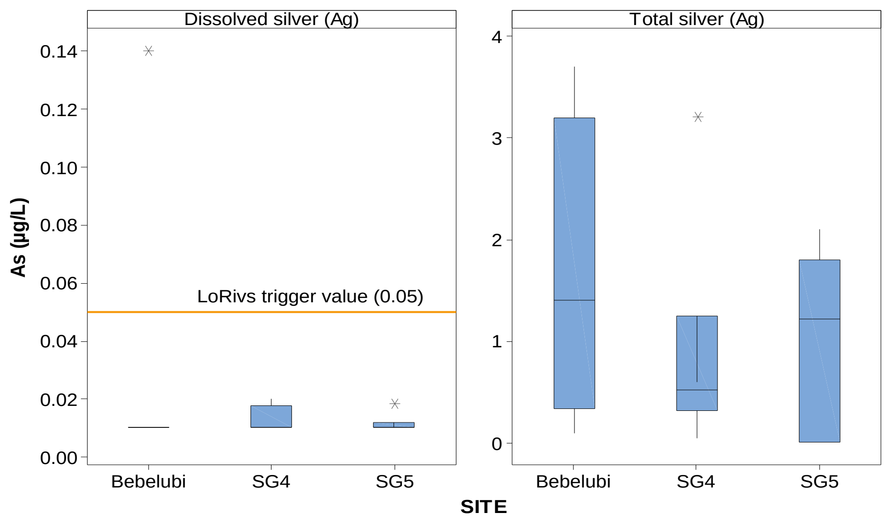


Figure D-8 Silver in water lower river test sites 2018

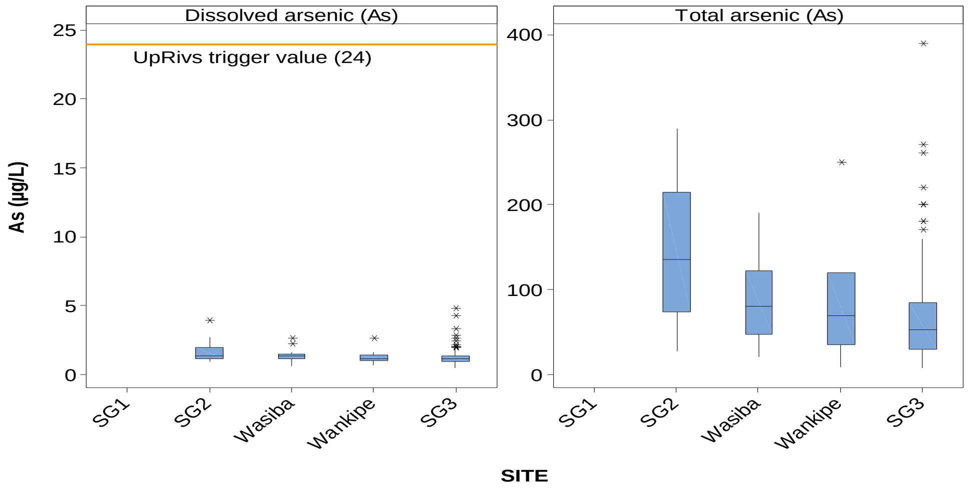


Figure D-9 Arsenic in water upper river test sites 2018

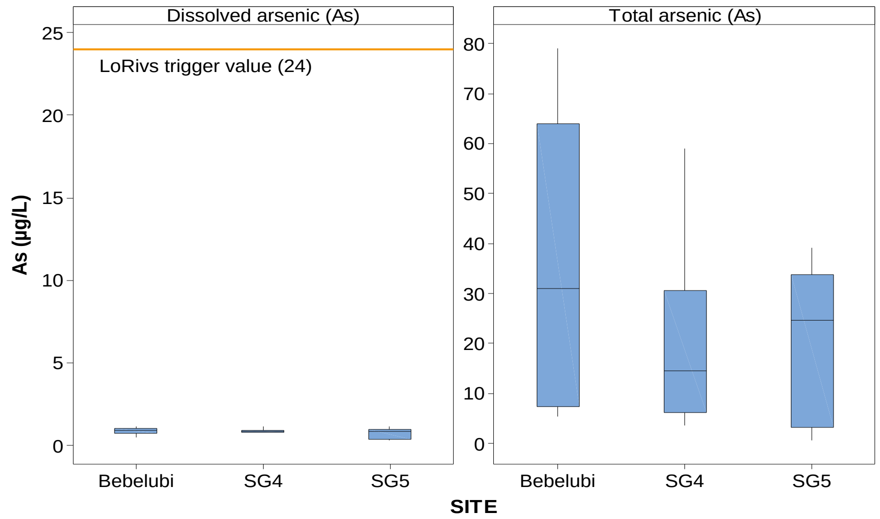


Figure D-10 Arsenic in water lower river test sites 2018

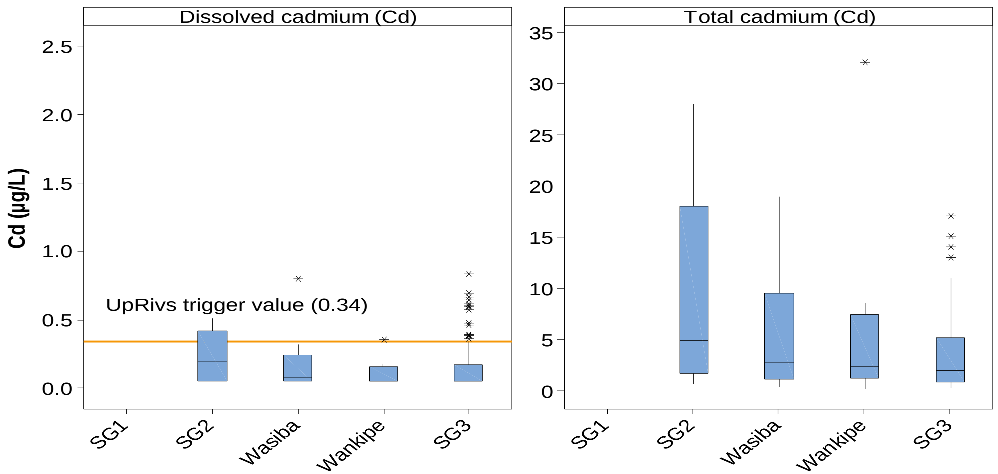


Figure D-11 Cadmium in water upper river test sites 2018

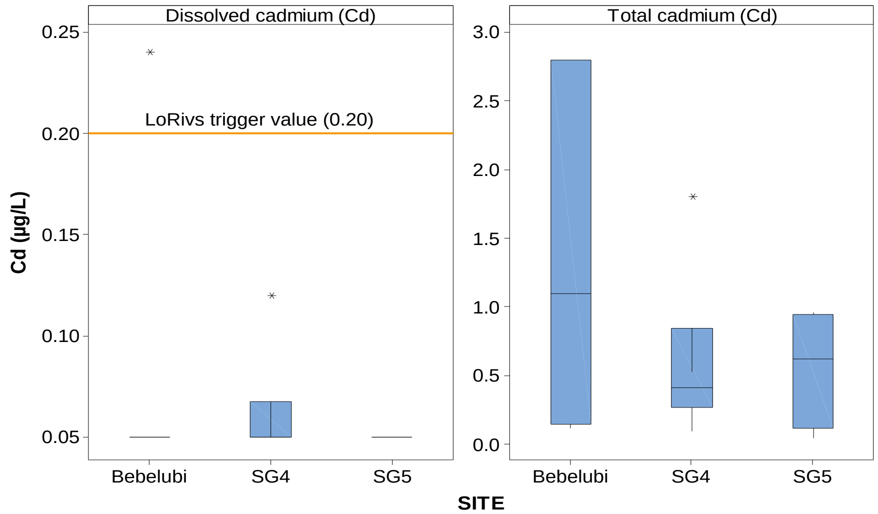


Figure D-12 Cadmium in water lower river test sites 2018

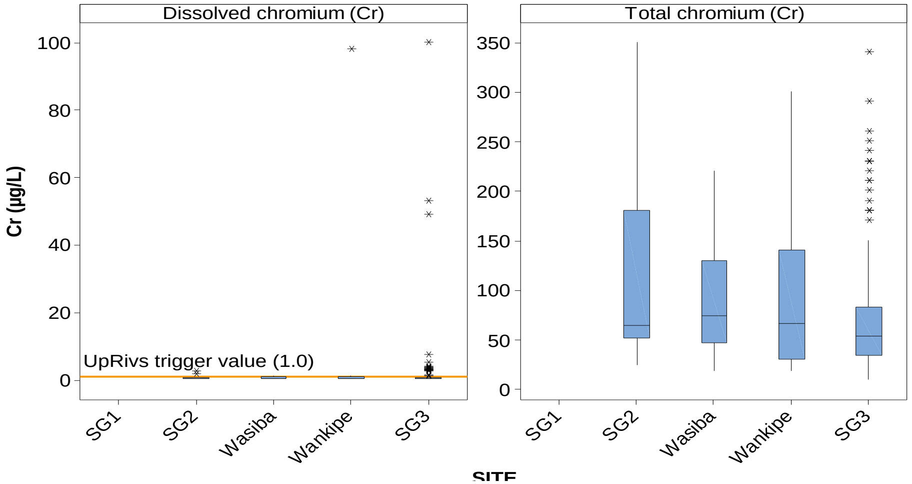


Figure D-13 Chromium in water upper river test sites 2018

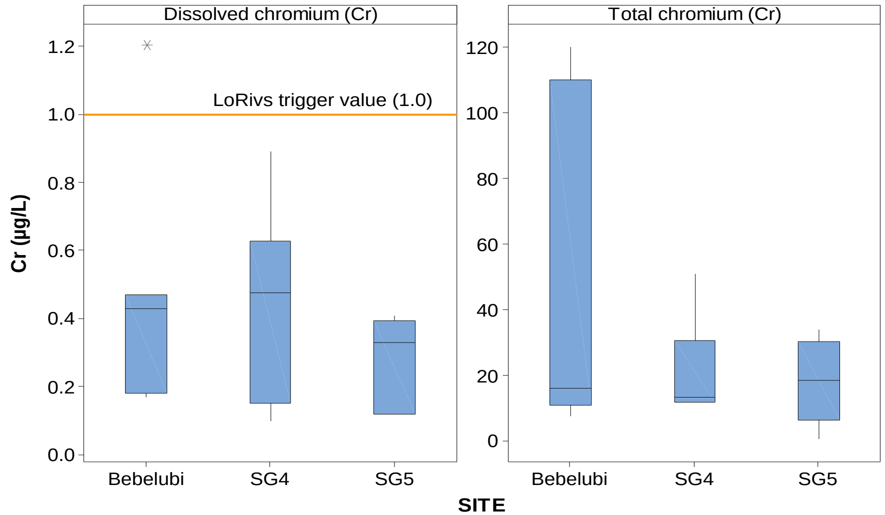


Figure D-14 Chromium in water lower river test sites 2018

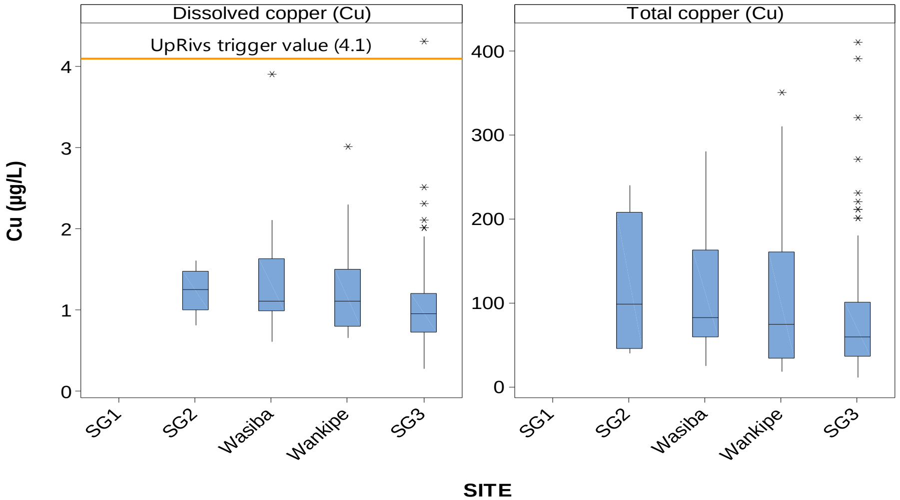


Figure D-15 Copper in water upper river test sites 2018

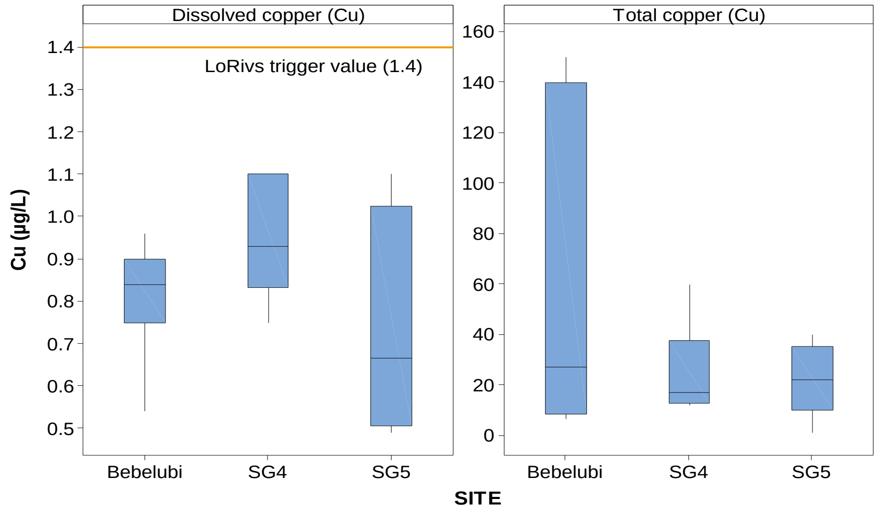


Figure D-16 Copper in water lower river test sites 2018

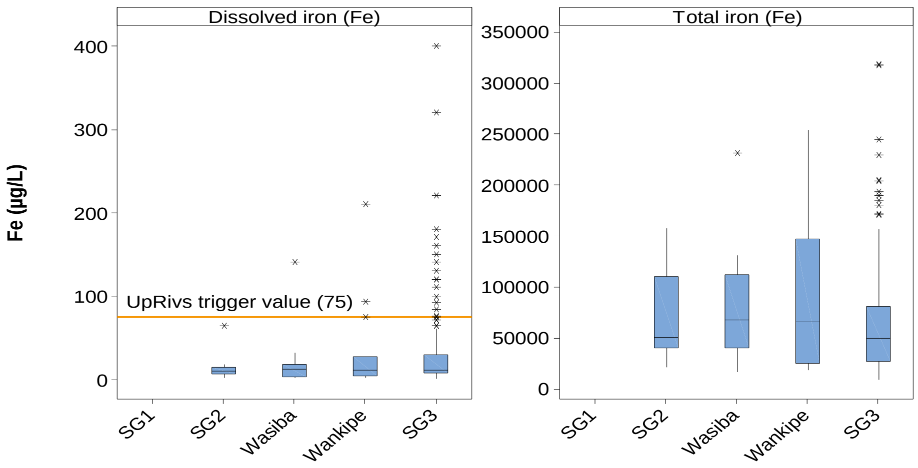


Figure D-17 Iron in water upper river test sites 2018

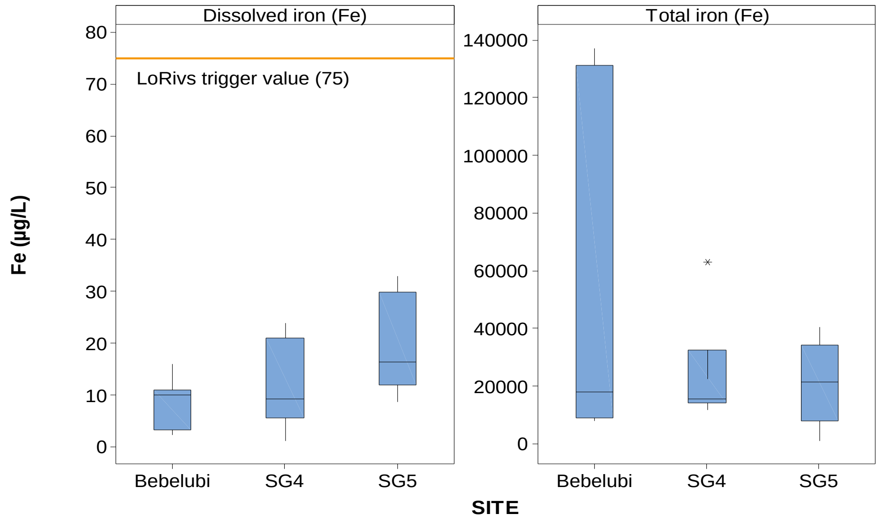


Figure D-18 Iron in water lower river test sites 2018

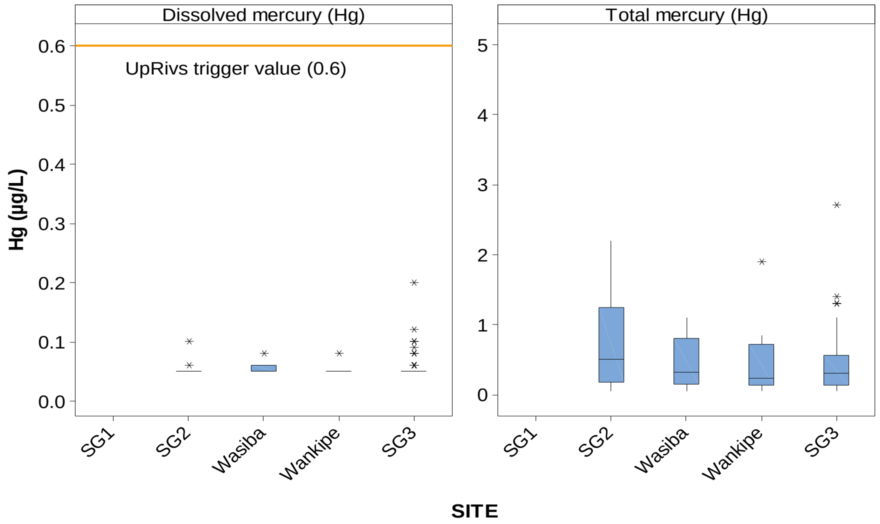


Figure D-19 Mercury in water upper river test sites 2018

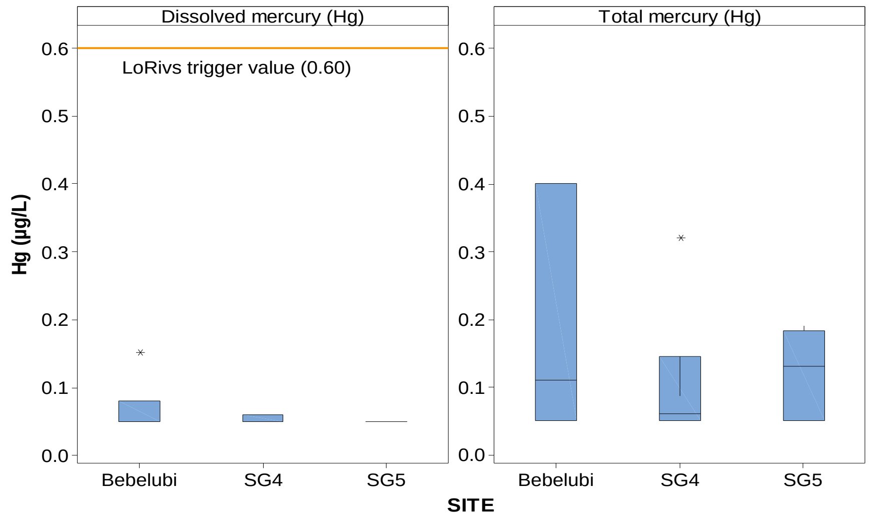


Figure D-20 Mercury in water lower river test sites 2018

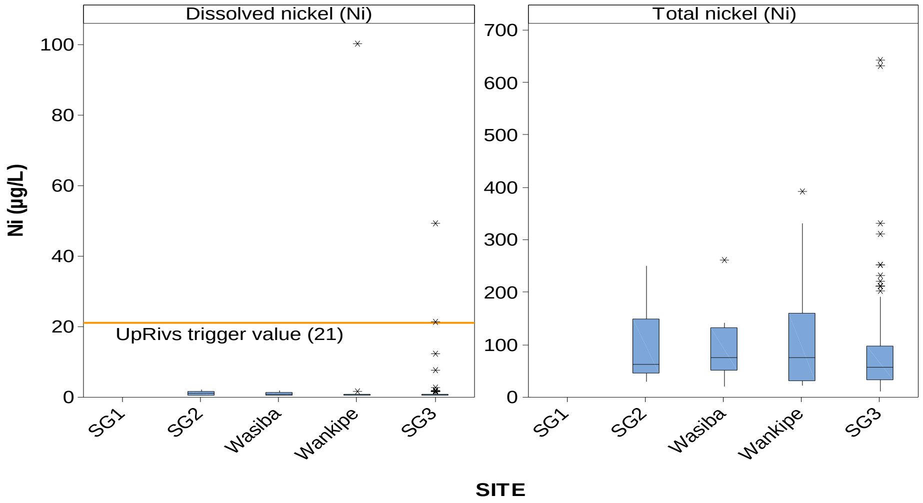


Figure D-21 Nickel in water upper river test sites 2018

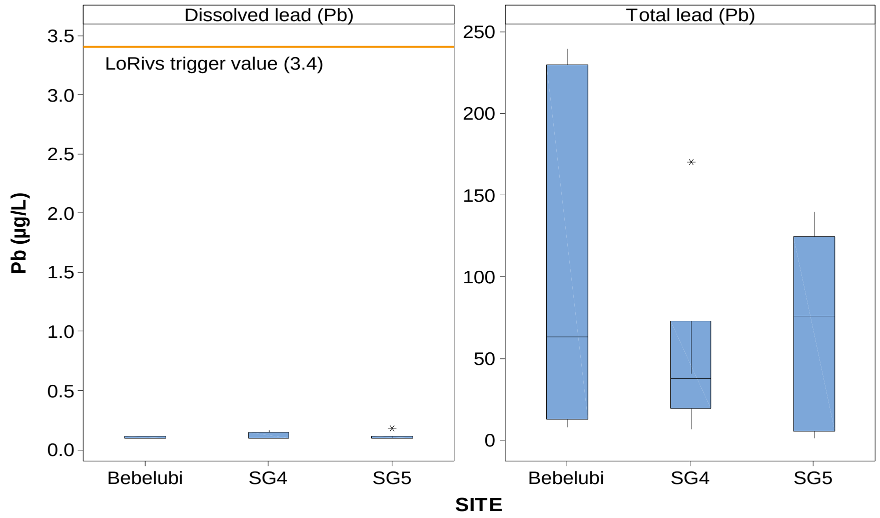


Figure D-22 Nickel in water lower river test sites 2018

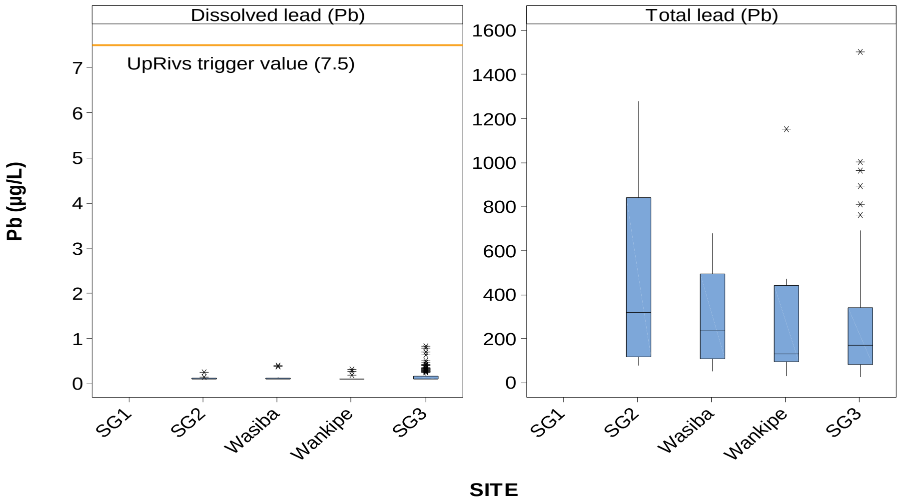


Figure D-23 Lead in water upper river test sites 2018

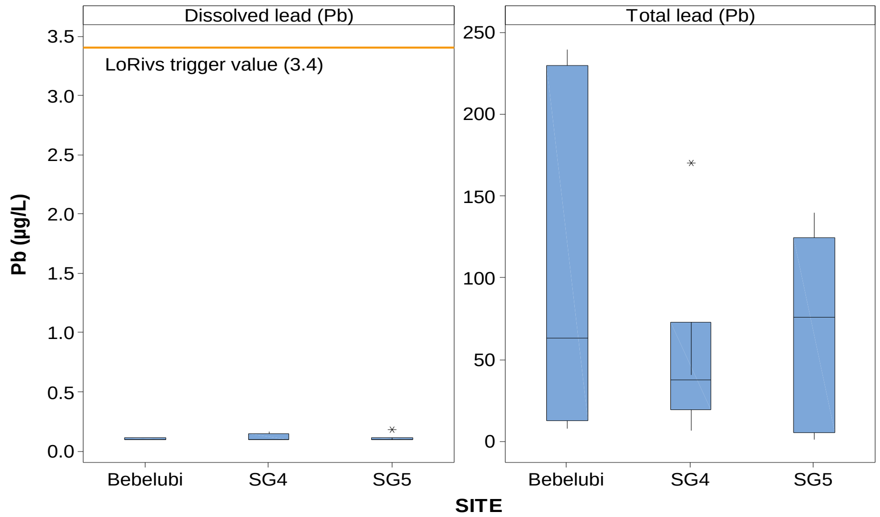


Figure D-24 Lead in water lower river test sites 2018

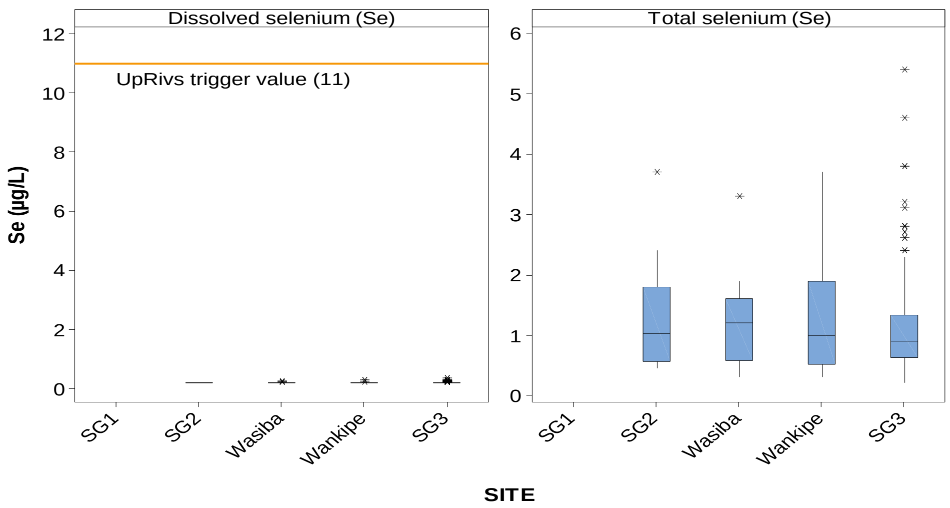


Figure D-25 Selenium in water upper river test sites 2018

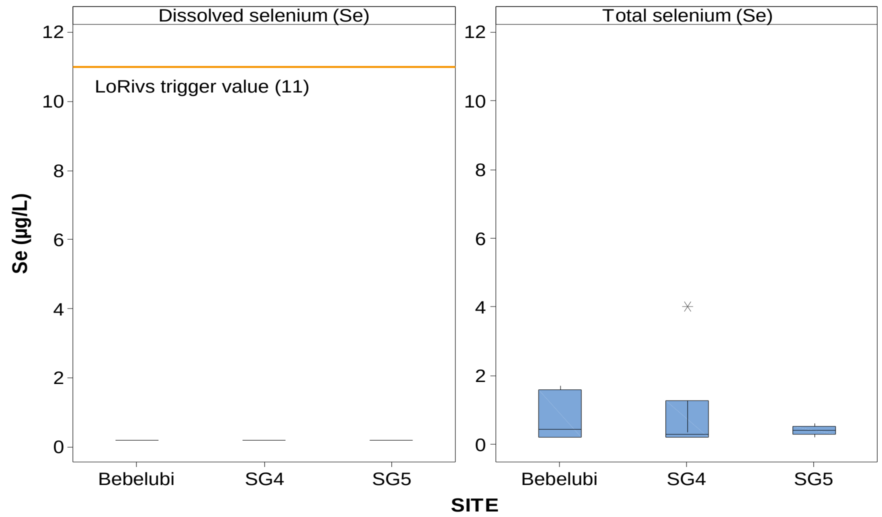


Figure D-26 Selenium in water lower river test sites 2018

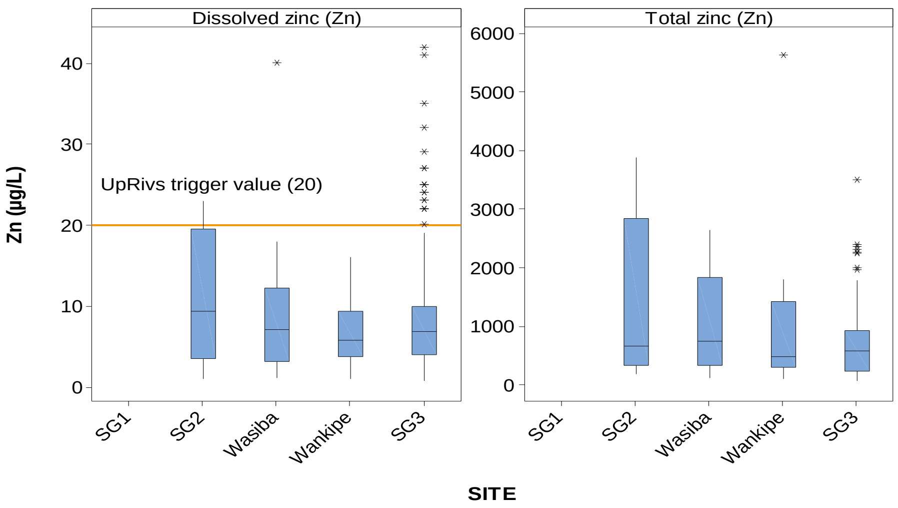


Figure D-27 Zinc in water upper river test sites 2018

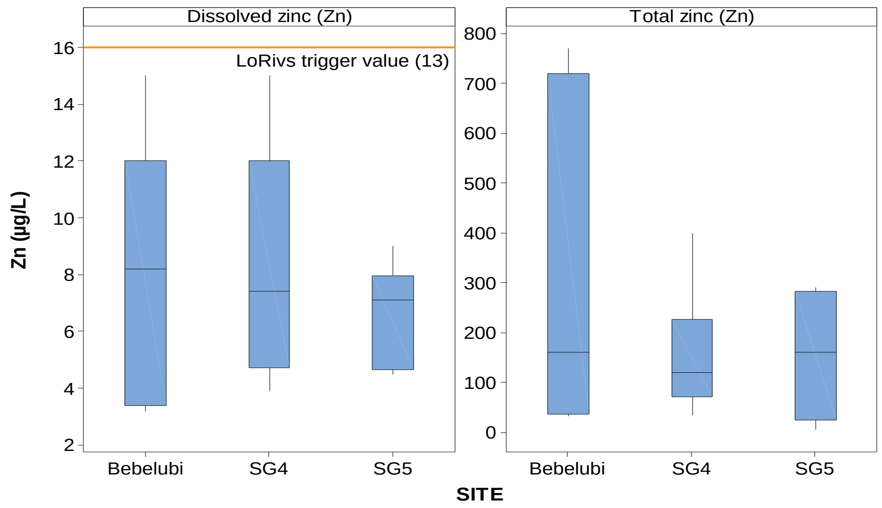


Figure D-28 Zinc in water lower river test sites 2018

Table D-10 Performance assessment – Based on the trend of water quality indicators (all data) at upper river test sites between 2009 and 2018 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2009 - 2018
SG1 (Trend of all data 2008 - 2015) Monitoring not conducted since 2015	pH	-0.03	0.802	No change over time
	TSS	-0.444	<0.001	Reduced over time
	EC	-0.551	<0.001	Reduced over time
	Ag-D*	-0.359	0.002	No change over time
	As-D	-0.578	<0.001	Reduced over time
	Cd-D*	-0.056	0.637	No change over time
	Cr-D	-0.71	<0.001	No change over time
	Cu-D	-0.158	0.179	No change over time
	Fe-D	0.029	0.807	No change over time
	Hg-D*	-0.515	<0.001	No change over time
	Ni-D	-0.132	0.262	No change over time
	Pb-D*	-0.249	0.032	Reduced over time
	Se-D*	-0.663	0.001	No change over time
	Zn-D	-0.064	0.588	No change over time
SG2 (Trend of all data 2009 - 2018)	pH	-0.286	0.002	Reduced over time
	TSS	-0.146	0.118	No change over time
	EC	-0.194	0.037	Reduced over time
	Ag-D*	-0.815	<0.001	Reduced over time
	As-D	-0.386	<0.001	Reduced over time
	Cd-D*	-0.184	0.047	Reduced over time
	Cr-D	-0.717	<0.001	Reduced over time
	Cu-D	-0.206	0.026	Reduced over time
	Fe-D	-0.084	0.369	No change over time
	Hg-D*	-0.766	<0.001	Reduced over time
	Ni-D	0.065	0.484	No change over time
	Pb-D*	-0.816	<0.001	Reduced over time
	Se-D*	-0.783	<0.001	Reduced over time
	Zn-D	-0.013	0.892	No change over time
Wasiba (Trend of all data 2009 - 2018)	pH	0.440	<0.001	Increased over time
	TSS	0.215	0.064	No change over time
	EC	-0.413	<0.001	Reduced over time
	Ag-D*	-0.772	<0.001	Reduced over time
	As-D	-0.258	0.023	Reduced over time
	Cd-D*	-0.239	0.035	Reduced over time
	Cr-D	-0.134	0.244	No change over time
	Cu-D	-0.231	0.042	Reduced over time
	Fe-D	0.251	0.027	Increased over time
	Hg-D*	0.137	0.232	No change over time
	Ni-D	-0.339	0.002	Reduced over time
	Pb-D*	-0.330	0.003	Reduced over time
	Se-D*	-0.379	0.001	Reduced over time
	Zn-D	0.154	0.178	No change over time

Water Quality Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2009 - 2018
Wankipe (Trend of all data 2009 - 2018)	pH	-0.410	<0.001	Reduced over time
	TSS	-0.130	0.142	No change over time
	EC	-0.317	<0.001	Reduced over time
	Ag-D*	-0.856	<0.001	Reduced over time
	As-D	-0.477	<0.001	Reduced over time
	Cd-D*	-0.543	<0.001	Reduced over time
	Cr-D	-0.689	<0.001	Reduced over time
	Cu-D	-0.018	0.841	No change over time
	Fe-D	0.135	0.125	No change over time
	Hg-D*	-0.759	<0.001	Reduced over time
	Ni-D	-0.558	<0.001	Reduced over time
	Pb-D*	-0.740	<0.001	Reduced over time
	Se-D*	-0.686	<0.001	Reduced over time
	Zn-D	0.295	0.001	Increased over time
SG3 (Trend of all data 2009 - 2018)	pH	-0.545	<0.001	Reduced over time
	TSS	-0.045	0.055	No change over time
	EC	-0.197	<0.001	Reduced over time
	Ag-D*	-0.819	<0.001	Reduced over time
	As-D	-0.362	<0.001	Reduced over time
	Cd-D*	-0.552	<0.001	Reduced over time
	Cr-D	-0.747	<0.001	Reduced over time
	Cu-D	-0.095	<0.001	Reduced over time
	Fe-D	0.218	<0.001	Increased over time
	Hg-D*	-0.767	<0.001	Reduced over time
	Ni-D	-0.694	<0.001	Reduced over time
	Pb-D*	-0.734	<0.001	Reduced over time
	Se-D*	-0.716	<0.001	Reduced over time
	Zn-D	0.284	<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-11 Performance assessment – Based on the trend of water quality indicators (all data) at lower river test sites between 2009 and 2018 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend 2009 - 2018
Bebelubi (Trend of all data 2009 - 2018)	pH	-0.813	0.035	Reduced over time
	TSS	-0.724	0.081	Reduced over time
	EC	-0.423	0.3	Reduced over time
	Ag-D*	-0.773	<0.001	Reduced over time
	As-D*	-0.223	<0.001	Reduced over time
	Cd-D*	0.015	<0.001	No change over time
	Cr-D	-0.727	<0.001	Reduced over time
	Cu-D*	-0.688	0.049	Reduced over time
	Fe-D	-0.768	0.898	Reduced over time
	Hg-D*	-0.798	<0.001	Reduced over time
	Ni-D	-0.694	<0.001	Reduced over time
	Pb-D*	-0.253	<0.001	Reduced over time
	Se-D*	0.126	<0.001	No change over time
	Zn-D	-0.210	<0.001	No change over time
SG4 (Trend of all data 2009 - 2018)	pH	-0.401	<0.001	Reduced over time
	TSS	-0.162	0.119	No change over time
	EC	0.068	0.516	No change over time
	Ag-D*	-0.755	<0.001	Reduced over time
	As-D*	-0.464	<0.001	Reduced over time
	Cd-D*	-0.686	<0.001	Reduced over time
	Cr-D	-0.690	<0.001	Reduced over time
	Cu-D*	0.032	0.753	No change over time
	Fe-D	-0.150	0.139	No change over time
	Hg-D*	-0.803	<0.001	Reduced over time
	Ni-D	-0.543	<0.001	Reduced over time
	Pb-D*	-0.614	<0.001	Reduced over time
	Se-D*	-0.798	<0.001	Reduced over time
	Zn-D	0.445	<0.001	Increased over time
SG5 (Trend of all data 2009 - 2018)	pH	-0.004	0.978	No change over time
	TSS	0.364	0.015	Increased over time
	EC	0.383	0.009	Increased over time
	Ag-D*	-0.915	<0.001	Reduced over time
	As-D*	-0.449	0.002	Reduced over time
	Cd-D*	-0.822	<0.001	Reduced over time
	Cr-D	-0.476	0.001	Reduced over time
	Cu-D*	-0.382	0.008	Reduced over time
	Fe-D	-0.467	0.001	Reduced over time
	Hg-D*	-0.766	<0.001	Reduced over time
	Ni-D	-0.773	<0.001	Reduced over time
	Pb-D*	-0.657	<0.001	Reduced over time
	Se-D*	≤LOR	≤LOR	No change over time
	Zn-D	0.122	0.413	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-12 Water quality Lake Murray and ORWB test sites - Central Lake Murray 2018 median (µg/L)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Central Lake	N	N (Test)	Median	Result	Go to			
pH	10	10	7.5	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.0	0.003 / 0.003	LOW
EC	10	10	21	TSM > Upper TV	Step 2	18	0.998	POTENTIAL
TSS	10	10	9.5	TSM < Upper TV	Step 1	15	0.004	LOW
Ag-D	10	10	0.01	TSM < Upper TV	Step 1	0.05	0.003	LOW
As-D	10	10	0.14	TSM < Upper TV	Step 1	24	0.003	LOW
Cd-D	10	10	0.05	TSM < Upper TV	Step 1	0.72	0.003	LOW
Cr-D	10	10	0.20	TSM < Upper TV	Step 1	1.0	0.003	LOW
Cu-D	10	10	0.53	TSM < Upper TV	Step 1	1.4	0.003	LOW
Fe-D	10	10	39.5	TSM < Upper TV	Step 1	340	0.003	LOW
Hg-D	10	10	0.05	TSM < Upper TV	Step 1	0.60	0.003	LOW
Ni-D	10	10	0.5	TSM < Upper TV	Step 1	11	0.003	LOW
Pb-D	10	10	0.11	TSM < Upper TV	Step 1	3.4	0.003	LOW
Se-D	10	10	0.2	TSM < Upper TV	Step 1	11	0003	LOW
Zn-D	10	10	8.4	TSM < Upper TV	Step 1	8.8	0.601	POTENTIAL

Table D-13 Water quality Lake Murray and ORWB test sites - South Lake Murray 2018 median (µg/L)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Southern Lake	N	N (Test)	Median	Result	Go to			
pH	10	10	7.5	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.0	0.003 / 0.003	LOW
EC	10	10	21	TSM > Upper TV	Step 2	18	0.998	POTENTIAL
TSS	10	10	14	TSM < Upper TV	Step 1	15	0.187	POTENTIAL
Ag-D	10	10	0.01	TSM < Upper TV	Step 1	0.05	0.003	LOW
As-D	10	10	0.17	TSM < Upper TV	Step 1	24	0.003	LOW
Cd-D	10	10	0.05	TSM < Upper TV	Step 1	0.72	0.003	LOW
Cr-D	10	10	0.25	TSM < Upper TV	Step 1	1.0	0.003	LOW
Cu-D	10	10	0.56	TSM < Upper TV	Step 1	1.4	0.010	LOW
Fe-D	10	10	27	TSM < Upper TV	Step 1	340	0.003	LOW
Hg-D	10	10	0.05	TSM < Upper TV	Step 1	0.60	0.003	LOW
Ni-D	10	10	0.5	TSM < Upper TV	Step 1	11	0.003	LOW
Pb-D	10	10	0.19	TSM < Upper TV	Step 1	3.4	0.003	LOW
Se-D	10	10	0.2	TSM < Upper TV	Step 1	11	0.003	LOW
Zn-D	10	10	5.9	TSM < Upper TV	Step 1	8.8	0.131	POTENTIAL

Table D-14 Water quality Lake Murray and ORWB test sites - SG6 2018 median (µg/L)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
SG6	N	N (Test)	Median	Result	Go to			
pH	4	4	7.4	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.0	Direct comparison	LOW
EC	4	4	45	TSM > Upper TV	Step 2	18	Direct comparison	POTENTIAL
TSS	4	4	11	TSM < Upper TV	Step 1	15	Direct comparison	POTENTIAL
Ag-D	4	4	0.01	TSM < Upper TV	Step 1	0.05	Direct comparison	LOW
As-D	4	4	0.54	TSM < Upper TV	Step 1	24	Direct comparison	LOW
Cd-D	4	4	0.05	TSM < Upper TV	Step 1	0.72	Direct comparison	LOW
Cr-D	4	4	0.28	TSM < Upper TV	Step 1	1.0	Direct comparison	LOW
Cu-D	4	4	0.45	TSM < Upper TV	Step 1	1.4	Direct comparison	LOW
Fe-D	4	4	52	TSM < Upper TV	Step 1	340	Direct comparison	LOW
Hg-D	4	4	0.05	TSM < Upper TV	Step 1	0.60	Direct comparison	LOW
Ni-D	4	4	0.5	TSM < Upper TV	Step 1	11	Direct comparison	LOW
Pb-D	4	4	0.13	TSM < Upper TV	Step 1	3.4	Direct comparison	LOW
Se-D	4	4	0.20	TSM < Upper TV	Step 1	11	Direct comparison	LOW
Zn-D	4	4	5.4	TSM < Upper TV	Step 1	8.8	Direct comparison	LOW

Table D-15 Water quality Lake Murray and ORWB test sites - Kukufionga 2018 median (µg/L)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Kukufionga	N	N (Test)	Median	Result	Go to			
pH	2	2	7.8	Lower TV < TSM < Upper TV	Step 1/2	6.0-8.0	Direct comparison	LOW
EC	2	2	273	TSM > Upper TV	Step 2	172	Direct comparison	POTENTIAL
TSS	2	2	75	TSM > Upper TV	Step 2	983	Direct comparison	LOW
Ag-D	2	2	0.01	TSM < Upper TV	Step 1	0.05	Direct comparison	LOW
As-D	2	2	1.5	TSM < Upper TV	Step 1	24	Direct comparison	LOW
Cd-D	2	2	0.05	TSM < Upper TV	Step 1	0.20	Direct comparison	LOW
Cr-D	2	2	0.11	TSM < Upper TV	Step 1	1.0	Direct comparison	LOW
Cu-D	2	2	0.77	TSM < Upper TV	Step 1	1.4	Direct comparison	LOW
Fe-D	2	2	9.8	TSM < Upper TV	Step 1	75	Direct comparison	LOW
Hg-D	2	2	0.08	TSM < Upper TV	Step 1	0.60	Direct comparison	LOW
Ni-D	2	2	0.5	TSM < Upper TV	Step 1	15	Direct comparison	LOW
Pb-D	2	2	0.10	TSM < Upper TV	Step 1	3.4	Direct comparison	LOW
Se-D	2	2	0.20	TSM < Upper TV	Step 1	11	Direct comparison	LOW
Zn-D	2	2	4.7	TSM < Upper TV	Step 1	13	Direct comparison	LOW

Table D-16 Water quality Lake Murray and ORWB test sites - Zongamange 2018 median (µg/L)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Zongamange	N	N (Test)	Median	Result	Go to			
pH	2	2	7.5	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.0	Direct comparison	LOW
EC	2	2	86	TSM < Upper TV	Step 1	172	Direct comparison	LOW
TSS	2	2	225	TSM > Upper TV	Step 2	983	Direct comparison	LOW
Ag-D	2	2	0.01	TSM < Upper TV	Step 1	0.05	Direct comparison	LOW
As-D	2	2	0.77	TSM < Upper TV	Step 1	24	Direct comparison	LOW
Cd-D	2	2	0.05	TSM < Upper TV	Step 1	0.20	Direct comparison	LOW
Cr-D	2	2	0.14	TSM < Upper TV	Step 1	1.0	Direct comparison	LOW
Cu-D	2	2	1.0	TSM < Upper TV	Step 1	1.4	Direct comparison	LOW
Fe-D	2	2	20	TSM < Upper TV	Step 1	75	Direct comparison	LOW
Hg-D	2	2	0.06	TSM < Upper TV	Step 1	0.60	Direct comparison	LOW
Ni-D	2	2	0.5	TSM < Upper TV	Step 1	15	Direct comparison	LOW
Pb-D	2	2	0.11	TSM < Upper TV	Step 1	3.4	Direct comparison	LOW
Se-D	2	2	0.2	TSM < Upper TV	Step 1	11	Direct comparison	LOW
Zn-D	2	2	8.6	TSM < Upper TV	Step 1	13	Direct comparison	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-17 Water quality Lake Murray and ORWB test sites - Avu 2018 median (µg/L)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Avu	N	N (Test)	Median	Result	Go to			
pH	4	4	7.1	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.0	Direct comparison	LOW
EC	4	4	50.5	TSM < Upper TV	Step 1	172	Direct comparison	LOW
TSS	4	4	49	TSM > Upper TV	Step 2	983	Direct comparison	LOW
Ag-D	4	4	0.01	TSM < Upper TV	Step 1	0.05	Direct comparison	LOW
As-D	4	4	0.86	TSM < Upper TV	Step 1	24	Direct comparison	LOW
Cd-D	4	4	0.05	TSM < Upper TV	Step 1	0.20	Direct comparison	LOW
Cr-D	4	4	0.27	TSM < Upper TV	Step 1	1.0	Direct comparison	LOW
Cu-D	4	4	0.9	TSM < Upper TV	Step 1	1.4	Direct comparison	LOW
Fe-D	4	4	220	TSM < Upper TV	Step 1	75	Direct comparison	LOW
Hg-D	4	4	0.05	TSM < Upper TV	Step 1	0.60	Direct comparison	LOW
Ni-D	4	4	0.64	TSM < Upper TV	Step 1	15	Direct comparison	LOW
Pb-D	4	4	0.35	TSM < Upper TV	Step 1	3.4	Direct comparison	LOW
Se-D	4	4	0.2	TSM < Upper TV	Step 1	11	Direct comparison	LOW
Zn-D	4	4	11.2	TSM > Upper TV	Step 2	13	Direct comparison	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-18 Water quality Lake Murray and ORWB test sites - Levame 2018 median (µg/L)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Levame	N	N (Test)	Median	Result	Go to			
pH	2	2	8.2	Lower TV < TSM < Upper TV	Step 1 / 2	6.0-8.0	Direct comparison	LOW
EC	2	2	235	TSM < Upper TV	Step 1	172	Direct comparison	POTENTIAL
TSS	2	2	19	TSM > Upper TV	Step 2	983	Direct comparison	LOW
Ag-D	2	2	0.02	TSM < Upper TV	Step 1	0.05	Direct comparison	LOW
As-D	2	2	1.2	TSM < Upper TV	Step 1	24	Direct comparison	LOW
Cd-D	2	2	0.05	TSM < Upper TV	Step 1	0.20	Direct comparison	LOW
Cr-D	2	2	0.13	TSM < Upper TV	Step 1	1.0	Direct comparison	LOW
Cu-D	2	2	0.80	TSM < Upper TV	Step 1	1.4	Direct comparison	LOW
Fe-D	2	2	90	TSM < Upper TV	Step 1	75	Direct comparison	POTENTIAL
Hg-D	2	2	0.05	TSM < Upper TV	Step 1	0.60	Direct comparison	LOW
Ni-D	2	2	0.5	TSM < Upper TV	Step 1	15	Direct comparison	LOW
Pb-D	2	2	0.13	TSM < Upper TV	Step 1	3.4	Direct comparison	LOW
Se-D	2	2	0.2	TSM < Upper TV	Step 1	11	Direct comparison	LOW
Zn-D	2	2	11.2	TSM > Upper TV	Step 2	13	Direct comparison	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.

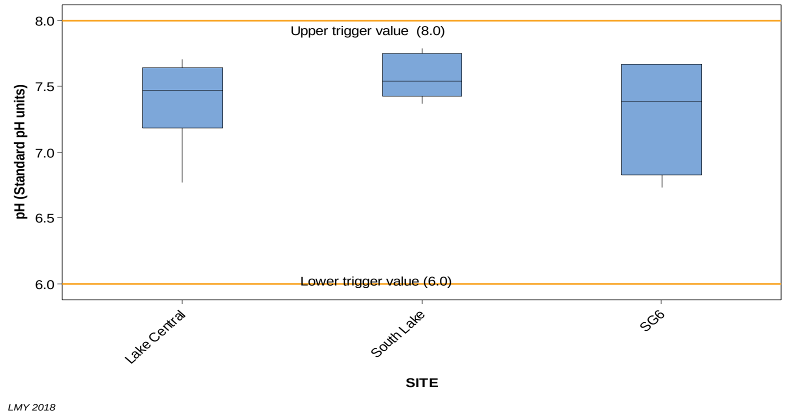


Figure D-29 pH in water Lake Murray test sites 2018

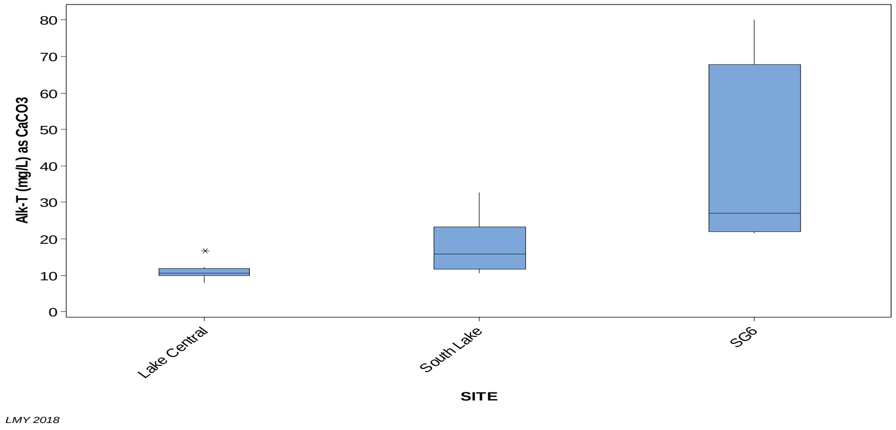


Figure D-30 Alkalinity in water Lake Murray test sites 2018

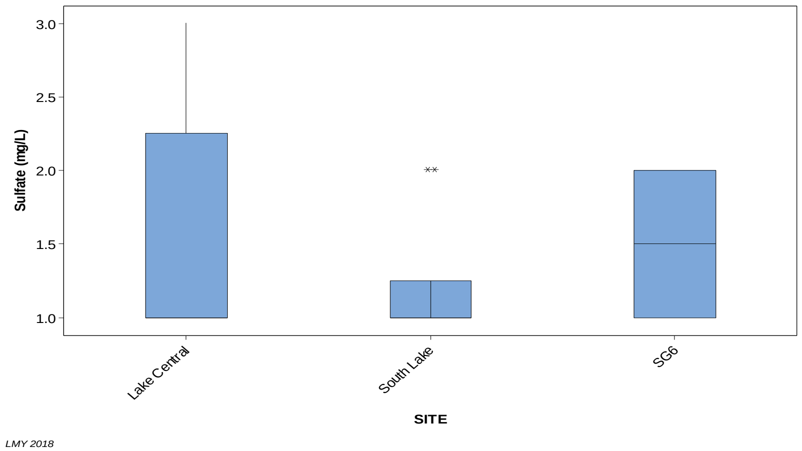


Figure D-31 Sulfate in water Lake Murray test sites 2018

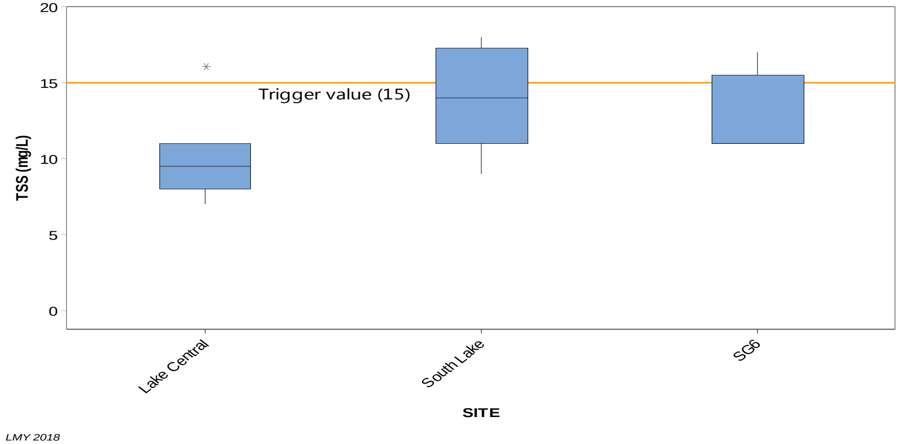


Figure D-32 TSS in water Lake Murray test sites 2018

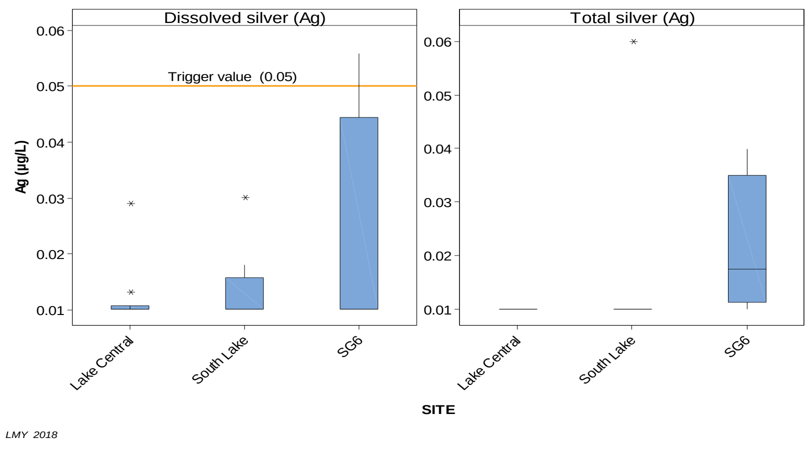


Figure D-33 Silver in water Lake Murray test sites 2018

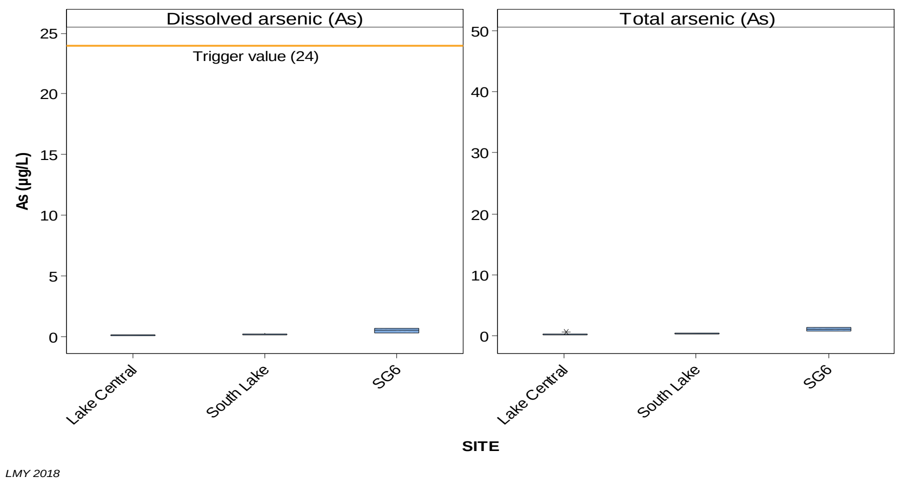


Figure D-34 As in water Lake Murray test sites 2018

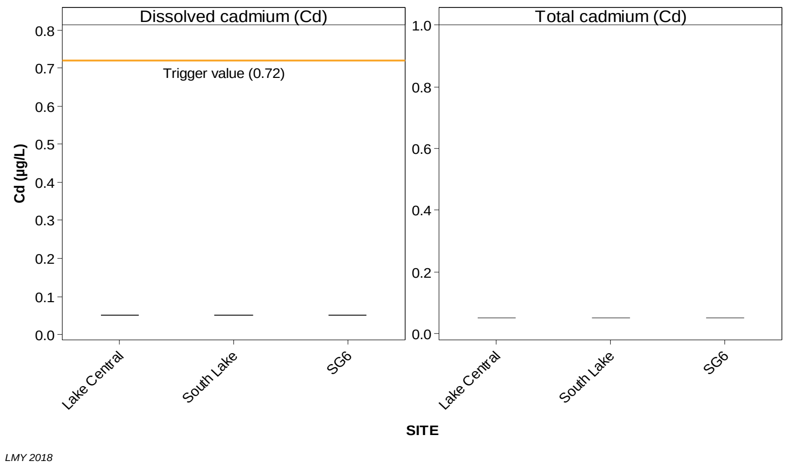


Figure D-35 Cadmium in water Lake Murray test sites 2018

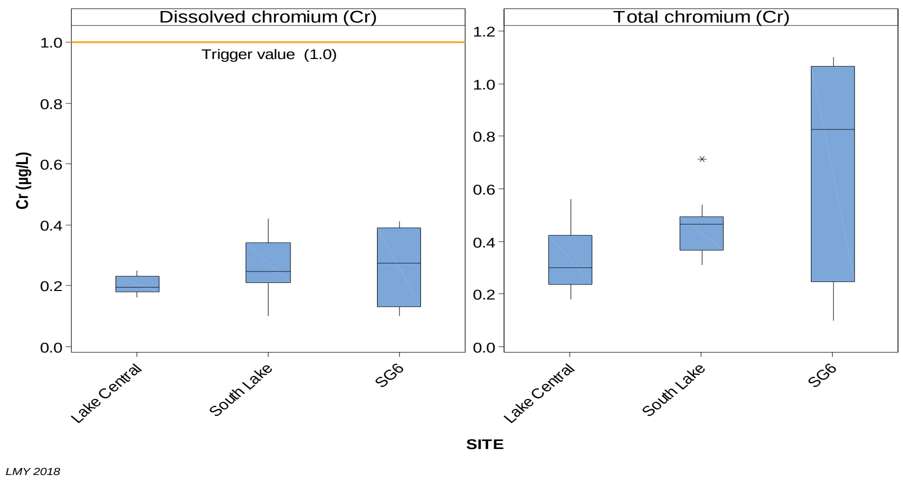


Figure D-36 Cr in water Lake Murray test sites 2018

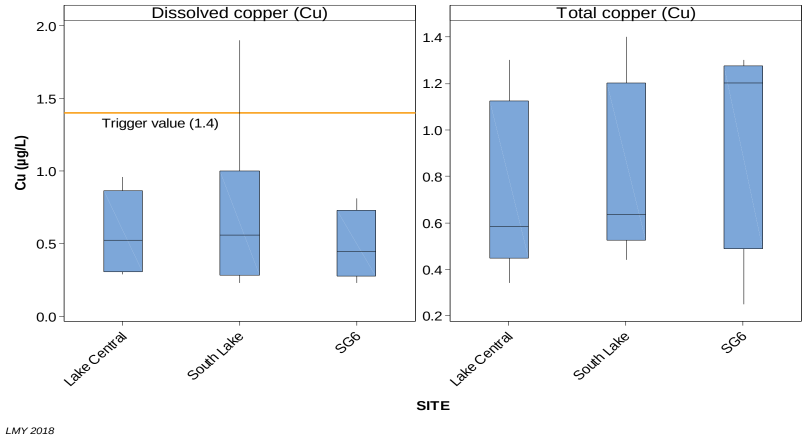


Figure D-37 Copper in water Lake Murray test sites 2018

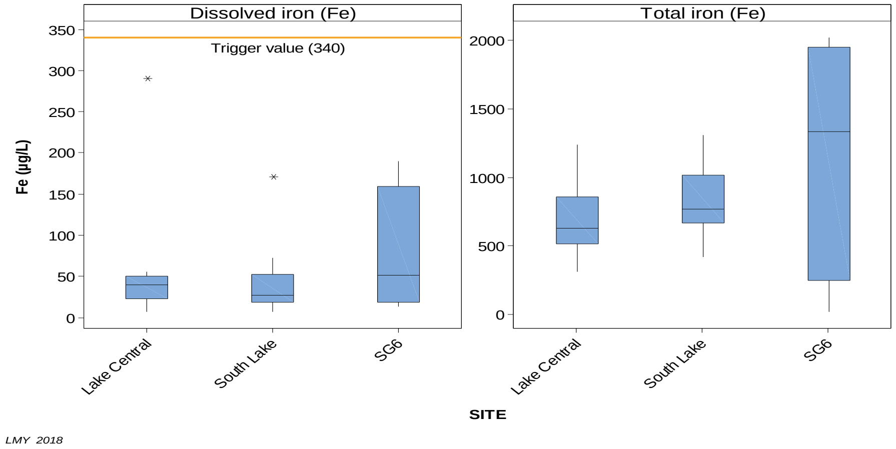


Figure D-38 Iron in water Lake Murray test sites 2018

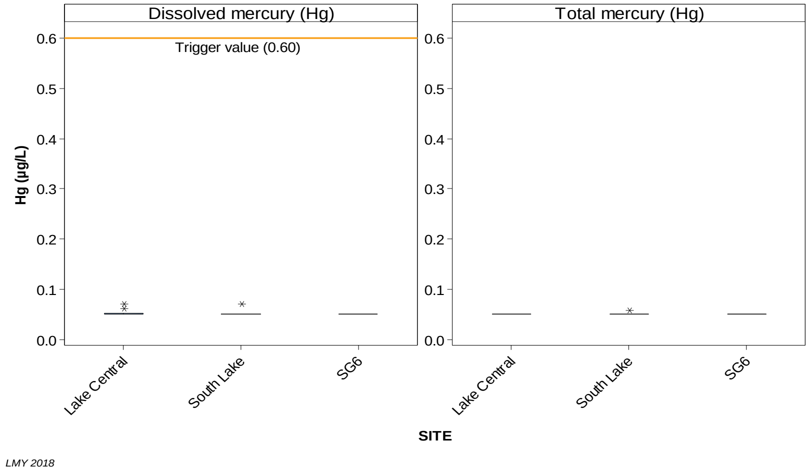


Figure D-39 Mercury in water Lake Murray test sites 2018

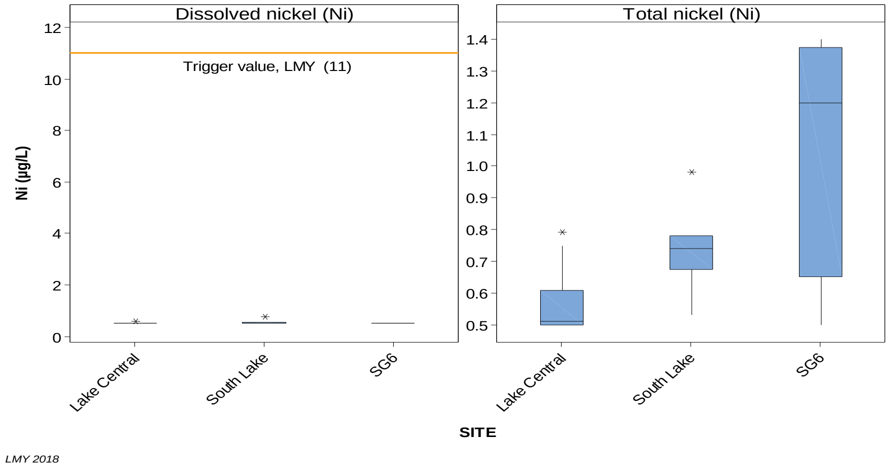


Figure D-40 Nickel in water Lake Murray test sites 2018

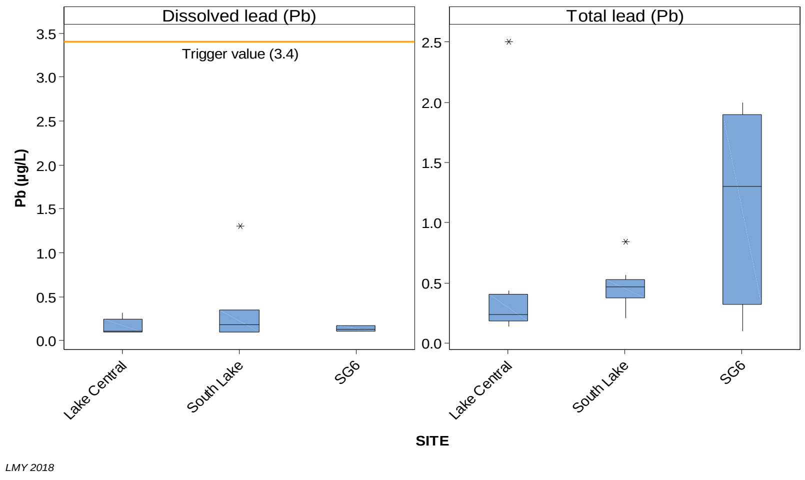


Figure D-41 Lead in water Lake Murray test sites 2018

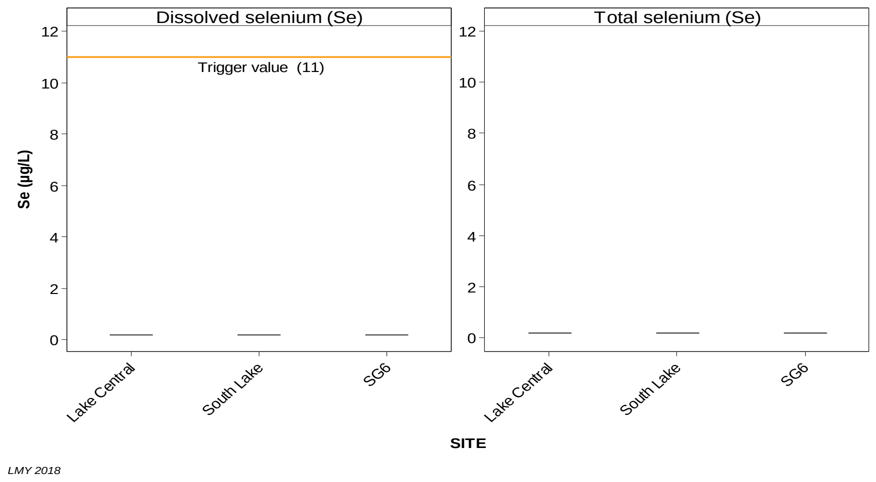


Figure D-42 Selenium in water Lake Murray test sites 2018

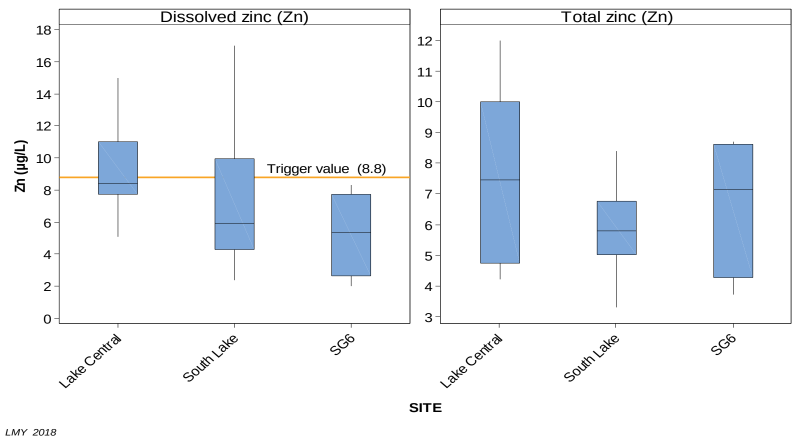


Figure D-43 Zinc in water Lake Murray test sites 2018

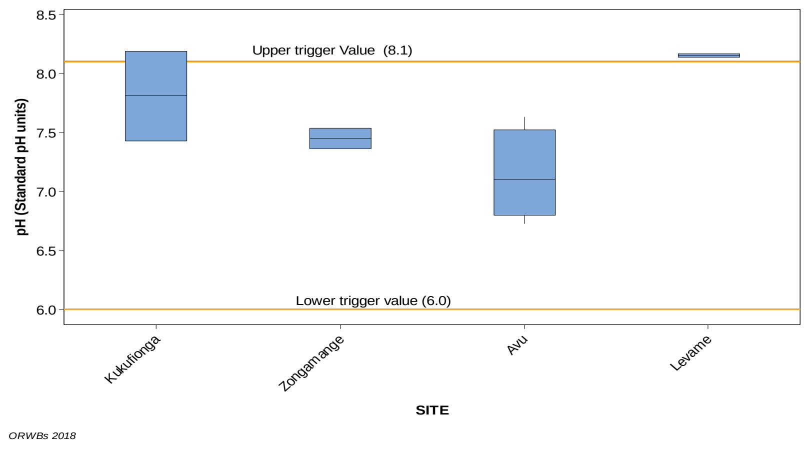


Figure D-44 pH in water ORWB test sites 2018

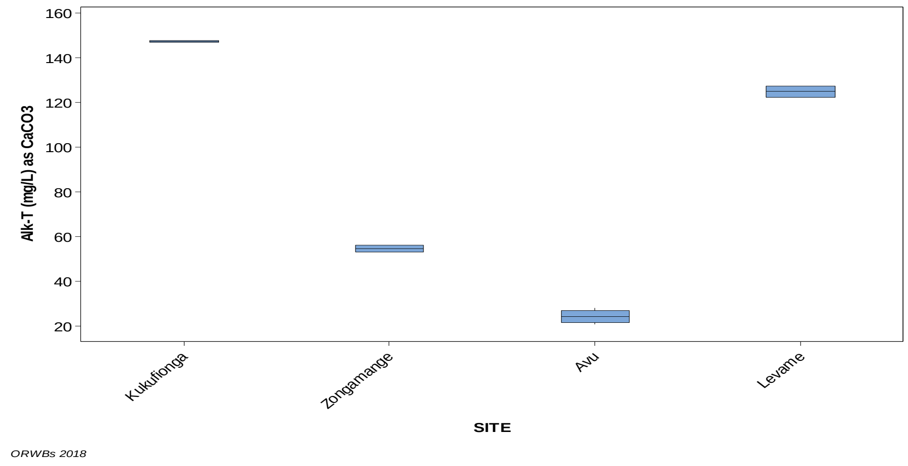


Figure D-45 Alkalinity in water ORWB test sites 2018

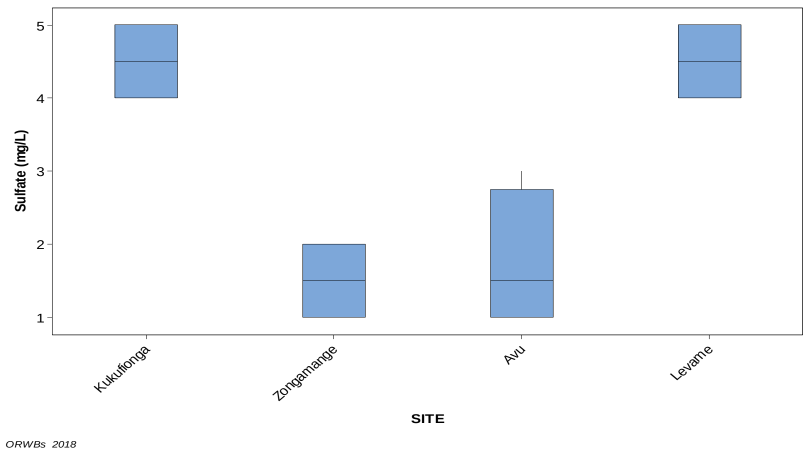


Figure D-46 Sulfate in water ORWB test sites 2018

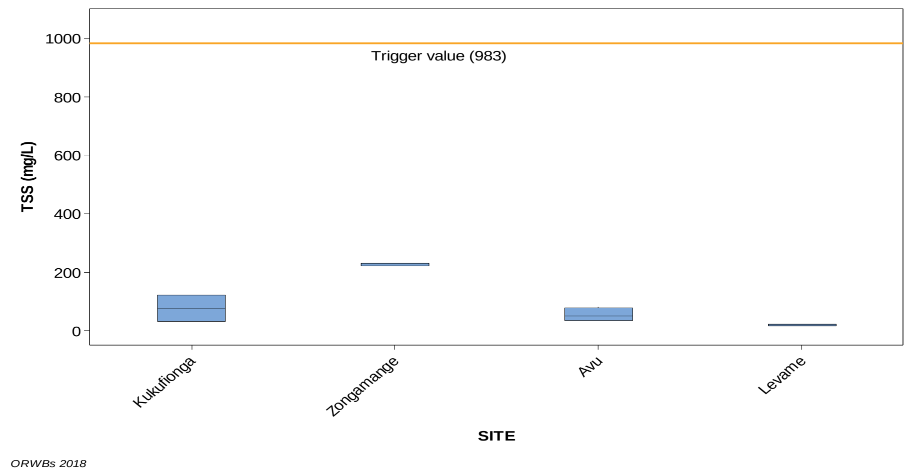


Figure D-47 TSS in water ORWB test sites 2018

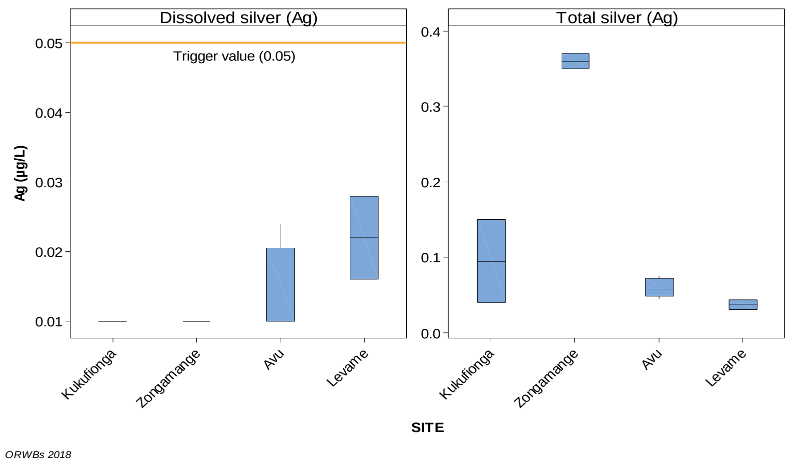


Figure D-48 Silver in water ORWB test sites 2018

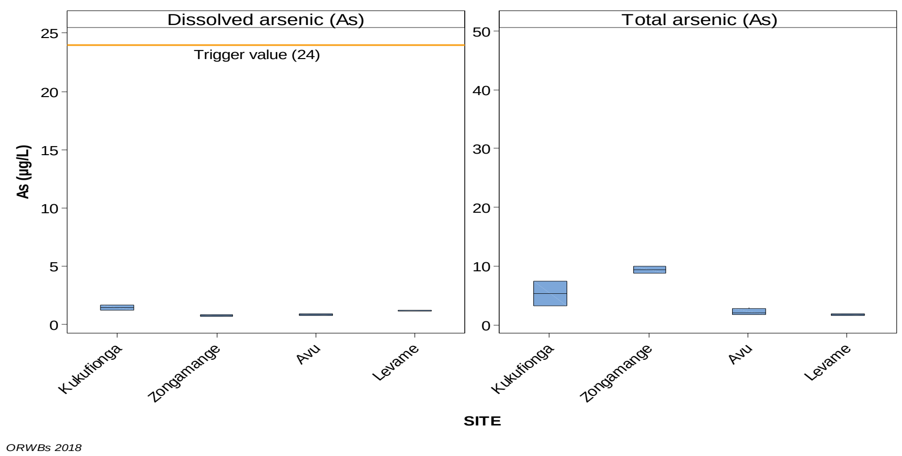


Figure D-49 As in water ORWB test sites 2018

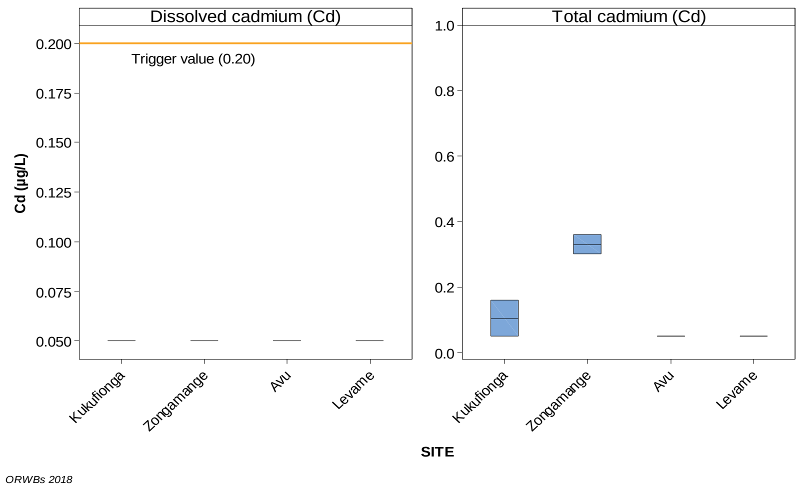


Figure D-50 Cadmium in water ORWB test sites 2018

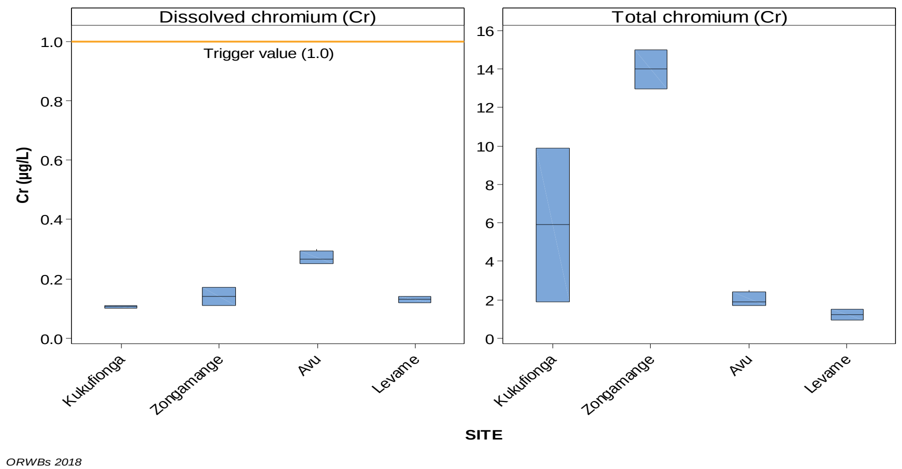


Figure D-51 Cr in water ORWB test sites 2018

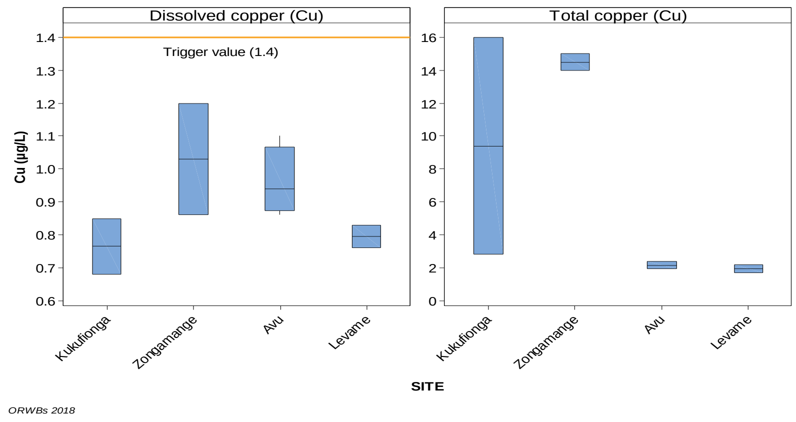


Figure D-52 Copper in water ORWB test sites 2018

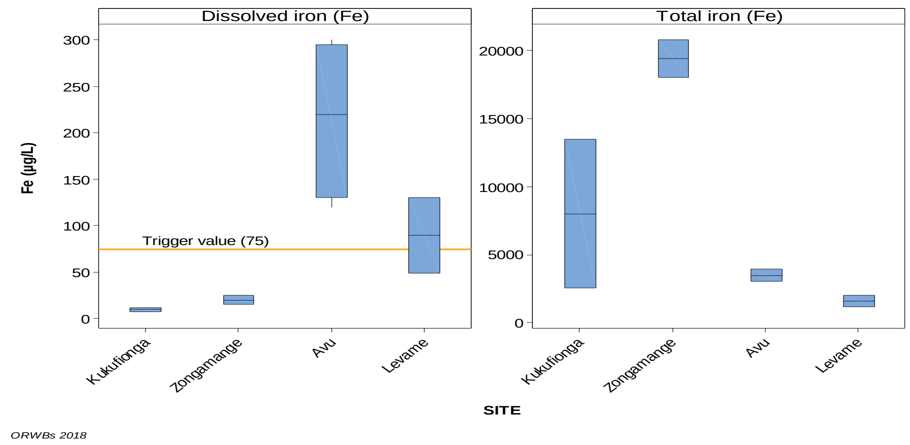


Figure D-53 Iron in water ORWB test sites 2018

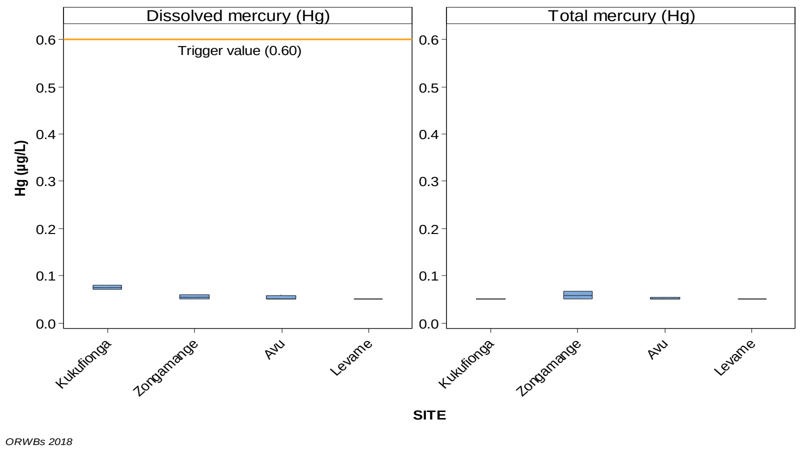


Figure D-54 Mercury in water ORWB test sites 2018

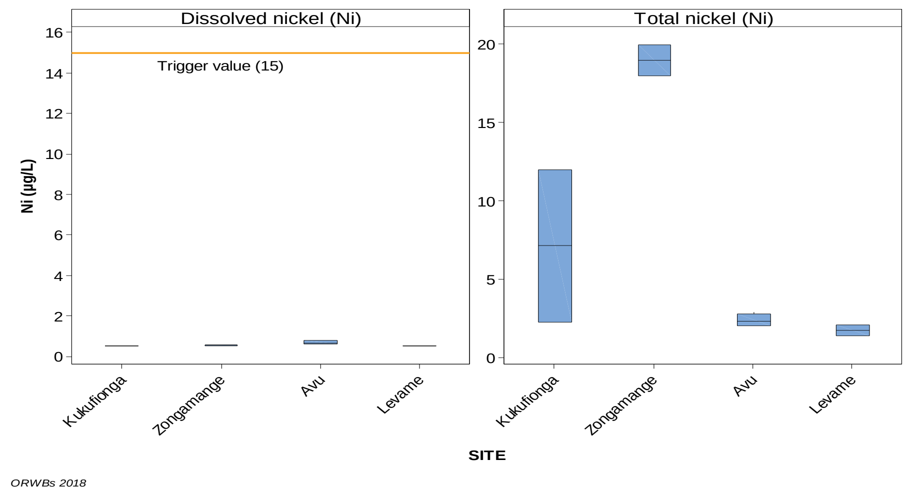


Figure D-55 Nickel in water ORWB test sites 2018

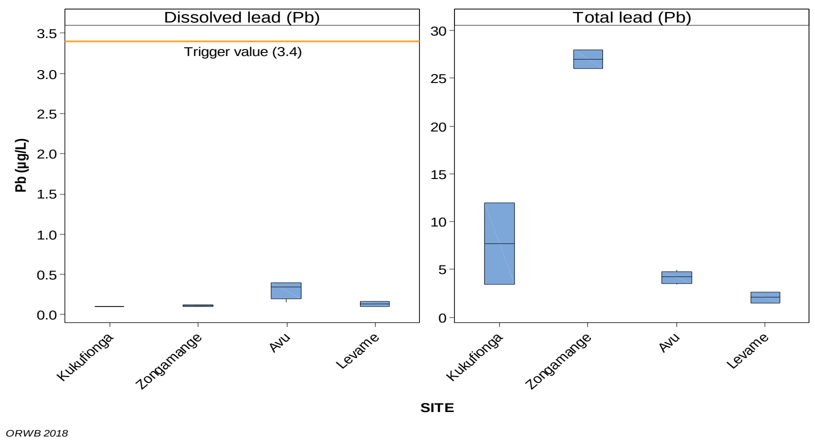


Figure D-56 Lead in water ORWB test sites 2018

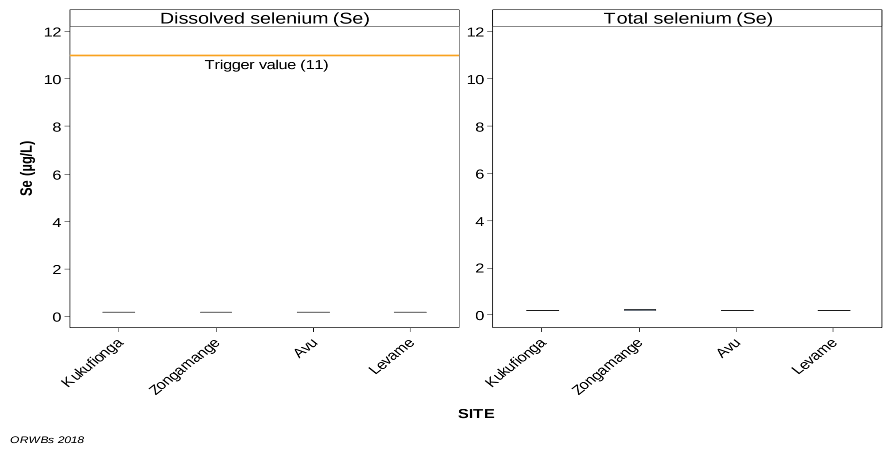


Figure D-57 Selenium in water ORWB test sites 2018

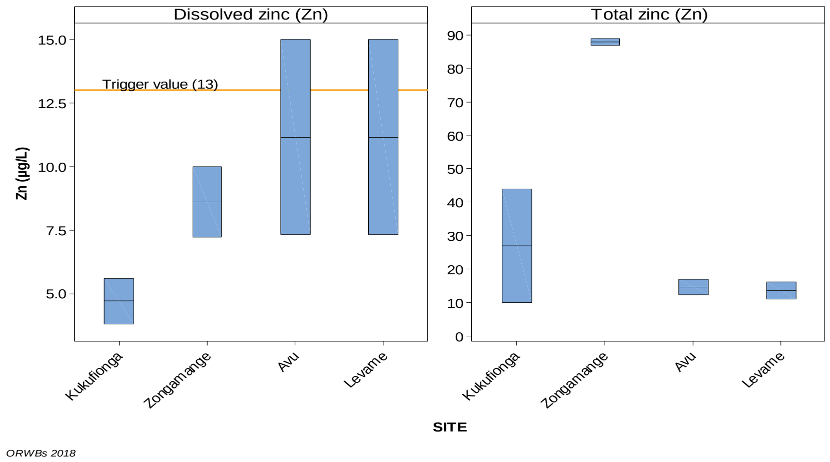


Figure D-58 Zinc in water ORWB test sites 2018

Table D-19 Performance assessment – Based on the trend of water quality indicators (all data) at Lake Murray and ORWB test sites between 2009 and 2018 using Spearman Rank Test.

Water Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend 2009 - 2018
Central (Trend of all data 2009 - 2018)	pH	0.739	<0.001	Increased over time
	TSS	0.318	0.012	Increased over time
	EC	-0.141	0.262	No change over time
	Ag-D	-0.899	<0.001	Reduced over time
	As-D	-0.594	<0.001	Reduced over time
	Cd-D	-0.699	<0.001	Reduced over time
	Cr-D	-0.414	0.001	Reduced over time
	Cu-D	-0.597	<0.001	Reduced over time
	Fe-D	-0.31	0.012	Reduced over time
	Hg-D	-0.652	<0.001	Reduced over time
	Ni-D	-0.56	<0.001	Reduced over time
	Pb-D	-0.407	0.001	Reduced over time
	Se-D	-0.399	0.003	Reduced over time
	Zn-D	0.417	0.001	Increased over time
Southern (Trend of all data 2009 - 2018)	pH	0.625	<0.001	Increased over time
	TSS	0.59	<0.001	Increased over time
	EC	0.409	<0.001	Increased over time
	Ag-D	-0.92	<0.001	Reduced over time
	As-D	-0.737	<0.001	Reduced over time
	Cd-D	-0.823	<0.001	Reduced over time
	Cr-D	-0.671	<0.001	Reduced over time
	Cu-D	-0.605	<0.001	Reduced over time
	Fe-D	-0.638	<0.001	Reduced over time
	Hg-D	-0.804	<0.001	Reduced over time
	Ni-D	-0.813	<0.001	Reduced over time
	Pb-D	-0.621	<0.001	Reduced over time
	Se-D	-0.653	<0.001	Reduced over time
	Zn-D	0.312	0.003	Increased over time
SG6 (Trend of all data 2009 - 2018)	pH	0.713	<0.001	Increased over time
	TSS	-0.032	0.876	No change over time
	EC	0.520	<0.001	Increased over time
	Ag-D	-0.825	<0.001	Reduced over time
	As-D	-0.067	0.723	No change over time
	Cd-D	-0.658	<0.001	Reduced over time
	Cr-D	-0.164	0.386	No change over time
	Cu-D	-0.515	0.004	Reduced over time
	Fe-D	-0.346	0.061	No change over time
	Hg-D	-0.648	<0.001	Reduced over time
	Ni-D	-0.429	0.018	Reduced over time
	Pb-D	-0.261	0.164	No change over time
	Se-D	-0.343	0.086	No change over time
	Zn-D	0.233	0.215	No change over time

Water Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend 2009 - 2018
Kukufionga (Trend of all data 2009 - 2018)	pH	0.434	0.027	Increased over time
	TSS	0.593	0.002	Increased over time
	EC	-0.443	0.023	Decreased over time
	Ag-D	-0.96	<0.001	Reduced over time
	As-D	-0.348	0.064	No change over time
	Cd-D	-0.759	<0.001	Reduced over time
	Cr-D	-0.563	0.001	Reduced over time
	Cu-D	-0.297	0.117	No change over time
	Fe-D	0.203	0.29	No change over time
	Hg-D	-0.68	<0.001	Reduced over time
	Ni-D	-0.759	<0.001	Reduced over time
	Pb-D	-0.591	0.001	Reduced over time
	Se-D	-0.37	0.082	No change over time
	Zn-D	0.081	0.676	No change over time
Zongamange (Trend of all data 2009 - 2018)	pH	0.707	0.001	Increased over time
	TSS	0.785	<0.001	Increased over time
	EC	0.215	0.391	No change over time
	Ag-D	-0.954	<0.001	Reduced over time
	As-D	-0.46	0.036	Reduced over time
	Cd-D	-0.754	<0.001	Reduced over time
	Cr-D	-0.51	0.018	Reduced over time
	Cu-D	0.244	0.286	No change over time
	Fe-D	-0.212	0.355	No change over time
	Hg-D	-0.638	0.002	Reduced over time
	Ni-D	-0.49	0.024	Reduced over time
	Pb-D	-0.357	0.112	No change over time
	Se-D	-0.425	0.089	No change over time
	Zn-D	0.233	0.309	No change over time
Avu (Trend of all data 2009 - 2018)	pH	0.62	0.001	Increased over time
	TSS	-0.197	0.356	No change over time
	EC	-0.140	0.504	No change over time
	Ag-D	-0.925	<0.001	Reduced over time
	As-D	-0.227	0.245	No change over time
	Cd-D	-0.68	<0.001	Reduced over time
	Cr-D	-0.446	0.017	Reduced over time
	Cu-D	-0.326	0.09	No change over time
	Fe-D	-0.378	0.048	Reduced over time
	Hg-D	-0.698	<0.001	Reduced over time
	Ni-D	-0.175	0.374	No change over time
	Pb-D	-0.391	0.039	Reduced over time
	Se-D	-0.36	0.084	No change over time
	Zn-D	0.433	0.022	Increased over time

Water Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend 2009 - 2018
Levame (Trend of all data 2015 - 2018)	pH	0.922	<0.001	Increased over time
	TSS	-0.368	0.296	No change over time
	EC	0.280	0.434	No change over time
	Ag-D	0.049	0.893	No change over time
	As-D	0.426	0.219	No change over time
	Cd-D	≤LOR	≤LOR	No change over time
	Cr-D	-0.370	0.293	No change over time
	Cu-D	-0.143	0.693	No change over time
	Fe-D	0.536	0.11	No change over time
	Hg-D	0.416	0.231	No change over time
	Ni-D	≤LOR	≤LOR	No change over time
	Pb-D	0.559	0.093	No change over time
	Se-D	≤LOR	≤LOR	No change over time
	Zn-D	0.367	0.297	No change 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.

APPENDIX E. SEDIMENT QUALITY – RISK AND PERFORMANCE ASSESSMENT – DETAILS OF STATISTICAL ANALYSIS AND BOX PLOTS - CHEMISTRY

Table E-1 Expanded risk matrix – sediment quality

<table>
<tr><th colspan="5">Initial Assessment Result</th><th>Go To</th></tr>
<tr><td colspan="5">TSM < TV</td><td>Step 1</td></tr>
<tr><td colspan="5">TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR</td><td>Step 2</td></tr>
<tr><td colspan="5">TSM = TV and TV, TSM and full TSM data set ≤ LOR</td><td>Step 3</td></tr>
<tr><th>Step</th><th>Alt Hypothesis</th><th>Null Hypothesis</th><th colspan="2">Sig Test Result</th><th>Risk Assessment</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">TSM < TV</td><td rowspan="3">TSM = TV</td><td>p < 0.05</td><td>Accept Alt</td><td>LOW</td></tr>
<tr><td>p > 0.05</td><td>Accept Null</td><td>POTENTIAL</td></tr>
<tr><td>Error</td><td>Accept Neither</td><td>ND</td></tr>
<tr><td>2</td><td colspan="4">TSM ≥ TV and TV, TSM and full TSM data set are ≰ LOR</td><td>POTENTIAL</td></tr>
<tr><td>3</td><td colspan="4">TSM = TV and TV, TSM and full TSM data set are ≤ LOR</td><td>LOW</td></tr>
</table>

TSM = Test Site Median

ND = No determination

Table E-2 Sediment quality upper river test sites - SG2 2018 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	0.21	TSM < Upper TV	Step 1	1.0	0.001	LOW
As-WAE	12	12	7.8	TSM < Upper TV	Step 1	20	0.001	LOW
Cd-WAE	12	12	0.7	TSM < Upper TV	Step 1	1.5	0.278	POTENTIAL
Cr-WAE	12	12	12	TSM < Upper TV	Step 1	80	0.001	LOW
Cu-WAE	12	12	14	TSM < Upper TV	Step 1	65	0.001	LOW
Hg-WAE	12	12	0.011	TSM < Upper TV	Step 1	0.15	0.001	LOW
Ni-WAE	12	12	13	TSM < Upper TV	Step 1	21	0..001	LOW
Pb-WAE	12	12	120	TSM > Upper TV	Step 2	50	0.999	POTENTIAL
Se-WAE	12	12	0.13	TSM < Upper TV	Step 1	0.16	0.115	POTENTIAL
Zn-WAE	12	12	140	TSM < Upper TV	Step 1	200	0.695	POTENTIAL

Table E-3 Sediment quality upper river test sites - Wasiba 2018 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	14	14	0.05	TSM < Upper TV	Step 1	1.0	0.001	LOW
As-WAE	14	14	3.8	TSM < Upper TV	Step 1	20	0.001	LOW
Cd-WAE	14	14	0.40	TSM < Upper TV	Step 1	1.5	0.002	LOW
Cr-WAE	14	14	2.6	TSM < Upper TV	Step 1	80	0.001	LOW
Cu-WAE	14	14	8.7	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	6.8	TSM < Upper TV	Step 1	21	0.011	LOW
Pb-WAE	14	14	33	TSM < Upper TV	Step 1	50	0.058	POTENTIAL
Se-WAE	14	13	0.11	TSM < Upper TV	Step 1	0.16	0.081	POTENTIAL
Zn-WAE	14	14	55	TSM < Upper TV	Step 1	200	0.019	LOW

Table E-4 Sediment quality upper river test sites - Wankipe 2018 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	13	13	0.05	TSM < Upper TV	Step 1	1.0	0.001	LOW
As-WAE	13	13	4.2	TSM < Upper TV	Step 1	20	0.001	LOW
Cd-WAE	13	13	0.32	TSM < Upper TV	Step 1	1.5	0.001	LOW
Cr-WAE	13	13	3.6	TSM < Upper TV	Step 1	80	0.001	LOW
Cu-WAE	13	13	8.7	TSM < Upper TV	Step 1	65	0.001	LOW
Hg-WAE	13	13	0.01	TSM < Upper TV	Step 1	0.15	0.001	LOW
Ni-WAE	13	11	8.0	TSM < Upper TV	Step 1	21	0.199	POTENTIAL
Pb-WAE	13	13	33	TSM < Upper TV	Step 1	50	0.015	LOW
Se-WAE	13	12	0.11	TSM < Upper TV	Step 1	0.16	0.030	LOW
Zn-WAE	13	13	61	TSM < Upper TV	Step 1	200	0.007	LOW

Table E-5 Sediment quality upper river test sites - SG3 2018 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	18	18	0.05	TSM < Upper TV	Step 1	1.0	<0.001	LOW
As-WAE	18	18	3.7	TSM < Upper TV	Step 1	20	<0.001	LOW
Cd-WAE	18	18	0.51	TSM < Upper TV	Step 1	1.5	<0.001	LOW
Cr-WAE	18	18	2.8	TSM < Upper TV	Step 1	80	<0.001	LOW
Cu-WAE	18	18	8.8	TSM < Upper TV	Step 1	65	<0.001	LOW
Hg-WAE	18	18	0.01	TSM < Upper TV	Step 1	0.15	<0.001	LOW
Ni-WAE	18	18	12	TSM < Upper TV	Step 1	21	0.158	POTENTIAL
Pb-WAE	18	18	25	TSM < Upper TV	Step 1	50	<0.001	LOW
Se-WAE	18	18	0.12	TSM < Upper TV	Step 1	0.16	0.018	LOW
Zn-WAE	18	18	70	TSM < Upper TV	Step 1	200	0.002	LOW

Table E-6 Sediment quality lower river test sites - Bebelubi 2018 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	0.050	TSM < Upper TV	Step 1	1.0	0.011	LOW
As-WAE	7	7	2.0	TSM < Upper TV	Step 1	20	0.011	LOW
Cd-WAE	7	7	0.21	TSM < Upper TV	Step 1	1.5	0.011	LOW
Cr-WAE	7	7	3.5	TSM < Upper TV	Step 1	80	0.011	LOW
Cu-WAE	7	7	4.4	TSM < Upper TV	Step 1	65	0.011	LOW
Hg-WAE	7	7	0.010	TSM < Upper TV	Step 1	0.15	0.011	LOW
Ni-WAE	7	7	6.2	TSM < Upper TV	Step 1	21	0.011	LOW
Pb-WAE	7	7	8.1	TSM < Upper TV	Step 1	50	0.011	LOW
Se-WAE	7	6	0.10	TSM = Upper TV	Step 1	0.14	0.018	LOW
Zn-WAE	7	7	34	TSM < Upper TV	Step 1	200	0.011	LOW

Table E-7 Sediment quality lower river test sites - SG4 2018 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	6	6	0.050	TSM < Upper TV	Step 1	1.0	0.018	LOW
As-WAE	6	6	1.4	TSM < Upper TV	Step 1	20	0.018	LOW
Cd-WAE	6	6	0.14	TSM < Upper TV	Step 1	1.5	0.018	LOW
Cr-WAE	6	6	3.5	TSM < Upper TV	Step 1	80	0.018	LOW
Cu-WAE	6	6	8.7	TSM < Upper TV	Step 1	65	0.018	LOW
Hg-WAE	6	6	0.010	TSM < Upper TV	Step 1	0.15	0.018	LOW
Ni-WAE	6	6	6.9	TSM < Upper TV	Step 1	21	0.018	LOW
Pb-WAE	6	6	7.8	TSM < Upper TV	Step 1	50	0.018	LOW
Se-WAE	6	6	0.11	TSM < Upper TV	Step 1	0.14	0.201	POTENTIAL
Zn-WAE	6	6	26	TSM < Upper TV	Step 1	200	0.018	LOW

Table E-8 Sediment quality lower river test sites - SG5 2018 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	6	6	0.050	TSM < Upper TV	Step 1	1.0	0.018	LOW
As-WAE	6	6	3.6	TSM < Upper TV	Step 1	20	0.018	LOW
Cd-WAE	6	6	0.34	TSM < Upper TV	Step 1	1.5	0.018	LOW
Cr-WAE	6	6	2.7	TSM < Upper TV	Step 1	80	0.018	LOW
Cu-WAE	6	6	12	TSM < Upper TV	Step 1	65	0.018	LOW
Hg-WAE	6	6	0.010	TSM < Upper TV	Step 1	0.2	0.018	LOW
Ni-WAE	6	6	6.9	TSM < Upper TV	Step 1	21	0.018	LOW
Pb-WAE	6	6	15	TSM < Upper TV	Step 1	50	0.018	LOW
Se-WAE	6	5	0.12	TSM < Upper TV	Step 1	0.14	0.295	POTENTIAL
Zn-WAE	6	6	51	TSM < Upper TV	Step 1	200	0.018	LOW

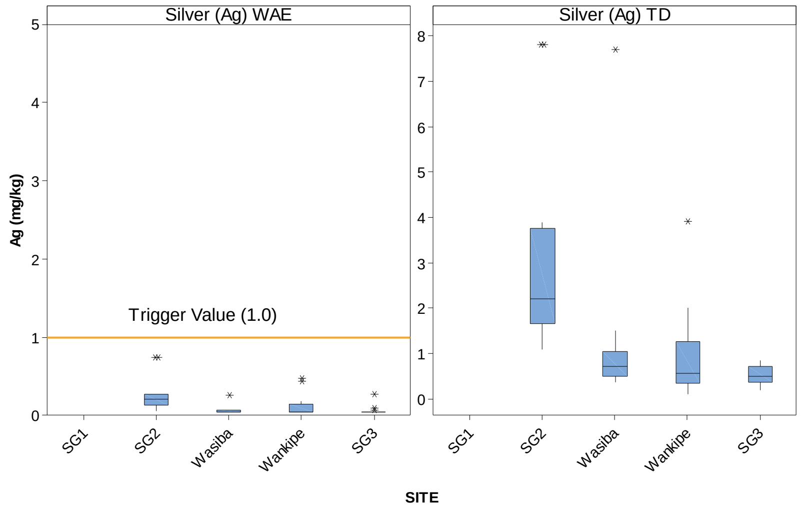


Figure E-1 Silver in sediment upper river test sites 2018

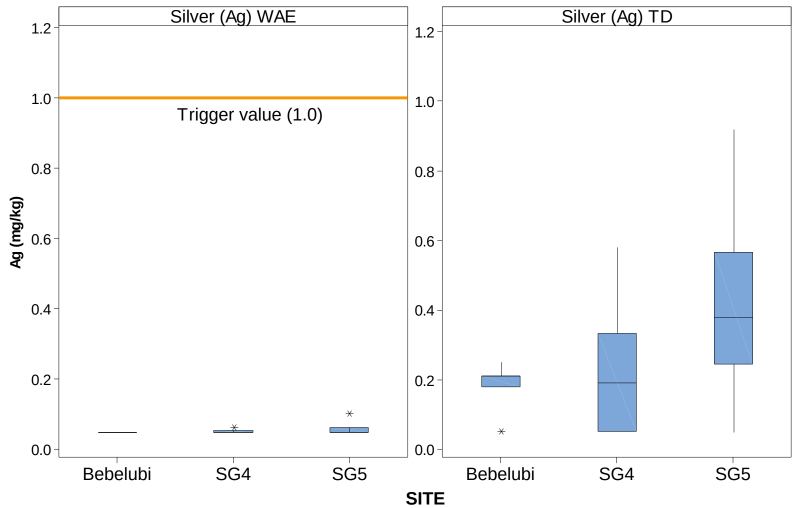


Figure E-2 Silver in sediment lower river test sites 2018

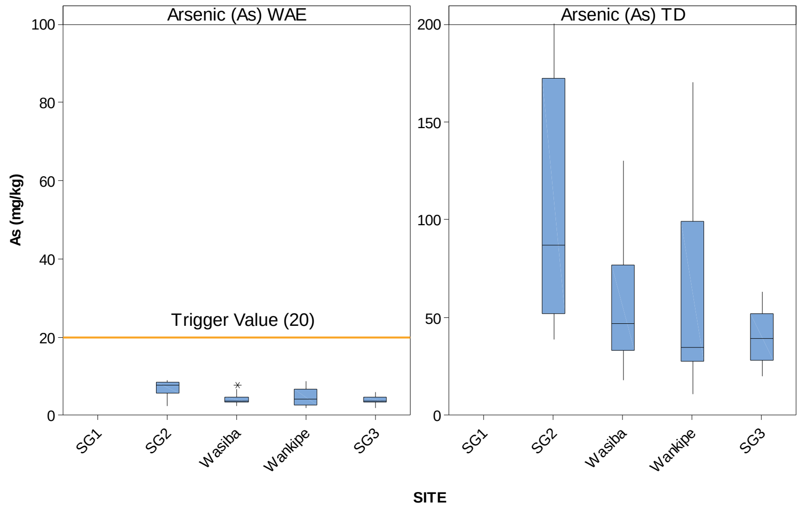


Figure E-3 Arsenic in sediment upper test sites 2018

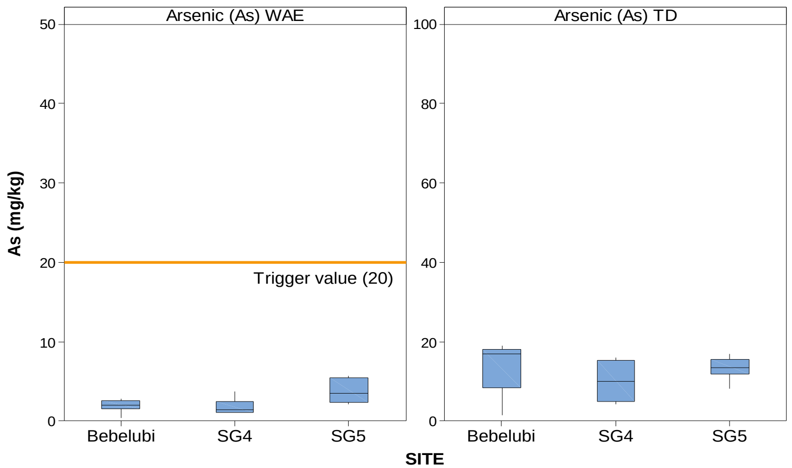


Figure E-4 Arsenic in sediment lower river test sites 2018

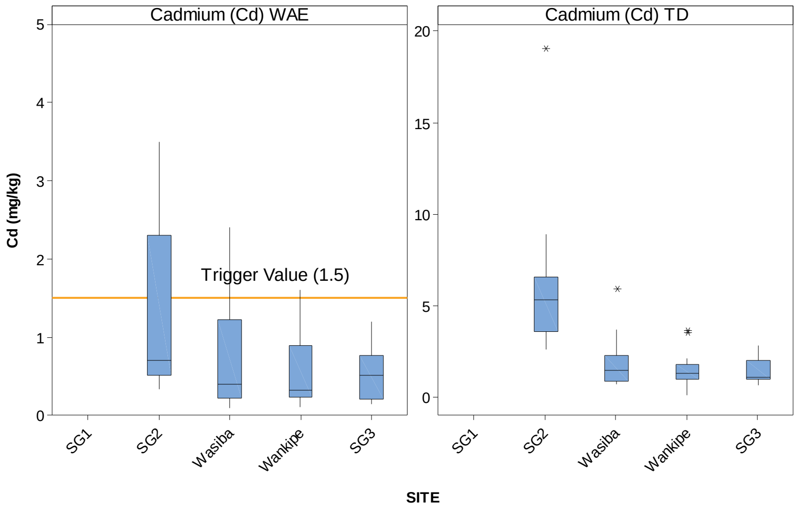


Figure E-5 Cadmium in sediment upper river test sites 2018

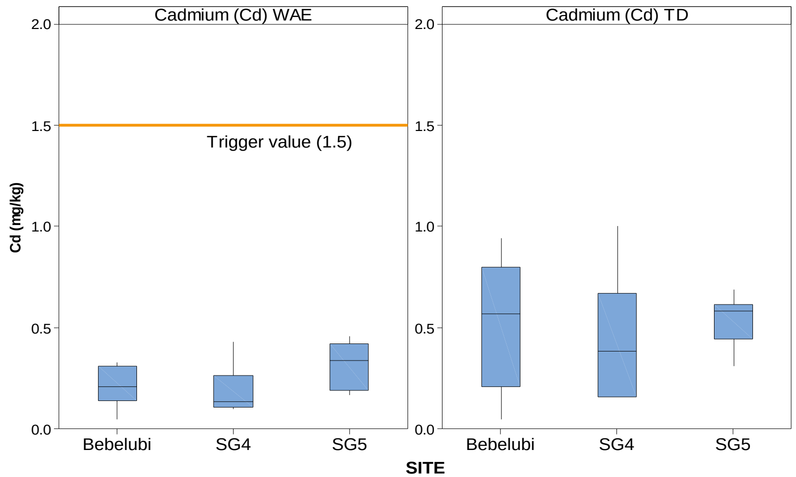


Figure E-6 Cadmium in sediment lower river test sites 2018

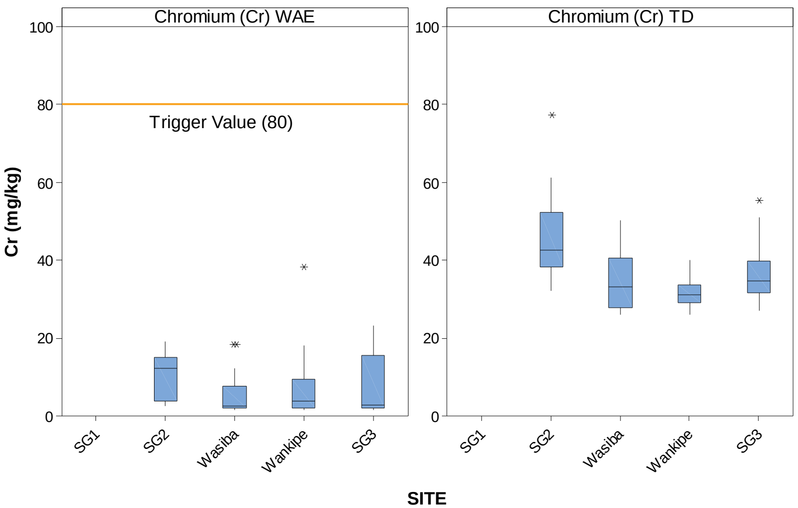


Figure E-7 Chromium in sediment upper river test sites 2018

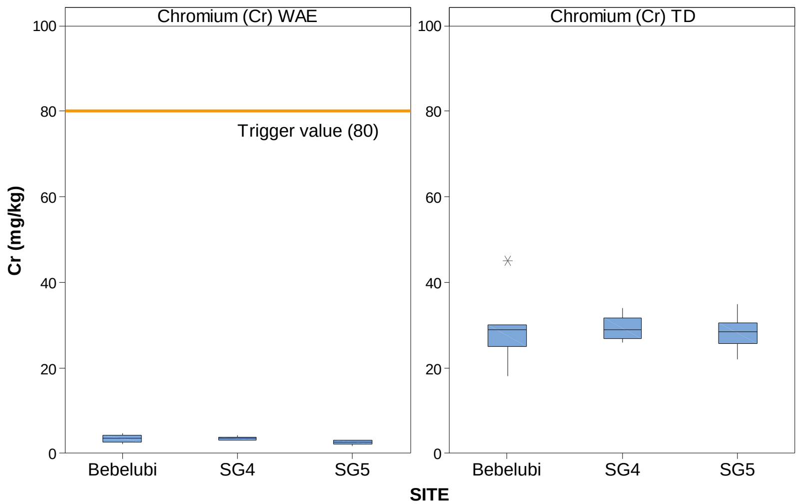


Figure E-8 Chromium in sediment lower river test sites 2018

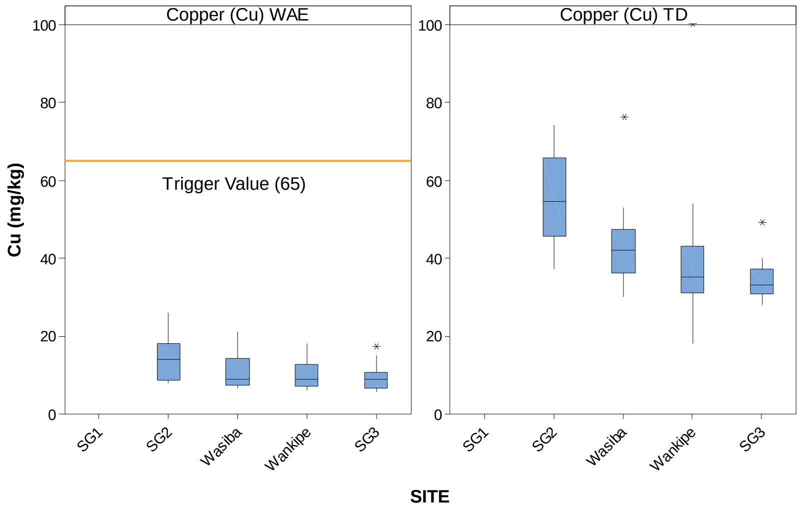


Figure E-9 Copper in sediment upper river test sites 2018

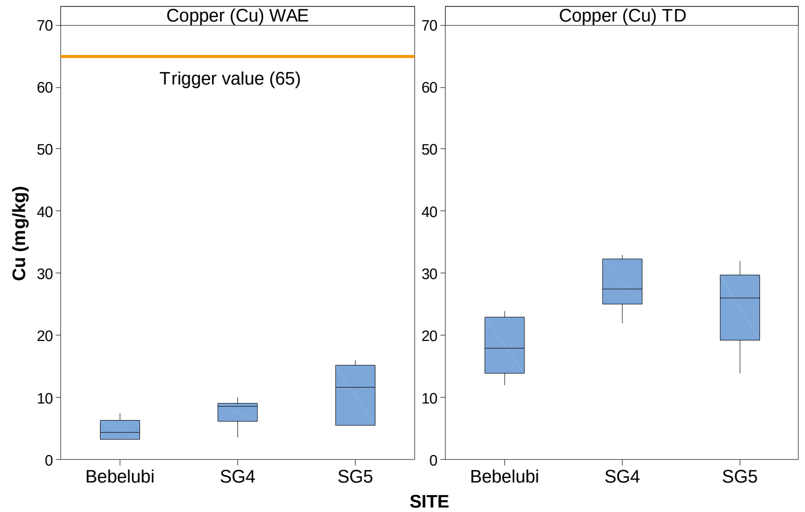


Figure E-10 Copper in sediment lower river test sites 2018

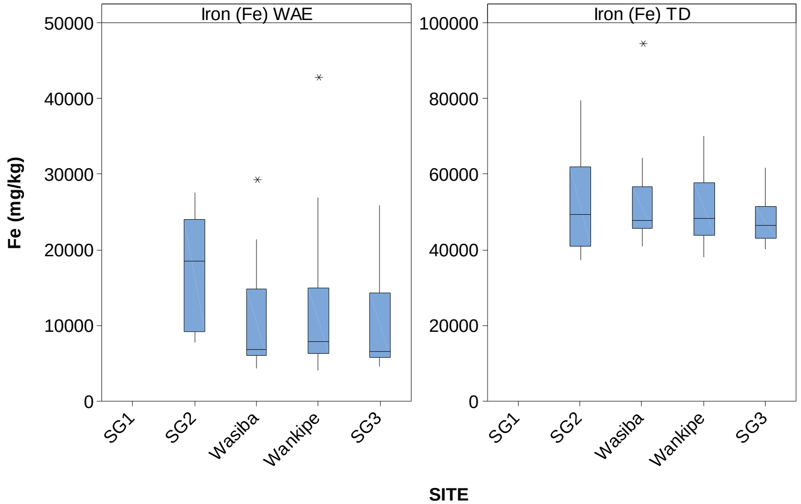


Figure E-11 Iron in sediment upper river test sites 2018

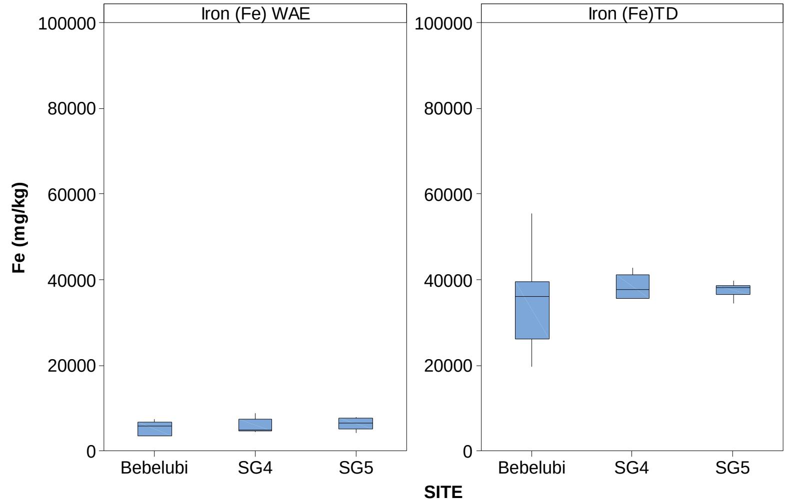


Figure E-12 Iron in sediment lower river test sites 2018

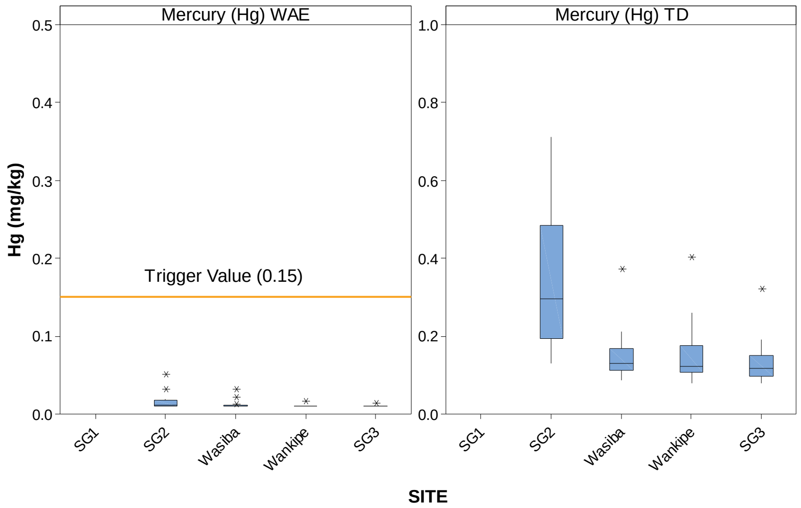


Figure E-13 Mercury in sediment upper river test sites 2018

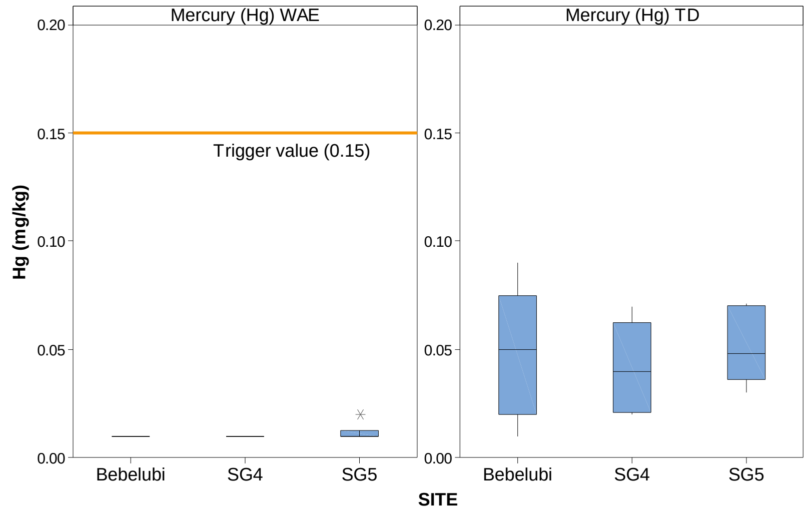


Figure E-14 Mercury in sediment lower river test sites 2018

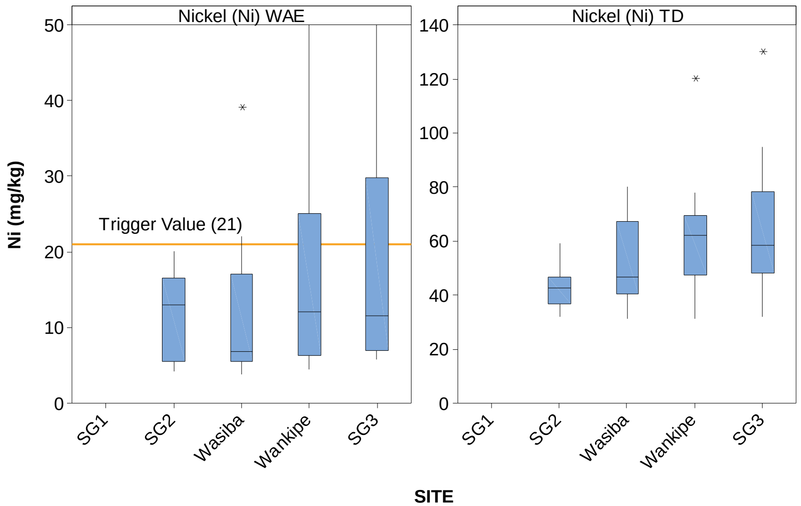


Figure E-15 Nickel in sediment upper river test sites 2018

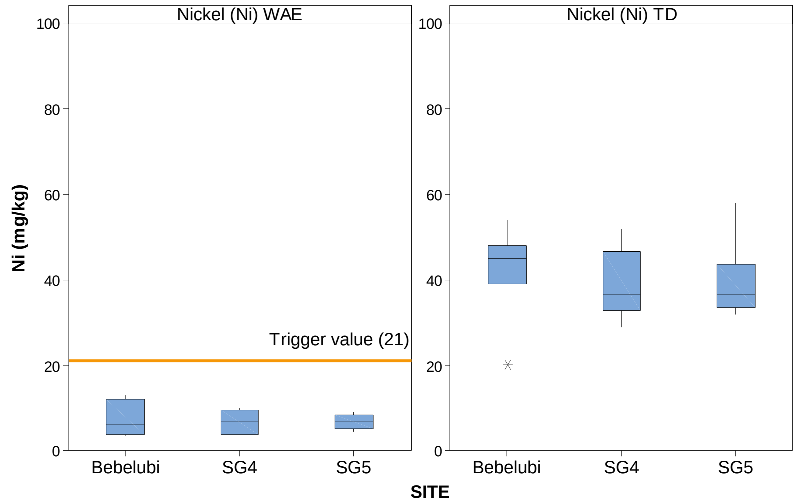


Figure E-16 Nickel in sediment lower river test sites 2018

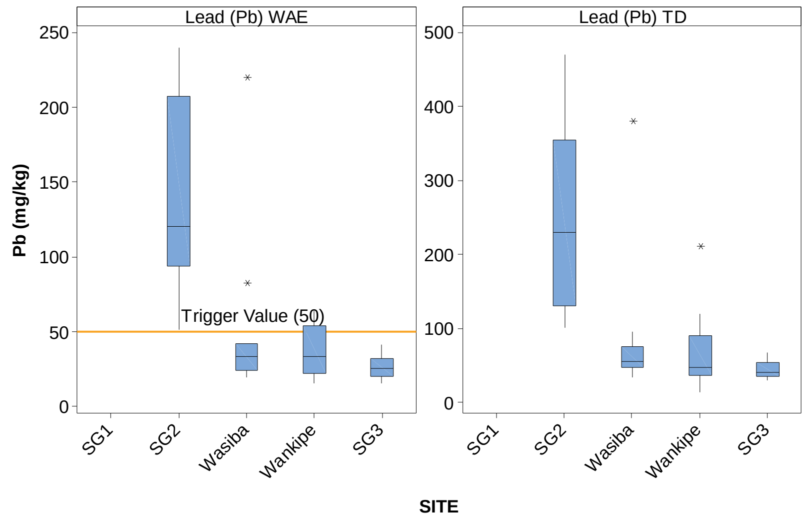


Figure E-17 Lead in sediment upper river test sites 2018

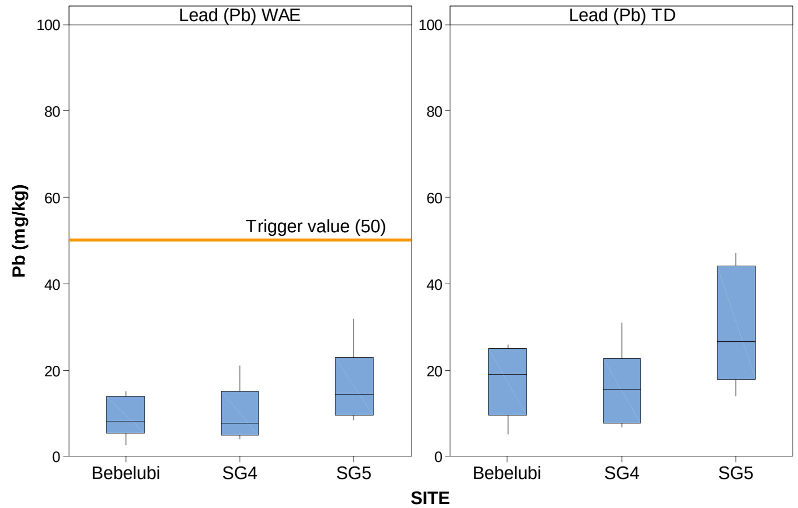


Figure E-18 Lead in sediment lower river test sites 2018

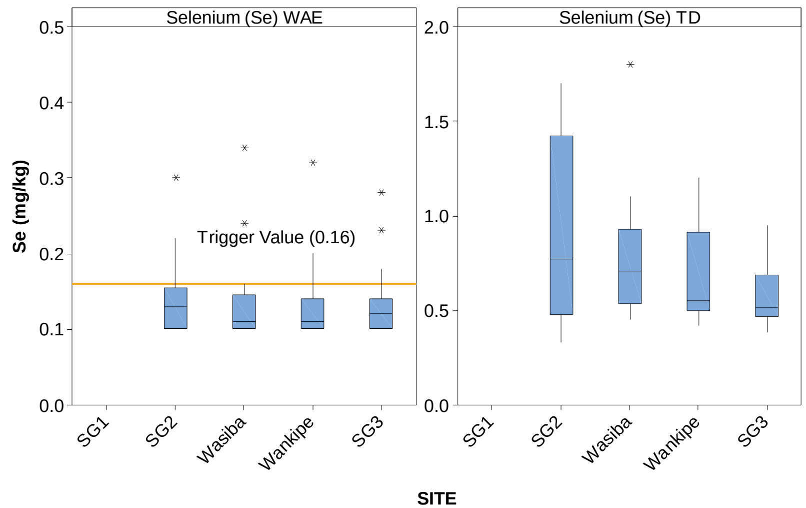


Figure E-19 Selenium in sediment upper river test sites 2018

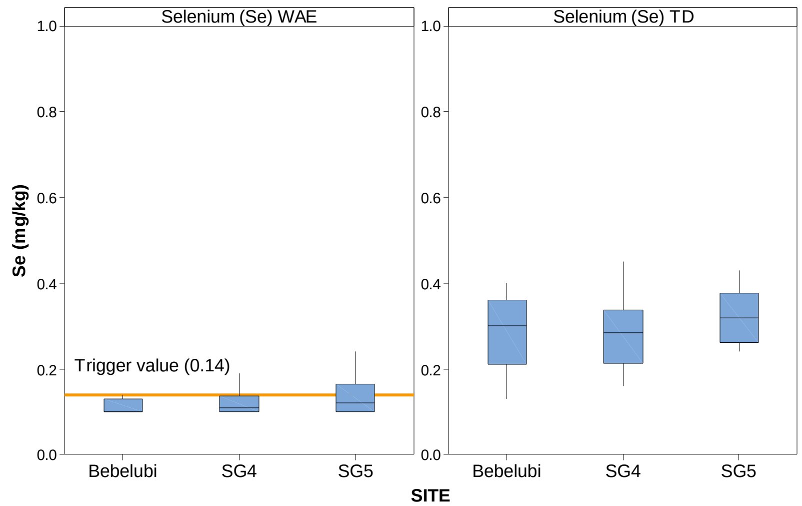


Figure E-20 Selenium in sediment lower river test sites 2018

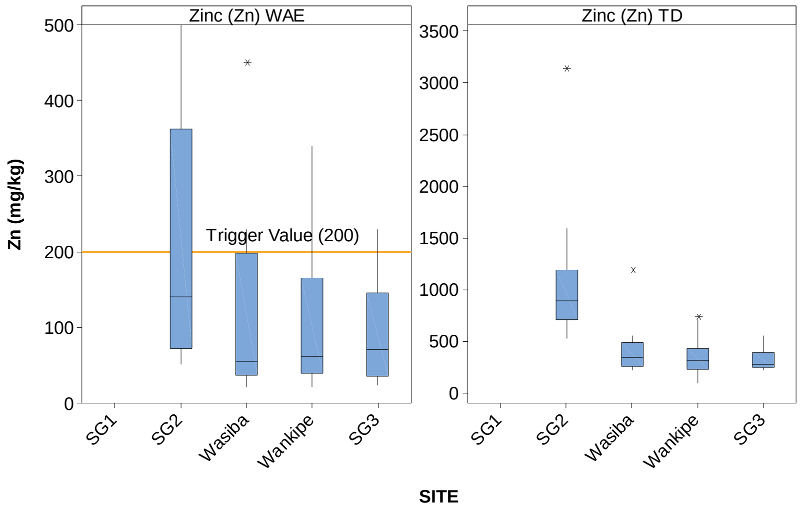


Figure E-21 Zinc in sediment upper river test sites 2018

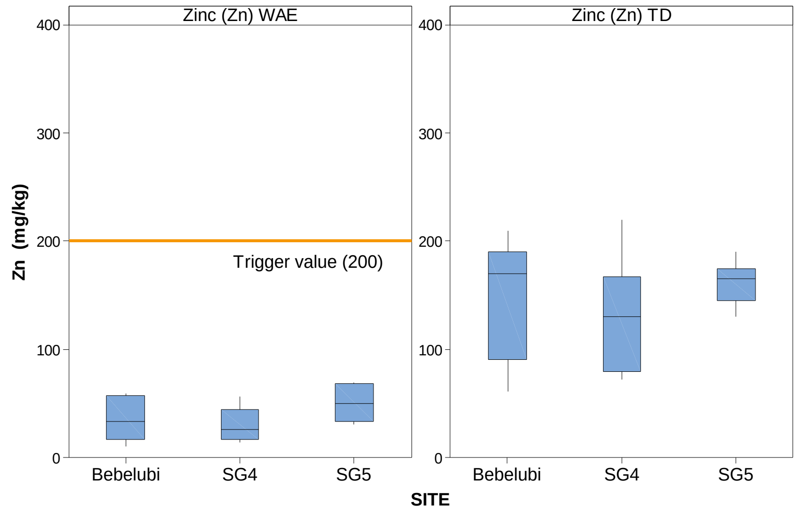


Figure E-22 Zinc in sediment lower river test sites 2018

Table E-9 Performance assessment – Based on the trend of sediment quality indicators (all data) at upper river test sites between 2013 and 2018 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 - 2018)	Ag-WAE	-0.605	<0.001	Reduced over time
	As-WAE	0.341	0.01	Increased over time
	Cd-WAE	0.218	0.106	No change over time
	Cr-WAE	0.486	<0.001	Increased over time
	Cu-WAE	0.096	0.481	No change over time
	Fe-WAE	0.492	<0.001	Increased over time
	Pb-WAE	0.416	0.001	Increased over time
	Hg-WAE	-0.324	0.015	Reduced over time
	Ni-WAE	0.378	0.004	Increased over time
	Se-WAE	-0.825	<0.001	Reduced over time
	Zn-WAE	0.338	0.011	Increased over time
Wasiba (Trend of all data 2013 - 2018)	Ag-WAE	-0.717	<0.001	Reduced over time
	As-WAE	-0.339	0.006	Reduced over time
	Cd-WAE	-0.158	0.209	No change over time
	Cr-WAE	-0.161	0.2	No change over time
	Cu-WAE	-0.104	0.409	No change over time
	Fe-WAE	-0.08	0.528	No change over time
	Pb-WAE	-0.312	0.011	Reduced over time
	Hg-WAE	-0.137	0.283	No change over time
	Ni-WAE	-0.104	0.41	No change over time
	Se-WAE	-0.703	<0.001	Reduced over time
	Zn-WAE	-0.042	0.737	No change over time
Wankipe (Trend of all data 2013 - 2018)	Ag-WAE	-0.776	<0.001	Reduced over time
	As-WAE	-0.089	0.458	No change over time
	Cd-WAE	-0.291	0.014	Reduced over time
	Cr-WAE	0.125	0.301	No change over time
	Cu-WAE	0.131	0.276	No change over time
	Fe-WAE	0.106	0.38	No change over time
	Pb-WAE	-0.066	0.584	No change over time
	Hg-WAE	-0.399	0.001	Reduced over time
	Ni-WAE	0.206	0.085	No change over time
	Se-WAE	-0.791	<0.001	Reduced over time
	Zn-WAE	0.068	0.573	No change over time

Sediment Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend
SG3 (Trend of all data 2013 - 2018)	Ag-WAE	-0.719	<0.001	Reduced over time
	As-WAE	0.52	<0.001	Increased over time
	Cd-WAE	-0.056	0.426	No change over time
	Cr-WAE	0.501	<0.001	Increased over time
	Cu-WAE	0.555	<0.001	Increased over time
	Fe-WAE	0.514	<0.001	Increased over time
	Pb-WAE	0.418	<0.001	Increased over time
	Hg-WAE	-0.116	0.099	No change over time
	Ni-WAE	0.144	0.039	Increased over time
	Se-WAE	-0.727	<0.001	Reduced over time
	Zn-WAE	0.466	<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-10 Performance assessment – Based on the trend of sediment quality indicators (all data) at lower river test sites between 2013 and 2018 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 - 2018)	Ag-WAE	-0.858	<0.001	Reduced over time
	As-WAE	-0.301	0.127	No change over time
	Cd-WAE	-0.729	<0.001	Reduced over time
	Cr-WAE	0.249	0.211	No change over time
	Cu-WAE	-0.191	0.34	No change over time
	Fe-WAE	-0.113	0.575	No change over time
	Hg-WAE	-0.302	0.125	No change over time
	Ni-WAE	-0.035	0.861	No change over time
	Pb-WAE	-0.422	0.028	Reduced over time
	Se-WAE	-0.859	<0.001	Reduced over time
	Zn-WAE	0.073	0.716	No change over time
SG4 (Trend of all data 2013 - 2018)	Ag-WAE	-0.826	<0.001	Reduced over time
	As-WAE	0.037	0.851	No change over time
	Cd-WAE	-0.747	<0.001	Reduced over time
	Cr-WAE	0.149	0.439	No change over time
	Cu-WAE	0.397	0.033	Increased over time
	Fe-WAE	0.028	0.886	No change over time
	Hg-WAE	-0.36	0.055	No change over time
	Ni-WAE	-0.125	0.518	No change over time
	Pb-WAE	0.08	0.681	No change over time
	Se-WAE	-0.867	<0.001	Reduced over time
	Zn-WAE	0.264	0.166	No change over time
SG5 (Trend of all data 2013 - 2018)	Ag-WAE	-0.846	<0.001	Reduced over time
	As-WAE	0.005	0.979	No change over time
	Cd-WAE	-0.716	<0.001	Reduced over time
	Cr-WAE	-0.466	0.009	Reduced over time
	Cu-WAE	0.185	0.329	No change over time
	Fe-WAE	-0.468	0.009	Reduced over time
	Hg-WAE	-0.03	0.876	No change over time
	Ni-WAE	-0.477	0.008	Reduced over time
	Pb-WAE	0.113	0.551	No change over time
	Se-WAE	-0.789	<0.001	Reduced over time
	Zn-WAE	-0.172	0.364	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-11 Sediment quality Lake Murray and ORWBs test sites Central Lake 2018 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	10	10	0.06	TSM < TV	Step 1	1.0	0.003	LOW
As-WAE	10	10	1.8	TSM < TV	Step 1	20	0.003	LOW
Cd-WAE	10	10	0.09	TSM < TV	Step 1	1.5	0.003	LOW
Cr-WAE	10	10	5.4	TSM < TV	Step 1	80	0.003	LOW
Cu-WAE	10	10	9.55	TSM < TV	Step 1	65	0.003	LOW
Hg-WAE	10	10	0.020	TSM < TV	Step 1	0.15	0.003	LOW
Ni-WAE	10	10	11	TSM < TV	Step 1	21	0.003	LOW
Pb-WAE	10	10	11	TSM < TV	Step 1	50	0.004	LOW
Se-WAE	10	10	0.11	TSM > TV	Step 1	0.23	0.003	LOW
Zn-WAE	10	10	46	TSM < TV	Step 1	200	0.003	LOW

Table E-12 Sediment quality Lake Murray and ORWBs test sites South Lake 2018 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	10	10	0.06	TSM < TV	Step 1	1.0	0.003	LOW
As-WAE	10	10	1.4	TSM < TV	Step 1	20	0.003	LOW
Cd-WAE	10	10	0.12	TSM < TV	Step 1	1.5	0.003	LOW
Cr-WAE	10	10	2.2	TSM < TV	Step 1	80	0.003	LOW
Cu-WAE	10	10	17	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	5.9	TSM < TV	Step 1	21	0.003	LOW
Pb-WAE	10	10	19	TSM < TV	Step 1	50	0.003	LOW
Se-WAE	10	10	0.10	TSM < TV	Step 1	0.23	0.003	LOW
Zn-WAE	10	10	34	TSM < TV	Step 1	200	0.003	LOW

Table E-13 Sediment quality Lake Murray and ORWBs test sites SG6 2018 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	4	4	0.09	TSM < TV	Step 1	1.0	Direct comparison	LOW
As-WAE	4	4	5.2	TSM < TV	Step 1	20	Direct comparison	LOW
Cd-WAE	4	4	0.29	TSM < TV	Step 1	1.5	Direct comparison	LOW
Cr-WAE	4	4	3.0	TSM < TV	Step 1	80	Direct comparison	LOW
Cu-WAE	4	4	16	TSM < TV	Step 1	65	Direct comparison	LOW
Hg-WAE	4	4	0.015	TSM < TV	Step 1	0.15	Direct comparison	LOW
Ni-WAE	4	4	8.0	TSM < TV	Step 1	21	Direct comparison	LOW
Pb-WAE	4	4	25	TSM < TV	Step 1	50	Direct comparison	LOW
Se-WAE	4	4	0.15	TSM < TV	Step 1	0.23	Direct comparison	LOW
Zn-WAE	4	4	61	TSM < TV	Step 1	200	Direct comparison	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-14 Sediment quality Lake Murray and ORWBs test sites Kukufionga 2018 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	2	2	0.05	TSM < TV	Step 1	1.0	Direct comparison	LOW
As-WAE	2	2	2.8	TSM < TV	Step 1	20	Direct comparison	LOW
Cd-WAE	2	2	0.35	TSM < TV	Step 1	1.5	Direct comparison	LOW
Cr-WAE	2	2	2.7	TSM < TV	Step 1	80	Direct comparison	LOW
Cu-WAE	2	2	11	TSM < TV	Step 1	65	Direct comparison	LOW
Hg-WAE	2	2	0.01	TSM < TV	Step 1	0.15	Direct comparison	LOW
Ni-WAE	2	2	6.6	TSM < TV	Step 1	21	Direct comparison	LOW
Pb-WAE	2	2	13	TSM < TV	Step 1	50	Direct comparison	LOW
Se-WAE	2	2	0.10	TSM < TV	Step 1	0.14	Direct comparison	LOW
Zn-WAE	2	2	50	TSM < TV	Step 1	200	Direct comparison	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-15 Sediment quality Lake Murray and ORWBs test sites Zongamange 2018 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	2	2	0.17	TSM < TV	Step 1	1.0	Direct comparison	LOW
As-WAE	2	2	5.4	TSM < TV	Step 1	20	Direct comparison	LOW
Cd-WAE	2	2	0.34	TSM < TV	Step 1	1.5	Direct comparison	LOW
Cr-WAE	2	2	2.9	TSM < TV	Step 1	80	Direct comparison	LOW
Cu-WAE	2	2	15	TSM < TV	Step 1	65	Direct comparison	LOW
Hg-WAE	2	2	0.01	TSM < TV	Step 1	0.15	Direct comparison	LOW
Ni-WAE	2	2	6.2	TSM < TV	Step 1	21	Direct comparison	LOW
Pb-WAE	2	2	29	TSM < TV	Step 1	50	Direct comparison	LOW
Se-WAE	2	2	0.12	TSM < TV	Step 1	0.14	Direct comparison	POTENTIAL
Zn-WAE	2	2	51	TSM < TV	Step 1	200	Direct comparison	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-16 Sediment quality Lake Murray and ORWBs test sites Avu 2018 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	4	4	0.16	TSM < TV	Step 1	1.0	Direct comparison	LOW
As-WAE	4	4	5.4	TSM < TV	Step 1	20	Direct comparison	LOW
Cd-WAE	4	4	0.34	TSM < TV	Step 1	1.5	Direct comparison	LOW
Cr-WAE	4	4	2.6	TSM < TV	Step 1	80	Direct comparison	LOW
Cu-WAE	4	4	19	TSM < TV	Step 1	65	Direct comparison	LOW
Hg-WAE	4	4	0.01	TSM < TV	Step 1	0.15	Direct comparison	LOW
Ni-WAE	4	4	7.6	TSM < TV	Step 1	21	Direct comparison	LOW
Pb-WAE	4	4	35	TSM < TV	Step 1	50	Direct comparison	POTENTIAL
Se-WAE	4	4	0.12	TSM < TV	Step 1	0.14	Direct comparison	LOW
Zn-WAE	4	4	56	TSM < TV	Step 1	200	Direct comparison	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-17 Sediment quality Lake Murray and ORWBs test sites Levame 2018 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	2	2	0.23	TSM < TV	Step 1	1.0	Direct comparison	LOW
As-WAE	2	2	8.5	TSM < TV	Step 1	20	Direct comparison	LOW
Cd-WAE	2	2	0.29	TSM < TV	Step 1	1.5	Direct comparison	LOW
Cr-WAE	2	2	3.8	TSM < TV	Step 1	80	Direct comparison	LOW
Cu-WAE	2	2	23	TSM < TV	Step 1	65	Direct comparison	LOW
Hg-WAE	2	2	0.01	TSM < TV	Step 1	0.15	Direct comparison	LOW
Ni-WAE	2	2	8.3	TSM < TV	Step 1	21	Direct comparison	LOW
Pb-WAE	2	2	49	TSM < TV	Step 1	50	Direct comparison	POTENTIAL
Se-WAE	2	2	0.16	TSM > TV	Step 1	0.14	Direct comparison	POTENTIAL
Zn-WAE	2	2	61	TSM < TV	Step 1	200	Direct comparison	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.

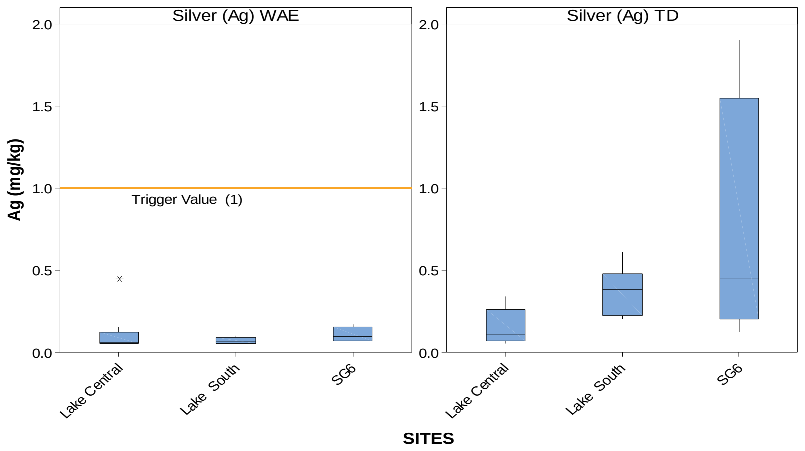


Figure E-23 Silver in sediment LMY test sites 2018

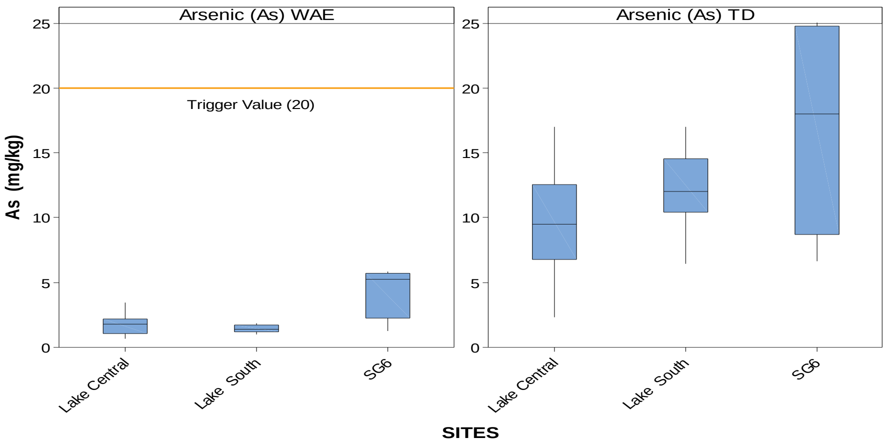


Figure E-24 Arsenic in sediment LMY test sites 2018

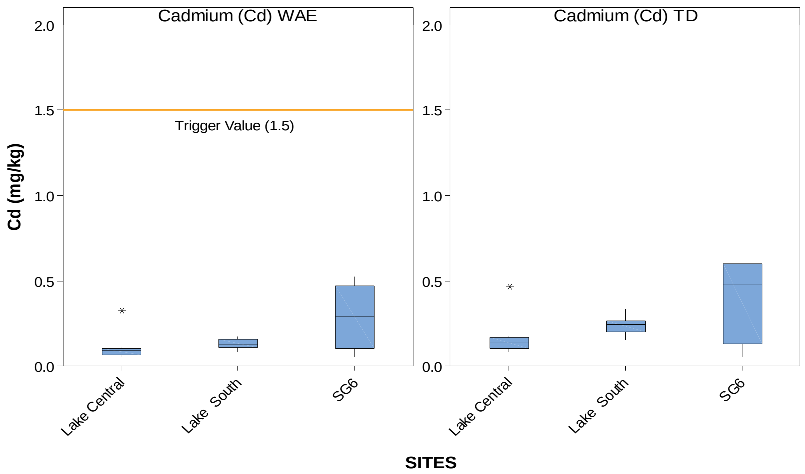


Figure E-25 Cadmium in sediment LMY test sites 2018

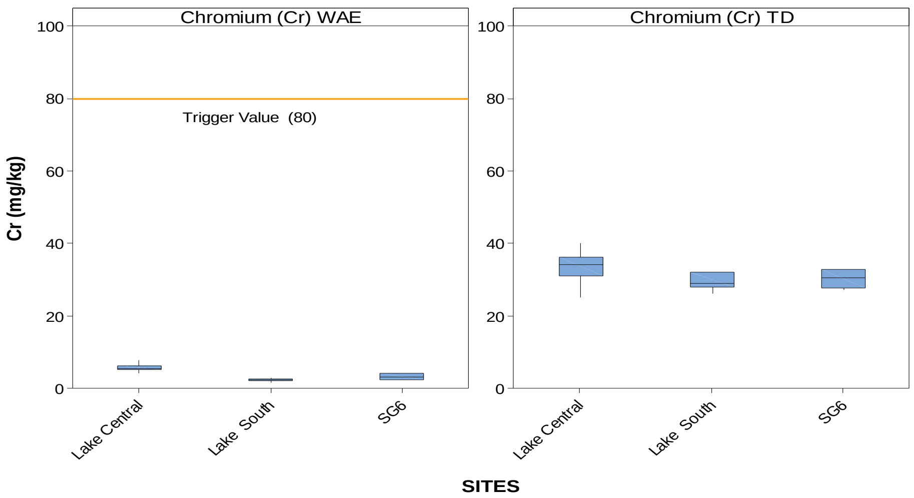


Figure E-26 Chromium in sediment LMY test sites 2018

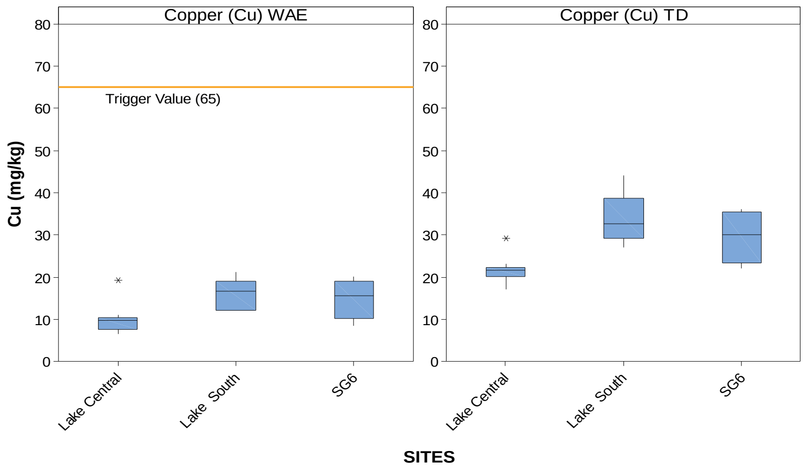


Figure E-27 Copper in sediment LMY test sites 2018

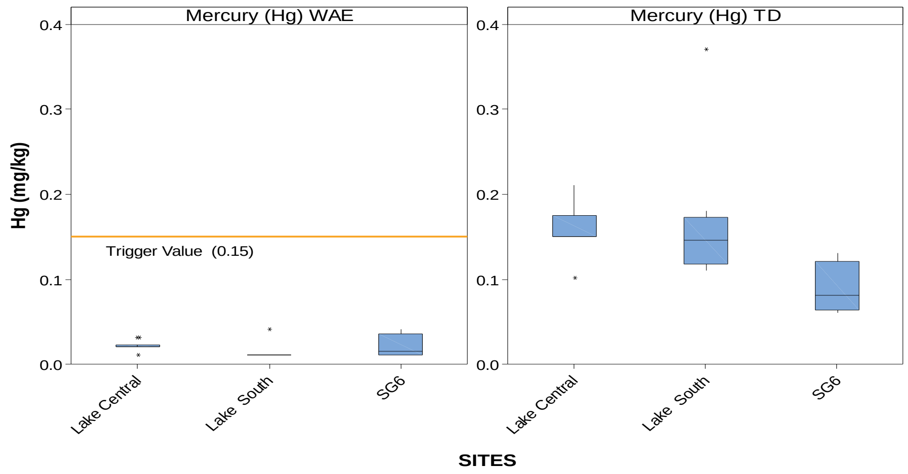


Figure E-28 Mercury in sediment LMY test sites 2018

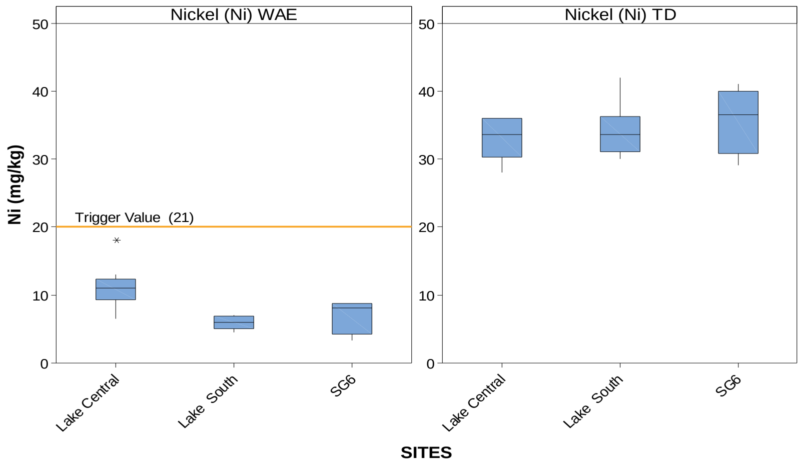


Figure E-29 Nickel in sediment LMY test sites 2018

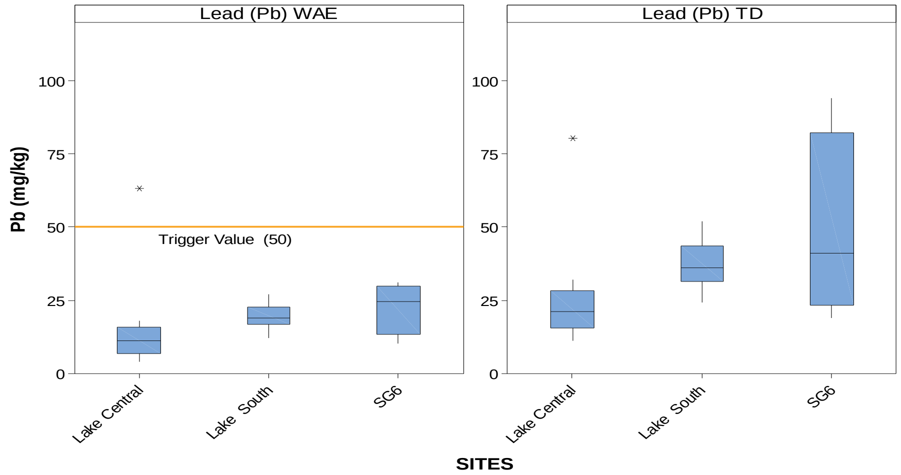


Figure E-30 Lead in sediment LMY test sites 2018

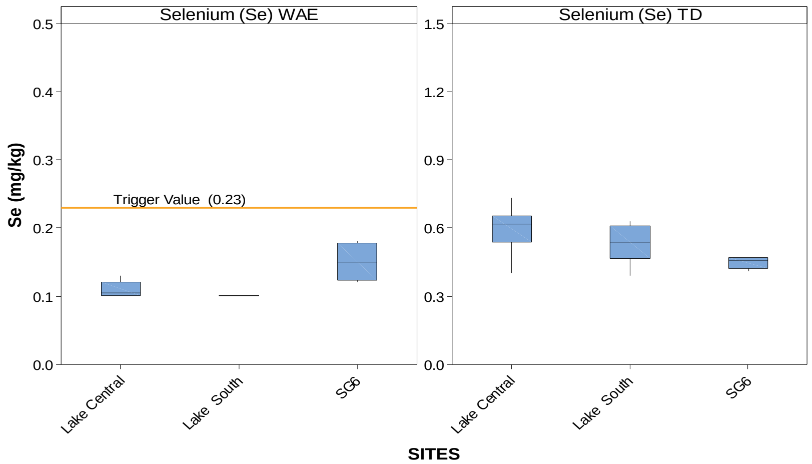


Figure E-31 Selenium in sediment LMY test sites 2018

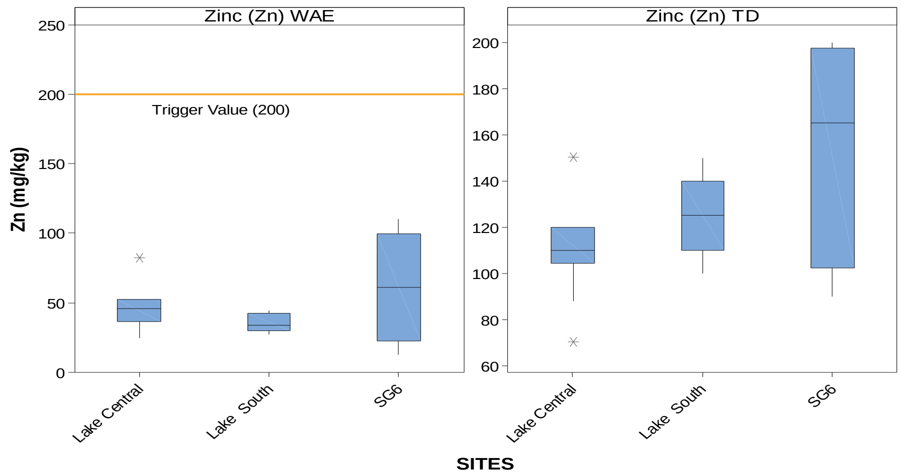


Figure E-32 Zinc in sediment LMY test sites 2018

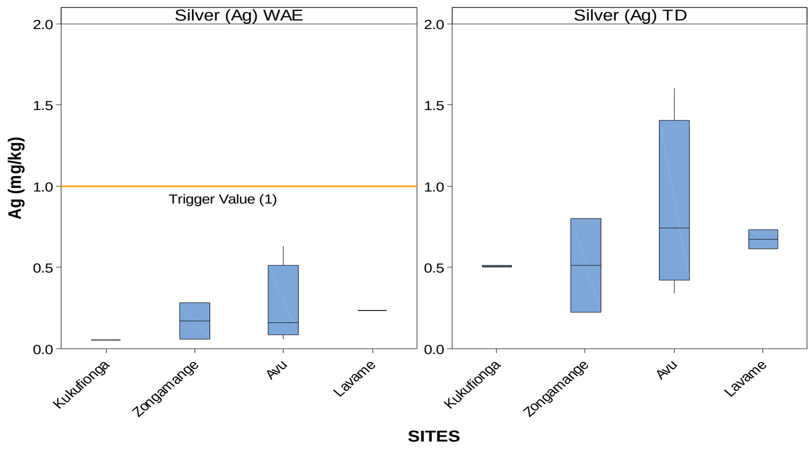


Figure E-33 Silver in sediment ORWB test sites 2018

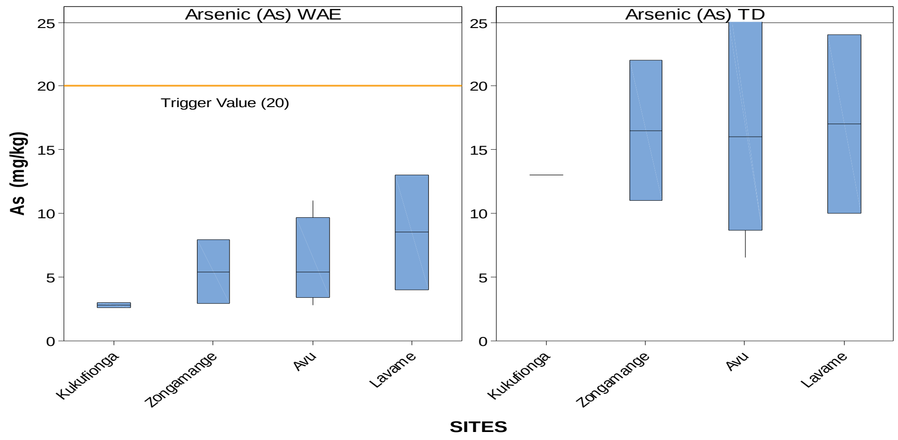


Figure E-34 Arsenic in sediment ORWB test sites 2018

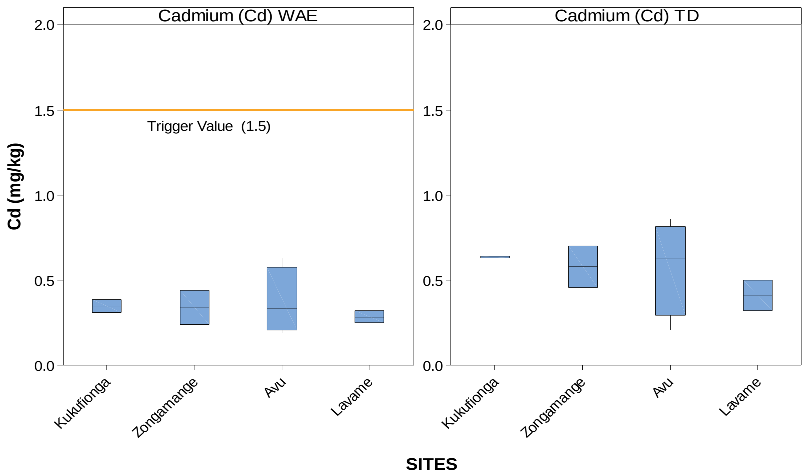


Figure E-35 Cadmium in sediment ORWB test sites 2018

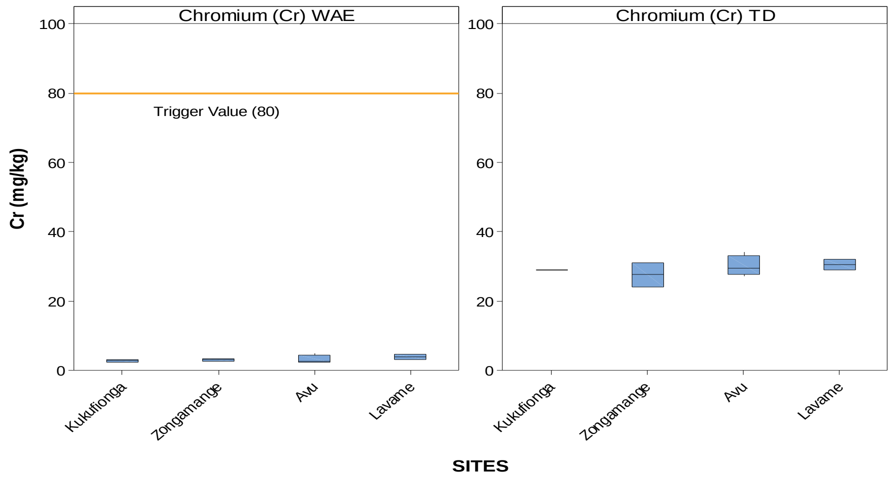


Figure E-36 Chromium in sediment ORWB test sites 2018

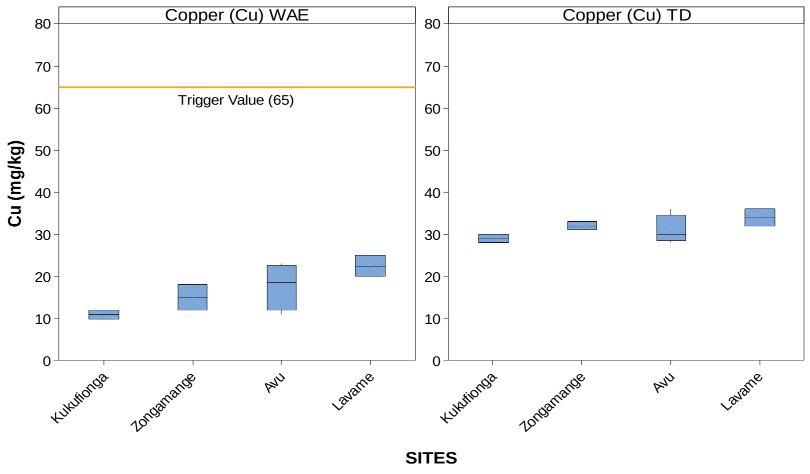


Figure E-37 Copper in sediment ORWB test sites 2018

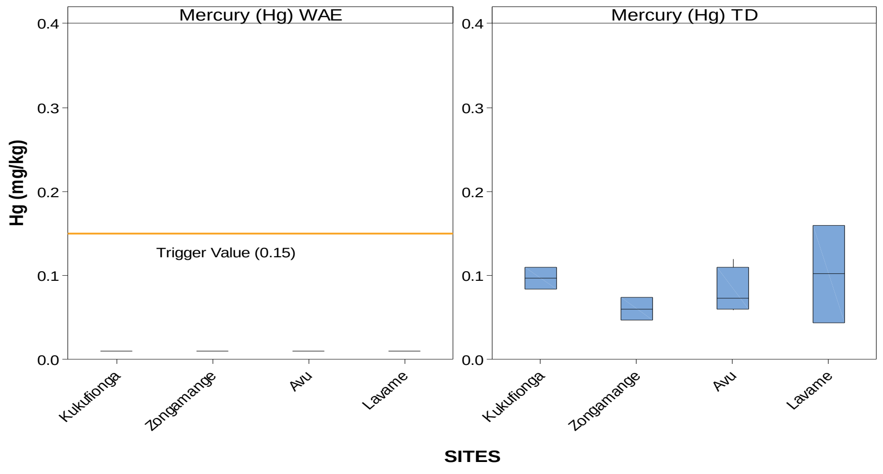


Figure E-38 Mercury in sediment ORWB test sites 2018

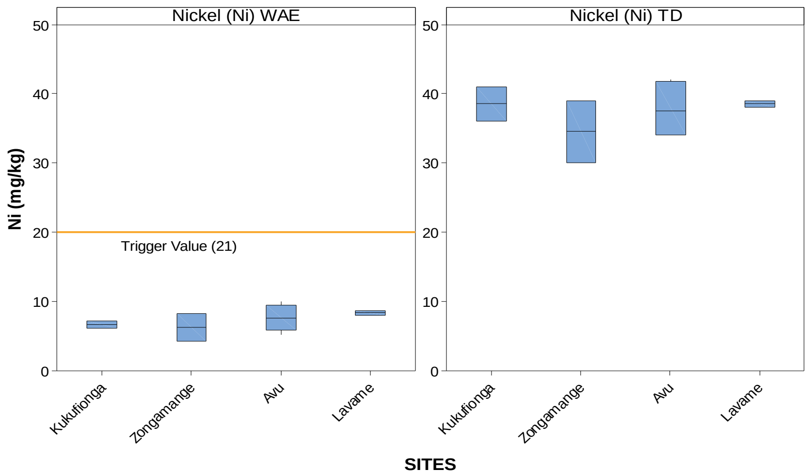


Figure E-39 Nickel in sediment ORWB test sites 2018

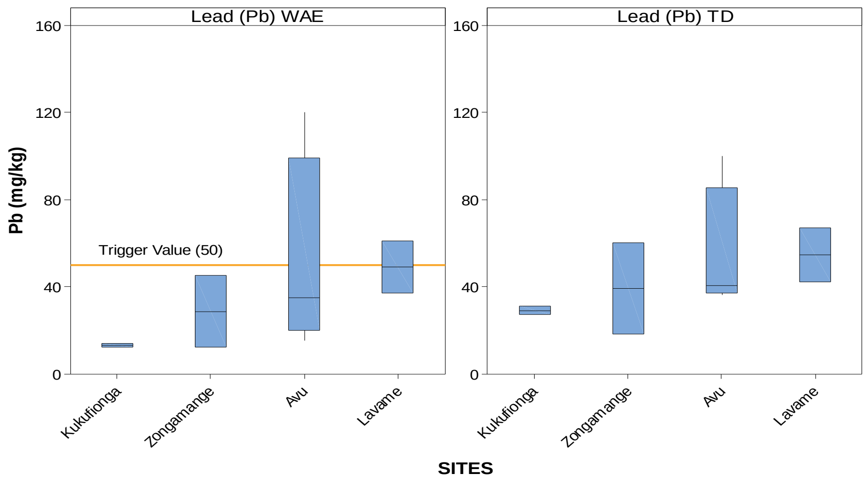


Figure E-40 Lead in sediment ORWB test sites 2018

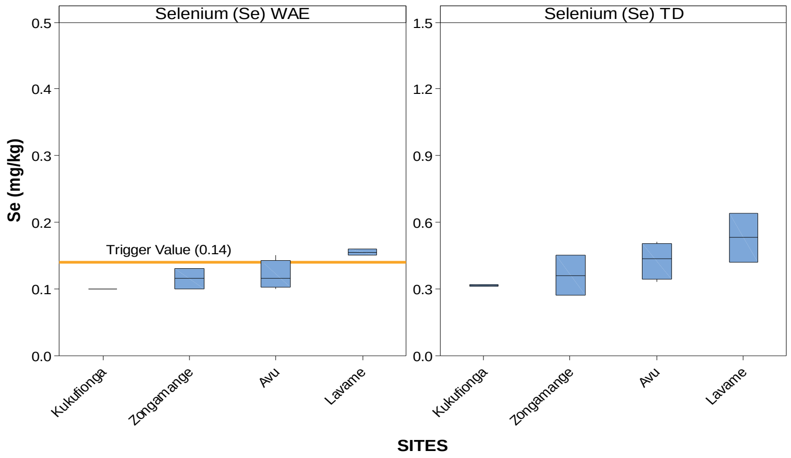


Figure E-41 Selenium in sediment ORWB test sites 2018

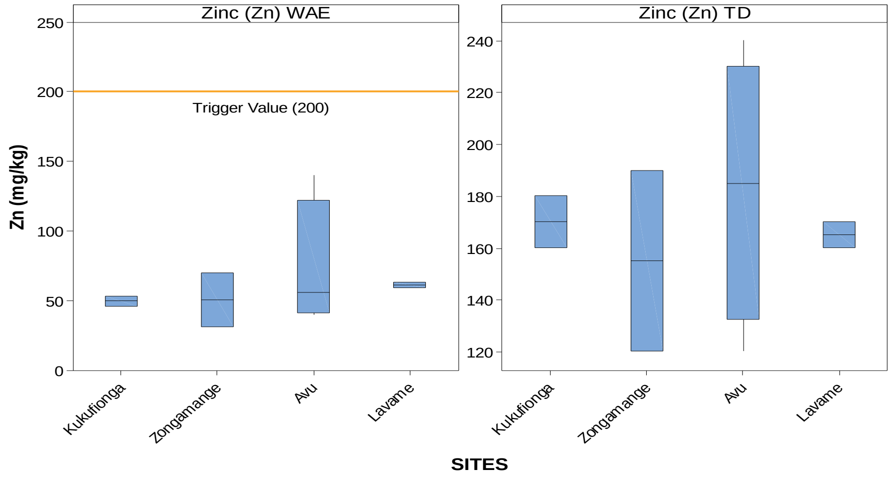


Figure E-42 Zinc in sediment ORWB test sites 2018

Table E-19 Performance assessment – Based on the trend of the annual median of sediment quality indicators at Lake Murray and ORWBs test sites relative to the trend of the annual median of water quality indicators at Lake Murray and ORWBs reference 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 - 2018)	Ag-WAE*	-0.726	<0.001	Reduced over time
	As-WAE	0.117	0.423	No change over time
	Cd-WAE*	-0.805	<0.001	Reduced over time
	Cr-WAE	-0.296	0.039	Reduced over time
	Cu-WAE	-0.035	0.809	No change over time
	Fe-WAE	-0.423	0.002	Reduced over time
	Pb-WAE	0.116	0.427	No change over time
	Hg-WAE*	-0.550	<0.001	Reduced over time
	Ni-WAE	-0.150	0.304	No change over time
	Se-WAE*	-0.648	<0.001	Reduced over time
	Zn-WAE	-0.095	0.515	No change over time
South (Trend of all data 2013 - 2018)	Ag-WAE*	-0.750	<0.001	Reduced over time
	As-WAE	-0.260	0.065	No change over time
	Cd-WAE*	-0.899	<0.001	Reduced over time
	Cr-WAE	-0.159	0.264	No change over time
	Cu-WAE	0.201	0.157	No change over time
	Fe-WAE	-0.227	0.109	No change over time
	Pb-WAE	-0.243	0.086	No change over time
	Hg-WAE*	-0.607	<0.001	Reduced over time
	Ni-WAE	-0.201	0.157	No change over time
	Se-WAE*	-0.827	<0.001	Reduced over time
	Zn-WAE	-0.393	0.004	Reduced over time
SG6 (Trend of all data 2013 - 2018)	Ag-WAE*	-0.801	<0.001	Reduced over time
	As-WAE	0.301	0.136	No change over time
	Cd-WAE	-0.550	0.004	Reduced over time
	Cr-WAE	-0.459	0.018	Reduced over time
	Cu-WAE	-0.224	0.271	No change over time
	Fe-WAE	-0.457	0.019	Reduced over time
	Pb-WAE	0.303	0.132	No change over time
	Hg-WAE	0.250	0.218	No change over time
	Ni-WAE	-0.485	0.012	Reduced over time
	Se-WAE*	-0.796	<0.001	Reduced over time
	Zn-WAE	0.270	0.182	No change over time
Kukufionga (Trend of all data 2013 - 2018)	Ag-WAE*	-0.813	<0.001	Reduced over time
	As-WAE	-0.614	0.002	Reduced over time
	Cd-WAE*	-0.782	<0.001	Reduced over time
	Cr-WAE	-0.625	0.001	Reduced over time
	Cu-WAE	-0.345	0.107	No change over time
	Fe-WAE*	-0.674	<0.001	Reduced over time
	Pb-WAE	-0.355	0.097	No change over time
	Hg-WAE	0.098	0.655	No change over time
	Ni-WAE	-0.634	0.001	Reduced over time
	Se-WAE*	-0.824	<0.001	Reduced over time
	Zn-WAE	-0.489	0.018	Reduced over time

Sediment Quality Site	Parameter	Spearman's rho	P-Value (P=0.05)	Trend
Zongamange (Trend of all data 2013 - 2018)	Ag-WAE	-0.728	0.001	Reduced over time
	As-WAE	-0.263	0.308	No change over time
	Cd-WAE*	-0.866	<0.001	Reduced over time
	Cr-WAE	-0.465	0.060	No change over time
	Cu-WAE	-0.417	0.096	No change over time
	Fe-WAE	-0.436	0.080	No change over time
	Pb-WAE	-0.265	0.305	No change over time
	Hg-WAE*	-0.878	<0.001	Reduced over time
	Ni-WAE	-0.514	0.035	Reduced over time
	Se-WAE*	-0.829	<0.001	Reduced over time
	Zn-WAE	-0.621	0.008	Reduced over time
Avu (Trend of all data 2013 - 2018)	Ag-WAE	-0.444	0.044	Reduced over time
	As-WAE	-0.230	0.315	No change over time
	Cd-WAE	-0.500	0.021	Reduced over time
	Cr-WAE	-0.475	0.029	Reduced over time
	Cu-WAE	-0.124	0.593	No change over time
	Fe-WAE	-0.414	0.062	No change over time
	Pb-WAE	0.027	0.906	No change over time
	Hg-WAE*	-0.836	<0.001	Reduced over time
	Ni-WAE	-0.507	0.019	Reduced over time
	Se-WAE	-0.880	<0.001	Reduced over time
	Zn-WAE	-0.124	0.593	No change over time
Levame (Trend of all data 2015 - 2018)	Ag-WAE	0.077	0.832	No change over time
	As-WAE	0.374	0.287	No change over time
	Cd-WAE	-0.349	0.323	No change over time
	Cr-WAE	0.319	0.369	No change over time
	Cu-WAE	0.718	0.019	Increased over time
	Fe-WAE	0.193	0.594	No change over time
	Pb-WAE	0.268	0.454	No change over time
	Hg-WAE	0.121	0.738	No change over time
	Ni-WAE	-0.112	0.758	No change over time
	Se-WAE	0.389	0.267	No change over time
	Zn-WAE	0.404	0.247	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 - BIOLOGY

Table F-1 Expanded risk matrix – tissue metal

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 metal fish flesh upper river test sites 2018 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Wasiba	N	N (Test)	Median	Result	Go to			
As	12	12	0.03	>	Step 2	0.02	0.001	POTENTIAL
Cd	12	12	0.004	<	Step 1	0.0064	0.007	LOW
Cr	12	12	0.01	<	Step 1	0.02	0.019	LOW
Cu	12	12	0.14	<	Step 1	0.48	0.999	POTENTIAL
Hg	12	10	0.06	<	Step 1	0.08	0.003	LOW
Ni	12	11	0.01	=	Step 2	0.01	1.000	POTENTIAL
Pb	12	12	0.01	<	Step 1	0.17	0.001	LOW
Se	12	12	0.42	<	Step 1	2.26	0.001	LOW
Zn	12	12	4.0	<	Step 1	10.4	0.019	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	0.02	=	Step 1	0.02	0.554	POTENTIAL
Cd	12	12	0.003	<	Step 1	0.0064	0.011	LOW
Cr	12	12	0.01	<	Step 1	0.02	0.112	POTENTIAL
Cu	12	12	0.14	<	Step 1	0.48	0.001	LOW
Hg	12	11	0.04	<	Step 1	0.08	0.002	LOW
Ni*	12	12	0.01	=	Step 2	0.01	-	LOW
Pb	12	12	0.01	<	Step 1	0.17	0.001	LOW
Se	12	12	0.30	<	Step 1	2.26	0.001	LOW
Zn	12	12	3.35	<	Step 1	10.40	0.002	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 metal prawn abdomens from upper river test sites 2018 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Wasiba	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	12	0.03	<	Step 1	0.05	0.002	LOW
Cd	12	9	0.005	>	Step 2	0.003	0.005	POTENTIAL
Cr	12	11	0.02	<	Step 1	0.03	0.395	POTENTIAL
Cu	12	12	4.25	<	Step 1	8.38	0.005	LOW
Hg	12	1	0.01	=	Step 2	0.01	1.000	LOW*
Ni	12	1	0.01	=	Step 2	0.01	1.000	POTENTIAL
Pb	12	5	0.01	=	Step 2	0.01	0.059	POTENTIAL
Se	12	10	0.56	>	Step 2	0.54	0.439	POTENTIAL
Zn	12	12	13.0	<	Step 1	15.4	0.019	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	0.030	<	Step 1	0.048	0.039	LOW
Cd	12	8	0.005	>	Step 2	0.003	0.007	POTENTIAL
Cr	12	12	0.02	<	Step 1	0.03	0.128	POTENTIAL
Cu	12	12	5.30	<	Step 1	8.38	0.019	LOW
Hg	12	1	0.01	=	Step 3	0.01	1.000	LOW*
Ni	12	1	0.01	=	Step 3	0.01	1.000	POTENTIAL
Pb	12	3	0.01	=	Step 2	0.01	0.181	POTENTIAL
Se	12	11	0.45	<	Step 1	0.54	0.004	LOW
Zn	12	12	14.0	<	Step 1	15.4	0.019	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-4 Tissue metal fish flesh lower river test sites 2018 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Bebelubi	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	9	9	0.01	<	Step 1	0.07	0.005	LOW
Cd	9	9	0.003	<	Step 2	0.003	0.005	LOW
Cr	9	9	0.01	<	Step 1	0.12	0.005	LOW
Cu	9	9	0.10	<	Step 1	0.17	0.078	POTENTIAL
Hg	9	8	0.05	<	Step 1	0.12	0.010	LOW
Ni	9	9	0.01	<	Step 1	0.17	0.005	LOW
Pb	9	9	0.01	<	Step 1	0.03	0.005	LOW
Se	9	8	0.15	<	Step 1	2.26	0.005	LOW
Zn	9	9	3.1	<	Step 1	7.5	0.005	LOW
Test Site				**Initial Assessment**		**TV**	**Statistical Test Result (p=0.05)**	**Risk Assessment**
SG4	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	12	0.01	<	Step 1	0.07	0.001	LOW
Cd	12	12	0.003	<	Step 2	0.003	0.005	LOW
Cr	12	12	0.01	<	Step 1	0.12	0.005	LOW
Cu	12	12	0.09	<	Step 1	0.17	0.003	LOW
Hg	12	12	0.06	<	Step 1	0.12	0.002	LOW
Ni	12	12	0.01	=	Step 1	0.17	0.001	LOW
Pb	12	12	0.01	<	Step 1	0.03	0.001	LOW
Se	12	12	0.14	<	Step 1	2.26	0.005	LOW
Zn	12	12	3.2	<	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.

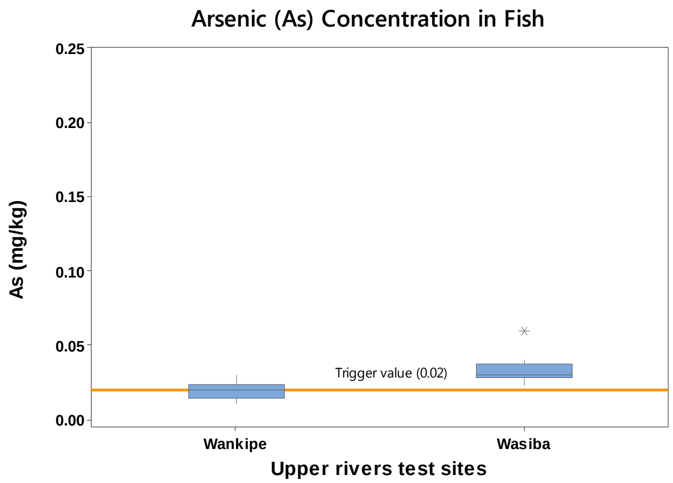
Table F-5 Bioaccumulation prawn abdomens lower river test sites 2018 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Bebelubi	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	11	11	0.09	>	Step 2	0.08	0.447	POTENTIAL
Cd	11	11	0.005	<	Step 1	0.009	0.153	POTENTIAL
Cr	11	11	0.03	<	Step 1	0.07	0.006	LOW
Cu	11	11	5.2	<	Step 1	11.0	0.002	LOW
Hg	11	-	0.01	=	Step 3	0.01	-	LOW*
Ni	11	-	0.01	=	Step 3	0.01	-	LOW*
Pb	11	-	0.01	=	Step 3	0.01	-	LOW*
Se	11	11	0.28	<	Step 2	0.32	0.038	LOW
Zn	11	10	11.0	<	Step 1	15.0	0.003	LOW
Test Site				**Initial Assessment**		**TV**	**Statistical Test Result (p=0.05)**	**Risk Assessment**
SG4	**N**	**N (Test)**	**Median**	**Result**	**Go to**			
As	12	12	0.07	<	Step 1	0.08	0.050	LOW
Cd	12	12	0.006	<	Step 1	0.009	0.216	POTENTIAL
Cr	12	12	0.02	<	Step 1	0.07	0.023	LOW
Cu	12	11	8.0	<	Step 1	11.0	0.002	LOW
Hg	12	-	0.01	=	Step 2	0.01	-	LOW*
Ni	12	1	0.01	=	Step 2	0.01	1.000	POTENTIAL
Pb*	12	-	0.01	=	Step 2	0.01	-	LOW*
Se	12	12	0.34	>	Step 2	0.32	0.500	POTENTIAL
Zn	12	12	12.5	<	Step 1	15.0	0.004	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 metal fish flesh from Lake Murray test site 2018 median (mg/kg)

Test Site				Initial Assessment		TV	Statistical Test Result (p=0.05)	Risk Assessment
Miwa	N	N (Test)	Median	Result	Go to			
As	1	-	0.01	<	Step 1	0.01	Direct comparison	LOW
Cd	1	-	0.003	=	Step 2	0.003	Direct comparison	LOW
Cr	1	-	0.01	<	Step 1	0.03	Direct comparison	LOW
Cu	1	-	0.09	<	Step 1	0.20	Direct comparison	LOW
Hg	1	-	0.37	<	Step 1	0.49	Direct comparison	LOW
Ni	1	-	0.01	=	Step 1	0.19	Direct comparison	LOW
Pb	1	-	0.01	<	Step 1	0.07	Direct comparison	LOW
Se	1	-	0.31	<	Step 1	2.26	Direct comparison	LOW
Zn	1	-	2.50	<	Step 1	3.12	Direct comparison	LOW



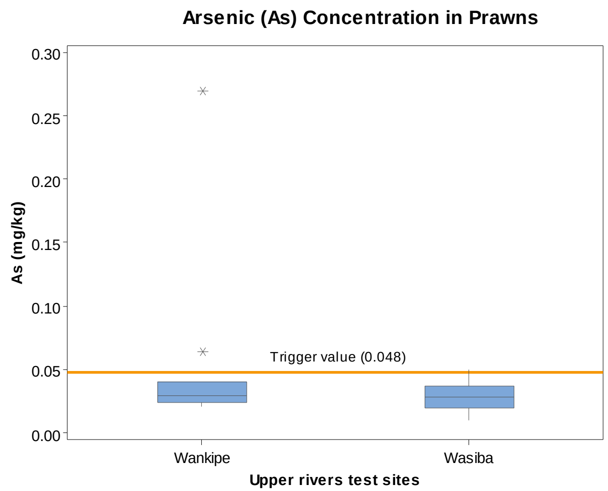
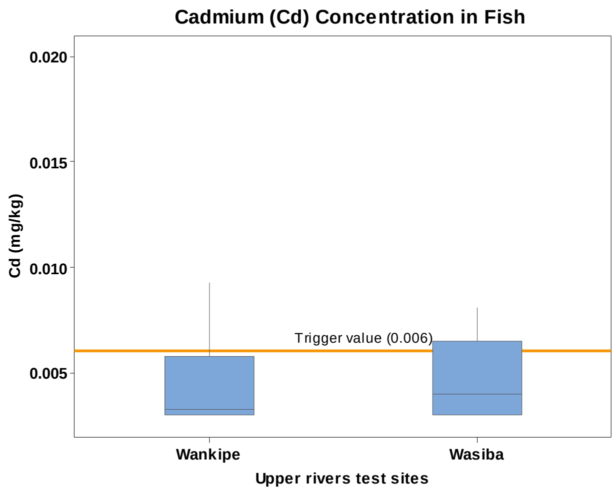


Figure F-1 Arsenic in fish flesh upper rivers test sites 2018

Figure F-2 Arsenic in prawn abdomen upper rivers test sites 2018



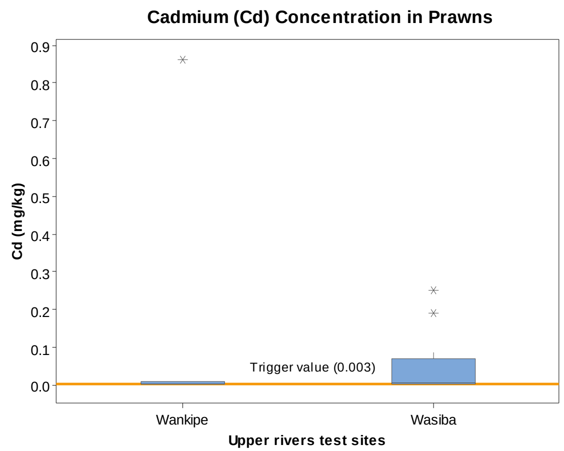


Figure F-3 Cadmium in fish flesh upper rivers test sites 2018

Figure F-4 Cadmium in prawn abdomen upper rivers test sites 2018

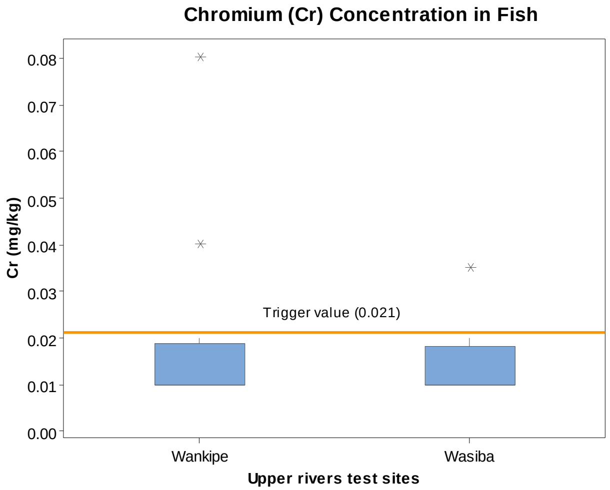


Figure F-5 Chromium in fish flesh upper rivers test sites 2018

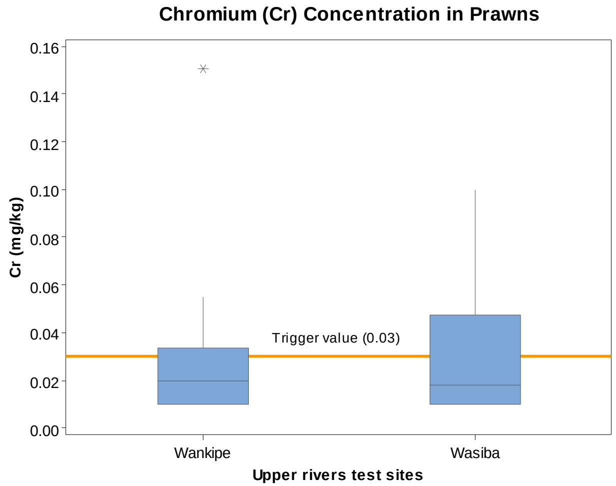


Figure F-6 Chromium in prawn abdomen upper rivers test sites 2018

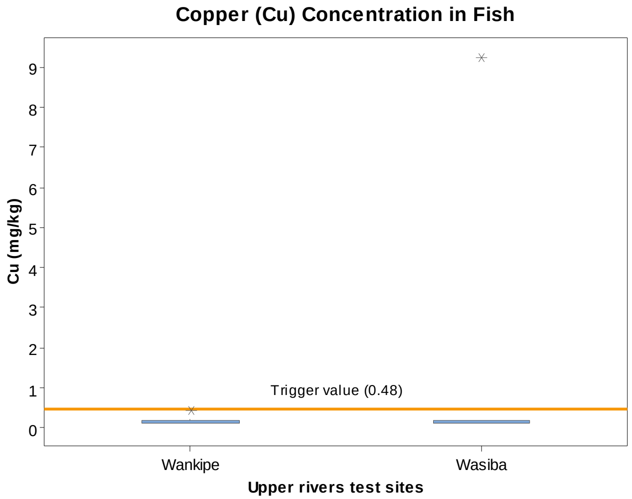


Figure F-7 Copper in fish flesh upper rivers test sites 2018

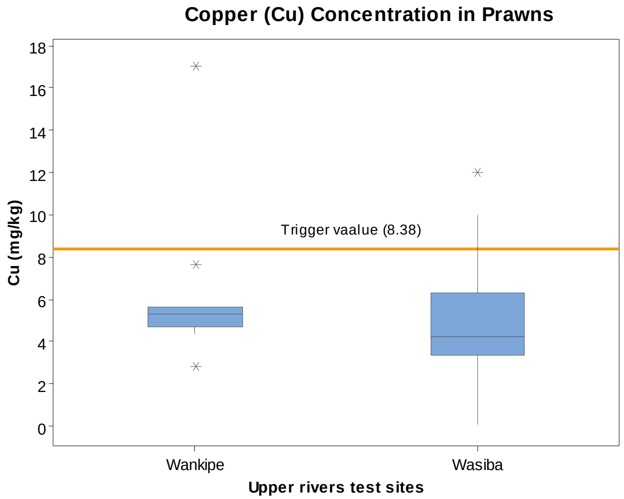


Figure F-8 Copper in prawn abdomen upper rivers test sites 2018

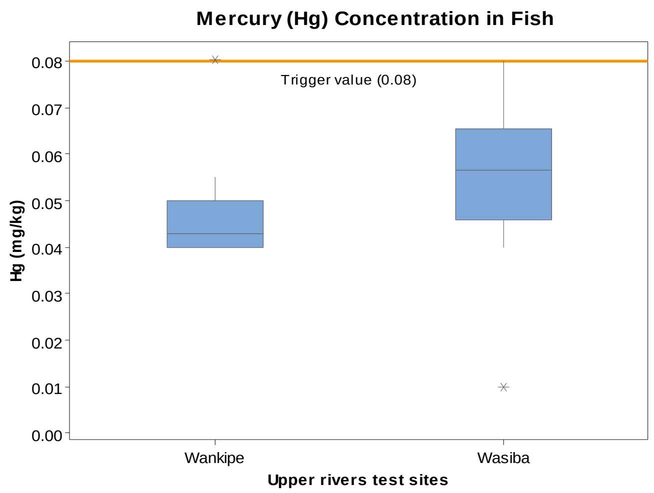


Figure F-9 Mercury in fish flesh upper rivers test sites 2018

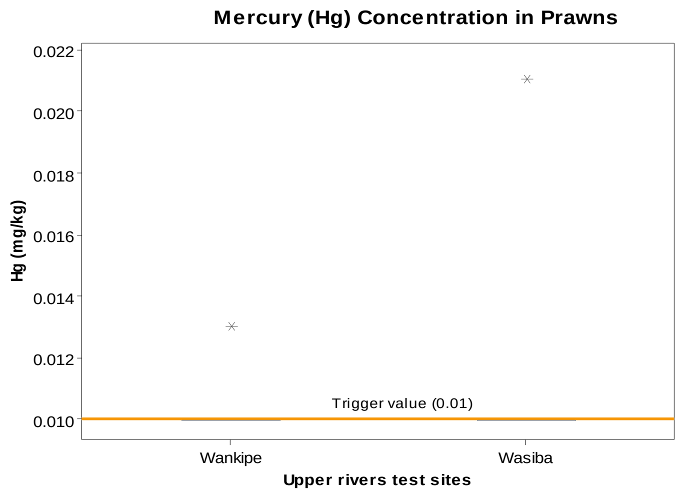


Figure F-10 Mercury in prawn abdomen upper rivers test sites 2018

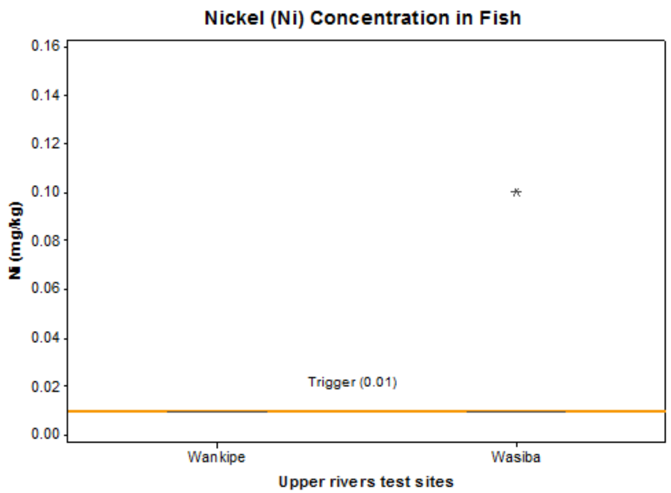


Figure F-11 Nickel in fish flesh upper rivers test sites 2018

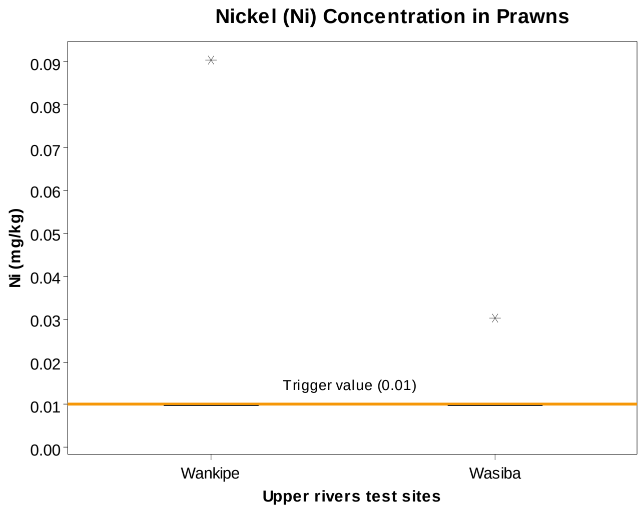


Figure F-12 Nickel in prawn abdomen upper rivers test sites 2018

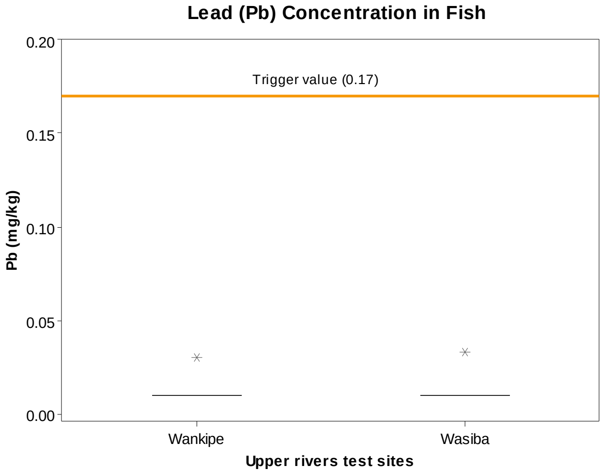


Figure F-13 Lead in fish flesh upper rivers test sites 2018

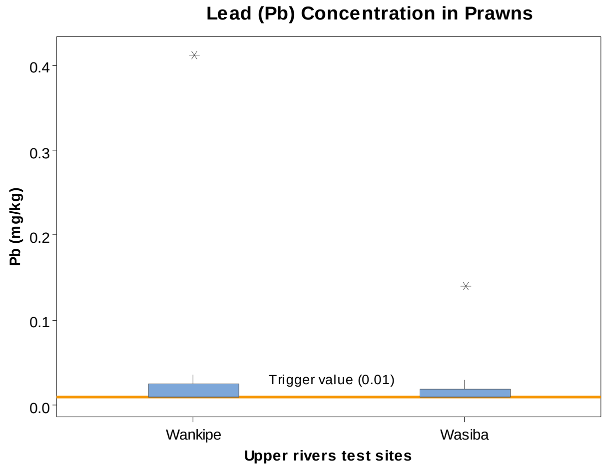


Figure F-14 Lead in prawn abdomen uppers river test sites 2018

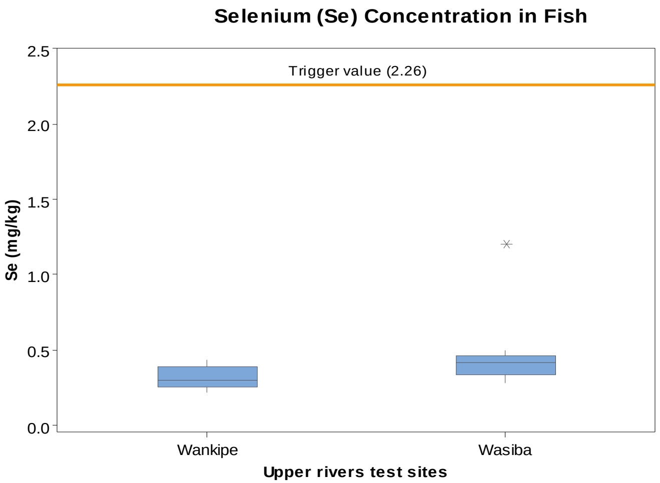


Figure F-15 Selenium in fish flesh upper rivers test sites 2018

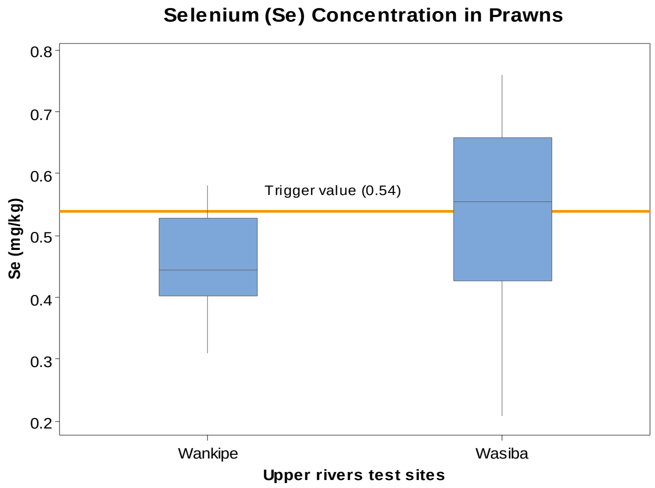


Figure F-16 Selenium in prawn abdomen uppers river test sites 2018

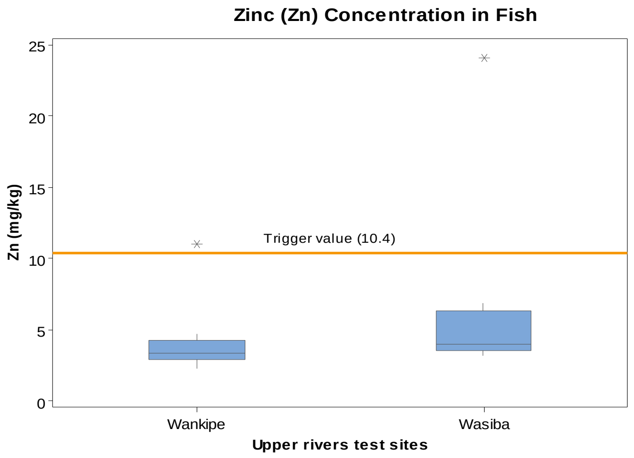


Figure F-17 Zinc in fish flesh upper rivers test sites 2018

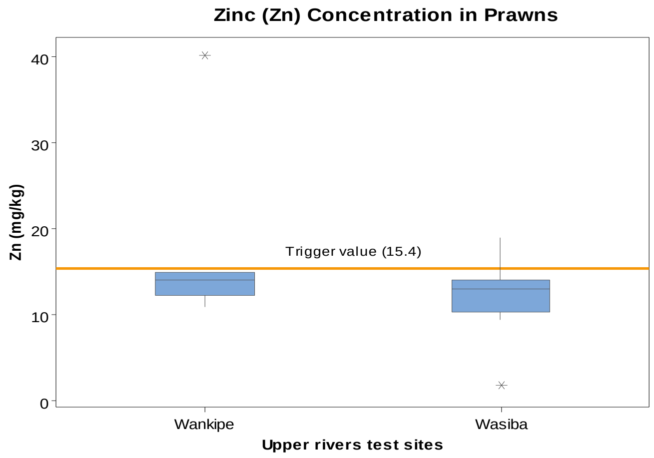


Figure F-18 Zinc in prawn abdomen upper rivers test sites 2018

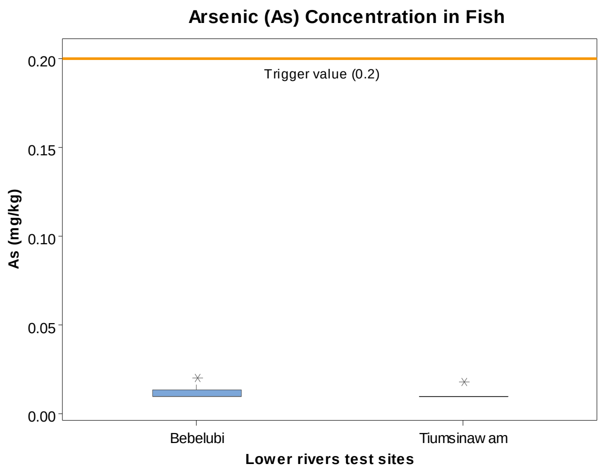


Figure F-19 Arsenics in fish flesh lower rivers test sites 2018

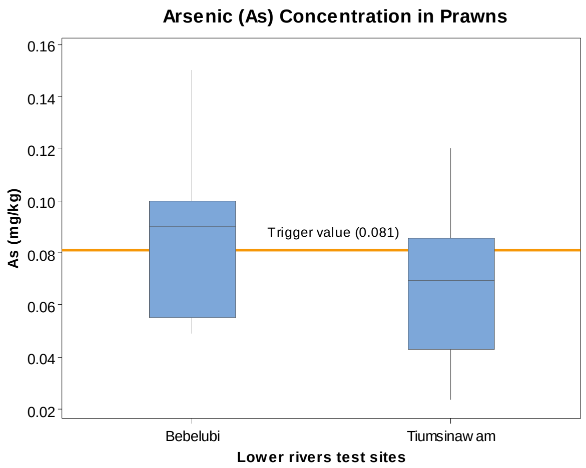


Figure F-20 Arsenic in prawn abdomen lower rivers test sites 2018

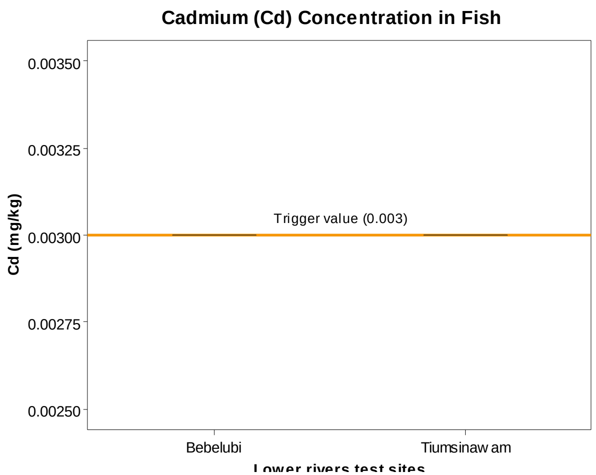


Figure F-21 Cadmium in fish flesh lower rivers test sites 2018

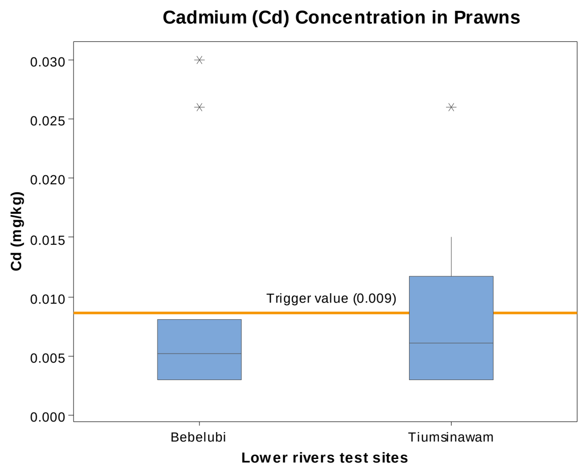


Figure F-22 Cadmium in prawn abdomen lower rivers test sites 2018

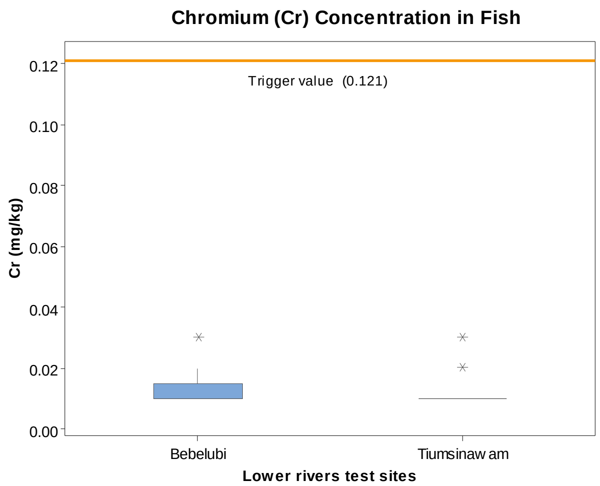


Figure F-23 Chromium in fish flesh lower rivers test sites 2018

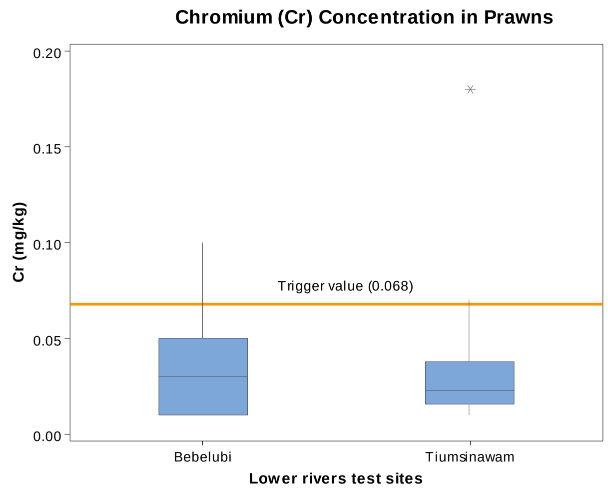


Figure F-24 Chromium in prawn abdomen lower rivers test sites 2018

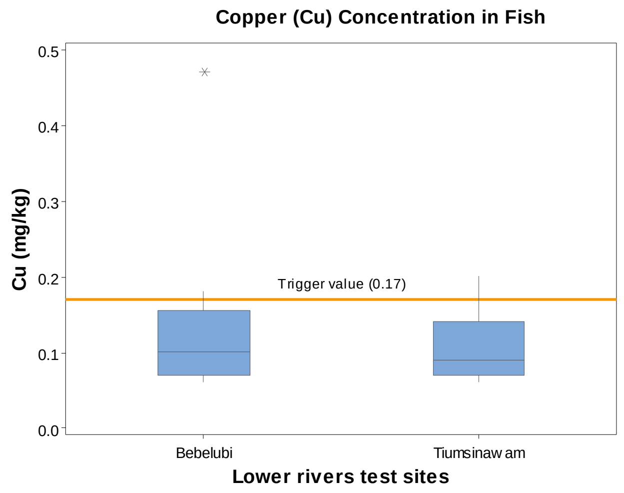


Figure F-25 Copper in fish flesh lower rivers test sites 2018

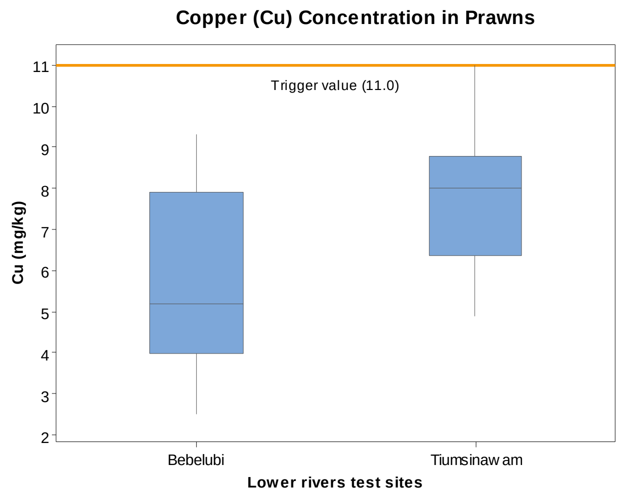


Figure F-26 Copper in prawn abdomen lower rivers test sites 2018

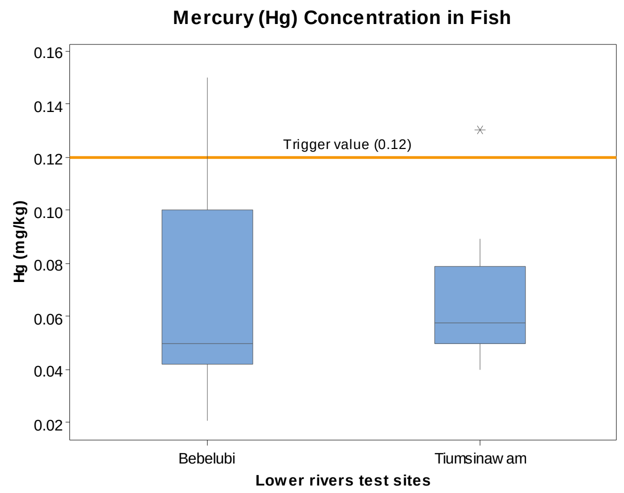


Figure F-27 Mercury in fish flesh lower rivers test sites 2018

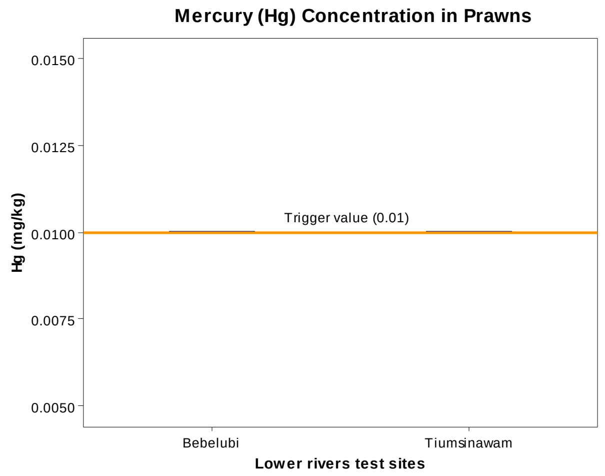


Figure F-28 Mercury in prawn abdomen lower rivers test sites 2018

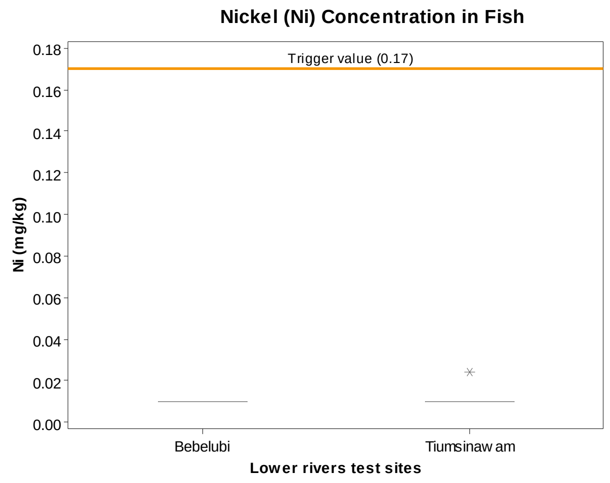


Figure F-29 Nickel in fish flesh lower rivers test sites 2018

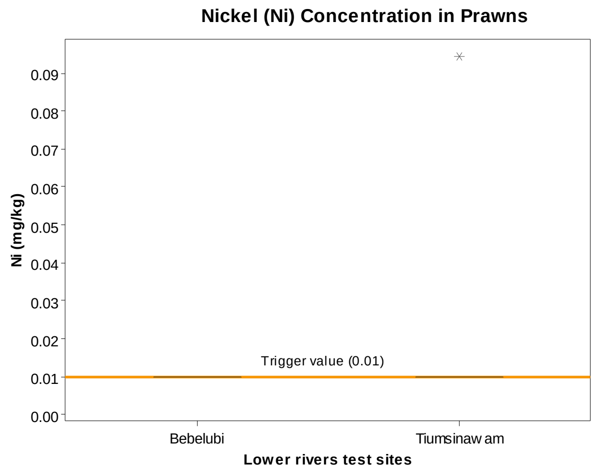


Figure F-30 Nickel in prawn abdomen lower rivers test sites 2018

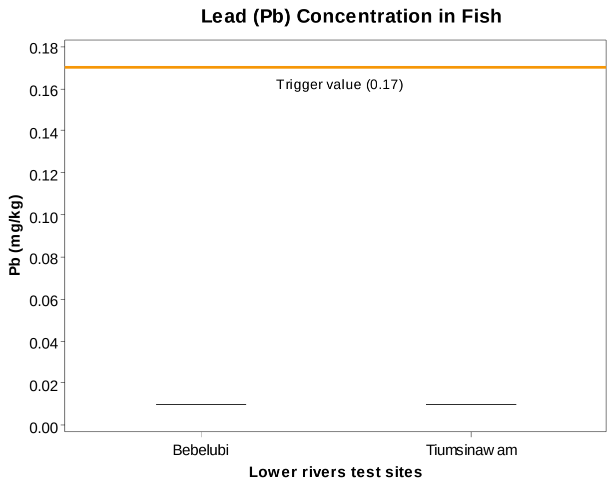


Figure F-31 Lead in fish flesh lower rivers test sites 2018

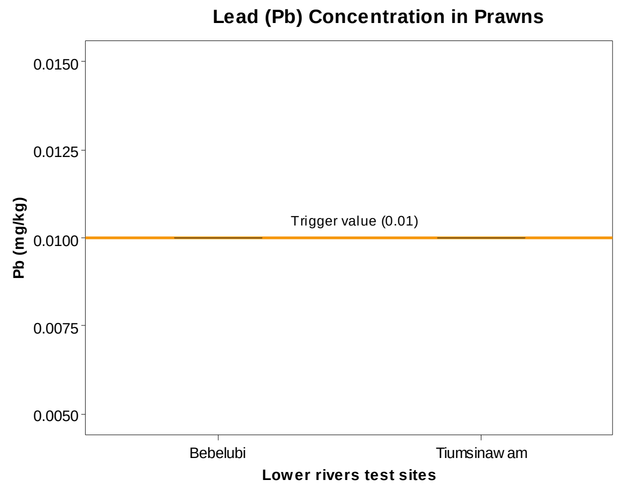


Figure F-32 Lead in prawn abdomen lower rivers test sites 2018

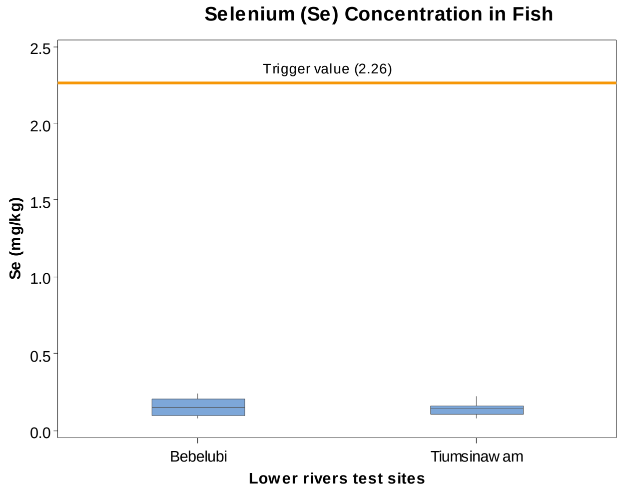


Figure F-33 Selenium in fish flesh lower rivers test sites 2018

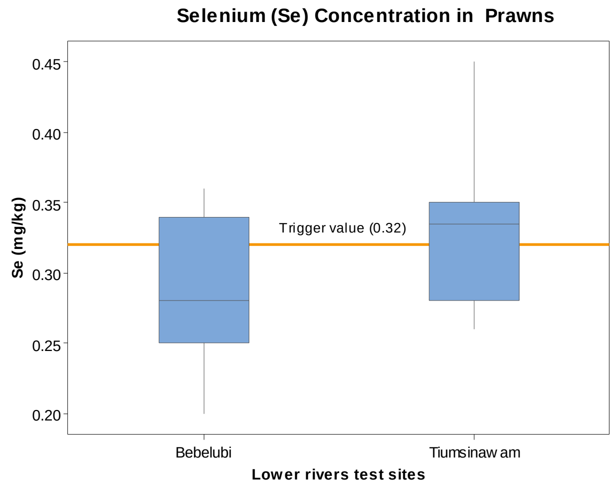


Figure F-34 Selenium in prawn abdomen lower rivers test sites 2018

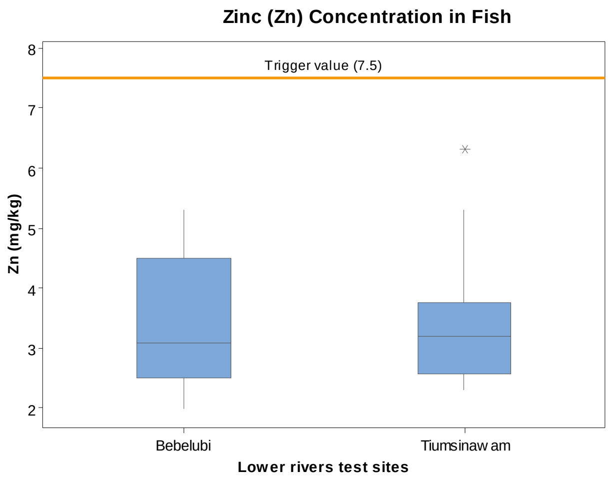


Figure F-35 Zinc in fish flesh at lower rivers test sites 2018

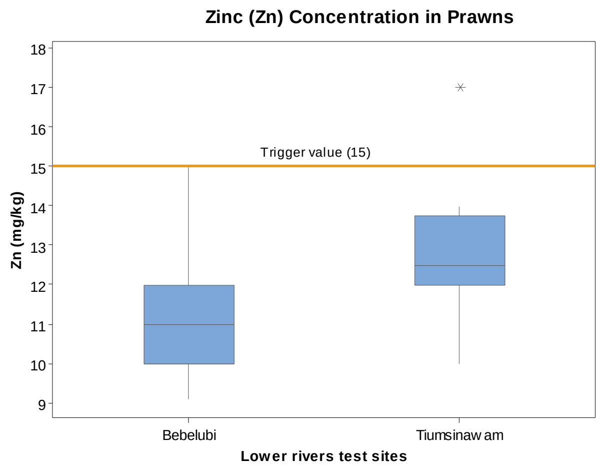


Figure F-36 Zinc in prawn abdomen lower rivers test sites 2018

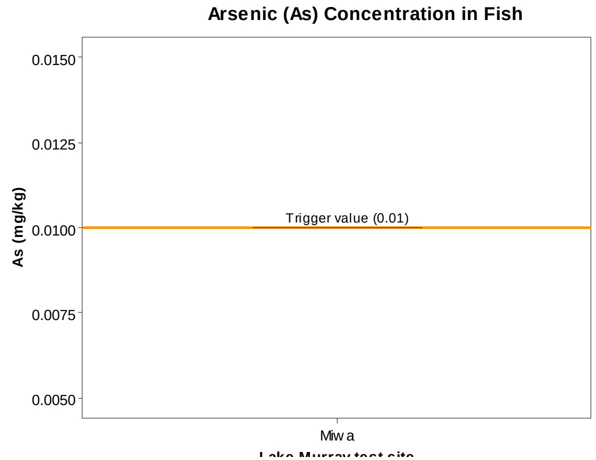


Figure F-37 Arsenic in fish flesh Lake Murray test site 2018

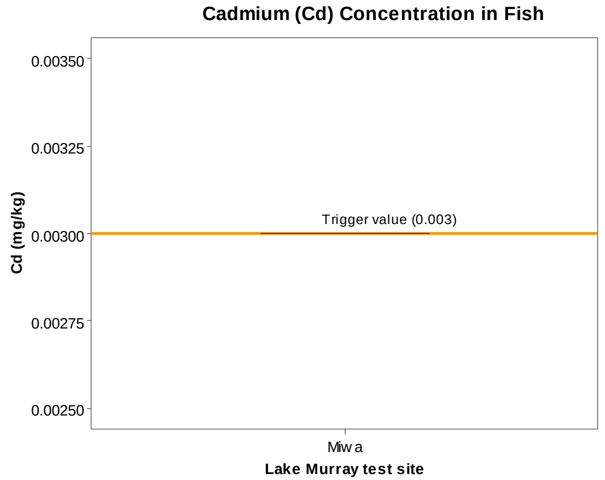


Figure F-38 Cadmium in fish flesh Lake Murray test site 2018

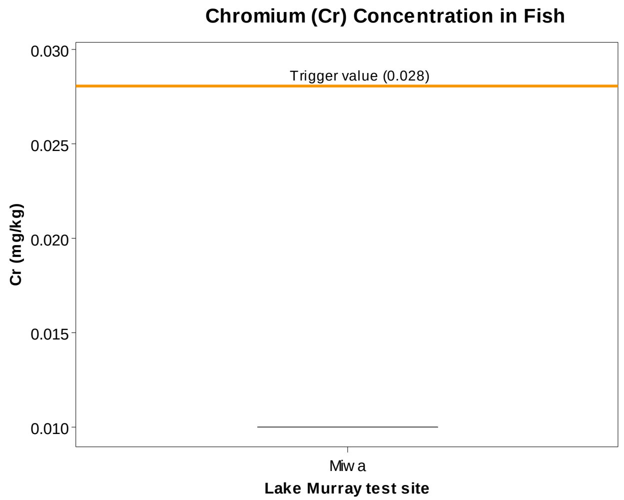


Figure F-39 Chromium in fish flesh Lake Murray test site 2018

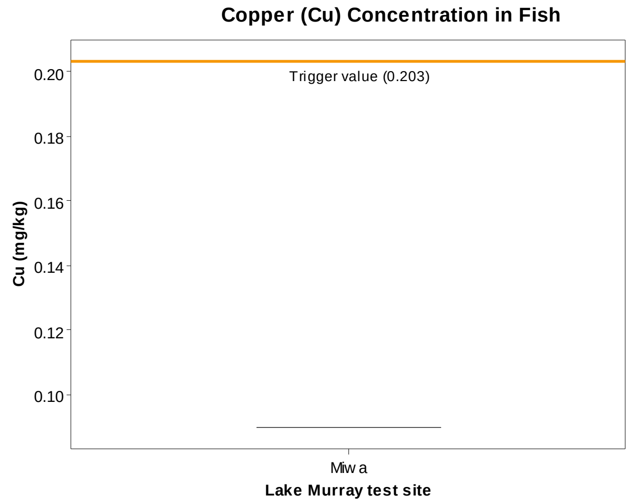


Figure F-40 Copper in fish flesh Lake Murray test site 2018

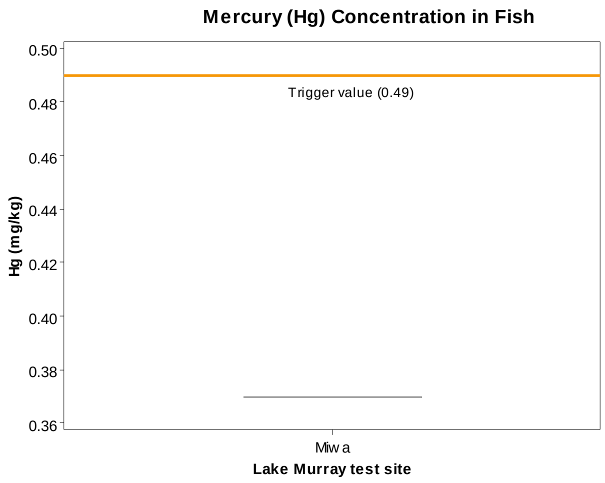


Figure F-41 Mercury in fish flesh Lake Murray test site 2018

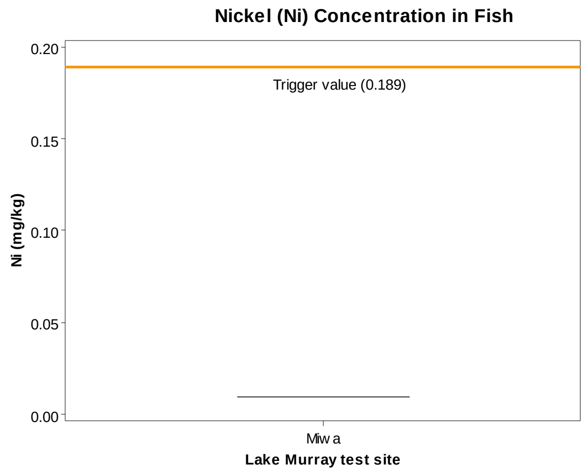


Figure F-42 Nickel in fish flesh Lake Murray test site 2018

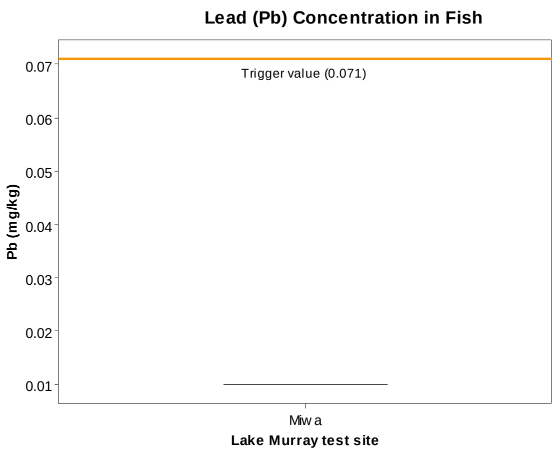


Figure F-43 Lead in fish flesh Lake Murray test site 2018

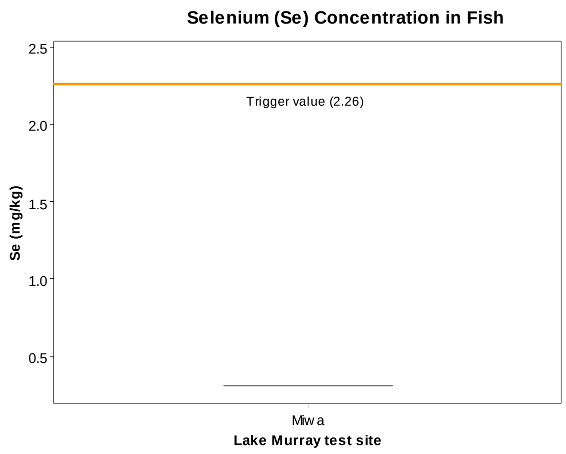


Figure F-44 Selenium in fish flesh Lake Murray test site 2018

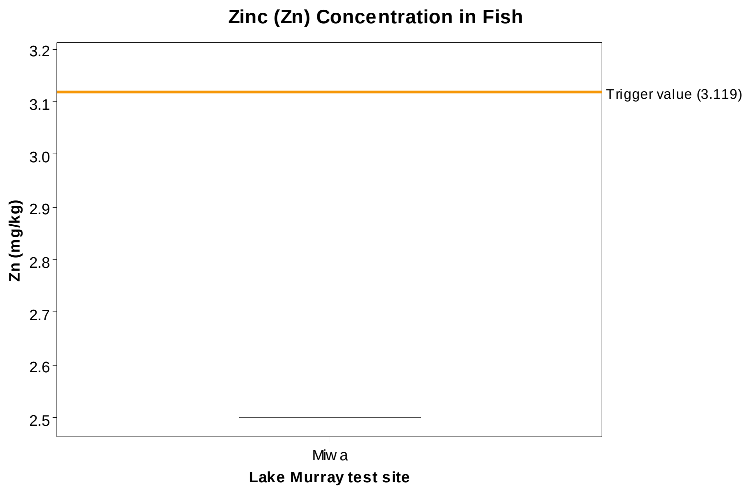


Figure F-45 Zinc in fish flesh Lake Murray test site 2018

Table F-7 Performance assessment – Based on the trend of tissue metals in fish flesh at upper river test sites from 2009-2018 using Spearman Rank Test.

Fish Flesh Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2009 - 2018
Wasiba (Trend of Annual Median 2009 - 2018)	As	-0.034	0.596	No change over time
	Cd	-0.723	<0.001	Reduced over time
	Cr	0.059	0.353	No change over time
	Cu	-0.265	<0.001	Reduced over time
	Hg	-0.024	0.705	No change over time
	Ni	-0.169	0.007	Reduced over time
	Pb	-0.116	0.067	No change over time
	Se	-0.368	<0.001	Reduced over time
	Zn	-0.165	0.009	Reduced over time
Wankipe (Trend of Annual Median 2009 - 2018)	As	-0.105	0.091	No change over time
	Cd	-0.711	<0.001	Reduced over time
	Cr	0.051	0.414	No change over time
	Cu	-0.127	0.041	Reduced over time
	Hg	0.006	0.928	No change over time
	Ni	-0.221	<0.001	Reduced over time
	Pb	0.059	0.346	No change over time
	Se	-0.229	<0.001	Reduced over time
	Zn	-0.236	<0.001	Reduced over time

Table F-8 Performance assessment – Based on the trend of tissue metals in prawn abdomen at upper river test sites from 2009-2018 using Spearman Rank Test.

Prawn Abdomen Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2009 - 2018
Wasiba (Trend of Annual Median 2009 - 2018)	As	-0.370	<0.001	Reduced over time
	Cd	-0.415	<0.001	Reduced over time
	Cr	0.193	0.002	Increased over time
	Cu	-0.067	0.290	No change over time
	Hg*	-	-	No change over time
	Ni	0.023	0.714	No change over time
	Pb	0.162	0.010	Increased over time
	Se	0.323	<0.001	Increased over time
	Zn	-0.066	0.299	No change over time
Wankipe (Trend of Annual Median 2009 - 2018)	As	-0.308	<0.001	Reduced over time
	Cd	-0.360	<0.001	Reduced over time
	Cr	0.032	0.595	No change over time
	Cu	-0.078	0.191	No change over time
	Hg*	-	-	No change over time
	Ni	0.216	<0.001	Increased over time
	Pb	0.108	0.072	No change over time
	Se	-0.018	0.762	No change over time
	Zn	-0.293	<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 2009-2018 using Spearman Rank Test.

Fish flesh Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2009 - 2018
Bebelubi (Trend of Annual Median 2009 - 2018)	As	-0.283	0.017	Reduced over time
	Cd	-0.853	<0.001	Reduced over time
	Cr	-0.254	0.033	Reduced over time
	Cu	-0.343	0.003	Reduced over time
	Hg	-0.532	<0.001	Reduced over time
	Ni	-0.310	0.008	Reduced over time
	Pb*	-	-	No change over time
	Se	-0.520	<0.001	Reduced over time
	Zn	-0.268	0.008	Reduced over time
SG4 (Trend of Annual Median 2009 - 2018)	As	-0.259	<0.001	Reduced over time
	Cd	-0.772	<0.001	Reduced over time
	Cr	0.161	0.010	Increased over time
	Cu	-0.180	0.004	Reduced over time
	Hg	0.050	0.425	No change over time
	Ni	-0.052	0.410	No change over time
	Pb	0.033	0.595	No change over time
	Se	-0.071	0.256	No change over time
	Zn	-0.012	0.853	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 2009-2018 using Spearman Rank Test.

Prawn Abdomen Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2009 - 2018
Bebelubi (Trend of Annual Median 2009 - 2018)	As	-0.038	0.517	No change over time
	Cd	-0.455	<0,001	Reduced over time
	Cr	0.093	0.117	No change over time
	Cu	0.264	<0.001	Increased over time
	Hg*	-	-	No change over time
	Ni	0.013	0.823	No change over time
	Pb	0.012	0.835	No change over time
	Se	0.154	0.009	Increased over time
	Zn	0.174	0.003	Increased over time
SG4 (Trend of Annual Median 2009 - 2018)	As	-0.171	0.002	Reduced over time
	Cd	-0.300	<0.001	Reduced over time
	Cr	0.063	0.254	No change over time
	Cu	0.230	<0.001	Increased over time
	Hg*	-	-	No change over time
	Ni	0.071	0.196	No change over time
	Pb	0.058	0.293	No change over time
	Se	0.154	0.005	Increased over time
	Zn	0.078	0.158	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 2003-2018 using Spearman Rank Test.

Prawn Abdomen Site	Parameter	Spearman's rho	p-Value (p=0.05)	Trend 2003 - 2018
Miwa (Trend of Annual Median 2003 - 2018)	As*	-1.000	*	No change over time
	Cd*	-1.000	*	No change over time
	Cr	0.500	0.667	No change over time
	Cu	-0.866	0.333	No change over time
	Hg	-0.866	0.333	No change over time
	Ni*	*	*	No change over time
	Pb*	*	*	No change over time
	Se*	1.000	*	No change over time
	Zn*	-1.000	*	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.